MONTREAL PROTOCOL ON SUBSTANCES THAT DEPLETE THE OZONE LAYER

U N E P

United Nations Environment Programme

Methyl Bromide Technical Options Committee

1998 Assessment of Alternatives to Methyl Bromide

United Nations Environment Programme (UNEP)

Methyl Bromide Technical Options Committee (MBTOC)
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Montreal Protocol
On Substances that Deplete the Ozone Layer

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Methyl Bromide Technical Options Committee (MBTOC)
1998 Assessment of Alternatives to Methyl Bromide

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Reproduction:	*** UNEP Nairobi Ozone Secretariat**
Date:	**30 October 1998**

Under certain conditions, copies of this report are available from:

United Nations Environment Programme
Ozone Secretariat
PO Box 30552
Nairobi, KENYA

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ISBN: 92-807-1703-8

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Pursuant to Article 6 of the Montreal Protocol, Decision IV/13 (1993) by the Parties to the Montreal Protocol

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ACKNOWLEDGEMENTS

MBTOC gratefully acknowledges the government and private organisation, consultancy and company support and for most members their voluntary personal contributions, that allowed MBTOC members to attend meetings to contribute to this report. MBTOC is also very grateful to UNEP for providing financial support to developing country members of MBTOC that also allowed them to attend each meeting.

MBTOC is indebted to the hard work of the co-chairs and sub-committee chairs for discussing, evaluating and deliberating with sub-committee members the merits or otherwise of each alternative and collating these discussions into the chapters presented in this report.

MBTOC is indebted to host institutions around the world for administrative support for three meetings including: staff from CSIRO-Canberra (especially Dr Jonathan Banks); Institute Agronomique et Vétérinaire Hassan II-Morocco (especially Professor Mohamed Besri); and USDA-Honolulu (especially Dr Ken Vick and Dr Jack Armstrong).

Finally, Dr Tom Batchelor acknowledges the support of the Department of Primary Industries, Water and Environment, which permitted his involvement with MBTOC and TEAP.

List of Contents

Chapter 1 : Executive summary

1.1 Methyl Bromide Technical Options Committee 1

1.2 Mandate 1

1.3 Introduction 2

1.3.1 General features of methyl bromide 2

1.3.2 Consumption 2

1.3.3 Methyl bromide control measures 3

1.4 Alternatives to Methyl Bromide 3

1.4.1 Definition of an alternative 3

1.4.2 Alternatives to methyl bromide for soil treatments 4

1.4.3 Alternatives to methyl bromide for durable commodities and structures 5

1.4.4 Alternatives to methyl bromide for perishable commodities 7

1.5 Developing Country Perspective 9

1.6 Quarantine and Pre-shipment 10

1.7 Emissions Reduction 11

1.8 Technology Transfer 12

1.9 The Future 13

Chapter 2 : Introduction

2.1 Methyl Bromide 15

2.2 MBTOC Mandate 15

2.3 Committee Composition 16

2.4 UNEP Assessments 17

2.5 Definition of an Alternative 17

2.6 New Information Since 1994 17

2.7 Report Structure 18

2.8 References 20

Chapter 3 : Methyl bromide production, consumption and limitations on use

3.1 Introduction 21

3.2 Uses of Methyl Bromide 21

3.3 Production and Supply 22

3.4 Consumption and Usage 23

3.4.1 Comparison of production with consumption 23

3.4.2 Usage by sector 24

3.4.3 Application methods 24

3.4.3.1 Soil fumigation 24

3.4.3.1.1 Manual application 24

3.4.3.1.2 Mechanised injection 25
3.4.3.2 Commodities and structures 25
3.5 Limitations on Methyl Bromide Use 26
3.5.1 Technical limitations 26
3.5.2 Legislative limitations 27
3.5.3 Consumer/market preferences 29
3.5.3.1 Importance of market factors in phase-out 29
3.5.3.2 Users and pest control companies taking leadership in alternatives 30
3.5.3.3 Supermarket policies on MB 30
3.5.3.4 Policies of manufacturers, traders and auction houses 31
3.5.3.5 Eco-labelling and product information 31
3.5.3.6 Levies and taxes on methyl bromide 32
3.5.3.6.1 Example of voluntary levy on MB 32
3.5.3.6.2 Taxes on ODS chemicals 32
3.5.3.6.3 Taxes on products 33
3.6 References 33

Chapter 4 : Alternatives to methyl bromide for soil treatment

4.1 Summary 35
4.2 Introduction 37
4.3 Integrated Pest Management 38
4.4 Non-chemical Alternatives 39
4.4.1 Crop rotation and fallow 39
4.4.2 Soil amendments and compost 39
4.4.3 Biofumigation 41
4.4.4 Planting time 41
4.4.5 Ploughing and tillage 41
4.4.6 Water management and flooding 42
4.4.7 Mulching and cover crops 42
4.4.8 Sanitation 42
4.4.9 Use of pathogen-free seeds and transplants 43
4.4.10 Soil-less culture 43
4.4.11 Biological control 44
4.4.11.1 Use of resistant varieties 45
4.4.11.2 Grafting 46
4.4.11.3 Plant growth promoting rhizobacteria 47
4.4.11.4 Endophytes 47
4.4.11.5 Mycorrhizae 48
4.4.12 Solarisation 48
4.4.13 Steam 49
4.4.14 Burning 50
4.5 Chemical Alternatives 50
4.5.1 Chloropicrin (trichloronitromethane) 50
4.5.2 1,3-Dichloropropene 51
4.5.3 Methyl isothiocyanate (MITC) and MITC generators 51
4.5.3.1 MITC 51
4.5.3.2 Metam sodium 51
4.5.3.3 Dazomet 52
4.5.4 Chemical alternatives which require further development 52
4.5.4.1 Methyl iodide 52
4.5.4.2 Propargyl bromide 53

4.5.4.3 Ozone 53
4.5.4.4 Formaldehyde 53
4.5.4.5 Sodium tetrathiocarbonate 53
4.5.4.6 Anhydrous ammonia 53
4.5.4.7 Inorganic azides 54
4.5.4.8 Naturally occurring compounds 54
4.5.5 Combinations of chemicals 54
4.5.6 Combinations of chemical and non-chemical methods 55
4.6 Alternatives to Methyl Bromide: Country Developments 55
4.7 Case Histories 56
4.8 References 56
Annex 4.1 Case History 1 : Alternatives to methyl bromide in Florida tomatoes and peppers 71
Annex 4.2 Case History 2 : Alternatives to methyl bromide for vegetable covered crops in Morocco 74
Annex 4.3 Case History 3 : Strawberry production in greenhouses in the Netherlands 77
Annex 4.4 Case History 4 : Cut flower production in Colombia without methyl bromide 79
Annex 4.5 Case History 5 : IPM strategies for control of *Sclerotium* rot in the Australian flower bulb Industry 81
Annex 4.6 Examples of alternatives in use for controlling one or more pests or weeds 83
Annex 4.7 Major soil-borne pathogens (nematodes, insects, weeds and parasitic plants) for which MB is used in one or more countries in various regions of the world in 1998 89
Annex 4.8 Examples of alternatives to soil fumigation with methyl bromide used in major crops in MB-user countries since restrictions were enforced 90
Annex 4.9 Relative difficulty of finding alternatives for major uses of methyl bromide for soil disinfestation in one or more countries in various regions of the world in 1998 95

Chapter 5 : Alternative treatments for durables, wood products and structures

5.1 Summary 97
5.2 Introduction 99
5.2.1 Target pests 100
5.2.2 Types of fumigation enclosures 100
5.3 Existing Uses of Methyl Bromide 101
5.3.1 Uses for which MBTOC did not identify alternatives 101
5.3.2 Uses for durables 101
5.3.3 Uses for wood and wood products 103
5.3.4 Uses for pests in structures 104
5.4 Description of Alternatives 104
5.4.1 Biological methods 105
5.4.2 Botanicals 106
5.4.3 Carbon bisulphide 106
5.4.4 Carbon dioxide at high pressure 107
5.4.5 Carbonyl sulphide 107
5.4.6 Cold treatments 107

5.4.7 Contact insecticides 108
5.4.8 Controlled atmospheres 109
5.4.9 Ethyl formate 110
5.4.10 Ethylene oxide 110
5.4.11 Heat treatment 111
5.4.12 Hydrogen cyanide 112
5.4.13 Inert dusts 112
5.4.14 Insect growth regulators 113
5.4.15 Integrated pest management 114
5.4.16 Irradiation 115
5.4.17 Other fumigants 116
5.4.17.1 Cyanogen 116
5.4.17.2 Methyl iodide 116
5.4.17.3 Methyl isothiocyanate 116
5.4.17.4 Methyl phosphine 116
5.4.17.5 Ozone 116
5.4.18 Pheromones 117
5.4.19 Phosphine 117
5.4.20 Sulphuryl fluoride 120
5.5 Durables 121
5.5.1 Introduction 121
5.5.2 Alternatives - grains and similar commodities 121
5.5.2.1 Biological control methods 124
5.5.2.2 Cold treatments for grain 124
5.5.2.3 Contact insecticides (grain protectants) 125
5.5.2.4 Controlled atmospheres 125
5.5.2.5 Heat treatment 126
5.5.2.6 Inert dusts 127
5.5.2.7 IPM strategies 127
5.5.2.8 Irradiation 127
5.5.2.9 Mechanical methods 128
5.5.2.10 Phosphine 128
5.5.2.11 Other potential fumigants 129
5.5.3 Alternatives - dried fruit, nuts, coffee and cocoa 129
5.5.3.1 Biological methods 131
5.5.3.2 Carbon dioxide at high pressure 131
5.5.3.3 Cold treatments 132
5.5.3.4 Controlled atmospheres 133
5.5.3.5 Ethyl formate 134
5.5.3.6 Heat treatments 134
5.5.3.7 IPM systems 134
5.5.3.8 Irradiation 134
5.5.3.9 Packaging 135
5.5.3.10 Phosphine 135
5.5.4 Alternatives - herbs and spices 135
5.5.4.1 Carbon dioxide at high pressure 137
5.5.4.2 Ethylene oxide 137
5.5.4.3 Extreme temperature treatments 137
5.5.4.4 Integrated pest management 137
5.5.4.5 Irradiation 137
5.5.4.6 Controlled atmospheres 138
5.5.4.7 Phosphine 138
5.5.5 Alternatives - tobacco 138
5.5.5.1 Heat and cold treatment 139
5.5.5.2 Insect growth regulators 139

5.5.5.3 IPM strategies....139
5.5.5.4 Irradiation....139
5.5.5.5 Phosphine....140
5.5.6 Alternatives – seeds for planting....140
5.5.6.1 Chemical soaking and fumigation....140
5.5.6.2 Cleaning....142
5.5.6.3 Cold treatment....142
5.5.6.4 Hot water treatment....142
5.5.6.5 IPM strategies....142
5.5.6.6 Phosphine....142
5.5.7 Alternatives - artefacts....142
5.5.7.1 Contact insecticides....144
5.5.7.2 Heat and cold treatments....144
5.5.7.3 Hydrogen cyanide....144
5.5.7.4 Integrated pest management....144
5.5.7.5 Irradiation....145
5.5.7.6 Controlled atmospheres....145
5.5.7.7 Phosphine....145
5.5.7.8 Sulphuryl fluoride and other fumigants....145
5.5.8 Alternatives - other products....146
5.5.8.1 Cheeses....146
5.5.8.2 Cotton....146
5.5.8.3 Dried fish, meat and seafood....146
5.6 Wood Products and Wood in Structures....147
5.6.1 Introduction....147
5.6.2 Wood products....148
5.6.2.1 Contact insecticides....148
5.6.2.2 Controlled atmospheres....149
5.6.2.3 Heat treatments....149
5.6.2.4 Integrated pest management strategies....149
5.6.2.5 Irradiation....149
5.6.2.6 Phosphine....150
5.6.2.7 Other fumigants and gases....150
5.6.2.8 Removal of bark....150
5.6.2.9 Sulphuryl fluoride....150
5.6.2.10 Under water dipping....150
5.6.3 Wood in structures....151
5.6.3.1 Construction/removal....151
5.6.3.2 Contact insecticides/preservatives....151
5.6.3.3 Heat treatments....152
5.6.3.4 Hydrogen cyanide....152
5.6.3.5 Controlled atmospheres....152
5.6.3.6 Phosphine....152
5.6.3.7 Spot treatments by electrocution....153
5.6.3.8 Spot treatments by liquid nitrogen....153
5.6.3.9 Spot treatments by microwaves....153
5.6.3.10 Sulphuryl fluoride....154
5.6.3.11 Miscellaneous....154
5.7 Treatment of Structures for Food Pests....154
5.7.1 Introduction....154
5.7.2 Alternatives for structures....155
5.7.2.1 Cold....155
5.7.2.2 Contact pesticides....156
5.7.2.3 Controlled atmospheres....156
5.7.2.4 Heat....157
5.7.2.5 Hydrogen cyanide....157

5.7.2.6 Inert dusts....157
5.7.2.7 Integrated pest management....157
5.7.2.8 Pheromone trapping....158
5.7.2.9 Phosphine....158
5.7.2.10 Sulphuryl fluoride....159
5.7.2.11 Treatment combinations....159
5.7.3 Alternatives for transport....160
5.7.3.1 Aircraft....160
5.7.3.2 Freight containers....160
5.7.3.3 Other vehicles....161
5.8 References....161
Annex 5.1 Case History 1 : Rice irradiation in Indonesia....178
Annex 5.2 Case History 2 : Development of integrated pest management manual for Canadian food processing facilities....180
Annex 5.3 Estimates of the minimum *ct*-product (ghm^{-3}) of methyl bromide for a 99.9 per cent kill of various stages of a number of insect species....182
Annex 5.4 Minimum exposure periods (days) required for control of all stages of the stored product pests listed, based on a phosphine concentration of 1.0 gm^{-3}....183
Annex 5.5 Methyl bromide dosage table....184

Chapter 6 : Alternatives to methyl bromide for perishable commodities

6.1 Summary....185
6.2 Introduction....187
6.2.1 Treatment on arrival....187
6.2.2 Country of origin treatments....188
6.2.3 Quarantine and pre-shipment....188
6.2.4 Development of alternatives to MB....189
6.2.5 Alternatives development....190
6.3 Alternatives to Methyl Bromide....190
6.4 Pre-harvest Practices and Inspection Procedures....191
6.4.1 Cultural practices leading to pest reduction....191
6.4.2 Pest-free zones and periods....193
6.4.3 Inspection and certification....193
6.5 Non-chemical Post-harvest Treatments....194
6.5.1 Cold....194
6.5.2 Controlled atmosphere....195
6.5.3 Heat....196
6.5.4 Irradiation....197
6.5.5 Modified atmosphere....199
6.5.6 Microwaves....200
6.5.7 Physical removal....200
6.5.8 Combination....200
6.6 Chemical Post-harvest Treatments....201
6.6.1 Fumigation....201
6.6.2 Dips....202
6.7 Constraints to Acceptance of Alternatives....203

6.8 Current Research Examples 204
6.9 Examples of Alternatives for Pest Control on Major Commodities 204
6.9.1 Apples and pears 205
6.9.1.1 Existing alternatives 205
6.9.1.2 Potential alternatives 205
6.9.2 Berryfruit 207
6.9.2.1 Existing alternatives 207
6.9.2.2 Potential alternatives 207
6.9.3 Bulbs 207
6.9.3.1 Existing alternatives 208
6.9.3.2 Potential alternatives 208
6.9.4 Citrus 208
6.9.4.1 Existing alternatives 208
6.9.4.2 Potential alternatives 209
6.9.5 Cucurbits 210
6.9.5.1 Existing alternatives 211
6.9.5.2 Potential alternatives 211
6.9.6 Cut flowers and ornamentals 212
6.9.6.1 Existing alternatives 212
6.9.6.2 Potential alternatives 213
6.9.7 Grapes 215
6.9.7.1 Existing alternatives 215
6.9.7.2 Potential alternatives 215
6.9.8 Root crops 216
6.9.8.1 Existing alternatives 216
6.9.8.2 Potential alternatives 216
6.9.9 Stonefruit 217
6.9.9.1 Existing alternatives 217
6.9.9.2 Potential alternatives 217
6.9.10 Subtropical fruit 218
6.9.10.1 Existing alternatives 219
6.9.10.2 Potential alternatives 219
6.9.11 Tropical fruit 219
6.9.11.1 Existing alternatives 220
6.9.11.2 Potential alternatives 221
6.9.12 Vegetables 222
6.9.12.1 Existing alternatives 222
6.9.12.2 Potential alternatives 223
6.10 Existing and Potential Alternatives to Methyl Bromide 223
6.11 Commodities Without Approved Non-MB Quarantine Treatments 226
6.12 Opportunities to Reduce Emissions 227
6.13 Research Priorities 227
6.13.1 Developing countries 227
6.13.2 Developed countries 228
6.14 Technology Transfer and Training 228
6.15 Developing Country Issues 229
6.16 References 229
Annex 6.1 Case History : Heat disinfestation treatments for papaya in Hawaii 243

Chapter 7 : Developing country perspective

7.1 Summary 245

7.2 Introduction 247

7.3 Methyl Bromide Use in Article 5(1) Countries 247

7.3.1 Trends in methyl bromide use 249
7.3.2 Evaluation and adoption of alternatives to methyl bromide 250
7.3.2.1 Alternatives to methyl bromide currently in use in Article 5(1) countries 251
7.3.3 Country specific information 251
7.3.3.1 Algeria 251
7.3.3.2 Argentina 252
7.3.3.3 Botswana 252
7.3.3.4 Brazil 252
7.3.3.5 Cameroon 252
7.3.3.6 China 253
7.3.3.7 Croatia 253
7.3.3.8 Egypt 253
7.3.3.9 India 253
7.3.3.10 Iran 254
7.3.3.11 Jordan 254
7.3.3.12 Kenya 254
7.3.3.13 Lebanon 255
7.3.3.14 Malaysia 256
7.3.3.15 Mexico 256
7.3.3.16 Morocco 256
7.3.3.17 Philippines 256
7.3.3.18 South Africa 257
7.3.3.19 Syria 258
7.3.3.20 Thailand 258
7.3.3.21 Turkey 258
7.3.3.22 Uruguay 259
7.3.3.23 Vietnam 259

7.4 Fumigation of Soil 259

7.4.1 Current uses of methyl bromide 259
7.4.2 Alternatives to methyl bromide 260

7.5 Fumigation of Durable Commodities and Structures 261

7.5.1 Current uses of methyl bromide 261
7.5.2 Alternatives for durables and structures 262

7.6 Fumigation of Perishable Commodities 263

7.6.1 Current uses of methyl bromide 263
7.6.2 Alternatives for perishable commodities 264

7.7 Quarantine and Pre-shipment Uses 264

7.7.1 Relevance of QPS to Article 5(1) countries 264

7.8 Replacement of Methyl Bromide 265

7.8.1 Technology transfer issues 266

7.9 Technical Issues Related to the Multilateral Fund 267

7.9.1 Multilateral Fund guidelines for projects 267
7.9.2 Ongoing and planned demonstration projects 268

7.10 Conclusions 270

7.11 Case Histories 270

Annex 7.1 Case History 1 : Sulphuryl fluoride on stored product pests in China 271
Annex 7.2 Case History 2 : Coconut substrate mixture as a soil fumigation alternative.....273
Annex 7.3 Case History 3 : Integrated pest management for crops in Morocco 275
Annex 7.4 Officially reported methyl bromide consumption by Article 5(1) countries.....277
Annex 7.5 Use of alternatives for soil-borne pests in Article (5)1 countries 281
Annex 7.6 Use of alternatives for durable commodities in Article (5)1 countries 289
Annex 7.7 Use of alternatives for perishable commodities in Article (5)1 countries 290
Annex 7.8 Use of alternatives for structural pests in Article (5)1 countries.....291

Chapter 8 : Quarantine and pre-shipment

8.1 Summary 293
8.2 Introduction 294
8.3 Status of QPS Under the Montreal Protocol 295
8.4 Definitions 295
8.4.1 Montreal Protocol 295
8.4.2 International Plant Protection Convention.....295
8.4.3 General comparison of MP and IPPC 296
8.4.4 Quarantine 296
8.4.5 Pre-shipment.....296
8.5 Implications of Inconsistent Interpretation of QPS for the Parties 297
8.6 TEAP Interim Explanatory Note 297
8.7 Examples that May Assist in the Interpretation of QPS.....298
8.7.1 Uses considered by MBTOC to be QPS treatments.....298
8.7.1.1 Official quarantine treatment in country of origin.....298
8.7.1.2 Official quarantine treatment on arrival 299
8.7.1.3 Eradication of a quarantine pest from an area 299
8.7.1.4 Official pre-shipment treatment in country of origin in relation to exports.....299
8.7.2 Uses considered by MBTOC to not be QPS treatments 300
8.7.2.1 Exporter carries out MB treatment prior to export as a quality control measure 300
8.7.2.2 Importing contractor requests treatment prior to export as a quality control measure 301
8.7.2.3 Contractor requests treatment as a quality control measure.....301
8.7.2.4 Treatment of commodities by the importing country found to be infested on receipt 301
8.7.2.5 Treatment of land prior to export of crop.....302
8.7.3 Categorising quarantine and pre-shipment treatments.....302
8.8 References.....302
Annex 8.1 Logic diagram to assist in categorising Quarantine and Pre-shipment treatments 303

Chapter 9 : Reducing methyl bromide emissions

9.1 Summary 305
9.2 Introduction 306
9.3 MB Emissions from Current Uses.....307
9.4 Emission Reduction Through Better Containment.....309

9.4.1 Soil fumigation....309
9.4.1.1 Use of plastic covers....309
9.4.1.2 Virtually impermeable films....310
9.4.1.3 Other factors affecting emissions from soils....311
9.4.1.3.1 Soil characteristics....311
9.4.1.3.2 Increasing the period of plastic sheeting....312
9.4.1.3.3 Irrigation....312
9.4.1.3.4 Organic amendments and fertilisers....312
9.4.1.3.5 Rolling the soil surface....312
9.4.1.3.6 Formulations....312
9.4.1.3.7 Reduction in rate....312
9.4.1.3.8 Depth of injection....313
9.4.1.3.9 Broadacre vs. bed....313
9.4.1.4 Practices to reduce emissions from soil....313
9.4.2 Structural and commodity fumigation....314
9.4.2.1 Fumigant recovery....315
9.4.2.2 Volume displacement techniques....316
9.4.2.3 Transfer of knowledge and training....316
9.5 Emission Reduction Through Recovery and Recycling....316
9.5.1 Activated carbon....316
9.5.2 Zeolite....318
9.5.3 Condensation and activated carbon....319
9.5.4 Refrigeration and condensation....320
9.5.5 Between-chamber transfer....320
9.5.6 Technologies under development....320
9.6 Emission Reduction Through Recovery and Destruction....320
9.6.1 Ozone destruction....320
9.6.2 Adsorption into reactive liquids....320
9.6.3 Thermal and catalytic destruction....321
9.7 Constraints....321
9.8 References....321
Annex 9.1 Calculation of percent emission of MB from treatments using the mass balance approach....324

Appendices

Appendix 1 : UNEP Methyl Bromide Technical Options Committee contact details....327
Appendix 2 : Montreal Protocol Decisions, Declarations and Resolutions relating to methyl bromide....335
Appendix 3 : Sources of information on methyl bromide and ozone depletion....353

List of Tables

Chapter 2 : Introduction

Table 2.1 Phase-out schedule agreed at the ninth meeting of the Parties in 1997 16

Chapter 3 : Methyl bromide production, consumption and limitations on use

Table 3.1 Gross production and consumption of methyl bromide, in tonnes 22

Table 3.2 Methyl bromide production (tonnes) as reported to the Ozone Secretariat by the Parties (by April 1998) 23

Table 3.3 Comparison of production and consumption data sets 24

Table 3.4 National legislation and policies for reducing or phasing out MB faster than the Montreal Protocol schedules 28

Chapter 4 : Alternatives to methyl bromide for soil treatments

Table 4.1 Integrated Disease Management programme for protected vegetable crops in Morocco 76

Table 4.2 Comparative costs of Dutch Iris produced using an IPM strategy or with soil treated with pre-plant applications of methyl bromide/chloropicrin (70:30). 82

Table 4.3 Examples of alternatives in use for controlling one or more pests or weeds, with indications of degree of development and adoption of the technique (ratings of scale of applications - see footnote; from TEAP April 1997 report). 83

Table 4.4 Major soil-borne pathogens (nematodes, insects, weeds and parasitic plants) for which MB is used in one or more countries in various regions of the world in 1998 89

Table 4.5 Non Article 5(1) countries which have phased out methyl bromide 90

Table 4.6 Non Article 5(1) countries with phase-out in 2005 or conforming to Montreal Protocol Restrictions 91

Table 4.7 Article 5(1) countries which have implemented alternative practices to soil fumigation with methyl bromide 94

Table 4.8 Relative difficulty of finding alternatives for major uses of methyl bromide for soil disinfestation in one or more countries in various regions of the world in 1998 95

Chapter 5 : Alternative treatments for durables, wood products and structures

Table 5.1 Types of buildings and structures fumigated against wood pests 104

Table 5.2 Uses and targets for structural fumigation to control urban and food pests 105

Table 5.3 The basic differences between contact insecticides and fumigants 109

Table 5.4 Examples of cereal and legume crops which may be fumigated with MB 122

Table 5.5 Principal pests of cereals and similar commodities 123

Table 5.6 Varieties of fruits and nuts sometimes treated with MB 130

Table 5.7 Target pests in coffee and cocoa 131

Table 5.8 Target pests of dried fruits and nuts 132

Table 5.9 Herbs and spices sometimes disinfested with MB 136

Table 5.10 Some target pests in herbs and spices 137

Table 5.11 Target pests in tobacco and related products 139

Table 5.12 Some nematodes transmitted by seeds 141

Table 5.13 Some common pests of artefacts made of wood, skin, feathers, wool and other organic materials 143

Table 5.14 Common pests in dried fish, meat and seafood 146

Table 5.15 Target insect pests in logs, timber and bark products 148

Table 5.16 Estimates of the minimum *ct*-product (ghm-3) of methyl bromide for a 99.9 per cent kill of various stages of a number of insect species at 10, 15, 25 and 30°C and 70% RH. (Heseltine and Thompson 1974) 182

Table 5.17 Minimum exposure periods (days) required for control of all stages of the stored product pests listed, based on a phosphine concentration of 1.0 gm^{-3}. This dosage is as recommended for good conditions and the dosage applied will usually need to be increased considerably in leaky situations (EPPO 1984) 183

Table 5.18 Methyl bromide dosage table. European Plant Protection Organization (1993) 184

Chapter 6 : Alternatives to methyl bromide for perishable commodities

Table 6.1 Alternative quarantine techniques, with examples of approved applications for fresh fruit, vegetables and cut flowers 224

Table 6.2 Examples of cold treatments approved for quarantine purposes 225

Table 6.3 Number of known cases where countries have approved an alternative quarantine technique for perishable commodities (or groups of similar commodities) 226

Chapter 7 : Developing country perspective

Table 7.1 Important uses of MB in Article 5 (1) countries 249

Table 7.2 Alternative treatments to MB for soil fumigation in India 254

Table 7.3 Support activities needed to ensure alternatives are adopted in developing countries 267

Table 7.4 Countries where MB demonstration projects are being prepared or implemented (as of July 1998) 269

Table 7.5 Integrated disease management programme for protected vegetable crops in Morocco 276

Table 7.6 Examples of pesticides used for soil disinfection in protected cultivation in Morocco (vegetables, bananas, ornamental plants, strawberries) 276

Table 7.7 Officially reported methyl bromide consumption by Article 5(1) countries 277

Chapter 9 : Reducing methyl bromide emissions

Table 9.1 Estimated usage of MB and emissions to atmosphere for different categories of fumigation by major use category (derived from 1996 production data) 308

Table 9.2 Estimated emission loss to the atmosphere from soil fumigation (Yates *et al.* 1997) 309

Table 9.3 Percentage emissions of MB from a sandy loam soil following application using buried drip tubes 313

Table 9.4 Fumigation of cereal grains on import into Japan (1992 data) with calculated emissions of MB based on bromide ion residue levels in commodity after treatment 324

List of Figures

Chapter 3 : Methyl bromide production, consumption and limitations on use

Figure 3.1 Trend in production (tonnes) of methyl bromide for fumigant uses 23

Figure 3.2 Analysis of global methyl bromide fumigant use by major sector. 24

Glossary

ACRONYMS AND TERMS COMMONLY USED IN THIS REPORT

Acronym/Term	Meaning
Activated carbon	Carbon or charcoal derived from a variety of sources which has been treated so that it can absorb a large quantity of gas.
APHIS	Animal and Plant Health Inspection Service. US Regulatory Agency responsible for quarantine
Article 5(1)	A developing country whose annual per capita ODS consumption is less than 0.3 kg per capita.
ASEAN	Association of South East Asian Nations.
Bio-fumigation	Amendment of soil with organic matter that releases gases which eliminate or control pests.
CA(s)	Controlled atmosphere(s), typically low oxygen and high carbon dioxide atmospheres that are externally controlled. They are used for extending the life of fresh and durable commodities. Some CAs have pesticidal qualities.
Condensation	The cooling process which turns gases into liquids.
Containment	Securing the fumigation site so that inadvertent leakage from the treatment area does not occur during the actual fumigation treatment.
ct-product	The product of the fumigant ***c***oncentration multiplied by the ***t***ime it is applied for. This figure is often used as a guide to the severity or lightness of a fumigation treatment.
DE	Diatomaceous earth. Abrasive, fossilised remains of diatoms consisting mainly of silica with small amounts of other minerals that cause damage mainly to arthropod pests.
Destruction	The chemical or physical destruction of methyl bromide recovered from fumigation operations.
Durables	Commodities with a low moisture content that, in the absence of pest attack, can be safely stored for long periods.
FAO	Food and Agriculture Organisation.
Feedstock	Methyl bromide which is used as a raw material for manufacturing other chemicals.
Grafting	Use of resistant rootstocks to protect susceptible annual and perennial crops against soil-borne pathogens.
HDPE Sheets	Plastic sheets or films made from High Density Polyethylene.
IAEA	International Atomic Energy Agency, based in Vienna.
IGR	Insect Growth Regulator. Specific chemical that disrupts the life-cycle of a pest.
IMO	International Maritime Organisation.
IPM	Integrated Pest Management: Pest monitoring techniques, establishment of pest injury levels and a combination of strategies and tactics to prevent or manage pest problems in an environmentally sound and cost-effective manner.
IPPC	International Plant Protection Convention
Irradiation	In practice, the use of gamma energy, accelerated electrons or X-rays to penetrate the commodity to sterilise or kill pests.
LDPE Sheet	Plastic sheets or films made from Low Density Polyethylene.

Acronym/Term	Meaning
MA(s)	Modified atmosphere(s).
MB	Methyl Bromide.
MBTOC	Methyl Bromide Technical Options Committee.
MF	Multilateral Fund.
NAPPO	North American Plant Protection Organisation.
Non-Article 5(1)	A developed country whose annual per capita ODS consumption is greater than 0.3 kg per capita.
ODS	Ozone depleting substance.
PE Sheets	Plastic sheets or films made from Polyethylene.
Perishables	Fresh fruit and vegetables, cut flowers, ornamental plants, fresh root crops and bulbs that generally have limited storage life.
Permeability	The degree to which MB can flow through a thin membrane or sheet.
Pest-free zone	Establishment of a certified area where a regulated quarantine pest does not exist.
Pheromone	A chemical produced by one member of a species that are externally transmitted and influence the behaviour or physiology of another member of the same species.
Phytotoxic	Toxic to plants.
QPS	Quarantine and pre-shipment.
Reclamation	The re-processing and upgrading of recovered methyl bromide by more complex physical or chemical treatments. Often this would involve storage for subsequent re-use, either on-site or at other sites.
Recovery	The collection and storage of methyl bromide from fumigation operations.
Recycling	The re-use of methyl bromide following a basic recovery and cleaning process. Normally this would only involve on-site processing.
Sanitation	Avoidance or elimination of pathogen inoculum or pest sources, such as infected plant residues, before planting.
Soil-less culture	A method in which plant growth substrates provide an anchoring medium that allows nutrients and water to be absorbed by plant roots.
Solarisation	When heat from solar radiation is trapped under clear plastic sheeting to elevate the temperature of moist soil to a level lethal to soil-borne pests including pathogens, weeds, insects and mites.
Systems approach	Combines biological knowledge with scientifically-derived, quantifiable operational actions that together act as multiple safeguards in the country of export and result in a consignment meeting the requirements of the importing country.
TEAP	Technology and Economics Assessment Panel.
UNEP	United Nations Environment Programme.
USDA	United States Department of Agriculture.
US-EPA	United States - Environmental Protection Agency.
VIF	Virtually Impermeable Film. Sheets of plastic for use in soil fumigation which are manufactured so that very little MB can pass through them.
WHO	World Health Organisation.
Zeolite	Alumino-silicate materials which although they do occur naturally, can also be manufactured to have special surface properties which allow them to be used to absorb large quantities of gases.

UNITS COMMONLY USED IN THIS REPORT

Unit	Meaning
bar	unit of pressure
h	hour
t	tonne, 1000 kg
kGy	1000 Gray, unit of radiation
gm^{-3}	grams per cubic meter, or g/m^3
kg	kilogram, 1000 grams
th^{-1}	tonnes per hour, or t/h
ml	millilitre, 1/1000 of a litre
gt^{-1}	grams per tonne or g/t

Citation format:

Anon. 1998. United Nations Environment Programme (UNEP) Methyl Bromide Technical Options Committee (MBTOC). *1998 Assessment of the Alternatives to Methyl Bromide*. United Nations Environment Programme, Nairobi: 374pp.

Chapter 1

Executive summary

1.1 Methyl Bromide Technical Options Committee

The Methyl Bromide Technical Options Committee (MBTOC) was established by the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer to identify existing and potential alternatives to methyl bromide (MB). This Committee, in particular, addresses the technical feasibility of chemical and non-chemical alternatives for the current uses of MB, apart from its use as a chemical feedstock.

MBTOC reports to the Technology and Economic Assessment Panel (TEAP) which advises the Parties on scientific, technical and economic matters related to the control of ozone depleting substances and their alternatives. MBTOC members have expertise in the uses of MB and its alternatives and come from 11 Article 5(1)[1] and 12 non-Article 5(1) countries. There are 39 members of MBTOC comprising 13 (33%) from developing and 26 from developed countries.

This MBTOC 1998 Assessment reports on MB usage; the quantities produced and consumed; existing and potential alternative treatments for its uses as a soil fumigant; as a fumigant of durable commodities and structures; and as a fumigant of perishable commodities. In addition, the report provides a developing country perspective, covers quarantine and pre-shipment issues and methods for reducing MB emissions.

1.2 Mandate

Under Decision VII/34, taken at the seventh Meeting of the Parties to the Protocol in December 1995, the Parties requested the Assessment Panels, including MBTOC, undertake full Assessment[2] reports and submit them to the Secretariat for consideration by the Open-ended Working Group and by the eleventh Meeting of the Parties in 1999.

[1] Article 5(1) refers to developing countries consuming less than 0.3 Kg ODS per capita; Non-Article 5(1) refers to industrialised or developed countries.

[2] MBTOC. 1995. Report of the Methyl Bromide Technical Options Committee. Montreal Protocol on Substances that Deplete the Ozone Layer. UNEP (Nairobi): 304pp.

1.3 Introduction

1.3.1 General features of methyl bromide

MB is a fumigant that has been used commercially for more than 40 years to control pests such as fungi, bacteria, soil-borne viruses, insects, mites, nematodes and rodents. It has sufficient phytotoxicity to control many weeds and seeds in soils. MB is used mostly for soil fumigation, a moderate amount is used for disinfestation of durable and perishable commodities and a minor amount is used for disinfestation of buildings, ships and aircraft.

It has features which make it a versatile chemical with a wide range of applications. In particular, it is quite penetrative and usually effective over a broad range of temperatures. Its action is usually sufficiently fast and it airs rapidly enough from treated systems to cause relatively little disruption to commerce or crop production.

Although MB is clearly a most useful pest management technique in specific instances, it was listed under the Montreal Protocol as an ozone depleting substance in 1992 which necessitates ultimately that its production must cease. There are also a number of concerns apart from ozone depletion which have led countries to impose restrictions on its use. These concerns include residues in food, toxicity to humans and associated operator safety and public health and detrimental effects on soil biodiversity. In some countries, pollution of surface and ground water by MB and its derived bromide ion are also concerns.

1.3.2 Consumption

Under the Montreal Protocol, MB consumption is defined as production plus imports minus exports, feedstock and quarantine/pre-shipment (QPS) uses.

Of the 1996 global production of methyl bromide of 71,425 tonnes, approximately 2,759 tonnes (3.9%) was used as a feedstock for chemical synthesis with the remaining 68,666 tonnes produced for fumigation. Based on official data, the 1996 global[3] consumption for fumigation (including that used for QPS) was estimated as 66,750 tonnes with approximately 76% of this being for soil treatment, 15% for fumigation of durable commodities and structures and 9% for perishable commodities. QPS use is 15,000 tonnes, equivalent to 22% of global fumigant use. Production for fumigation peaked in 1992 at 72,967 tonnes and has decreased by 5.9% in 1996 reflecting the freeze already implemented on 1 January 1995 by developed countries.

The Committee noted that some developing countries expect to increase their use of MB substantially, possibly due to an increase in the trade of commodities requiring MB fumigation, while other developing countries expect to decrease their use as strategies are in place to curtail and eventually eliminate MB.

[3] Data quoted on MB consumption excludes feedstock in further quotes in this Executive summary.

1.3.3 Methyl bromide control measures

The current control measures, agreed by the Parties at their ninth Meeting in Montreal in September 1997, can be paraphrased as:

> *For non-Article 5(1) Parties operating under the Protocol (developed countries) a 25% cut in production and consumption, based on 1991 levels, from 1 January 1999, a 50% cut from 1 January 2001, a 70% cut from 1 January 2003 and phase out by 1 January 2005 with provision for exemptions for any critical uses. A freeze on MB production and consumption based on 1991 levels already applies from 1 January 1995.*
>
> *For Parties operating under Article 5(1) of the Protocol (developing countries) a 20% cut in production and consumption, based on the average in 1995-98, from 1 January 2005 and phase out by 1 January 2015 with exemptions for any critical uses. There is also a freeze on MB production and consumption based on 1995-98 levels from 1 January 2002 which was agreed at the ninth Meeting of the Parties in 1997.*

The Protocol provides an exemption under Article 2H paragraph 5 for all Parties for the amounts of MB used for QPS purposes (refer Section 1.6). For those Parties wishing to consider the impact of the QPS exemption MBTOC has provided further information in a chapter in the report on QPS which may be of assistance.

In light of an Assessment to be provided by the Technology and Economic Assessment Panel in 2002 the Parties agreed in Decision IX/5 that for Parties operating under Article 5(1) decisions would be taken in 2003 on further specific interim reductions on MB for the period 2005 and beyond.

1.4 Alternatives to Methyl Bromide of alternative alternative

1.4.1 Definition of an alternative

MBTOC defined alternatives as those non-chemical or chemical treatments and/or procedures that are technically feasible for controlling pests, thus avoiding or replacing the use of MB. Existing alternatives are those in present or past use in some regions. Potential alternatives are those in the process of investigation or development.

MBTOC assumed that an alternative demonstrated in one region of the world would be applicable in another unless there were obvious constraints to the contrary e.g., a very different climate or pest complex.

MBTOC is not required in its terms of reference to conduct economic studies on MB and alternatives[4]. Additionally, while local registration, environmental and social impacts of an

[4] TEAP. 1996. Corrigendum to the TEAP March 1995 Report Concerning Methyl Bromide. Montreal Protocol on substances that deplete the ozone layer. UNEP Technology and Economic Assessment Panel, June 1996: Section 4.1, P118.

alternative were often discussed, these may be specific to the country or local region. Therefore, MBTOC did not consider it appropriate to omit alternatives on such grounds.

MBTOC could find no existing alternatives to MB for about 2500 tonnes of MB per annum used for non-QPS treatments. Based on this relatively small consumption of MB and bearing in mind the above definition of an alternative, there are existing alternatives for more than 95% of the current tonnage of MB, excluding QPS. Significant effort must now be undertaken to transfer these alternatives to as many locations as possible and optimise the conditions under which they can be most effective.

Because of the controls that have been imposed on MB, both globally via the Montreal Protocol and via different national control schedules, a number of agricultural research institutions and private sector organisations are now engaged in work to develop and implement economically viable and environmentally sound alternatives to MB. It is likely that these efforts will result in a wider array of alternatives than are currently available.

1.4.2 Alternatives to methyl bromide for soil treatments

MB as a soil fumigant is the single largest use category accounting for about 76% of global use. It is used as a pre-plant soil fumigant in locations where a broad complex of soil-borne pests limit economic production of crops and particularly in situations where the same crops are grown repeatedly on the same land. MB has been successfully used under a wide variety of cropping systems. The major current categories of use include vegetables, fruits, ornamentals, tobacco and some nursery crops.

Since the 1995 Assessment, significant progress has been made in identifying alternatives to MB for soil fumigation. Approximately 70% of the references in this chapter in the 1998 Assessment have been published since 1994 which is indicative of the amount of research that has been undertaken in the past 4 years. There are a number of examples of alternatives in commercial use in developing and developed countries today. Factors affecting acceptance of alternatives include local availability, registration status, costs, labour inputs and efficacy against target pests.

In spite of the widespread use of MB as a soil fumigant, MBTOC did not identify a single crop that cannot be produced successfully without MB. However, increased investment in research and technology transfer will be necessary to fully implement alternative pest management systems world-wide.

Integrated pest management (IPM) strategies which combine various pest management methods (non-chemical and/or chemical) are the best alternative approach to the use of MB for soil fumigation. The following technologies are important components of IPM programmes:

- Cultural practices such as crop rotation, soil-less culture, organic amendments, biofumigation, planting time, water management and flooding, mulching, cover crops and sanitation.

- Biological control, plant growth promoting rhizobacteria, resistant plant varieties and grafting of annual and perennial crops.
- Physical methods such as soil solarisation and steam treatments.
- Strategic applications of selective pesticides.

As with MB, alternative strategies both chemical and non-chemical, may have human health and environmental consequences which need to be taken into consideration. Some chemicals are effective when used individually against pests where MB was used. Complex pest problems may require the use of combinations of chemicals. Use of these chemicals can result in yields comparable to those obtained with MB.

The chemical alternatives which have recently proven effective for replacing MB in certain situations include, chloropicrin alone, combinations of 1,3-D with MITC generators (metam sodium and dazomet) and combinations of either 1,3-D or MITC generators with chloropicrin. With recently improved application technology, metam sodium and dazomet are used commercially in some countries and can result in yields comparable to those obtained with MB. Considerable success has been obtained with mixtures of 1,3-dichloropropene and chloropicrin in the crops for which most MB is used i.e. tomato, pepper and strawberry production.

There are still chemicals which require research and development to determine their potential as alternatives to MB, e.g. inorganic azides, anhydrous ammonia and furfural.

Advances in research on combinations of fumigants with other chemicals, e.g. herbicides and with non-chemical techniques, e.g. solarisation, improved the efficacy of the chemicals and provided the opportunity for lowering dosage rates and decreasing solarisation periods.

In spite of significant progress in the development of alternatives to MB in the last four years, MBTOC recognises that the complexity of soil pest problems and the diversity of environments in agriculture, require the continued development of non-chemical and chemical methods to broaden the ability to manage pest problems. For example, replant problems in areas with limited land availability and some certified pest-free propagation materials are difficult to solve without MB. These two cases are estimated to use less than 2500 tonnes per annum.

1.4.3 Alternatives to methyl bromide for durable commodities and structures

Durables are commodities with a low moisture content that, in the absence of pest attack, can be safely stored for long periods. They include foods such as grains, dried fruits and beverage crops; and non-foods such as wood products and tobacco. Wood products include: museum artefacts and other items of historical significance; unsawn timber, timber products and bamboo ware; and packaging materials and items of quarantine significance.

Structures include entire buildings and portions thereof which are being treated to control wood-destroying organisms and other pests in non-food facilities. Treatment of structures may also include food production and storage facilities for control of stored product insects

and other pests. Transport vehicles, including ships, aircraft, freight containers and others, may require treatment to control stored product insects, rodents and other pests.

Currently, MB is primarily used to disinfest grain stacked in bags; to disinfest food processing facilities such as mills; to treat durable commodities such as cocoa, grain, certain dried fruit and nuts at the time of export and post-entry; and a variety of quarantine applications, notably treatment of logs.

It is estimated that approximately 12% of the global consumption of MB is for the disinfestation of durable commodities and about 3% for structures. Some of the MB uses for durables, wood products and structures fall within the QPS exemption.

There is a variety of existing alternatives to MB for disinfestation of durable commodities and structures. The principal alternatives in use for durables are phosphine, heat, cold and contact pesticides; for wood products, they are sulphuryl fluoride, chemical wood preservatives and heat; for structures, they include sulphuryl fluoride and heat. The choice of appropriate alternatives is dependent on the commodity or structure to be treated, the situation in which the treatment is required, the accepted level of risk, the speed of action required and the cost. There has been considerable research and implementation activity in this area.

About 40% of the references quoted for this sector in the 1998 Assessment Report have been added since 1994, indicating considerable research and implementation activity in this area in the past 4 years.

There are some current non-QPS uses of MB for which MBTOC did not identify any existing alternatives. For durables, these were: disinfestation of fresh chestnuts; disinfestation of fresh walnuts for immediate sale; elimination of seed-borne nematodes from alfalfa and some other seeds for planting; and control of organophosphate-resistant mites in traditional cheese stores. In the treatment of mills and food processing facilities where IPM systems have failed, it may be necessary to resort to occasional use of MB. Where hydrogen cyanide is not available as an alternative, for example, for disinfestation of aircraft, there are no proven alternatives to MB. The total of these uses is unlikely to exceed 50 tonnes per annum.

MBTOC also did not identify alternatives for a number of QPS uses for MB.

In many cases, an integrated programme combining several different measures can effectively replace a particular use of MB. Some IPM strategies require constant maintenance in order to succeed. Occasional full-site or curative treatments may be required to supplement IPM programmes. These may involve fumigation, possibly with MB, or other processes.

Phosphine is the only available in-kind alternative extensively used, principally for stored cereals and similar products. There are several other fumigants which may have limited potential as alternatives for MB. Treatment with controlled atmospheres based on carbon dioxide or nitrogen offers an alternative to fumigation for insect pest control, but not fungal pests.

Physical methods of insect control, including mechanical measures, cold, heat and irradiation treatments, offer further potential as non-chemical alternatives in individual circumstances. Cold treatments are now used as part of IPM systems for stored products and artefacts. Heat treatment technologies are now used and match the speed of treatment afforded by MB and other fast-acting fumigants. Heating can also synergise the effects of other treatments, for example fumigants, controlled atmospheres and inert dusts.

Where registered for use, contact insecticides may provide persistent protection against reinfestation. In some situations, the use of dichlorvos (although non-persistent) offers a direct alternative to MB for disinfestation of bulk grain at point of export.

Biological agents and botanical compounds have limited application as part of IPM systems at this time. Inert dusts, such as those based on diatomaceous earth, can provide effective pest control in dry grain and as part of an IPM programme in structures.

1.4.4 Alternatives to methyl bromide for perishable commodities

Perishable commodities include fresh fruit and vegetables, cut flowers, ornamental plants, fresh root crops and bulbs. About 9% of global MB consumption is used for disinfestation of perishable commodities, with about half used for disinfestation of fruit for quarantine purposes.

Although global consumption for disinfestation is relatively low in volume, this amount of MB is nevertheless very significant as, in the absence of site-specific alternatives, it allows import and export of high-value perishable commodities. MB used for quarantine treatments is currently exempt from control under the Montreal Protocol.

One of the major uses of MB in this category is to disinfest consignments intercepted on arrival with pests deemed unacceptable to the importing country. If one or more pests are detected, MB fumigation is by far the most predominant treatment to meet importing country phytosanitary requirements. Mandatory treatments in the exporting country may be required if pests are difficult to detect or if the pest is of extreme concern to the importing country.

These disinfestation treatments are crucial for minimising the risk of plant pests becoming established in new regions. Quarantine pests accidentally released into a country or region previously free of them can result in considerable cost to the importing country caused by suspension of exports, eradication measures and implementation of a disinfestation treatment for export commodities if eradication is not achievable. In addition, a minor quantity of MB is used to prevent the spread of exotic pests domestically.

MBTOC identified at least thirteen different categories of alternative treatments e.g. heat, cold, irradiation, that are approved by regulatory agencies in one or more countries for disinfestation of perishable commodities, but only for very specific applications. Only a small proportion of commodities in commercial trade are treated in the export country using these alternatives as most countries have specific requirements for proving the efficacy for each commodity-pest combination. Post-entry alternative treatments used by the importing country are particularly problematical because many alternatives have neither been approved

for treating a specific product on arrival, nor would they be easy to implement. To solve this problem, a range of alternatives are urgently needed to cope with a large and highly varied volume of produce entering via multiple air and sea ports. Such treatments would need to be able to treat perishable commodities quickly in order to avoid congestion at air and sea ports.

In the future if MB for quarantine treatments is not permitted and if no alternatives to MB are available to disinfest consignments intercepted with pests of quarantine concern, infested consignments may be prohibited until satisfactory on-arrival treatments are developed and approved, or the consignments may be re-shipped or destroyed. Alternatively, import of consignments considered high risk for pest infestation may be prohibited, until an alternative treatment has been implemented in the exporting country to reduce pest contamination to a level acceptable to the importing country.

Alternatives to MB for perishable commodities include those based on: (1) pre-harvest practices and inspection procedures; (2) non-chemical treatments; and (3) chemical treatments.

Those based on pre-harvest practices include a description of cultural techniques leading to pest reduction, agreement on pest-free zones and inspection certification. In these cases, regulatory approval depends on a number of factors including: knowledge of the pest-host biology; evidence of commodity resistance to the pest; trapping and field treatment results; surveillance for pests and diseases; and careful documentation.

Non-chemical treatments kill pests by exposure to changes in temperature and/or atmospheric conditions, or high energy processes such as irradiation and microwaves, or physical removal using air or water jets. Often a combination of treatments is required to kill pests because they can be tolerant to treatments applied singularly. A greater understanding of the physiological changes occurring in both pests and commodities will be essential to expedite the development of disinfestation treatments based on these non-chemical alternatives.

Chemical fumigation treatments are feasible, but the number of chemicals is currently limited mainly because companies are reluctant to make submissions for registration, due to the high costs of demonstrating compliance with health and safety standards. However, in some circumstances e.g. cut-flower exports, chemical dips can be a practical and efficacious method to control pests, particularly if occupational standards for their safe use and disposal are implemented and the treatment is approved by the importing country.

For each category of alternative to MB, MBTOC noted country-specific regulatory agency approval for specific commodities or several commodities within a class (e.g. citrus): heat treatments for at least eleven commodities including citrus, mango, papaya, bell pepper, eggplant, pineapple, squash, tomato and zucchini; chemical treatments for citrus, vegetables, cut flowers and bulbs; cold treatments for apples, pears, citrus, grapes, kiwifruit, carambola and avocado; pest-free zones for apples, berryfruit, some vegetables, cucurbits, avocado and papaya; the systems approach for citrus, apples and melons; and irradiation for papaya, litchi and carambola. Currently, there are no approved alternatives for economically important exports such as apple, pear and stonefruit hosts to codling moth; for berryfruit; for grapes

infested with, for example mites, exported to some countries; and many root crops exported by countries if soil is present or pests of concern are detected on arrival.

MBTOC identified where alternative research was possible within each category. Commercialisation of any of these treatments as replacements for MB will depend on a number of factors that includes: proven treatment efficacy; commodity tolerance; equipment design and commercial availability; cost competitiveness; regulatory approval; logistical capability; availability and agreement on the scientific research required for regulatory approval; and technology adoption. Given all of these considerations, the time from conception to implementation of a disinfestation treatment for perishable commodities can vary from 2 to 15 years.

1.5 Developing Country Perspective

Based on official data, MBTOC estimate Article 5(1) Parties consume 15,350 - 17,500 tonnes of MB per annum which is equivalent to 23-26% of global consumption. MB is used in developing countries mainly as a pre-plant soil fumigant for producing certain high value exports such as tobacco, cut flowers, strawberries, bananas, melons; and tomatoes, peppers and some other vegetables. MB s other significant use in developing countries is for disinfestation of durable commodities. About 70% of MB is used for pre-plant fumigation and about 20% for durable commodities. MB is not used in the production of staple foodstuffs.

The quantities of MB used in developing countries varies widely. Some countries have officially phased out or greatly reduced their consumption over the past four years. Decrease in MB use may be due to the adoption of alternatives such as: (1) non-chemicals (crop rotation, soil amendments and compost, resistant varieties, grafting, cultural practices, soil-less culture, solarisation) and chemicals (metam sodium, dazomet, chloropicrin and others) for soil borne pests; (2) phosphine (alone or in combination with carbon dioxide) for grain treatment; (3) heat treatments for perishable commodities; and (4) sulphuryl fluoride for structures and non-food commodities.

In contrast, some countries have substantially increased their usage and in some cases production and may increase MB use still further unless alternatives are adopted. Increase in MB use may be due to a combination of factors including: lack of national strategies for phasing out MB; the slow transfer of alternative technologies; marketing of MB by manufacturers and suppliers; and concern regarding pest resistance to phosphine. It is also possible that some countries are importing MB to stockpile as a hedge against price increases.

Developing countries are concerned that MB use may shift from developed to developing countries in the future as a result of earlier phase out in the developed country. In view of the changing pattern of MB consumption in Article 5(1) countries, it would be prudent to monitor both the policies and practices that encourage or discourage the use of MB and its alternatives, in order to avoid developing countries being left with outdated pest control technology.

Alternatives to MB in developing countries are similar to those in developed countries. At present there is no single in-kind alternative for all uses of MB in developing countries. The adaptation of alternatives is often constrained by socio-economic conditions, level of infrastructure and other conditions found in many of these countries. These constraints can be overcome by actions such as early recognition of problems, a national-international focus on seeking solutions and mechanisms for providing technical and financial assistance.

There are a number of crop protection methods that can, together, address the pest problems for which MB is now used. Potential chemical alternatives to MB can be hazardous to humans and the environment and may require registration, regulation and specific training to promote safe and effective use. It should be noted that MB is also hazardous to humans and the environment, requires skilled application and substantial precautions for safe and effective use. Lack of appropriate skills can be a constraint to use of both MB and alternatives in many developing countries.

While it is possible to use alternative materials and methods to substitute for most MB uses, the conditions prevailing in developing countries require that the alternatives to MB be appropriately adapted to specific climatic conditions, cropping techniques, resource availability and target pests. Some replacements to MB may involve significant effort in areas such as research and field testing to adapt alternatives to local conditions, on-farm demonstrations, technology transfer, user education, institutional capacity building, information exchange and training. UNEP-IE and other agencies continue to conduct workshops promoting alternatives to MB in developing countries.

Concern has been expressed regarding future trade restrictions which may be imposed by importing entities upon developing countries that use MB in the production or treatment of export commodities. Such a situation may render the 10-year grace period, currently up to 2015, ineffective. This could be unfavourable to Parties whose growers do not have access to viable alternatives. Furthermore, some Article 5(1) countries report slow progress on implementation of demonstration projects and other conditions necessary to provide growers with the proper pest control strategies to grow, store and export food without MB.

The Executive Committee of the Multilateral Fund under the Montreal Protocol has provided strategy and guidelines for MB projects which will be eligible for funding. A number of projects have already been approved. MBTOC noted that it would be helpful to monitor these projects as part of an overall effort to focus future strategies for the successful adoption of alternatives. Strategies include support for implementation of successful demonstration projects, review of lessons learned from these projects and the need for policy measures and training.

1.6 Quarantine and Pre-shipment

Quarantine applications, as defined under Decision VII/5 of the Montreal Protocol, are treatments that aim *to prevent the introduction, establishment and/or spread of quarantine pests, or to ensure their official control, where official control is that performed by, or authorised by, a national plant, animal or environmental protection or health authority.* .

Pre-shipment applications, defined under the same Decision, are *those 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 use of MB for quarantine and pre-shipment (QPS) is a remaining emissive use which is unregulated under the Montreal Protocol. Although there are some limited essential use exemptions agreed by the Parties for other ODS such as CFCs these only apply after phase-out. Under present controls QPS uses remain exempt from the freeze, reductions and phase-out schedules.

QPS use currently accounts for about 22% of world-wide MB consumption. Preliminary data from four countries indicate that MB used for QPS is increasing for both developing and developed countries.

MBTOC noted that there is some inconsistency in the interpretation of the terms quarantine and pre-shipment. For example, treatment of commodities with MB required contractually, rather than officially, does not qualify as QPS but some Parties appear to be incorrectly exempting this use. This inconsistency would result in an understatement of an individual country s calculated annual controlled consumption in a particular year.

MBTOC noted that there may be inconsistency in the interpretation of pre-shipment treatment defined as directly preceding export . The interpretation may result in multiple applications when a single application of MB just prior to shipment would fully satisfy the sanitary or phytosanitary requirements of the importing or exporting country. In order to be clear for practical implementation of this measure, Parties may wish to define pre-shipment applications as those carried out within 14 days prior to shipment in addition to meeting the phytosanitary and sanitary requirements of the importing or exporting countries.

From current use world-wide, MBTOC provided examples it considered complied with the QPS definition and those which did not. MBTOC also designed a logic diagram to assist in differentiating between Q and PS uses.

Further data collection is required to assess the volume and uses of MB under QPS, the extent of the development of alternatives, the likely operation of exemptions in the future once MB is phased out and the regulations governing the use of QPS treatments.

1.7 Emissions Reduction

Emissions from fumigation operations occur through leakage and permeation during treatment (inadvertent emissions) and from venting at the end of a treatment (intentional emissions). Estimates of the proportion of MB used that is released into the atmosphere vary widely because of differences in usage patterns, the condition and nature of fumigated materials, the gas-tightness of enclosures and local environmental conditions. Also, some MB may react during use, so it is incorrect to equate production with emissions as at least part of MB applied is converted in use to non-volatile materials.

Under current usage patterns, the proportions of applied MB eventually emitted to the atmosphere globally are estimated by MBTOC to be: 32 - 87%, 85 - 95%, 69 79% and 90

- 95% of applied dosage for soil, perishable commodities, durable commodities and structural treatments respectively. These figures correspond to a range of 43 - 87% overall emission from agricultural and related uses, with a best estimate of overall emissions of 73% or 50,240 tonnes (based on 1996 production data).

Available containment techniques for decreasing MB leakage are in limited use world-wide. Lack of adoption is constrained particularly by lack of promotion of relevant technologies and by perceived or real increases in costs, regulatory and logistical problems. A high degree of containment is a prerequisite for efficient recovery of the used MB.

Better sealing of enclosures and the use of less permeable sheeting is an immediately applicable, technically proven means of reducing emissions from soil, durable commodity and structural fumigations. These measures may permit reduced dosage levels while still achieving the required degree of pest control. Many facilities used for fumigating perishables, particularly for quarantine, already have a high standard of gas-tightness leading to very low leakage rates (often less than 2% of dosage).

There has been some limited further research into the development of recovery and recycling systems for MB. Most development work is directed at recovery from commodity fumigation which represents about 21% of global consumption. Some more recent research is aimed at developing simple recycling technologies whereas most of the potential recovery and recycling systems previously considered were complex and too expensive to install compared with the cost of the fumigation facility itself. Some systems would also have had high running costs associated with energy requirements and many would have required a level of technical competence not normally found at fumigation facilities. Only a few special examples of recovery equipment are in current commercial use.

Unlike some other ozone depleting substances where the interim needs of developing countries can be met in part by banks of recycled material, it is unlikely that this method will be practical for MB. This is because some of the MB used in any application reacts and breaks down and because some of the recovery and recycling technologies under development are only suitable for in-plant recycling.

If recovery is to be recognised as an acceptable method of reducing MB emissions to the atmosphere, it will be necessary to set specifications on equipment efficiency, tolerable levels of emission and other factors.

1.8 Technology Transfer

Most technical information generally transfers from developed to developing countries. However, developed countries can learn from developing countries who, through management of pests and diseases in some cases without chemicals, have extensive experience on the use of IPM techniques for controlling pests in soil. Developed countries, on the other hand, have gained extensive experience in post-harvest disinfestation for durable and commodity crops largely as a result of the drive to gain market access for agricultural commodities.

There are therefore benefits to be gained by both developed and developing countries in:

- Effective exchange of information.
- Selecting the appropriate technology for the climatic conditions, cropping techniques, resource availability and target pests.
- Adapting this technology to the local conditions.
- Obtaining sufficient funds to undertake research, technology transfer and demonstration of efficacy.
- Training personnel to carry out new treatments.

Some replacements to MB may involve significant effort in areas such as: accessing new information; research and field testing to adapt alternatives to local conditions; on-farm demonstrations; technology transfer; user education; institutional capacity strengthening; information exchange; and training.

Additional investment in research and technology transfer is required to promote further implementation of alternatives to MB world-wide. Factors affecting their acceptance include local availability, registration status, costs, labour inputs and efficacy against target pests. Developing and developed countries will continue to benefit from technical and financial assistance in introducing and/or adapting alternatives to MB.

1.9 The Future

Approximately 60% of this report is based on scientific literature and private sector expertise not cited in the 1994 Assessment (MBTOC 1995). This suggests that there has been considerable research effort and some adoption of alternatives in the past 4 years, particularly by scientists seeking to find alternatives to MB as a soil fumigant which accounts for more than three quarters of its use.

Increased investment in research and technology transfer will be necessary to fully implement alternative pest management systems for MB world-wide.

Chapter 2

Introduction

2.1 Methyl Bromide

Methyl bromide (MB) is a fumigant that has been used commercially for more than 40 years to control a wide spectrum of pests including fungi, bacteria, soil-borne viruses, insects, mites, nematodes and rodents. A major amount of MB is used for soil fumigation, a moderate amount for disinfestation of durable and perishable commodities, while a minor amount is used for disinfestation of buildings, ships and aircraft.

MB has features that make it a versatile and convenient material for many pest control applications. In particular, it is quite penetrative reaching pests located in relatively inaccessible locations in soil, commodities, buildings and vehicles. Treatment periods including venting and aeration vary from 2-3 hours to about four days according to target pest(s), the concentration required for efficacy and other specifications and regulations.

Although MB is clearly a most useful pest management technique in specific instances, it was listed under the Montreal Protocol as an ozone depleting substance (ODS) in 1992. A phase-out schedule was subsequently agreed by Parties necessitating curtailment of its use in the future (Table 2.1).

There are also a number of concerns apart from ozone depletion which have led countries to impose restrictions on its use. These concerns include: residues in food; toxicity to humans and associated operator safety and public health; and detrimental effects on soil biodiversity. In some countries, pollution of surface and ground water by MB and derived bromide ion is also of concern.

2.2 MBTOC Mandate

The Methyl Bromide Technical Options Committee (MBTOC) was established in 1992 by the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer to identify existing and potential alternatives to MB. MBTOC, in particular, addresses the technical feasibility of chemical and non-chemical alternatives for the uses of MB, apart from its minor use as a chemical feedstock. MBTOC reports to the Technology and Economic Assessment Panel (TEAP) which informs the Parties on scientific, technical and economic matters related to ozone depleting substances and their alternatives.

Information contained in MBTOC s reports contributes to the Parties deliberations on appropriate controls for MB.

Table 2.1 Phase-out schedule agreed at the ninth meeting of the Parties in 1997

Year	Non-Article 5(1) (Developed countries)	Article 5(1) (Developing countries)
1991	Consumption baseline	
1995	Freeze	
1995-98 average		Consumption baseline
1999	25% reduction	
2001	50% reduction	
2002		Freeze
2003	70% reduction	Review of reductions
2005	Phase-out	20% reduction
2015		Phase-out
Critical and emergency uses may be permitted after phase-out if they meet agreed criteria. Quarantine and pre-shipment (QPS) uses are exempt from reductions and phase-out.		
Decisions encouraging advanced phase-out: • Countries may take more stringent measures than those required by the schedules (Article 2 of the Montreal Protocol). • In applying the QPS exemption, all countries are urged to refrain from use of methyl bromide and to use non-ozone-depleting techniques wherever possible (Decision VII/5). • Within the limits of available funding (US$50 million) the Executive Committee of the Multilateral Fund in 1998 and 1999 should approve sufficient financial resources for methyl bromide projects to assist Article 5 Parties to fulfil their obligations in advance of the agreed phase-out schedule (Decision IX/5). • A number of developing and industrialised countries signed Declarations in 1992, 1993, 1995 and 1997 stating their determination to phase out methyl bromide as soon as possible, to reduce the human and environmental impacts of ozone depletion.		

2.3 Committee Composition

MBTOC members come from 11 developing and 12 industrialised countries. There are 39 members of MBTOC comprising 13 (33%) from developing and 26 from developed countries. Representation from diverse geographic regions of the world promotes reasonably balanced documentation of alternatives to MB, based on the wide-ranging expertise of Committee members. Most Article 5(1) MBTOC members are nominated by their governments. A list of members, the sub-committee chairs and contact details for all members is provided in Appendix 1.

MBTOC members participate in a personal capacity as experts and do not function as representatives of governments, industries, Non-Government Organisations (NGOs) or others. Members of MBTOC contribute substantial amounts of work in their own time. To produce each chapter as efficiently as possible, MBTOC members were divided into sub-committees and topics affecting all chapters were discussed and agreed in plenary. The sub-committee chairs for each chapter and MBTOC members are listed in Appendix 1.

For this report, MBTOC met in 1998 in developing and developed countries on three occasions. In addition to progressing work on each chapter, MBTOC viewed examples of alternatives in commercial use and under development on each occasion.

2.4 UNEP Assessments

The first interim assessment for the Protocol on MB was completed in 1992. A full assessment of the alternatives to MB was completed in 1994 and reported to the Parties in 1995 (MBTOC 1995) as a result of Decisions taken at the fourth Meeting of the Parties to the Montreal Protocol held in Copenhagen (Appendix 2). Progress Reports on Methyl Bromide and other issues were subsequently provided to TEAP by MBTOC (TEAP 1996, 1997).

This report has been produced to fulfil Article 6 and Decision VII/34 of the Protocol, requiring a full Assessment of technical and other information on ODS every four years.

2.5 Definition of an Alternative

In this report, MBTOC defined alternatives as:

> *Those non-chemical or chemical treatments and/or procedures that are technically feasible for controlling pests, thus avoiding or replacing the use of MB. Existing alternatives are those in present or past use in some regions. Potential alternatives are those in the process of investigation or development.*
>
> *MBTOC assumed that an alternative demonstrated in one region of the world would be applicable in another, unless there were obvious constraints to the contrary e.g. a very different climate or pest complex.*
>
> *MBTOC is not required in its terms of reference to conduct economic studies on MB and alternatives. Additionally, while local registration, environmental and the social impact of an alternative were often discussed, these may be specific to the country or local region. Therefore, MBTOC did not consider it appropriate to omit alternatives on such grounds.*

2.6 New Information Since 1994

Approximately 60% of the references in this report have been published since the 1994 MBTOC Assessment (MBTOC 1995) which is indicative of the increase in the number of published articles on non-chemical and chemical alternatives to MB. Many of these publications have been presented at international technical workshops and conferences held in Brazil, Spain and the United States of America. These conferences have been well attended by MB stakeholders including scientists, regulators, farmers, environmental NGOs and commercial organisations.

2.7 Report Structure

Chapter 3: Methyl Bromide Production, Consumption and Limitations on Use provides information on the technical and legislative restrictions on MB use and consumer/market limitations in addition to information on production and consumption by sector.

Chapter 4: Alternatives to Methyl Bromide for Soil Treatment covers a range of alternatives for this currently major MB-use area. Discussion of Integrated Pest Management (IPM) strategies predominates and includes:

- Cultural practices (crop rotation, soil-less culture, organic amendments, biofumigation, planting time, water management and flooding, mulching, cover crops and sanitation).
- Biological control plant growth promoting rhizobacteria, resistant plant varieties and grafting of annual and perennial crops.
- Physical methods such as soil solarisation and steam treatments.
- Strategic applications of specific pesticides.
- Combination treatments for obtaining greater efficacy and reducing dosage.
- Case studies on alternatives.

Chapter 5: Alternatives to Methyl Bromide for Treatment of Durables, Wood Products and Structures includes discussions on:

- Phosphine, heat, cold and contact pesticides.
- Sulphuryl fluoride, chemical wood preservatives and heat for wood products.
- Sulphuryl fluoride and heat applied separately for buildings.
- IPM approach combining several different measures.
- Controlled atmospheres.
- Physical measures such as mechanical treatments, cold, heat and irradiation.
- Contact insecticides for persistent protection against re-infestation.
- Biological agents and botanical compounds as part of IPM systems.
- Inert dusts such as those based on diatomaceous earth for use in grain and as part of an IPM programme for pest control in buildings.
- Case studies on alternatives.

Chapter 6: Alternatives to Methyl Bromide for Perishable Commodities includes examples of alternatives currently in use and those under development; highlights current difficulties with the development of alternatives for perishable products; and describes post-harvest pest control alternatives based on:

- Cultural techniques.
- Pest-free zones.
- Inspection-certification.
- Changes in temperature and/or atmospheric conditions.
- High energy processes such as irradiation and microwaves.
- Physical removal using air or water jets.

- Chemical treatments.
- Combinations of one or more of these treatments.
- Case studies on alternatives.

Chapter 7: Developing Country Perspective highlights key factors facing developing countries including:

- MB usage trends.
- Country-specific consumption data.
- MB and its alternatives for soil, durables/structures and perishables.
- Quarantine and pre-shipment uses.
- Technology transfer and project funding.

Chapter 8: Quarantine and Pre-shipment discusses key issues associated with this area which is exempt from controls under the Protocol. Quarantine and pre-shipment (QPS) treatments are common to both Chapter 5 (Durables) and Chapter 6 (Perishables). This chapter:

- Compares key QPS definitions under the Protocol with those allied to it under the International Plant Protection Convention.
- Outlines the implications of inconsistent interpretation of QPS for Parties.
- Provides examples that assist in categorising treatments as QPS or non-QPS.
- Provides a logic diagram to assist Parties to accurately categorise, monitor and report on QPS use.

Chapter 9: Reducing Methyl Bromide Emissions discusses:

- Inadvertent versus intentional MB emissions.
- Emissions estimated from soil, perishable and durable commodities and structural treatments.
- Available containment techniques.
- Research on the development of MB recovery and recycling systems.

At the end of the *Contents* pages, there is a:

- Glossary guide to commonly used terms.
- Citation format.

The *Appendices* contain:

- List of MBTOC members and their contact details (Appendix 1).
- Protocol Decisions relating to the use of MB (Appendix 2).
- World Wide Web locations for information on MB and general information on ozone depletion (Appendix 3).

2.8 References

MBTOC. 1995. United Nations Environment Programme (UNEP) Methyl Bromide Technical Options Committee (MBTOC) 1994 Assessment of the Alternatives to Methyl Bromide. UNEP, Nairobi: 304 pp.

TEAP. 1996. Part IV: Methyl Bromide Studies. *In: June 1996 Report.* United Nations Environment Programme (UNEP) Technology and Economic Assessment Panel (TEAP). UNEP, Nairobi: 162 pp.

TEAP. 1997. The MBTOC April 1997 Progress Report to TEAP and Miscellaneous Methyl Bromide Issues. *In: April 1997 Report Volume I.* United Nations Environment Programme (UNEP) Technology and Economic Assessment Panel (TEAP). UNEP, Nairobi: 221 pp.

Chapter 3

Methyl bromide production, consumption and limitations on use

3.1 Introduction

Methyl bromide (MB) has features that make it a versatile and convenient material for many pest control applications. Exposure periods and concentrations depend on the system under treatment and the target pest(s); and quarantine, contractual, regulatory and other specifications.

This chapter has been written in 4 sections. The first gives a general overview of the uses of MB; the second discusses production and supply; the third consumption and usage by sector and application methods; and the final section discusses the technical and legislative limitations affecting further use of MB including market forces, food retailer policies, eco-labelling and levies.

3.2 Uses of Methyl Bromide

For uses that exceed 400 tonnes per annum, MB can be divided into the following categories:

In soil:

- as a preplant treatment against insect, nematode and fungal pests and for weed control in production of cut flowers, strawberries, tobacco, cucurbits, tomatoes and peppers;
- as a replant treatment for deciduous fruit trees against 'replant disease';
- as a treatment of seed beds principally against fungi for production of a wide range of seedlings, notably tobacco;
- as a treatment to ensure production of pest-free propagation stock, e.g. strawberry runners.

In durables:

- as a treatment against insect pests for cereal grain and similar commodities in storage to restrict damage to the commodity and at point of import or export as quarantine, phytosanitary or contractual measures;
- to control pests of dried fruit and nuts in storage and trade;
- as a quarantine measure for treatment of exported or imported timber, principally against insects and some fungal pests.

In perishables:

- as a phytosanitary or quarantine treatment against insect pests in many fresh fruit, vegetables and cut flowers in export trade.

In structures and transport:

- as a treatment for flour mills and similar premises against established insect infestations;
- as a fumigant, principally against termites, in domestic premises;
- as a treatment of ships and freight containers, either empty or containing durable cargo, against rodents and insect pests, often as a quarantine or contractual measure.

3.3 Production and Supply

MB has a boiling point of 4°C under normal atmospheric pressure. It is normally supplied and transported as a liquid in pressurised steel cylinders or cans. Typically the cylinders range in size from 10 kg to 200 kg capacity. There is also trade in larger cylinders of up to 18 t capacity and in small disposable steel cans, typically of 0.4 1 kg capacity. Decision VIII/14 recognises supply in all of these forms as trade in bulk. MB is usually applied directly from the cans or cylinders in which it is transported, though it may also be decanted from large cylinders and directly applied. Decanting is not permitted in some countries. Supply in small disposable cans or cylinders is common in some regions of the world.

Estimates of MB production and consumption from 1984 to 1996 are given in Table 3.1 and graphed in Figure 3.1. The table includes production figures previously reported by MBTOC together with estimates of production for chemical feedstock. MBTOC did not obtain data on production in the Democratic Republic of Korea. Table 3.2 provides the production data as reported to UNEP by the Parties.

Table 3.1 Gross production and consumption of methyl bromide, in tonnes

Year	North America	Europe	Asia	China, India & former USSR	Other	Total Production	Feed-stock	Fumigant Use
1984	19,659	11,364	10,678	nd	3,871	45,572	3,997	41,575
1985	20,062	14,414	9,743	nd	4,054	48,273	4,507	43,766
1986	20,410	13,870	11,278	nd	4,897	50,455	4,004	46,451
1987	23,004	15,339	12,816	nd	4,531	55,690	2,710	52,980
1988	24,848	17,478	13,555	nd	4,729	60,610	3,804	56,806
1989	26,083	16,952	14,386	nd	5,149	62,570	2,496	60,074
1990	28,101	19,119	14,605	nd	4,074	65,899	3,693	62,206
1991	31,924	18,020	17,396	3,160	6,260	76,760	4,071	72,689
1992	29,466	18,521	16,944	4,040	6,654	75,625	2,658	72,967
1993	30,723	18,286	17,185	1,500	6,463	74,157	3,000	71,157
1994	31,981	18,052	17,427	890	6,271	74,621	3,000	71,621
1995	28,965	16,350	15,784	2,078	5,680	68,857	2,458	66,339
1996	29,679	16,753	16,173	3,000	5,820	71,425	2,759	68,666

Data Sources: nd = no data available

1991 1996 Production for China, India & former USSR: MBTOC estimates
1984 1992 Production for all other regions: MBTOC 1994 Assessment
1993 1996 Production for all other regions: Consultancy Study for US-EPA by Kaiser-ICF
1993 1994 Production for feedstock: MBTOC estimates
1995 - 1996 Production for feedstock: Figures supplied to UNEP by Parties

Figure 3.1 Trend in production (tonnes) of methyl bromide for fumigant uses.

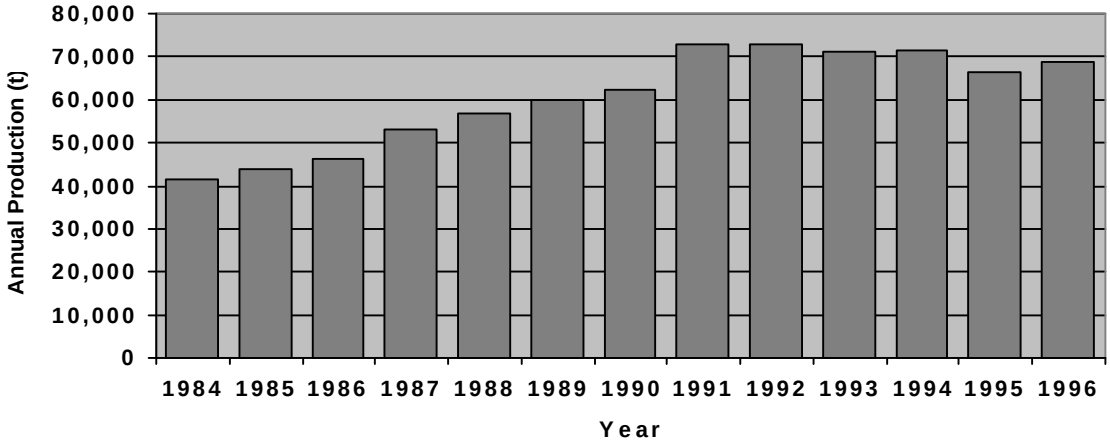


Table 3.2 Methyl bromide production (tonnes) as reported to the Ozone Secretariat by the Parties (by April 1998)

Party	Base	1992	1993	1994	1995	1996
France	3,649	nd	nd	nd	3,294	4,458
Israel	24,500	nd	nd	nd	24,213	23,678
Japan	5,627	nd	nd	nd	5,270	5,015
Romania	nd	nd	4	21	36	18
USA	31,826	nd	nd	28,215	23,941	26,866
Ukraine	0	nd	nd	nd	1,402	1,402
China	nd	nd	nd	nd	nd	1,100
India	124	nd	nd	nd	nd	nd
Total reported	65,726	0	4	28,236	58,156	62,537

nd = no data

3.4 Consumption and Usage

3.4.1 Comparison of production with consumption

There is some discrepancy between the data on production and consumption from various sources. Parties to the Montreal Protocol report data to the Ozone Secretariat for production, imports and exports. Table 3.1 presents data compiled from several sources (listed below the table). A comparison between the various data sets is given in Table 3.3. It can be seen that the discrepancies between the figures are not large, but the data reported to the Ozone Secretariat are generally lower than MBTOC estimates. These discrepancies are probably due to inventory changes, trade with non-Parties and differences in reporting procedures.

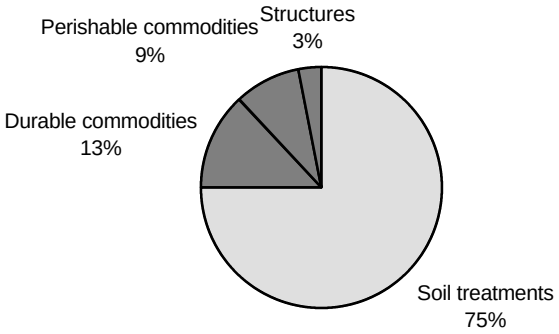
Table 3.3 Comparison of production and consumption data sets

Category of Information and Source		1995 (tonnes)	1996 (tonnes)
Gross Production	Reported by the Parties to the Ozone Secretariat	58,156	62,537
Gross Production	Estimated by MBTOC and for US-EPA by Kaiser-ICF	68,857	71,425
Gross Consumption	Estimated by MBTOC from official data	67,706	66,749
Gross Consumption	Reported by the Parties to the Ozone Secretariat	67,743	64,910

3.4.2 Usage by sector

Global sales of MB from 1984 to 1992 (excluding China, India and former USSR) for major use sectors were reported in the 1995 MBTOC Assessment. MBTOC considers that there has not been a significant shift in consumption by sector from 1992 - 1998 and thus the proportions have remained approximately constant during this period. This 1998 Assessment uses the proportions reported in the MBTOC (1995) Assessment, summarised in Figure 3.2.

Figure 3.2 Analysis of global methyl bromide fumigant use by major sector.



3.4.3 Application methods

3.4.3.1 Soil fumigation

MB is applied by manual application or mechanised injection.

3.4.3.1.1 Manual application

Manual application involves applying MB to soil which has been pre-tarped with plastic sheets. The main method in this application is the so-called hot gas method where liquid MB from cylinders under pressure is vapourised in a heat exchanger and then introduced under the plastic covers.

World-wide except for the USA, this is the principal method of application and almost exclusively the only method used in fumigating soil in greenhouses (glass and plastic houses). In many countries, this method is widely used for outdoor fumigation. In some situations, field fumigation is carried out with mulched strips (strip fumigation) of 0.8 - 1.2 m wide, particularly for row crops such as cucurbits, tomatoes and peppers.

When applied from small steel cans of less than 1 kg capacity, MB is not normally vapourised, but discharged directly from the can under its own pressure, preferably using a specially developed opener. This can be done so as to release MB under the plastic cover without damage to the cover.

MB is often supplied as a mixture containing 2% chloropicrin, added as a warning agent in many instances to comply with national safety regulations.

3.4.3.1.2 Mechanised injection

The second method involves mechanised injection and is the principal method used in the USA, several European countries, Israel, Australia and South Africa. MB from cylinders is applied by injecting the fumigant at a controlled depth, typically 10 - 25 cm into the soil (called shallow injection) the treated area being simultaneously sealed by plastic sheeting. The process is normally carried out as a broad-acre fumigation where one sheet is glued to the previous one. However, some MB application is done under strips of plastic with the edges of the strips buried by the machinery in the soil.

Another system of mechanised injection is deep injection (approximately 80 cm depth) of MB without covering the area with plastic sheets. Deep injection of MB is carried out mainly prior to planting and replanting in deciduous orchards, vineyards and other plantations, mainly in the USA.

A variety of mixtures of MB and chloropicrin are used in this type of fumigation. In many situations a 2% chloropicrin in methyl bromide mixture is used, but under certain conditions, 30 - 70% chloropicrin may be included in the formulation.

3.4.3.2 Commodities and structures

MB is typically applied direct from the cylinder through a narrow bore application line (or series of lines) culminating in an atomising jet or series of jets which are designed to enhance the speed of vapourisation of the fumigant. The rate at which the liquid fumigant becomes a vapour is largely dependent on the ambient air temperature. These lines and jets are laid out either on the commodity, or throughout the structure, to try to ensure an even distribution of fumigant. Alternatively, MB is passed through a heat exchanger which vapourises the fumigant before it is applied through suitably perforated distribution pipes, again laid out in such a way to facilitate even MB distribution.

The dose of MB is calculated according to label, contractual, or legislative (e.g. quarantine) requirements. The required dose is applied by weighing the cylinder of liquid MB and allowing the correct amount to be released, taking into account the volume of space and commodity.

In the case of fumigation facilities for commodities, this will vary from well-sealed, purpose-built fumigation chambers (portable and fixed) to very poorly sealed bagged stacks. In between these extremes, are ships holds (sometimes very well sealed, but not always); freight containers (often not very gas-tight); and well-sealed bagged stacks with laminated sheeting (can be very gas-tight).

In the case of structural fumigation, the gas-tightness varies from aircraft (sometimes very gas-tight); ships holds; modern food factories and mills (can be very gas-tight); to older buildings such as many flour mills (often not very gas-tight and in many cases, impossible to make more than partially gas-tight).

Normally, in all these situations fumigation is carried out for a pre-determined period to try to ensure sufficient time for MB to penetrate to the target pest(s) and that the *ct*-product needed to eradicate all stages of the pest life-cycle has been achieved in the most difficult-to-penetrate part of the enclosure under treatment.

Technology exists to enable the *ct*-product to be monitored during the fumigation. Generally, much lower doses can be utilised in many cases to achieve the same results compared with unmonitored treatments. The concentration must be achieved in critical areas of the treatment enclosure, e.g. in the centre of the commodity bulk. Quality assurance programmes will normally specify that concentrations are monitored, but in practice monitoring is rarely carried out as it is normally cheaper to use more MB than to measure concentration and adjust treatment accordingly.

In structures such as buildings, ships and aircraft the same principles and application techniques apply, but the *ct*-product must consider the floors, walls and machinery where deep-seated and inaccessible pests are the targets. Accurate monitoring, lower doses and the ability to add more fumigant are increasingly becoming more widely used, rather than the still widely practiced method of over-dosing to try to guarantee success.

In many countries, commodity and structural treatments are now carried out with 100% MB formulations, superseding formulations containing 2% chloropicrin.

3.5 Limitations on Methyl Bromide Use

3.5.1 Technical limitations

Although MB is well recognised as being a most useful fumigant, there are a number of technical factors which restrict its application. Not only have these tended to limit its field of application, apart from direct economic considerations, but some have also led to legislative and other restrictions independent of its detrimental effect on the ozone layer.

MB can have adverse effects on a number of commodities, causing taint and odours. These are listed in Bond (1984). It also has substantial phytotoxicity. This makes it an effective treatment for controlling weeds, but it can limit its usefulness in pest control of growing plants and perishable commodities, sometimes resulting in reduced storage life (e.g. of cut flowers) or preference for alternatives.

Treatments with MB result in production of bromide ion residues. These may accumulate to excessive levels in commodities that are fumigated several times. In the case of soil fumigation, bromide ion residues have been a cause for concern in ground water in some European countries such as the Netherlands (see Section 3.5.2).

A major limitation to MB use is its toxicity to humans. Many countries restrict the actual application of MB to trained and licensed fumigators. The regulations may specify appropriate safety equipment and airing times for removal of residual gas after treatments. Additionally, there may be stringent controls on allowable concentrations in workspaces and in the environment around fumigation sites. The toxicity to humans has been reviewed in detail (WHO/IPCS 1995).

3.5.2 Legislative limitations

A number of countries have introduced regulations or policies that restrict the use of MB. Some have introduced restrictions in response to its status as an ozone-depleting substance (ODS) but others such as the Netherlands put restrictions in place in response to concerns over local environmental contamination (mainly MB in the air and bromide ion residues in the surface water).

The 1994 TEAP Report contains a summary of legislative controls on MB in various countries. Since that report, the EU, Italy, Canada, Sweden and Denmark have all increased their present or future restrictions on MB.

The European Union currently controls ozone depleting substances through Council Regulation (EC) No 3093/94 on substances that deplete the ozone layer, which came into force on 23 December 1994. The EU introduced a 25% cut in the production and supply of MB based on 1991 levels from 1 January 1998 in advance of the Protocol. The Regulation requires all precautionary measures practicable to be taken to prevent leakage from MB fumigation and notes that regular review of permitted uses of MB is desirable.

The European Commission adopted a proposal for a new EC regulation on ozone depleting substances in July 1998. The proposal would introduce, *inter alia*, a phase-out of MB from 1 January 2001 and removal of the QPS exemption. It also contained provision for a critical use exemption system to apply after phase-out. The Commission s proposal has yet to be agreed with the Member States of the European Union.

In 1994, Denmark agreed to a Regulation to phase-out its major use of MB (greenhouse tomatoes) by 1996 and to phase-out all remaining uses by 1998 (Ministry of the Environment 1994). The Regulation does not provide any exemptions for QPS use. The Ministry may grant permission for a fumigation in exceptional circumstances, if an applicant can prove no alternatives can be used and that efforts have been made to develop an alternative. Denmark successfully completed its phase-out of MB by January 1998 (Ministry of the Environment 1998).

The Netherlands completed its phase-out of the use of MB for soil fumigation by 1992 with very restricted uses still permitted for some commodity treatments.

Table 3.4 lists examples of countries that have adopted legislation or policies for phasing out MB faster than agreed under the Montreal Protocol schedules.

Table 3.4 National legislation and policies for reducing or phasing out MB faster than the Montreal Protocol schedules

Country	Measure and year adopted	Agreed phase-out or reductions
Canada	Policy Regulation 1994	Phase-out by 2001 25% cut in 1998 • Permit required for importing MB for QPS
Austria	Policy Regulation	Phase-out by 2000 Phase-out storage facility use by 1998
Denmark	Regulation 1994	Phase-out by 1998 • Certain uses eliminated by 1995 • Main use (glasshouse tomatoes) phased out by 1996
Finland	Regulation	Phase-out by 1999
Sweden	Regulation 1994	Phase-out by 1998 • Soil treatments phased out by 1993 • Other uses: 25% cut in 1995 • Other uses: 50% cut in 1996/7
Colombia	Resolution 1996	Phase-out required (1)
Indonesia	Decree 1994	Phase-out imports by 1998
European Union	Regulation 1994 Proposal July 1998	25% cut in 1998 • Requiring all practicable measures to prevent leakage • Noting that regular review of permitted uses is desirable Phase-out by 1 January 2001 No exemption for QPS Critical use exemption after phase-out
Germany	*(1)*	Soil treatments for food crops and treatments for stored grains have been phased out
Netherlands	*(1)*	All soil treatments have been phased out
Switzerland	*(1)*	Soil treatments not permitted
Italy	Regional Ordinance 1983 National Ordinance 1994 *(2)*	MB use prohibited in region of Lake Bracciano • Fields may be fumigated only one year in two • Buffer zones • Application rate (dose) reduced

Note: Some regulations allow exemptions for essential uses or for QPS uses.

(1) Introduced because government agencies were primarily concerned about water contamination, food residues and/or occupational and community safety.

(2) Introduced as a pesticide control measure by the Ministry of Health.

Several Article 5(1) (developing) countries have also introduced regulations to restrict the use of MB. Colombia's Ministry of Health banned the production, marketing and use of MB in 1996, giving 3 months for the elimination of stocks. Use of MB for quarantine was exempted from the ban until substitutes become available (Isaza 1997, Ministerio de Salud 1996). Indonesia introduced a Decree in 1994 which aimed to phase-out MB imports by 1998 due to its threat to the ozone layer and harm to humans (Menteri Pertanian 1994). Limited exemptions may be allowed in future.

A number of Article 5(1) countries have previously restricted use of MB because of safety concerns. Belize, for example, used limited amounts of MB in the past for grain fumigation, but all use of MB was prohibited by pesticide controls because it was considered 'highly toxic to man' among other factors. Belize may however permit MB for emergency quarantine situations (Pesticides Control Board 1998). Tunisia has not registered MB as a pesticide, so it cannot be used for soil (Besri 1998).

Under its Clean Air Act, the USA finalised regulations for early phase-out by 2001. In October 1998, an addition was made to the Appropriations Bill for the Department of Transportation and related agencies, which delays phase-out to 2005 and introduces consumption cuts that comply with the Protocol schedule (Anon 1998).

3.5.3 Consumer/market preferences

In addition to technical and legislative limitations, there are a number of commercial and market limitations on the use of MB. Decision VII/29 of the Parties requested TEAP provide information on possible uses of market-based measures relating to MB (TEAP 1997). This section up-dates information on market measures, covering government promotion of market mechanisms and cases where companies have provided leadership in reducing reliance on MB.

3.5.3.1 Importance of market factors in phase-out

A Multilateral Fund study has identified the importance of market factors in the timing and success of phase-out for ozone-depleting substances (ODS): "*The first primary factor affecting the phase-out relates to the markets for ODS technologies and the associated alternatives. Various market forces drive enterprises to stop using ODS. These include, for example, international and domestic trade pressures and the prices of both ODS and alternative technologies. The nature and direction of these forces play an important role...*" (UNEP 1994).

TEAP identified the significant role of market factors and voluntary actions by leadership companies, when it reviewed the lessons from phase-out of CFCs and halons in industrialised countries. TEAP noted that many experts and users in 1987 felt CFCs and halons would be largely irreplaceable. In retrospect, these early perspectives failed to appreciate the potential for technical innovation, the power of market forces, the efficiency of public/private partnerships and the influence of chemical companies and user industries that supported ozone-layer protection and the leadership of specific companies that pledged early phase-out (TEAP 1995).

Users, suppliers, supermarkets and manufacturers in some regions have adopted, or are starting to adopt, alternatives in response to concerns about ozone depletion or as part of policies to reduce reliance on pesticides in general. Market changes, such as the ones identified below, are likely to become more prevalent as companies and the public become more aware that MB is a controlled ODS.

3.5.3.2 Users and pest control companies taking leadership in alternatives

In recent years, farmers and pest control suppliers in some regions have adopted alternatives reported extensively in other chapters of this Assessment. In some cases, users have taken a significant leadership role in adopting alternatives and examples include the following:

- A major US pest control company, Fumigation Service and Supply Inc and its sister company Insects Ltd, took the lead in trials and the commercial adoption of alternatives for commodities such as grains and structures, e.g. food processing plants and flour mills.
- The Canadian government has strongly encouraged Canadian companies to take a leadership role in the development and adoption of alternatives. For example, many individual farmers growing strawberry nursery plants for the USA took the economic chance of switching to other alternatives. Of particular note has also been the contribution of individual member companies of the Canadian Pest Control Association and the Food and Grocery Products Manufacturers. These companies have participated in joint demonstration projects aimed at testing the effectiveness of alternative techniques to MB fumigation in structures. Working co-operatively, they are now implementing complex IPM procedures which have eliminated and/or greatly reduced their need for MB (Environment Canada 1995, Agriculture & Agri-Food Canada 1996; Agriculture & Agri-Food Canada 1997).

3.5.3.3 Supermarket policies on MB

Supermarkets purchase large quantities of fruit and vegetables from around the world. Several supermarket chains have adopted policies on MB, for example:

- Sainsburys, a major supermarket in the UK reports that some of its contracts with suppliers specifically prevent the use of MB. Under Sainsburys IPM programme the use of MB is not permitted for certain crops and for all other crops " *use is being reduced as much as possible as soon as possible* " (Prospect 1997).
- The Co-op supermarket in the UK, reports that they " *have taken the lead in banning the use of MB as a soil fumigant on our own farms and are talking to our suppliers about phasing out its use.*" in the cultivation of other produce sold in Co-op shops (Prospect 1997).
- Another UK supermarket, Waitrose, reports that it is " *actively discouraging the use of this chemical* " (Prospect 1997).
- In Sweden, several supermarkets have contacted suppliers of canned tomatoes in Italy, to ascertain whether MB was used when growing the tomatoes (Berkow 1997).

3.5.3.4 Policies of manufacturers, traders and auction houses

Companies manufacturing food and tobacco products, wholesalers, auction houses and other trading companies often set conditions or specifications for product quality and other parameters in contracts. Grain importers, for example, sometimes specify in commercial contracts that grain must be treated with MB before shipment. In several cases, manufacturers or traders have now ruled out the use of MB.

Some European tobacco companies have informed tobacco producers in Zimbabwe that they will no longer accept post-harvest or pre-shipment treatments with MB. This is because MB can adversely affect the quality of tobacco and because of its environmental effects. Phosphine is now frequently used instead (Miller *et al.* 1996).

Some tobacco companies purchasing tobacco from Asian producers have also stated that they do not want tobacco to be treated with MB in storage or prior to shipment (UNDP 1995).

Major flower auction houses in Europe (the Netherlands) successfully operate an environmental quality scheme in which flowers are produced according to standards on pesticide use, water and energy waste. The scheme does not allow the use of pesticides that are not registered (permitted) in the Netherlands which eliminates the use of MB. The auction houses and several flower export farms in Kenya and Israel have started pilot projects monitoring environmental impact, including use of MB. Their performance will be evaluated after one year to determine whether the exporters are able to qualify for the environmental quality scheme (Klijnstra 1998).

3.5.3.5 Eco-labelling and product information

A number of countries, including developing countries, have initiated eco-labelling or environmental labelling schemes for refrigerators and other products that utilise ODS. Factual labelling allows purchasers to select products with fewer environmental impacts if they wish, enabling consumers and the market to express preferences. For example, under the Clean Air Act in the USA, products manufactured with CFCs and other ODS, with the exception of MB, are required to carry a special consumer label which reads "*Warning: manufactured with [name of ODS], a substance which harms public health and environment by destroying ozone in the upper atmosphere*" (Clean Air Act section 611).

Under Decision VII/29, TEAP analysed the role of eco-labelling in relation to MB, noting that "*The purchasing decisions of consumers can also be influenced by product information on the environment which in turn affects production, use and disposal of specific products. Eco-labelling systems are widely used. Those Parties that are not yet using Eco-labelling systems to promote the objectives of the Montreal Protocol might consider the benefits of adding such a market-based measure to their ozone protection policies.*" (TEAP 1997).

MBTOC is not aware of any cases where products grown or treated with MB are labelled. However, in limited cases, strawberries, bread and nut products have been labelled to inform customers that MB has not been used. For example, one label reads *Ozone friendly Methyl Bromide* was <u>not</u> used in growing and storing this fruit (*A toxic pesticide that attacks the ozone layer)* . Labels are used on a very small range of products at present.

Consumer and environmental organisations in several regions have requested labelling so that purchasers can exercise a choice. For example, the Food Commission, a consumer advocacy group in the UK, has asked supermarkets to label fruit and other produce: "*Grown without the use of Methyl Bromide*". The Commission reports that it has requested labelling " *so customers can choose environmentally-friendly fruit* " (Food Commission 1997). In the USA, Friends of the Earth, the Natural Resources Defence Council, Pesticides Action Network and other organisations have requested labelling of products produced with or without MB (NRDC *et al.* 1993, MBAN 1995).

3.5.3.6 Levies and taxes on methyl bromide

In some countries levies or taxes have been placed on ODS and pesticides for environmental purposes, such as raising revenue for the development of alternatives and raising prices of environmentally damaging activities to encourage users to adopt alternatives. Several governments have introduced such taxes as a step towards implementing the polluter pays principle.

3.5.3.6.1 Example of voluntary levy on MB

In 1995 MB users in Australia decided to introduce a levy of about AU$ 0.20 per kilogram of MB sold (Prospect 1997). Recently, the National Consultative Group (of users and other stakeholders) agreed in principle to double the levy from 1998, to about AU$ 0.40 per kg of MB (Environment Australia 1998). The levy is collected at wholesale level by the importers. In 1998 it raised approximately AU$250,000 which was matched by funds from the national Horticultural Development Corporation, giving about AU$500,000 for research and demonstration in addition to funds specifically for communication about alternatives to farmers (Porter 1998). In addition, the increased prices have made alternatives more attractive for commercial use and increased grower acceptance of the need for research.

3.5.3.6.2 Taxes on ODS chemicals

The Czech Republic's Ozone Protection Legislation (1995) placed a tax on producers and importers of ozone depleting substances. The revenue is used by the State Environmental Fund for ozone protection. From January 1996 the tax was applied to MB (Parliament of the Czech Republic 1995).

Since 1996, the Environmental Protection Agency in Australia (now called Environment Australia) has required MB importers to purchase import licences at a cost of about AU$10,000 for each two-year period. In addition, the Australian EPA charges an administrative handling fee of about AU$90 per tonne of imported MB (Australian EPA 1996). Some of these funds are put into an Ozone Fund to contribute to phasing out MB and other ODS.

Some countries have experience of taxes and levies on pesticides in general, providing other models. In Sweden, an environmental levy of approximately US$1.50 per kg of active pesticide ingredient raises about US$3 million per year for research and extension in non-chemical and IPM methods (Watts 1996). Denmark has also placed an environmental tax on pesticides as a polluter pays measure, raising about US$40 million in 1996 for

environmental programmes and research on non-chemical techniques (Agrow 1995). India charges an 18% duty on imports of most pesticides (UNEP 1998).

3.5.3.6.3 Taxes on products

TEAP notes the following point about potential domestic product taxes on MB:

> *The market prices of goods produced using MB could be driven up to discourage demand by imposing specific product taxes. Such measures would require a means of differentiating between products which have been produced or treated with MB and those that have not and a certification process for the proper implementation of a tax.* (TEAP 1997).

Certification systems for food products are in existence and examples can be found in the international and national certification procedures for organic food products. MBTOC is not aware of any cases where taxes or levies have been placed on products grown using MB.

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Chapter 4

Alternatives to methyl bromide for soil treatment

4.1 Summary

Since the 1995 MBTOC Assessment, a great deal of research has been conducted world-wide to replace methyl bromide (MB) for soil treatments. In the past, this fumigant was considered irreplaceable for soil treatments but now MB is considered fully replaceable as shown by each alternative that is successfully implemented. Major achievements have been realised in the development of alternatives for soil fumigation, indicated by 70% of the references in this chapter having been published since 1994.

Alternatives developed to replace MB aim to do so without loss of crop yield and quality. Factors affecting acceptance of alternatives include local availability, registration status, costs, labour inputs and efficacy against target pests.

Integrated pest management (IPM) which combines various pest management methods is the best alternative to the use of MB for soil fumigation. The following technologies are important components of IPM programmes which have the potential to replace MB.

Crop rotation is the planting of successive crops that are non-hosts, less suitable hosts, or are trap or antagonistic crops for the target pathogens. The efficacy of crop rotation systems depends on the life cycle and other characteristics of the pests. While crop rotation has historically been associated with field agriculture, new crop rotation systems in intensive greenhouse production of vegetables are now providing solutions for some pest problems.

Organic amendments such as composts, composted sewage sludge, animal manures, green manure, by-products from agriculture, forest and food industries are used in many countries to control soil-borne pests in various crops. Their use is localised, limited by the availability of suitable raw materials and transportation costs.

Biofumigation is the amendment of soil with organic matter that releases gases which control pests. It is already in practice in some countries and is a promising control method that needs further development for wider acceptance.

Other cultural practices such as appropriate planting time, water management and flooding, mulching, cover crops and sanitation, can also contribute to the control of various soil-borne pests.

Soil-less culture is a method in which substrates provide an anchoring medium that allows nutrients and water to be absorbed by plant roots. One of the purposes of using this system is to avoid soil-borne pathogens. The methodology of culturing on different kinds of substrates is widely used, primarily for greenhouse and tunnel culture. Under appropriate conditions, soil-less substrates increase yields and present a better cost-benefit ratio than MB.

Biological control of soil-borne pests is the use of beneficial organisms as control agents. There are some commercial products in use in several crops in many countries. They can be used in combination with other disease control strategies e.g. steam, solarisation or chemical controls.

Production of disease resistant plant varieties involves incorporation of special one or more genes for resistance or tolerance. Resistant varieties are used universally to control pests for which MB is used. The lack of sources of resistance, the appearance of new races and instability of resistant genes under unfavorable environmental conditions (e.g. high soil temperatures and high salinity) limit the use of this strategy.

Grafting is a method that consists of using resistant rootstocks for susceptible annual and perennial crops to control soil-borne pests. Recent application of grafting technology to annual crops has replaced the use of MB in the production of tomatoes, watermelons and other curcurbits in some countries.

Plant growth promoting Rhizobacteria (PGPR) can prevent attacks from several soil-borne pathogens. Existing PGPR-based products and strains of PGPR are commercially available and have proven to be beneficial components in integrated strategies to replace MB in some countries.

Soil solarisation occurs when heat from solar radiation is trapped under clear, plastic sheeting to raise the temperature of moist soil to that lethal to soil-borne pests. Solarisation is also efficiently used for the disinfestation of agricultural material, such as nursery substrates and plant stakes. While it was first used in hot arid and semi-arid areas, recent advances in technology have extended its use to other cooler regions of the world where it was once regarded as impractical.

Steaming for soil pasteurisation is a well established and effective technique for control of all soil-borne pests in bulk soil, in greenhouses, for nursery beds and small-scale field operations. Energy-efficient steaming techniques are now commercially available. Use of steam for large-scale, open-field production systems requires further development.

Several combinations of chemicals are effective for replacing MB for soil fumigation. Use of these chemicals can result in yields comparable to those obtained with MB. Some chemicals are effective when used individually against single pests where MB was used. This demonstrates that it is not always necessary to have the broad spectrum activity provided by MB to solve some pest problems. A considerable amount of research involving multiple growing seasons, locations and pest pressures is being conducted to expand the use of chemical alternatives. As with MB, use of chemical alternatives may have human health and environmental consequences which must be taken into consideration.

The chemical alternatives which have recently proven effective for replacing MB in certain situations include, chloropicrin alone, combinations of 1,3-Dichloropropene (1,3-D) with MITC generators (metam sodium or dasomet) and combinations of either 1,3-D or MITC generators with chloropicrin. With recently improved application technology metam sodium and dasomet are used commercially in some countries and can result in yields comparable to those obtained with MB. Considerable success has been obtained with combinations of 1,3-D with chloropicrin in crops for which most MB is used i.e. tomato, pepper and strawberries.

Recent advances in research on combinations of control measures e.g. herbicide combined with solarisation, has provided the opportunity for reduced rates and treatment time without reducing treatment efficacy.

There are some instances where MB replacement will be very difficult. For example, it is likely that MB will be required for some time to solve replant problems that occur in areas where the same land is used repeatedly due to limited land availability and for producing pest-free propagation materials.

Despite the widespread use of MB as a soil fumigant, MBTOC did not identify a single crop that cannot be produced successfully without MB. Although significant progress in developing alternatives to MB has been made in the last four years, MBTOC recognises that the complexity of soil pest problems and the diversity of environments in agriculture require the continued development of non-chemical and chemical methods to broaden the ability of farmers to manage pest problems. In order to achieve this, further investment in research and technology transfer will be necessary to implement alternative pest management systems more widely.

4.2 Introduction

The 1995 MBTOC Assessment identified a wide range of procedures that under particular circumstances can act individually or in combination to replace or reduce the need for MB treatments. Advances in their use are discussed below. These are arranged as in the 1995 Report, with the addition of emerging techniques such as 'biofumigation' which were not previously reported (MBTOC 1997). There are a number of chemical and non-chemical technologies that can replace MB fumigation in specific crops and situations.

Since 1994 a great deal of research has been conducted and is continuing world-wide to develop technologies that will replace MB fumigation without loss of crop yield or quality in crops where MB was once regarded to be irreplaceable (Bello *et al.* 1997b, 1998a; Bello and Tello 1997; Muller 1997a; Rodríguez-Kábana 1998a,b; Thomas 1997). Prominent in these research efforts is the development of Integrated Pest Management (IPM) systems suitable

for MB-dependent crops. It should be noted that repeated soil fumigation with MB can result in significant changes in the composition and activities of soil organisms (Marull *et al.* 1997). For alternatives which depend on the activities of soil organisms for their efficacy (e.g. biofumigation, soil amendments and compost) this can be a serious limitation when used in soil with a history of MB fumigation. Therefore, in such cases, re-establishment of the diverse biota typical of non-fumigated soil is a prerequisite and this may take some time.

In spite of the widespread use of MB as a soil fumigant there is no single crop that cannot be produced successfully without MB. Examples of alternatives in use for controlling one or more pests or weeds are shown in Table 4.3 (refer Annex 4.6, this chapter). However, significant investment in research and development and in technology transfer will be necessary to successfully implement alternative pest management systems world-wide. In spite of the development of many effective alternatives, their adoption will be determined by factors such as pest pressure, soil type and climate. It is also recognised by MBTOC that the adoption of alternatives will be influenced by the social, economic, regulatory and political factors within a particular country or region.

4.3 Integrated Pest Management

IPM is based on pest monitoring techniques, establishment of pest injury levels and a combination of strategies and tactics to prevent or manage pest problems in an environmentally sound and cost-effective manner (Daar 1997). It is a strongly recommended approach to the solution of pest problems throughout the world. Site-specific treatment programmes combine two or more methods selected from biological, cultural, physical, mechanical and chemical methods.

The development and establishment of IPM systems require a great deal of effort devoted to the training of technicians and growers. The training must encompass not only technical aspects of production but also matters pertaining to sociology, economics, legal aspects and even anthropology.

There is wide agreement that some IPM systems are needed to replace MB-based systems since no single one-in-kind alternative is currently or likely to become available. The integration of multiple alternative technologies in IPM programmes is the best alternative to the use of MB for soil fumigation (Bello *et al.* 1996, 1998a; Rodríguez-Kábana 1998a,b). The success of these efforts is exemplified by containerised conifers in Canadian nurseries and fresh market tomatoes in northern Florida, bulbs and cut flowers in Australia and Columbia and vegetables in the Netherlands (Banks 1995; Porter *et al.* 1997). IPM techniques are common throughout the Mediterranean area in all manner of intensive agricultural production (Chellemi *et al.* 1996; Cartia 1998; Gullino and Clini 1998; Goncalves 1998; Gullino and Garibaldi 1998; Porcuna *et al.* 1997; Porter *et al.* 1997; Tio 1998). The overwhelming majority of tomatoes in Spain, for example, are produced without MB fumigation (Tello 1998a,b). There are good examples of IPM techniques being used commercially in Italy, Egypt, Jordan, Morocco as well as in other areas of the world (Besri 1997a,b; Bello *et al.*1998a; Boye 1998; Cartia 1998; Chellemi *et al.*1996; Kampf and Maller 1997; Liebman and Daar 1995; Müller 1997a,b; Gullino and Clini 1998; Rodríguez-Kábana 1998b; Yabase 1997).

4.4 Non-chemical Alternatives

4.4.1 Crop rotation and fallow

Crop rotation is the cultivation of successive crops that are non-hosts, less-suitable hosts, or trap and antagonistic crops for the target pests. It is one of the oldest and most reliable methods used in agriculture (Rodríguez-Kábana 1998a).

Fallow consists of temporarily taking land out of production to reduce soil pest populations by denying them hosts or substrate for their development and exposing them to adverse environmental conditions. However, it should be noted that in order to use these methods, additional land may be required to achieve the same production as that obtained from MB-treated soil.

The efficacy of crop rotation and fallow is dependent on the life cycle and other characteristics of the pathogens. For example, some pathogens are long-lived (e.g. microsclerotia of *Verticillium dahliae*, chlamydospores of *Fusarium* spp., oospores of *Phytophthora* spp.). Some survive as saprophytes in competition with the soil flora and fauna, e.g. *Rhisoctonia solani*; and some (e.g. *Verticillium* spp.) have a wide host range. Rotation crops must be selected carefully, because a particular crop may reduce the population of particular pests, while increasing the level of other pests. Such crops must also be selected to consider not only suitability as a non-host crop, but also crop production system economics.

The introduction of crop rotation as an alternative to MB should be encouraged but depends on long term research. Crop rotation systems in intensive greenhouse production of vegetables have provided, in certain cases, solutions for pest problems in Spain (Bello *et al.* 1996, 1997b, Bello 1998; Tello 1998a,b; Vares 1998). Long term rotations of citrus with fruit trees have been effective for suppression of nematode problems (Pastrana 1998). Flower producers in Colombia routinely alternate chrysanthemums and carnations as a way of dealing with soil-borne pests (Rodríguez-Kábana 1998b). Crop rotation for pest control is used in strawberry production in some parts of the USA and Korea (Daar 1997; Kim and Chun 1996). In Morocco, crop rotation in combination with metam sodium (as a fumigant) applied through the drip irrigation system, is successfully used in protected cultivation to control some soil-borne pathogens. The rotation adopted on a 3-year basis includes melon, pepper (hot and sweet) peas, cucumber, tomato and squash (Besri 1997a,b). The combination of fast-growing (short-cycle) crops (mainly crucifers) and organic amendments is effective for controlling root-knot nematode (*Meloidogyne incognita)*. In these systems fast-growing crops serve as trap crops and as sources of organic matter releasing nematotoxic mustard oils (Bello 1998; Kirkegaard *et al.*1993; Mathiessen and Kirkegaard 1993)

4.4.2 Soil amendments and compost

Organic amendments such as composts, composted sewage sludge, animal manures, green manure by-products from agriculture, forest and food industries are used in many countries to control certain soil-borne pests in various crops. However, compost must be held to quality control standards to maintain aerobic conditions to prevent the compost from partially fermenting, producing a sour compost containing organic acids that can be toxic to plants (Hoitink 1988).

Soil amendments including composted softwood and hardwood bark reduce the incidence of many soil-borne pathogens such as *Pythium ultimum*, a pathogen that causes damping-off under greenhouse and field conditions. The addition of chitin into the soil suppresses *Rhisoctonia solani* and additionally may reduce nematodes. Chitin amendments to soil are also known to increase beneficial soil populations of actinomycetes (Rodríguez-Kábana 1998a). Compost has reduced or eliminated MB use in a number of large commercial nurseries in California (Quarles and Grossman 1995). Municipal wastes are increasingly used as compost in the US (Segall 1995; Renkow *et al.* 1994).

Successful organic amendments generally require large amounts (>50 t per ha) of materials to be added to soil. Consequently, their use is localised, limited by the availability of raw material and transportation cost. These limitations can be overcome by using local by-products of agriculture and agro-industry. D'Addabbo (1995) reviewed the literature on organic amendments from 1982-1994. He found a total of 221 papers demonstrating continuing interest in this approach to nematode control. Most of the work is still concentrated in developing countries. Oil cakes were the most frequently used as efficacious amendments, but also green manures and agro-industrial wastes were extensively studied. Most attention has been focused on determining the underlying mechanisms of the nematicidal action of these materials.

Pereira *et al.* (1996) reviewed the suppressive effects of organic composts. Methods based on composting are by definition regionalised and effort should be made to develop composts from inexpensive, locally-available materials. This has been tested in some developing countries such as Morocco, Chile and Brazil. Quality control in compost production is essential to assure its efficacy in pest control. The degree of efficacy of soil-borne pathogens will also vary regionally so that composts that control pathogens in one region may not do so in another region.

Composts from crop residues are used by the Colombian flower industry to amend soil and suppress problems caused by soil-borne pests. At the same time, these crop residues provide plant nutrients and reduce production cost (Rodríguez-Kábana 1998b). Pepper residues are used as amendments in Valencia and Murcia (Spain). Municipal compost residues could be used for control of root-knot nematodes in tomato and pepper crops (Bello *et al.* 1997a; Marull *et al.* 1997). In Castilla-La Mancha (Spain) the application of organic matter in vineyards is normally made by farmers on alternating sides of the row each year so that the quantity of manure necessary is reduced by 50% (Bello 1998).

The combination of calcium cyanamid and shredded wheat straw applied with solarisation (see soil solarisation, section 4.4.12) resulted in >99% suppression of *Fusarium solani* f. sp. *cucurbitae* in Greece (Bourbos *et al.* 1997). In Morocco, cattle manure (60 t/ha) reduces the incidence of *Fusarium* spp. and *Verticillium* spp. wilts in tomato (Besri 1997a). Results from Canada suggest that high nitrogen-containing amendments can be used to control soil-borne pathogens, based on a wide spectrum of organic materials including animal by-products, manures and bio-solids, added to soil in these laboratory and field tests (Lazarovitts *et al.* 1998).

4.4.3 Biofumigation

Biofumigation is the amendment of soil with organic matter that releases gases which eliminate or control pests. This treatment was not reported in the previous 1994 MBTOC Assessment. Biofumigation may be combined with plastic or other soil covers to trap the heat from solar energy, to raise the soil temperature and to retain gases generated during the process. The technique can result in the selection of specific beneficial microflora.

An example of biofumigation is the incorporation of residues of some brassicas and various compositae into the soil (Bello 1998; Bello *et al.* 1997a,1998b). These give off volatile chemicals such as methyl isothiocyanate and phenethyl isothiocyanate which have herbicidal, fungicidal, insecticidal and/or nematicidal properties (Gamliel and Stapleton 1997).

Potential disadvantages of biofumigation have not been clearly defined, but they could include release of phytotoxic compounds, lack of available organic amendments and additional time before planting waiting for amendment decomposition. These potential phytotoxic effects could be eliminated by delaying planting if this is feasible.

There is active research in biofumigation in many crops not currently utilising MB as part of the production process, but now research is being conducted specifically to test the feasibility of biofumigation as a replacement for MB. Preliminary results utilising a brassica biofumigation for tobacco seed-beds in Australia have shown responses similar to that from MB (Angus *et al.* 1994; Kirkegaard *et al.* 1993; Mathiessen and Kirkegaard 1993). The possibilities for developing biofumigation techniques are as diverse as the types of available by-products for the preparation of amendments. The nature of active gases clearly depends on the type of organic matter added to soil.

Biofumigation considerably shortens the time necessary to accomplish acceptable pest control through solarisation and has been used successfully in the production of bananas, tomatoes, grapes, melons, peppers and other vegetables (Bello 1998; Sanz *et al.* 1998). Biofumigation results in the stimulation of soil microbial activity with increased populations of microbivorous (those nematodes that feed on bacteria or fungi) and beneficial predatory nematodes.

4.4.4 Planting time

Many diseases can be avoided by choosing an appropriate planting time. *Fusarium* spp. develop under relatively high temperatures while *Verticillium* spp. favour low temperatures. Tomatoes are attacked both by *Fusarium oxysporum* f. sp. *lycopersici* and *Verticillium dahliae*. Planting these crops during summer months will control *Verticillium* spp. wilt while planting during winter months controls *Fusarium* spp. (Besri 1997a). In the Canary Islands, root-knot nematode in tomatoes can also be controlled by choosing the appropriate planting time (Bello 1998).

4.4.5 Ploughing and tillage

An alternative tomato production system consisting of strip tillage in rotation with pasture has been developed for Florida tomatoes, as a part of an integrated system. Tomatoes are

grown in narrow cultivated beds strip-tilled into bahiagrass (*Paspalum notatum*) pasture. With this system, Florida growers produce commercially marketable yields without MB. The strip-till system produces significant savings (Chellemi *et al.* 1997b).

4.4.6 Water management and flooding

Proper irrigation management can reduce incidence of *Phytophthora* spp. rot and many other soil-borne diseases. There is no doubt that proper water management in the production of vegetables in greenhouses has contributed to improved health of crops in southeastern Spain and many other countries (Tello 1998a). Rainwater is harvested in all Colombian cut flower farms and most growers are currently using drip irrigation to reduce labour costs, accurately control soil moisture and avoid damage from soil-borne pests (Rodríguez-Kábana 1998b). Management of soil moisture by drip, furrow or overhead irrigation, integrated with genetic disease resistance, is used for control of *Phytophthora* spp. in vegetable crops (Café Filho 1997; Café Filho and Dunweg 1995; Café Filho *et al.* 1995).

Control of soil moisture by overhead irrigation has been used to suppress carpogenic germination of *Sclerotinia sclerotiorum* (Ferraz *et al.* 1996). Certain irrigation regimes may increase disease incidence, especially furrow irrigation. Summer flooding and drying helps in control of root-knot nematodes in carrots on muck soils. However, flooding is less effective on sandy soils infested with root-knot and sting nematodes. In some areas of Florida, flooding is used for control of insects (Hall and Cherry 1993). Strawberries are being used in Korea as a rotation crop with paddy rice to reduce weed pressure in rice (Kim and Chun 1996). The availability and quality of water are limiting factors in applying this technique.

4.4.7 Mulching and cover crops

Mulches (soil covers), cover crops and green manures such as various brassicas (e.g. rapeseed) are used for control of a wide range of soil-borne pathogens and insects (Elberson *et al.* 1997). Recent work in Idaho (USA) indicates the potential value of mulching for strawberry and nursery crops such as potted rhododendrons, but more research is needed to make this an economically viable alternative. A red plastic mulch was found superior to black plastic for solarisation of tomato beds to control root-knot nematodes and weeds (Kasperbauer 1997). Translucent, photo-selective, infrared-transmitting mulch films significantly suppressed emergence of yellow and purple nutsedge (*Cyperus* spp.) in both greenhouse and field trials (Patterson 1997). Grass mulches have been used to control *Sclerotinia sclerotiorum* (Ferraz *et al.* 1996).

4.4.8 Sanitation

Sanitation is the avoidance or elimination of pathogen inoculum or pest sources, such as infected plant residues, before planting. Seed bed sanitation in commercial production permits better management of disease problems in horticultural and other crops (Armada 1995; Daar 1997; Tello and Lacasa 1997; Tello 1998a). Sanitation is essential and may even be legally required (Silveira *et al.* 1994).

Sanitation is used for control of fan leaf virus transmitted by nematodes (*Xiphinema index*) in grape production (Arias *et al.* 1997a,b). When sanitation measures are properly implemented, there is no need for soil fumigation with MB (Salles and Belarmino 1997; Tio 1998).

In the production of ornamentals, mother plants are propagated under very rigorous conditions for disease prevention. These include *in vitro* tissue culture in isolated and specialised greenhouse facilities. Fresh, steam sterilised, rice hulls are incorporated into the soil in cut flower production in Colombia to avoid contamination (Banks 1995). In that country, control of *F. oxysporum* f.sp. *dianthi* in carnation greenhouses relies on strict sanitation in addition to other precautions.

The great majority of potential seedling pests can be controlled by means of preventive methods. For producing citrus seedlings, several Brazilian states and other countries require nematode and other pest-free certificates. Space solarisation of greenhouses by closing them during the hot season is a very effective method of sanitation (Shlevin *et al.* 1996).

Physical measures can play a role in the control of soil-borne and bulb-borne pathogens. Dipping bulbs and corms in hot water alone or combined with a pesticide greatly reduces the severity of *Fusarium* spp. rot in gladiolus, iris and ixia (Garibaldi and Gullino 1990; Garibaldi and Migheli 1988; Migheli and Garibaldi 1990; Pandolfo and Garibaldi 1987).

4.4.9 Use of pathogen-free seeds and transplants

Many soil-borne pathogens such as *Alternaria* spp., *Didymella* spp., *Fusarium oxysporum*, *Clavibacter michiganensis* subsp. *michiganensis*, *Verticillium* spp., *Pseudomonas* spp. are also seed-borne pathogens. For these pathogens the primary source of infection can be contaminated transplants or seeds. In some cases, transplants are symptomless when they are moved from the seed beds into the greenhouse. Infected seeds could infest the soil and could also introduce new races of some pathogens such as *Fusarium* spp. in the soil. In general, when infected seeds are used, the disease incidence is higher in disinfested soils than in non-disinfested ones as antagonistic fauna are absent. The use of pathogen-free seeds should therefore be considered as an important component of any IPM programme (Besri 1978, 1997a,b; Gabarra and Besri 1997; Richardson 1990).

4.4.10 Soil-less culture

Soil-less culture is a method in which plant growth substrates provide an anchoring medium that allows nutrients and water to be absorbed by plant roots. Requirements for the method include the substrate and systems for water and nutrient movement, decontamination and sanitation. The method can be applied at various levels of technological complexity. One of the purposes of using this system is to avoid, rather than control, soil-borne pathogens. If re-circulated or discharged irrigation water is used, it requires disinfection to remove certain pathogens (e.g. *F. oxysporum* f. sp. *radicis lycopersici*, *Pythium* spp., *Phytophthora* spp., bacteria) if they have accidentally become established.

Substrates include artificial and natural materials including rock wool, tuff stone, clay granules, solid foams (e.g. polyurethane) glass wool, peat, coconut plant materials, volcanic gravel (lapilli) and pine bark (Aquino 1997; Diaz *et al.*1998). Soil-less culture is used with

numerous crops, including tomatoes, strawberries, cut flowers, melons, cucurbits, bananas, nursery-grown vegetable transplants and tobacco seedlings (Arbelo *et al.* 1998; Arias 1998; Reis 1998; Bello *et al.* 1997b,1998a; Cartia 1998; Cartia and Asero 1994a; Gullino and Garibaldi 1994; Tello 1998a,b).

At this stage, most of the soil-less culture occurs in covered agriculture that can be achieved using facilities such as plastic greenhouses or tunnels in mild climates and glass greenhouses in cold climates (Barry 1998). There are some examples of open field operations under suitable climatic conditions.

Substrates of different types and with various technologies are used in several regions of the world, including some Article 5(1) countries. In Morocco, about 20 ha of protected vegetables are grown on lapilli as substrate to control various soil-borne pathogens (Besri 1997a,b).

The methodology of culturing on different kinds of substrates is broadly available. It is efficient, performs consistently and increases yields (Banks 1995; Blanco 1997). Where potential substrates are locally available, feasibility studies are needed to determine whether the methodology is applicable. In Brazil the use of MB for soil disinfestation is being replaced by substrates in vegetable production (culturing in bags or slabs) (Aquino 1997; Fonseca and Miyamoto 1997; Kampf and Maller 1997; Muller 1997a, 1998). The aim of this new technique is to increase productivity by avoiding salinisation and minimising problems with nematode infestations which make the use of MB necessary.

Under appropriate conditions, the soil-less method offers a better cost-benefit ratio than treating with MB (Canovas-Martines 1997). Another example of soil-less culture is greenhouse hydroponics using sterile media as an alternative way to provide disease-free strawberry runner plants that can be potted and sold as nursery stock. The hydroponic system can use purified wastewater. Small-scale farmers in Florida are using the system to grow strawberries, vegetables and herbs without MB (Adler *et al.* 1996; Takeda *et al.* 1997).

4.4.11 Biological control

Biological control of root pests uses non-pathogenic bacteria, fungi and other organisms that compete for space and nutrients or are antagonistic in some other manner toward pathogens in the rhizoplane, the rhizosphere or inside the root. In most cases they act as protectants against root infection. Some non-pathogenic root associations induce systemic resistance of plants to pathogens called 'induced systemic resistance' (Liu *et al.* 1995).

There is a large body of literature available describing many species of organisms antagonistic to plant pathogens. Research on utilising antagonists to control plant pathogens has been going on for more than a century (Belarmino *et al.* 1994; MBTOC 1995; Gomis *et al.* 1996).

Biological control agents are generally highly specific and could provide some level of overall disease management only if used with other disease control strategies, i.e. fumigation, steam, or solarisation. IPM strategies using biological control as part of a disease control arsenal hold greater promise as a control tactic than biological control alone. It is most effective

when combined with compatible chemical means of control at reduced dosage or genetic resistance where the plant's period of susceptibility is short and/or under cultural circumstances where heavy inoculation with microbial agents offers a distinctive competitive advantage over pathogens (Winterbottom 1990; Winterbottom *et al.* 1996). This area of research is growing.

Protection of roots against pathogens in field crops requires that biological control agents grow in the rhizophere (root zone) near the root tip, the site of infection by most root pathogens, during periods of susceptibility (Tjamos and Fravel 1997). This can be achieved using seed dressings or other appropriate methods. Inoculation with non-pathogenic *Fusarium* spp. that inhibit attack on sweet potato plants is in commercial use in Japan (Ogawa 1988; Ogawa and Komoda 1984; Ogawa and Watanabe 1992).

In certain cases, biocontrol agents are effective when used alone. Several *Trichoderma* spp. are present in solarised soil and are antagonistic to a number of economically important soil-borne pathogens of horticultural crops (Tjamos 1998; Tjamos and Niklis 1990; Tjamos and Paplomatas 1988). The presence of antagonistic *Trichoderma* spp. decreased incidence of problems caused by the pathogens (Cartia 1998; Cartia and Causarano 1996; Tio 1998).

Entomopathogenic nematodes have received considerable attention as biological insecticides because of their ability to search out and kill hosts rapidly (Lopes-Robles *et al.* 1997; Lopes-Robles and Martines-Pena 1998). The antibiotics produced by their associated bacteria appear promising for control of many plant pathogenic fungi and other soil-borne pathogens (Chen *et al.* 1994). The bacterium, *Pasteuria penetrans* is effective for control of root-knot nematodes (*Meloidogyne* spp.*)* in cucumbers and other specific field situations (Stirling *et al.* 1995; Tzortsakakis and Gowen 1994). Pathogen-antagonistic *Fusarium* spp. proved effective against *F. oxysporum* f.sp. *dianthi* and *F. oxysporum* f.sp. *gladioli* and have been exploited commercially as biocontrol agents (Gullino 1995; Minuto *et al.* 1995; Postma and Rattink 1992).

In Japan MB is used for control of tobamoviruses (CGMMV in cucurbits and PMMV (TMV-P) in green-pepper) in soil since no other fumigant can eliminate these viruses. Attenuated strains of these viruses have been developed in Japan and have been used by some growers (Tan *et al.* 1997; Motoyoshi and Nishiguchi 1988; Murata *et al.* 1989).

4.4.11.1 Use of resistant varieties

Production of resistant cultivars involves incorporation of specific one or more genes for resistance or tolerance and the selection for horticulturally acceptable types. The use of plant breeding to select and develop crop varieties resistant or tolerant to pests is as old as agriculture. Its use as an alternative to pre-plant soil MB fumigation is limited by the time and resources, both genetic and financial, required for developing multiple-resistant cultivars with appropriate commercially acceptable quality and yield (Celada 1997, 1998).

When feasible, using varieties resistant or tolerant to soil-borne pests is a desirable component method in IPM systems because of their relatively low environmental impact. There are resistant or tolerant varieties for most crop species today. These include resistance to root-knot nematodes or to pathogenic fungi in genera such as *Phytophthora, Fusarium,*

Verticillium and often bacteria (Besri 1997a; Fery and Dukes 1996; Cartia 1998; Reis 1998; Monma *et al.* 1997; Sakata *et al.* 1996). Resistant varieties are widely used as substitutes for soil fumigation in Spain, Portugal, Greece, Morocco, France, Israel and Italy (Cartia 1998; Reis 1998;Tello 1998a,b; Varés 1998; Vlahopoulos 1998). Cultivars of carnations resistant to *F. oxysporum* f.sp. *dianthi* are commercially available (Garibaldi and Gullino 1990). Disease-resistant varieties are used within IPM systems in the production of cut flowers in Colombia (Rodríguez-Kábana 1998b).

New resistant varieties to individual pests can be developed for some crops within 5 to 15 years depending on crop species and genetic resources. However, genes for resistance to certain diseases have not been identified. There are limitations to what can be done through plant breeding even with the recent advances in molecular techniques (Celada 1997, 1998). It is difficult to develop multi-resistant varieties as most fields are infested with a multiplicity of major and minor plant pathogens. The use of varieties resistant to only a limited number of pathogens may result in increased severity of disease caused by pathogens to which variety is susceptible. Even for a single pathogen, cultivars may be resistant to a narrow spectrum of races within the pathogen's genome. This can result in the appearance of new races through selection by the use of these resistant cultivars (Besri *et al.* 1984).

Some resistant genes are unstable in unfavourable environmental conditions, e.g. high soil temperatures, high salinity and may limit the efficacy of resistant plants (Besri 1993; Cap *et al.* 1993). Tomato varieties resistant to *Fusarium* spp. and *Verticillium* spp. wilts became susceptible when the irrigation water had a high salt content. Reducing the water salt content decreased the incidence and severity of these two diseases and resistance was maintained (Besri 1981). Resistant cultivars can be integrated within crop rotation systems to enhance pathogen suppression.

4.4.11.2 Grafting

Grafting uses resistant rootstocks to protect susceptible annual and perennial crops against soil-borne pathogens. It is used with excellent results for controlling pathogens such as root-knot nematodes and fungal pathogens such as *Fusarium* spp., *Verticillium* spp. (vegetable and fruit crops) and *Phytophthora* spp. (fruit trees, citrus).

Grafting can be as effective as resistant varieties (Miguel 1997a,b,c, 1998). For example, resistant rootstocks for cucurbits include *Cucurbita ficifolia* and *Benincasa carifera.* For tomatoes, various wild species of *Lycopersicon* spp. are used. Rootstocks used for citrus include sour lemon for the control of *Phytophthora* spp. diseases and *Poncitrus trifoliata* for the citrus nematode, *Tylenchulus semipenetrans.* Some nematode-resistant rootstocks for grapes and fruit trees are available.

Rootstock resistance may break down with the emergence of new races and under some environmental conditions e.g. high temperature, salinity. However, it may be possible to regulate temperature by cultural practices such as watering and mulching. There are many reasons to use grafting techniques as an alternative to MB.

New grafting techniques have been developed in Japan (Oda 1995). For example, if a new race of the pathogen appears, it is easier to replace the rootstock than to develop a

commercial resistant variety. Grafting of annual crops is widely used in some developing countries such as Morocco, Tunisia, Lebanon, Egypt, Jordan and Cyprus. Presently, 100% of the watermelon crop in Almeria (Spain) is raised from grafted plants, a practice that eliminated the use of MB on the crop in the Spanish south east (Tello 1998a).

Resistant rootstocks provide excellent control of many vegetable diseases. This technique which formerly was considered too expensive is now in wide use in many developed and developing countries. In Morocco, grafting is widely used at a commercial level for the control of the root-knot nematodes, *Fusarium* spp. and *Verticillium* spp. wilts. Susceptible but high-yielding cultivars are grafted in specialised nurseries on resistant rootstocks. Plant grafting is a control method that could replace soil disinfestation with MB (Besri 1997a,b; Gabarra and Besri 1997).

4.4.11.3 Plant growth promoting rhizobacteria

Plant Growth Promoting Rhizobacteria (PGPR) bacteria stimulate plant growth or are antagonists to pathogens by colonising the roots and establishing a "biological shield" to prevent or delay invasion of a pest or pathogen. Occupation of the roots by rhizobacteria could prevent attack from several pests or pathogens (Kloepper *et al.* 1988).

There are now several PGPR-containing products that have been tested under field conditions. Combinations of PGPR with other biological control methods, such as the use of organic amendments, offers promise as a practical alternative to MB fumigation. PGPR products are widely sold in China as "yield-increasing bacteria" (Kloepper 1998).

In China and the the United States, most of the PGPR-based products contain spore-forming actinomycetes or bacilli which are easier to formulate in a stable viable product than non-sporulating bacteria. Results indicate that without MB, seed treatment with PGPR can still lead to systemic protection against foliar pathogens and moreover, the magnitude of protection is greater without MB.

Existing PGPR-based products and strains of PGPR under commercial development, have proven beneficial in integrated strategies for replacing MB (Keel *et al.* 1990).

4.4.11.4 Endophytes

Endophytic micro-organisms develop in most plant species with beneficial or detrimental effects (McInroy and Kloepper 1995; Bell *et al.* 1995). There is evidence that the endophyte in the plant triggers a broad-spectrum defense response of the plant against pathogens. Extensive research efforts continue to elucidate 'induced systemic resistance' which is also referred to as 'systemic acquired resistance'.

The use of non-pathogenic endophytes to control or prevent plant diseases is a recent development in biological control (Hallmann *et al.* 1997, 1998a,b). Currently, there are no commercial products useful for soil treatments.

4.4.11.5 Mycorrhizae

In nature, most plant roots develop symbiotic relationships with specialised fungi forming a complex, the mycorrhizae. These complex associations increase the adsorptive root surface area permitting plants to survive and thrive in environments where nutrients are limiting or are difficult to extract (Krikum *et al.* 1990; Perrin *et al.* 1998).

There is also evidence that plants with mycorrhizae are more resistant to some soil-borne diseases and nematodes (Matsubara *et al.* 1995; Calvet *et al.* 1993; Dumas-Gaudot *et al.* 1994; Fitter and Garbaye 1994; Gollotte *et al.* 1996; Newsham *et al.* 1995). Mycorrhizal soil infectivity decreases dramatically after soil fumigation particularly after MB application.

Various mechanisms have been suggested for the protection afforded by mycorrhizas and these are summarised in a recent review by (Perrin and Salerno 1996). The use of mycorrhizae for protecting plants against soil-borne pathogens is increasing (Borrás 1998; Chet 1987; Duchesne, 1994; Unestam and Damm 1994; Soulas *et al.*1997).

4.4.12 Solarisation

Soil solarisation occurs when heat from solar radiation is trapped under clear plastic sheeting to elevate the temperature of moist soil to a level lethal to soil-borne pests including pathogens, weeds, insects and mites (Katan 1993). There are some important pests e.g. root-knot nematode, nutsedge and *Macrophomina* spp., which are not consistently controlled by solarisation alone (Katan and DeVay 1991). Despite extensive research soil solarisation when used alone has only gained acceptance for commercial use in warm climates.

Soil solarisation has been studied in over 50 countries (Katan 1993; Ghini 1997; Tjamos 1998). This includes non-Article 5(1) countries such as Japan (Horiuchi 1991); Italy (Vannacci *et al.* 1993; Tamietti 1994; Gullino and Minuto 1997; Correnti and Triolo 1998); Greece (Antoniou *et al.* 1993, 1995; Antoniou 1995; Bourbos and Skoudridakis 1996; Bourbos *et al.* 1997; Tjamos 1998); USA (Chellemi *et al.* 1997a,b,c,d); Spain (Mejias *et al.* 1995, 1996; Cenis 1997; del Moral 1998; Romero 1998); Portugal (Borges 1994; Reis 1994); and Israel (Harts *et al.* 1993; Katan 1993). It has also been studied in Article 5(1) countries such as Brazil (Silveira and Caixinhas 1994); Syria (Greco *et al.* 1991); Jordan (Abu-gharbieh *et al.* 1991); Libya (Ali *et al.* 1991;) Iraq (Matrod *et al.* 1990); Egypt (Satour *et al.* 1991); Morocco (Besri 1991) and Turkey (Yucel 1995).

Solarisation was originally developed for open field culture in Israel and greenhouses in Japan to control various soil-borne pests. Although it was first commonly used in arid or semi-arid regions with intense sunshine and minimal rainfall, recent advances in technology have extended its use to other regions where it was once regarded as impractical (Chellemi *et al.* 1997b; Le Bihan *et al.* 1997 Horiuchi 1991; Gullino and Minuto 1997).

Solarisation can also be used for disinfestation of containerised nursery soil (Stapleton and Ferguson 1996) and plant supports by storing these materials in empty plastic greenhouses during the off-season in hot climates (Besri 1991).

New technologies to improve the efficacy of solarisation and broaden its applicaton are under development including sprayable mulches, double-layer plastic and Virtually Impermeable Film (VIF) (Gamliel and Stapleton 1993; Tjamos and Niklis 1990). Solar collectors have been used to disinfest soil in Brazil to control fungi, nematodes and weeds (Ghini 1993; Ghini *et al.* 1992, 1998).

The efficacy of solarisation can be improved when it is combined with fungicides, biological antagonists and appropriate cultural practices (Cartia and Asero 1994b; Stevens *et al.* 1996; Cartia 1997; Cartia *et al.* 1997). Solarisation combined with dazomet or calcium cyanamid resulted in good control of root-knot nematodes and corky root in tomatoes (Bourbos *et al.* 1997). In Australia, solarisation combined with low dose rates of dazomet dramatically improved control of *Plasmodiophora brassicae* on crucifers and solarisation combined with fungicides enhanced control of *Sclerotinia minor* on lettuce. The same studies demonstrated the long term benefits of repeated use of solarisation over three seasons combined with fungicide treatments (Porter 1991; Porter *et al.* 1991). Therefore, solarisation is most effective when used as a component of an IPM system (Chellemi *et al.* 1997b; Katan and DeVay 1991).

4.4.13 Steam

Steaming is the introduction of water vapor (>100°C) into soil to elevate soil temperatures to levels lethal (70-80°C) to soil-borne pests. When properly conducted steaming is effective against all soil-borne pests. Soil temperature and treatment duration determine whether complete elimination (sterilisation) or only partial removal of soil microflora (pasteurisation) occurs.

Steaming is a well-established and effective technique for soil-borne pest control and is extensively used for bulk soil, soil treatments within greenhouses and some small-scale nursery plant operations (Nakano and Botton 1997). Previous research demonstrated the undesirable effects of soil sterilisation (pathogen recolonisation, release of heavy metals and phytotoxic materials) thus soil pasteurisation is preferred (Runia 1983). Negative pressure steaming technology currently available, improves energy efficiency by providing better dispersal of steam throughout the soil and reducing treatment time (Runia 1983). 'Cool' aerated steaming (60°C for 30 minutes) kills pathogens while conserving beneficial soil organisms (Baker 1970).

Steaming is an alternative to MB soil fumigation for protected production systems and small scale, open-field production, e.g. bulbs and cut flowers and woody fruit and ornamental plants (Cori and Triolo 1994; Correnti and Triolo 1998; Rodríguez-Kábana 1998a,b). Steam is being used in many countries in the greenhouse industry with vegetables and ornamental crops to replace MB. The use of steam has yet to be proven economical and practical when large, unprotected areas are treated. More widespread use of steam for large-scale, open-field production systems is currently under study and will require technological improvements and adequate water supplies (Grossman and Liebman 1995).

4.4.14 Burning

Orobanche crenata and *O. aegyptiaca* are very important parasitic higher plants on many crops particularly on vegetables in the Mediterranean area. No resistant variety to these parasites is known. In protected cultivation MB is widely used to control these parasites. Preliminary experiments have found that burning the orobanche plants at the end of the growing season decreases the orobanche seed population in the soil and consequently the parasite incidence and severity (Besri 1998).

4.5 Chemical Alternatives

No single chemical provides an alternative to all pre-plant uses of MB in terms of consistency and efficacy against target pests. For a specific pest there may be a single chemical alternative, however, for pest complexes, combinations of chemicals and/or other pest control methods will usually be necessary. Some combinations of chemicals have already been shown effective and many are only effective if they are utilised as part of an integrated crop management system (Porter *et al.* 1997; Dickson 1997; Duniway *et al.*1997; Gullino and Minuto 1997; Keddy *et al.* 1997; Loscasio *et al.* 1997; Barry 1998). These programmes can include combinations of chemicals (e.g. fumigants, soil applied nematicides, fungicides) and non-chemicals (crop rotation, resistant varieties, solarisation). Additional research over multiple growing seasons, locations and pest pressures is underway to determine required application rates and procedures for pre-plant soil treatments.

Factors affecting acceptance of alternatives include local availability, registration status, costs, labour requirements and efficacy against target pests. Depth of penetration in soil, poor dispersion of chemicals under various conditions and narrow effective temperature ranges may affect efficacy. Quality and production patterns, as well as total yield are important considerations. As with MB, use of chemical alternatives may have human health and environmental consequences, which must be taken into consideration. Regulatory actions within each country may limit the availability of an alternative chemical in specific geographical areas.

It is important to note that most studies conducted to date were performed in previously fumigated fields (i.e., where fields were relativly free from weeds and soil-borne pathogens). It is important that future studies on alternatives also consider performance in soils without a history of fumigation with MB.

4.5.1 Chloropicrin (trichloronitromethane)

Chloropicrin is a liquid injected into the soil which is then covered with plastic. This material is highly effective for controlling soil-borne fungi (approximately 20 times more effective than MB, Desmarcheliar 1998) and some arthropods (Wilhelm and Westerlund 1994). It is a weak nematicide but does kill germinated weeds. It does not kill dormant or non germinating weed seeds. In the absence of nematodes, improved growth and yield responses with chloropicrin are similar or superior to MB alone.

Preliminary results have indicated that chloropicrin alone as a pre-plant soil fumigant for strawberries in isolated instances can be equally effective as MB against *Verticillium dahliae*

(Duniway *et al.* 1997). However, much research is still needed to determine effective and economical application rates. Chloropicrin/MB mixtures (33/67,50/50) have successfully replaced MB (pure or with warning agents) for broad acre use in many horticultural industries in response to reduced supplies of MB (Duniway *et al.* 1997; Porter *et al.* 1997).

4.5.2 1,3-Dichloropropene

The soil fumigant 1,3-dichloropropene (1,3-D) is well known and considered a valuable alternative to MB for nematode control. It is primarily active as a nematicide. With current use practices, 1,3-D alone usually provides effective control of nematodes and insects and suppresses some weeds and pathogenic fungi (Aguirre 1997, 1998; Gonsales-Pedreno 1997; Noling and Becker, 1994; Raski and Goheen 1988; Soler 1997). Accelerated degradation of 1,3-D by soil micro-organisms has been observed in rare instances resulting in less chemical residue and reduced yield (Leistra 1972). However, recent work in Florida demonstrated that accelerated microbial degradation of the chemical does not impair its nematicidal efficacy (Riegel *et al.* 1998).

Research is underway to improve the efficacy of 1,3-D, in combination with other materials and practices, against nematodes and some soil-borne pests (Lópes-Robles and Martínes-Peña 1998; Soler 1997; Visbeck 1998). This research focuses on treatment combinations e.g. 1,3-D and chloropicrin which enhance the spectrum of activity of 1,3-D and the development of safer more effective application methods (Dickson 1997; Becker *et al.* 1997; Duniway *et al.* 1997; Hamm 1997).

Tomato yields in soils fumigated with 1,3-D with chloropicrin (17%) and the herbicide pebulate ranged from 81% to 117% of that obtained using MB fumigation in large-scale field demonstration/validation studies conducted on commercial tomato and pepper production farms in Florida. Uniform incorporation of pebulate was found to be a critical step to avoid early season phytotoxicity and 19% reduction in yield (Gilreath *et al.* 1997a,b).

4.5.3 Methyl isothiocyanate (MITC) and MITC generators

MITC and compounds that generate MITC (dazomet, metam sodium) are highly effective for controlling a wide range of soil-borne fungi, but are less effective against nematodes and bacteria. When incorporated into moist soil, MITC generators decompose to produce methyl isothiocyanate. To assure efficacy and avoid phytotoxicity, a prolonged preplant period of up to 8 weeks may be required. The waiting period is especially critical because the activity of these products is dependent on microbial decomposition and adequate soil moisture. All these materials have been commercially available for 40 years (Rodríguez-Kábana *et al.* 1977).

4.5.3.1 MITC

This liquid compound is injected into the soil and is effective for the control of arthropods, some weeds and soil-borne pathogens, principally fungi and a limited number of plant parasitic nematode species. It is mostly used in combination with 1,3-D which enhances the nematicidal activity (Thomson 1992; Rodríguez-Kábana *et al.* 1977).

4.5.3.2 Metam sodium

Metam sodium is a liquid preplant soil chemical effective for controlling arthropods, some weeds and soil-borne pathogens, principally fungi and a limited number of parasitic nematodes. Studies have shown that direct injection of metam sodium in bands to soil does not provide consistent control due to non-uniform distribution in the soil. It does not disperse well and requires water for good movement and efficacy. Reduced efficacy has also been attributed to a build-up of micro-organisms that degrade the chemical and lower its performance (Thomson 1992).

However, with improved technology (e.g. better understanding of movement in soils, better surface sealing improvements in application machinery and the use of plastic covers) applications of metam sodium to soil can result in yields similar to those obtained with MB. In some cases, yields have been obtained which were higher than those resulting from MB application, e.g. vegetables in Almería, Spain and strawberries in Catalonia, Spain.

The high water-solubility of metam sodium makes it suitable for application to soil via irrigation systems such as injection or drip irrigation under plastic. However, compliance with local regulatory requirements may be necessary to apply metam sodium through overhead sprinklers. This application technique has been used successfully for control of weeds, fungi and nematodes and has been used successfully in many regions including Morocco, Spain, Southern France, Israel, Italy and the USA (Laita 1997; Nakano and Botton 1997; Pocino 1997a,b 1998; Rabasse 1998; Tió 1998; Yabase 1997).

4.5.3.3 Dazomet

Dazomet is a granular pre-plant soil chemical. Dazomet requires uniform distribution in soil by mechanical means for good movement and efficacy. It gives satisfactory control of weeds, nematodes and fungi in Argentina, Australia, Europe and Japan where it is well known. Like metam sodium, the efficacy of dazomet could be increased by improving methods of application and/or by combination with other treatments. Banded applications of dazomet have been equally as effective as broadcast applications and may reduce costs and increase reliability (Harris 1990; Porter *et al.* 1991; Daguenet and Schroeder 1994; Speakman and Daguenet 1994; Eitel 1995; Fritsch and Huber 1995; Mappes 1995; Middleton and Lawrence 1995; Ufer *et al.* 1995; Fenolio 1997; Kampf and Maller 1997; Yabase 1997; Anon. 1998; Fernandes and Armada 1998; Gonçalves 1998; Schroeder 1998).

4.5.4 Chemical alternatives which require further development

4.5.4.1 Methyl iodide

Methyl iodide is a liquid pre-plant soil chemical. Recent studies from California and Florida have shown that alone and in combination with chloropicrin it is effective against soil-borne fungi, plant pathogenic nematodes and weeds. Methyl iodide is reported as a one-to-one replacement for MB pre-plant soil fumigation. It is not considered to be an ozone depletor since it degrades readily in the lower atmosphere. However, it is not registered as a soil fumigant which is a major limitation. Most of the research on methyl iodide has been carried out in the past 3 years (Becker *et al.* 1997, 1998; Dowler *et al.* 1997; Gan and Yates

1997; Gan *et al.* 1997; Hutchinson *et al.* 1997; McMillan *et al.* 1997; Noling and Gilreath 1995; Ohr *et al.* 1996a,b; Sims *et al.* 1996a,b; Yates 1996; Zhang *et al.* 1997,1998).

4.5.4.2 Propargyl bromide

Propargyl bromide was used in the 1960s to enhance the performance of chloropicrin and MB in a product called Trizone. It controlled a wide range of soil-borne pests, but was discontinued in 1968. There is renewed interest in propargyl bromide as a potential alternative to MB. Laboratory research is in progress to determine its behavior and safety in the environment. Research is needed to determine if it is an ozone depletor (Yates and Gan 1997a,b).

4.5.4.3 Ozone

Research has been conducted since 1994 to evaluate this gas as an alternative fumigant to MB for the control of nematodes, other soil-borne diseases and pests of fresh market carrots and strawberries in California. Results are inconsistent. Movement of ozone through several soil types at different moisture levels is being evaluated for nematode control in California (Smith 1994, 1995).

4.5.4.4 Formaldehyde

Formaldehyde may be applied as a liquid solution or can be generated in soil after application of granular paraformaldehyde (Rodríguez-Kábana *et al.* 1977; Johnson and Feldmesser 1987; Thomson 1992). This compound is primarily a bactericide with limited activity against ectoparasitic nematodes and some fungi. Early use of this material was limited because of phytotoxicity problems. The waiting period following treatment is highly temperature dependent.

4.5.4.5 Sodium tetrathiocarbonate

This compound is water soluble, salt formulated in stabilised concentrated aqueous solutions which can be applied to soil where it decomposes releasing carbon disulphide (CS_2) (Young 1990). It is registered for commercial use in California for *Phylloxera* spp. control in grapes. Recent studies on tomatoes in Florida gave poor results (Locascio *et al.* 1997).

4.5.4.6 Anhydrous ammonia

Ammonia (NH_3) is a gas at standard atmospheric pressure. It is sold in pressurised containers for use as a fertiliser and is injected into the soil and not covered. It has broad spectrum activity against soil-borne pests (Rodríguez-Kábana *et al.* 1981, 1982; Punja 1985). Its high solubility in water (pH dependent) and retention in clay and soil organic matter impede its diffusion and movement through soil. This may account for the variable results obtained when used against soil-borne pests.

Naturally produced ammonia is a key agent in biofumigation strategies, but anhydrous ammonia requires further research on application methods to obtain adequate distribution in soil (Lazarovitts *et al.* 1997).

4.5.4.7 Inorganic azides

These materials are solids and can be formulated as granules or liquids. When added to soils they release hydrazoic acid (HN_3) which escapes to the atmosphere or is converted to nitrate in soil. Azides applied to the soil demonstrated broad spectrum activity against weeds and soil-borne phytopathogenic fungi, but higher rates were required for nematode control (Kelley and Rodríguez-Kábana 1979a; Rodríguez-Kábana *et al.* 1972; van Wambeke *et al* 1984, 1985; van Wambeke and van den Abeele 1983).

Rate reductions are possible provided the soil is covered after application. Microbiological studies of soil treated with NaN_3 for several years indicated enrichment of treated soils with a group of fungi antagonistic to many soil-borne phytopathogenic fungi (Kelley and Rodríguez-Kábana 1975, 1979b, 1981).

A limitation to the use of NaN_3 or KN_3 is the possibility of formation of explosive azides. This risk can be mitigated by formulating the compounds in granules containing sodium or potassium carbonate as a buffer.

4.5.4.8 Naturally occurring compounds

Research on the nematicidal and microbiocidal properties of some volatile, naturally-occurring compounds has shown promise for development of new soil treatments for the management of nematodes and other soil-borne plant pathogens (Soler-Serratosa *et al.* 1996). One of these compounds, furfuraldehyde, is a by-product of sugar cane processing and has been shown to be effective for the management of nematodes and some phytopathogenic fungi (Canullo *et al.* 1992; Rodríguez-Kábana and Walters 1992). Addition of this volatile material to soil enhances populations of fungi and bacteria that are known antagonists of many plant pathogens. Likewise, benzaldehyde has also shown similar activity to furfuraldehyde (Soler-Serratosa *et al.* 1996).

Ethylene dibromide, carbon bisulphide, dichloro-isopropyl-ether discussed previously in the 1994 MBTOC Assessment are not discussed here because they are no longer considered valid alternatives.

4.5.5 Combinations of chemicals

When a specific problem is identified, the application of the proper combination of commercial pesticides can offer excellent results. There are numerous commercially available pesticides that can be used in such combinations. For example in Spain, there are six soil disinfectants, six nematicides, eleven fungicides, more than 15 insecticides and numerous herbicides registered for control of various soil-borne pests and weeds (Pocino 1997a). Combinations can be developed to control a spectrum of pests, however, these systems may be limited by their ability to control certain key pests such as some nematodes.

Considerable work has been done with mixtures of fumigants and mixtures of fumigants with other chemicals (Csinos *et al.* 1997). For example, trials with chloropicrin and 1,3-D in strawberries (California) and tomatoes (Florida) produced acceptable yields generally equivalent to those obtained with MB and chloropicrin combinations (Dickson 1997;

Duniway *et al.* 1997; Locascio *et al.* 1997). In Australian studies on strawberries and on flowers, yields generally equivalent to those obtained with MB and chloropicrin have been achieved with combinations of chloropicrin and metam sodium, chloropicrin and dazomet and chloropicrin and 1,3-D for pest complexes which include strawberry disease complex, *Sclerotium rolfsii* and weeds (Porter *et al.* 1996, 1997). In Florida, combinations of chloropicrin and 1,3-D require the addition of herbicide treatments (pebulate, devrinol) for effective weed control (Gilreath *et al.* 1997a,b). Formulated products containing combinations of chloropicrin, 1,3-D and metam sodium are being used as replacements for MB on sandy soils in the Canadian strawberry nursery industry (Keddy *et al.* 1997).

Combinations of 1, 3-D and MITC are used in Europe, Canada and other countries (Thomson 1992). A 1,3-D pre-plant soil treatment followed by a drench of metam sodium was shown to be the most promising alternative to MB for replanting perennial crops in California.

4.5.6 Combinations of chemical and non-chemical methods

Combinations of chemicals with non-chemical alternatives can be very effective. Combinations of chemicals with solarisation have reduced the time required for effective pest control as well as allowing a reduction in the dosage of chemical required. For example, metam sodium with solarisation and dazomet with solarisation have been used successfully for pink root in onions and for club root in brassicas. In Argentina, a combination of chemicals (fungicides and herbicides) with solarisation and nematode resistant rootstock is recommended by the Estacion Experimental Agroindustrial Obispo Colonbres (EEAOC) of Tucuman Province to avoid use of MB and thereby retaining the beneficial effects of mycorrhizae in citrus seedbeds and nursery soil.

Studies are being conducted to evaluate additional combinations and to optimise ratios of chemicals and improved methods of application (Pocino 1997a; Goncalves 1998; Gulino and Garibaldi 1998; Nakano and Botton 1997; Rodríguez-Kábana 1998b).

4.6 Alternatives to Methyl Bromide: Country Developments

Despite the diversity of soil-borne pest problems world-wide, there are relatively few pests and diseases that require control in agriculture. Table 4.4 (Annex 4.7) summarises soil-borne pathogens (nematodes, fungi, bacteria, insects and weeds) currently controlled by MB.

Examples of alternatives to MB that have been implemented in non Article 5(1) countries which have already phased out MB are provided in Table 4.5 (Annex 4.8). Table 4.6 (Annex 4.8) gives examples of non Article 5(1) countries which are due to phase-out MB for soil uses in 2005. Some Article 5(1) countries have implemented a number of alternatives to MB for soil fumigation and these are shown in Table 4.7 (Annex 4.8). Finally, the relative difficulty of finding alternatives to MB for soil disinfestation in one or more countries in various regions of the world is shown in Table 4.8 (Annex 4.9).

4.7 Case Histories

Alternatives to MB treatment have been implemented in many countries for controlling soil-borne pests. In this report, five case studies covering vegetables, strawberries and ornamentals are reported from: North America (Florida); North Africa (Morocco); Europe (Netherlands); South America (Columbia); and Australia.

Each case history reports on the pests, commodity, alternatives used, regulatory acceptance and commercial uses, as well as the difficulty in developing and implementing the strategy used to replace MB. The case histories clearly show that alternatives can be developed and implemented in both Article 5(1) and non-Article 5(1) countries (see Annexes 4.1 - 4.5).

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ANNEX 4.1 Case History 1 : Alternatives to methyl bromide in Florida tomatoes and peppers

1. **Crop:** Fresh Market Tomatoes and Peppers

2. **Pests:**

	Nematodes:	Root-knot (*Meloidogyne* spp.) Reniform (*Rotylenchulus reniformis*)
	Pathogens:	Bacterial wilt of tomato (*Ralstonia solanacearum*) *Fusarium* wilt of tomato (*Fusarium oxysporum* f. sp. *lycopersici*, races 1, 2 and 3) *Fusarium* crown rot of tomato (*F. oxysporum* f. sp. *radicis-lycopersici*) Southern blight of pepper and tomato (*Sclerotium rolfsi*) *Phytophthora* blight of pepper (*Phytophthora capsici*) *Pythium* root rot of pepper (*Pythium myriotilum* and *P. aphanidermatum*)
	Weeds:	Purple nutsedge (*Cyperus rotundus*) Yellow nutsedge (*C. esculentus*) Purslane (*Portulaca oleracea*)

3. **History:**

Soil fumigation with MB has been used for production of the majority of fresh market tomatoes and peppers in Florida (USA) for many years.

4. **Description of the alternatives:**

Incorporating strip solarisation into the standard A-raised-bed plastic mulch tomato/pepper production system can produce yields similar to that produced with MB. Strip solarisation represents no added expense as plastic mulches are part of normal production. Following the solarisation period, the clear plastic is painted with a white water-based latex paint. The white plastic then serves as a production mulch for the subsequent crop. Since many growers prefer to prepare a proportion of their beds in advance, the extra time period required is not a limiting factor.

Soil solarisation was shown to be cost-effective, compatible with other pest management tactics, readily integrated into standard production systems and a valid alternative to pre-plant fumigation with MB. Tomato yields obtained with solarisation ranged from 85- 106% of those found with MB. Yields of pepper obtained with solarisation ranged from 93- 106% of those with MB. Painting of the plastic at the termination of the solarisation period was found to be a critical procedure to avoid yield losses caused by heat stress to transplants.

Soil solarisation of tomato/pepper crops in Florida is limited to autumn production systems, as solar radiation in winter is not sufficient to provide the soil temperature required for successful solarisation. This limits use of this method to 50% of Florida's production acreage.

Large demonstration/validation plots have been established on commercial tomato farms using combinations of 1,3-dichloropropene plus 17% chloropicrin and the herbicide pebulate to replace MB. Tomato yield ranged from 81% to 117% of yield obtained in MB-treated plots. Uniform incorporation of pebulate was found to be a critical step to avoid early season phytotoxicity and yield reductons evidenced by the 81% yield figure.

5. **Regulatory agency acceptance:**

Solarisation does not require registration. The fumigant 1,3-dichloropropene plus 17% chloropicrin (Telone^R + C17) and the herbicide pebulate (Tillam^R) are registered in Florida on tomato. Pebulate is phytotoxic to pepper and thus is not currently recommended for that crop. However, this research found that uniform incorporation of the herbicide minimises phytotoxicity.

Both pesticides also have labelling restrictions which may present obstacles to their widespread adoption. However, modifications of the label requirements and adjustments in application are feasible.

Pebulate is not currently registered for use on hand-transplanted tomatoes. Tomato operations in Florida use a semi-mechanical transplanter in which the worker hand-feeds the transplant into a tube which feeds the plant to the hole. Acceptance of this use will depend upon the interpretation of the label.

Telone C-17 has a worker safety clause on the label which restricts application to fields in which all workers are wearing protective gear, including respirator, gloves, Tyvec suit and rubber boots. This will be difficult to enforce in July and August due to the heat in Florida. Currently, there can be as many as 50 labourers in the field (migrant labour) during the preparation of beds. One solution to this would be to add Telone^R by broadcast application 72 hours before laying plastic. This approach needs to be explored.

6. **Were the treatments difficult to develop?**

Alternative fumigants posed no problems as standard label practices and efficacy trials were used. Use of solarisation was a little more difficult because it had to be adapted to the present production system. The most difficult problem will be the transition from a single tactic approach to an IPM approach for management of soil-borne pests.

7. **Were the treatments difficult to implement?**

No

8. **Is the effect of the treatments on other crops being determined?**

Studies on strawberries, cucumbers and watermelons are underway.

9. **Current commercial use:**

Both alternative methods described here are beginning to be adopted on large commercial farms.

10. **References:**

Chellemi, D.O., S.M. Olson, D.J. Mitchell, I. Secker and R. McSorley. 1997. Adaptation of soil solarisation to the integrated management of soilborne pests of tomato under humid conditions. *Phytopathology* 87: 250-258.

Chellemi, D.O., R.C. Hochmuth, T. Winsberg, W. Guetler, K.D. Shuler, L.E. Datnoff and D.T. Olson. 1997. Application of solarisation to fall production of cucurbits and peppers. *Proc. Fla. State Hort. Soc.* 110:333-336.

Chellemi, D.O., R. McSorley, J.R. Rich and S.M. Olson. 1997. Field validation of soil solarisation for fall production of tomato. *Proc. Fla. State Hort. Soc.* 110:330-332.

Gilreath, J.P., J.W. Noling, P.R. Gilreath and J.P. Jones. 1997. Field validation of 1,3-dichloropropene + chloropicrin and pebulate as an alternative to methyl bromide in tomato. *Proc. Fla. State Hort. Soc.* 110:273-276.

Locascio, S.J., J.P. Gilreath, D.W. Dickson, T.A. Kucharek, J.P. Jones and J.W. Noling. 1997. Fumigant alternatives to methyl bromide for polyethylene mulched tomato. *Hortscience* 32:1208-1211.

Annex 4.2 Case History 2 : Alternatives to methyl bromide for vegetable covered crops in Morocco

1. **Commodities:** Vegetables including tomatoes, melon, cucumber and pepper.

2. **Pests:** A list of target pests is provided in Table 4.1 at the end of this case history.

3. **History:**

In Morocco MB is widely used to control soil-borne pathogens in covered crops such as vegetables, cut flowers, strawberries and bananas. To decrease the use of MB, an IPM programme for protected crops based mainly on local research results was implemented in several regions of the country in collaboration with farmers.

An example of IPM programme for covered vegetables is also given in Table 4.1. This IPM programme integrates all the suitable alternatives in a compatible way to maintain soil pest populations at levels below the economic threshold level.

The IPM programme is implemented at the various stages of crop production and includes: choice of the field and measures to be taken to reduce the pathogen populations e.g. crop rotation, field sanitation, choice of the cultivars to be grown; grafting; quality of the seeds and plants; sowing date; seeding and planting densities; soil preparation; soil disinfestation (solarisation, chemical soil disinfection); and cultural practices.

4. **Alternatives:**

Crop rotation in combination with metam sodium applied through the drip irrigation system as a fumigant is successfully used to control soil-borne pathogens. The rotation adopted on a 3-year basis includes melon, hot pepper, peas, cucumber, tomato and squash.

Soil amendments with cattle manure (60 t/ha) reduces the incidence of *Fusarium* spp. and *Verticillium* spp. wilts of tomato.

The use of resistant varieties and pathogen-free seeds and transplants are very common alternatives. Grafting is now a very common alternative to MB. Resistant rootstocks proved excellent for control of many vegetable diseases. This technique, which was at one time considered too expensive, is now widely used in Morocco. Grafting is used at commercial level for the control of root-knot nematodes (*Meloidogyne* spp.) *Fusarium* spp. and *Verticillium* spp. wilts. Susceptible but high yielding cultivars are grafted onto resistant rootstocks in specialised nurseries.

About 20 ha of protected vegetables are grown on volcanic gravel (lapilli) as substrate to control various soil-borne pathogens. This type of soil-less culture will probably develop in the future.

Soil solarisation is successfully employed to control *Fusarium* spp. and *Verticillium* spp. wilts and also *Didymella* sp. stem canker of tomato. Solarisation of *Didymella*-infested tomato stakes is done by storing them in empty plastic greenhouses during the hot months of the

year. Experiments are currently conducted to control *Orobanche crenata* (parasitic plant) on vegetables by soil solarisation.

Various chemicals are used as alternatives to Methyl Bromide. Some of these chemicals are Aldicarb, Caduzophos, Carbofuran, Dazomet**, 1,3 Dichloropropene*, Ethoprop, Fenamiphos, Isazophos, Metam sodium**, Oxamyl and Terbufos. Those with '**' are fumigants (MITC generators) and those with '*' are fumigants non-MITC generators.

5. **Regulatory agency acceptance:**

All the alternatives did not require registration. Alternatives pesticides were registered.

6. **Current commercial use:**

Most of the described alternatives are widely used by farmers.

7. **Were the alternatives difficult to develop?**

Yes. Research was conducted locally for many years to develop new alternatives or to adapt the existing ones.

8. **Were the alternatives difficult to implement?**

No. Most of the research was conducted in close collaboration with the farmers and also with the regional extensionists. To implement the alternatives, visits of the demonstration plots were organized.

9. **Effect on other crops:**

The same research and development programme will be conducted for some other crops such as strawberrries, ornamentals and bananas.

10. **References:**

Besri, M. 1991. Solarisation of soil and agricultural materials for control of *Verticillium* wilt and *Didymella* stem canker in Morocco. *In*: *Soil solarisation,* eds J. Katan and J.E. Devay. CRS Press: 237-243.

Besri, M. 1997. Integrated management of soilborne pests in protected cultivation: Constraints and perspectives. *Proceedings of the second international conference on soil solarisation and integrated management of soilborne pests.* Aleppo, Syria, 16-21 March, 1997.

Besri, M. 1997. Integrated management of soilborne diseases in the Mediterranean protected vegetable cultivation. *In: Integrated control in protected crops "Mediterranean climate".* R. Albajes and A. Carnero (eds.) *IOBC Bulltetin*, 20, 4, 45-57.

Besri, M. 1997. Alternatives to methyl bromide for preplant protected cultivation of vegetables in the Mediterranean developing countries. *Proceedings of the international research conference on methyl bromide alternatives and emissions reductions.* November 3-5, 1997, San Diego, California.

Gabarra R. and M. Besri. 1997. *Implementation of IPM: Case studies.* Tomato. *In*: *Integrated pest and disease management in greenhouse crops.* R. Albajes, M.L. Gullino, J.C. van Lenteren and Y. Elad. Kluwer Academic Publishers: In press.

Table 4.1 Integrated Disease Management programme for protected vegetable crops in Morocco

Disease	Pathogens	Alternatives
Fusarium spp. wilt and *Fusarium* spp. crow root rot	*Fusarium oxysporum* f.sp. *lycopersici* and *Fusarium oxysporum* f.sp. *radicis-lycopersici*	Resistant varieties, certified seeds, soil solarisation, rotations, use of non-saline water, weed control, destruction of crop residues, soil treatment, grafting.
Verticillium spp. wilt	*Verticillium dahliae*	As for *Fusarium* spp. wilt.
Late blight	*Phytophthora infestans*	Good ventilation, chemicals, crop rotation.
Didymella sp. stem canker	*Didymella lycopersici*	Certified seeds, tomato support solarisation, chemical control, wound protection.
White rot	*Sclerotinia sclerotiorum*	Crop rotation, use of non contaminated seeds, resistant varieties, drainage.
Bacterial canker	*Clavibacter michiganensis*	Crop rotation, disease free seeds.
Angular leaf spot	*Pseudomonas syringae p.v. tomato*	Resistant varieties, soil solarisation, rotations, destruction of crop residues, chemical soil treatment, grafting.
Root-knot nematodes	*Meloidogyne* spp.	

Annex 4.3 Case History 3 : Strawberry production in greenhouses in the Netherlands

1. **Crop:** Strawberries.

2. **Pests:**

	Nematodes:	*Pratylenchus penetrans* *Meloidogyne hapla*
	Pathogens:	*Verticillium albo-atrum* *V. dahliae* *Phytophthora cactorum* *P. fragariae*

3. **History:**

Environmental concerns in the Netherlands about MB led the Dutch government to a phased withdrawal of MB. Soil fumigation with MB was used for strawberry production from the 1960s until it was banned in 1992.

4. **Description of alternatives:**

Since the ban of MB, virtually 100% of strawberry production in greenhouses are grown on artificial substrates in the form of peat contained in plastic bags. Six plants are transplanted into each peat bag. Water and nutrients are supplied by drip irrigation. This substrate is also being used in plastic tunnels.

5. **Regulatory agency acceptance:**

Not required.

6. **Current commercial use:**

There are approximately 2000 ha of strawberries grown in the Netherlands. In 1993, 30,000 tonnes of strawberries were produced of which 15,000 tonnes were from greenhouses using peat bag substrates. Greenhouse production represented 120 ha.

7. **Was the alternative difficult to develop?**

Yes. The substrate technology had to be developed in the early 1980s and numerous problems overcome. After being optimised, yield increases with the substrate exceeded 100% of that obtained with MB.

8. **Was the treatment difficult to implement?**

No. Adequate government support for technology transfer was provided. The increase in farmer ' s income was a decisive stimulus.

9. **Effects on other crops:**

While peat bag substrates are mainly used for strawberries. Other substrates such as rock wool and coconut material are widely used in other crops such as tomatoes and cut flowers.

10. **Reference:**

De Barro, P.T. and B. Edwards. 1995. Strawberry production in the Netherlands without methyl bromide. pp 29-42 *In:* Banks, H.J.(Ed): *Agricultural Production Without Methyl Bromide-Four Case Studies. CSIRO. Canberra, Australia.* 67 pp.

Annex 4.4 Case History 4 : Cut flower production in Colombia without methyl bromide

1. **Crop:** Carnations, roses and chrysanthemums

2. **Pests:**

Carnation	Nematode:	*Heterodera* spp
	Pathogens:	*Fusarium oxysporum* f. sp. *dianthi* *Rhizoctonia* spp. *Pythium* spp.
Rose	Nematode:	*Meloidogyne* spp.
	Pathogen:	*Agrobacterium tumefaciens*
Chrysanthemum	Nematode:	*Patylenchus* spp.
	Pathogen:	*Rhizoctonia* spp

3. **History:**

Colombia is among the largest exporters of floricultural products in the world, commanding a 10% share of the total exports. There are approximately 4,200 ha in plastic greenhouses under cultivation. MB was introduced into Colombian flower production in the late 1970s. Early attempts to use MB quickly determined that this type of fumigation was not very useful. Among reasons for the abandonment of MB were high cost, delayed planting due to acidic soils that retain MB, phytotoxicity, the complex handling required of the fumigant and the need for significant staff training. Currently, virtually no flower growers use MB.

4. **Description of the alternatives:**

IPM systems were used to replace MB and now include:

- Steam sterilisation is used to clean raised beds where mother stock plants are produced and occasionally in production beds.
- Disease resistant varieties are used when available.
- Strict sanitation measures are used extensively. This includes shallow walk-through ponds containing biocide liquid at the entrances to all greenhouses, followed by lime wells through which all operators and visitors must pass as they enter the houses.
- Composted organic matter and steam-sterilised rice hulls used in the planting beds to stimulate soil suppressiveness against plant pathogens.
- All producers invest heavily in monitoring for soil-borne pests.
- Biological control agents are applied against soil-borne pests. These include the fungus *Paecilomyces lilacinus* to control *Pratylenchus* spp. and species of *Trichoderma*. and *Gliocladium* to suppress *Rhizoctonia*.sp. in chrysanthemum.

5. **Regulatory agency acceptance:**

Most of the alternative methods did not require registration. Alternative pesticides were registered in Colombia.

6. **Current commercial use:**

The alternatives described above are used by virtually all cut flower growers in Colombia.

7. **Was the system difficult to develop?**

A great deal of knowledge had to be acquired with respect to the identity and dynamics of the soil-borne pests.

8. **Was the treatment difficult to implement?**

The system was implemented gradually as knowledge became available.

9. **Is the effect of this treatment on other crops being determined?**

Yes. The industry is diversifying into additional flower crops including alstroemeria, aster, bouvardia, gerbera, gypsophila, limonium and snapdragon. The same production system is being used to produce these crops.

10. **Reference:**

R. Rodríguez-Kábana and N. Martinez-Ochoa. 1995. Cut flower production without methyl bromide. pp 8-28 *In:* Banks, J. (Ed). *Agricultural Production Without Methyl Bromide - Four Case Studies*. CSIRO Division of Entomology and UNEP-IE Ozone Action Programme. 67 pp.

Annex 4.5 Case History 5 : IPM strategies for control of *Sclerotium* rot in the Australian flower bulb industry

1. **Crop:** Flower bulbs: Dutch Iris, Liliums, Amaryllus.

2. **Pathogen:** *Sclerotium rolfsii.*

3. **History:**

In 1992, *Sclerotium* rot, *Sclerotium rolfsii*, was the major disease problem in the SE Australian flower bulb industry. This region produces about two thirds of Australia's bulb production. Losses due to this disease were estimated at $AUD 5 million.

This industry has been solely dependent on fumigation with MB/chloropicrin mixtures 98:2 (100 g/m^2) and 70:30 (50g/m^2) in open fields and protected crops for over 20 years. Soil disinfestation was used mainly for control of *Sclerotium* rot and also for weed control and the uniform growth obtained after fumigation.

4. **Description of the alternative:**

The programme relies on use of clean planting material, monitoring of the pathogen in soil, minimal cultivation and strategic use of fungicides (diniconazole, fluazinam, tebuconazole). It has successfully achieved healthy bulb yields equivalent to those obtained with MB and reduced disease incidence from 80% to less than 5%.

Comparatively, the IPM programme was more economical (see Table 4.2 below). However, farmers still needed soil disinfestation to eradicate the fungus from soil. For this reason a combination of IPM and fumigation is used. Clean planting stock also enabled fumigation to be 99% effective.

5. **Regulatory agency acceptance and current commercial use:**

Currently, 100% of growers have adopted some components of the IPM programme. Full implementation is being hampered by lack of registration of two of the fungicides because of minor use registration problems, i.e. the market size is considered too small.

6. **Was the system difficult to develop?**

Four years of research were necessary to identify all factors contributing to disease development and to develop cost effective, strategic application methods for fungicides which were not phytotoxic.

Table 4.2 Comparative costs of Dutch Iris produced using an IPM strategy or with soil treated with pre-plant applications of methyl bromide/chloropicrin (70:30).

	Methyl bromide $/ha	IPM $/ha
Fumigation	6,500	nil
Plastic removal and disposal	100	nil
Soil sampling and sclerote extractions	nil	300
Bulb dips, pre-sowing	nil	200
Other fungicides	2,500	2,500
Herbicides	900	900
Hand weeding	600	600
Extra Herbicides	nil	160 x 2 = 320
Extra hand weeding	nil	600
Total costs	10,600	5,420

Note: In general, costs which are identical to both programmes have not been included, e.g. planting, pre-storage dips, etc. Australian labour costs have been calculated @ AUS$17.50 /hour.

7. Was the system difficult to implement?

No. Bulb dipping facilities already existed in the industry. Currently they are importing disease-free bulbs from Holland.

8. Is the effect of this approach on other crops being determined?

The treatment was developed for Dutch Iris, but is/could be used on 11 crops in the industry.

9. Reference:

Porter, I.J., R.W. Brett, B. Wiseman and J. Rae. 1997. Methyl bromide for preplant soil disinfestation in temperate horticultural crops in Australia in perspective. *Annual International Conference on Methyl Bromide Alternatives and Emission Reduction,* 3-5 November, San Diego, California, USA.

Annex 4.6 Examples of alternatives in use for controlling one or more pests or weeds

Table 4.3 Examples of alternatives in use for controlling one or more pests or weeds, with indications of degree of development and adoption of the technique (ratings of scale of applications - see footnote; from TEAP April 1997 report).

	Treatment	Region
CUCURBITS		
Non-Chemical	Resistant Varieties	Developed countries(4); Article 5(1) countries (4)
	Grafting	Developed countries (3); Egypt (3); Jordan (3); Lebanon (3); Morocco (3); Tunisia (3)
	Solarisation	Developed countries (2-3); Brazil (2); Egypt (2-3); Jordan (3); Morocco (2-3); Syria (2-3); Tunisia (2-3)
	Steam (protected cultivation)	Brazil (2); Europe (4); US (2)
	Biological Control	Brazil (3); Europe (3); Mexico (2); Morocco (2); US (2-3)
	Biofumigation	Developed countries (3); Brazil (2); Mexico (2)
	Soil-less Culture (protected cultivation)	Brazil (2); Egypt (2-3); Europe (4); Jordan (2-3); Lebanon (2-3); Morocco (2-3); US (2-3)
	Crop Rotation	Universal (4)
Chemical	Chloropicrin	Developed countries (3); Zimbabwe (3)
	1,3-D	Developed countries (3-4); Costa Rica (3-4); Honduras (3-4); Mexico (3-4); Morocco (3-4)
	Metam sodium	Developed countries (3-4); Brazil (2); Costa Rica (3-4); Egypt (3-4); Jordan (3-4); Lebanon (3-4); Mexico (3-4); Morocco (3-4); Tunisia (3-4)
	Other specific soil treatments (e.g. Ethotrop, Aldicarb, Carbofuran, Oxamyl, Fenamiphos)	Developed countries (3-4); Brazil (3-4); Costa Rica (3-4); Egypt (3-4); Jordan (3-4); Lebanon (3-4); Morocco (3-4); Syria (3-4); Tunisia (3-4)
CUT FLOWERS		
Protected Cultivation	Steam	Brazil (2); Colombia (4); Europe (4); US (2)
	Solarisation	Developed Countries (2-3); Jordan (1-2); Lebanon (3-4); Morocco (2-3)
	Biocontrol	Developed countries (1-2)

	Treatment	Region
	Substrates	Brazil (3); Canada (4); Europe (4); Morocco (1); Tanzania (2-3); US (2-3)
	Organic Amendments (compost, etc.)	Universal (4)
	Crop Rotation/Fallow	Universal (4)
	Resistant Varieties	Universal (3-4)
	Biofumigation	Developed Countries (1-2)
	Metam sodium	Developed Countries (2-4); Jordan (2-3); Lebanon (2-3); Morocco (2-3)
Open Field	MITC generators (dazomet, metam sodium)	Developed countries (2-4); Brazil (3); Costa Rica (3); Egypt (2-3); Jordan (2-3); Lebanon (2-3); Morocco (2-4); Tunisia (2-4)
	1,3-D	Developed countries (2-4); Colombia (3-4)
	Chloropicrin	Developed Countries (3-4); Zimbabwe (3)
	Organic Amendments (compost, etc.)	Universal (4)
	Crop Rotation/Fallow	Universal (4)
	Resistant Varieties	Universal (2-4)
	Solarisation	Developed countries (2-3)
NURSERY CROPS (VEGETABLES AND FRUIT)		
	Steam (protected cultivation)	Widespread (4)
	Steam (open field)	Denmark (3)
	Solarisation	Widespread (3-4)
	Biocontrol	Canada (3); Germany (3); Israel (3); Mauritius (3); Netherlands (3); Switzerland (3); UK (3)
	Substrates(protected cultivation)	Brazil (4); Canada (4); Chile (4); Denmark (4); Germany (4); Israel (4); Mexico (4); Morocco (4); Netherlands (4); Spain (4); Switzerland (4); UK (4); US (4); Zimbabwe (4)
	Soil Amendments (compost, etc.)	Widespread (4)
	Crop Rotation/Fallow	Widespread (4)
	Resistant Varieties	Widespread (3); including Egypt, Jordan, Lebanon, Morocco, Tunisia
	Grafting	Widespread (4)
	Biofumigation	Brazil (3); Israel (3); Mexico (3); US (3)

	Treatment	Region
PERENNIAL CROPS (REPLANT)		
Banana	Soil Amendments	Universal (3-4)
	Biological Control	Canary Is. (1); Brazil (2)
	Biofumigation	Canary Is. (1)
	Solarisation	Canary Is. (1); Morocco (1)
	Substrates	Canary Is. (4)
	Chloropicrin + 1,3-D	Costa Rica (1)
	1,3-D	Costa Rica (3-4)
	Metam sodium	Costa Rica (1-2); Egypt (1-2); Lebanon (1-2); Morocco (1-2)
	Dazomet	Costa Rica (1-2); Egypt (1-2); Morocco (1-2)
	Crop rotation	Brazil (2)
	Resistant cultivars	Brazil (2)
Perennial Vines	Biological Control	Australia (1-2)
	Substrates	Canary Is. (2-3)
	Grafting	Universal and pest specific (4)
Nuts	Substrates	US (1)
	Grafting	Universal and pest specific (4)
Stone & Pome Fruit	Biological Control	US (crown gal) (1-3)
	Grafting	Universal, very specific to soil pests (2-4)
	1,3-D	Spain (3-4); US (3-4) (stone fruit only)
Citrus	Biological Control	Florida (root weevil) (4)
	1,3-D	Florida (3); Spain (3)
	Solarisation	Spain (1); US (1)
Roses	Biological Control	Morocco (crown gal) (1-3); US (1-3)
	Resistant Varieties	Universal (3-4)
	Grafting	Universal (3-4)
	Substrates	Belgium (4); Denmark (4); Greece (1-2); Italy (1-2); Morocco (1-2); Netherlands (4); Spain (1-2); US (1-2)
	1,3-D	Egypt (2-3); France (2-3); Greece (2-3); Italy (2-3); Jordan (2-3); Lebanon (2-3); Morocco (2-3); Portugal (2-3); Spain (2-3); Tunisia (2-3); US (2-3)

	Treatment	Region
	Metam sodium	Egypt (2-3); France (2-3); Greece (2-3); Italy (2-3); Jordan (2-3); Lebanon (2-3); Morocco (2-4); Portugal (2-3); Spain (2-4); Tunisia (2-4); US (2-3)
	Dazomet	Egypt (2-3); France (2-3);Greece (2-3); Italy (2-3); Japan (3); Jordan (2-3); Lebanon (2-3); Morocco (2-3); Portugal (2-3); Spain (2-3); Tunisia (2-3); US (2-3)
	Solarisation	Israel (4)
	Steam (protected cultivation)	Belgium (4); Netherlands (4)
STRAWBERRIES (RUNNER AND FRUIT PRODUCTION)		
	Steam	Developed countries (1)
	Solarisation	Developed countries (2-3)
	Biocontrol	Developed countries (1); Japan (2-3)
	Substrates	Indonesia (3); Malaysia (3); Netherlands (4); UK (3); US (1-2)
	Organic Amendments (compost, etc.)	Universal (4)
	Crop Rotation/Fallow	Universal (4)
	Resistant Varieties	Denmark (4); Japan (3); Mexico (1); Spain (1); UK (1); US (1)
	Biofumigation	US (1)
	Metam sodium	Egypt (3); Jordan (3); Lebanon (3); Morocco (3-4); Netherlands (4); Spain (4); Tunisia (3-4); UK (2); US (2)
	Dazomet	Egypt (3); Jordan (3); Lebanon (3); Morocco (3); Netherlands (4); Spain (4); Tunisia (3); UK (3); US (2)
	1,3-D	Netherlands (4); Spain (2); UK (3); US (2)
	Chloropicrin + 1,3-D	US (2)
	MeBr/Chloropicrin mixtures & reduced usage MeBr	Australia (4); Italy (4); Mexico (3-4); Spain (3-4); US (3-4)
	Chloropicrin	Japan (3); UK (3); US (1-2)
TOMATO & PEPPER		
Protected	Steam	Belgium (4); Netherlands (4); UK (3); US (1)
	Solarisation	Egypt (1-2); Japan (3); Jordan (1-2); Lebanon (1-2); Morocco (2-3)

	Treatment	Region
	Substrates	Brazil (2); Belgium (4); Canada (3); Denmark (4); Morocco (2-3); Netherlands (4); Spain (2-3); UK (3); US (2-3)
	Biofumigation	Southern Europe (1-2)
	Metam sodium and dazomet	Egypt (3); Europe (3-4); Jordan (3); Lebanon (3); Morocco (3); Tunisia (3); US (2-3)
Open Field	Solarisation	Egypt (1-2); Israel (3-4); Japan (3); Jordan (1-2); Lebanon (1-2); Morocco (1-2); Spain (1-2); Tunisia (1-2); US (1-3)
	Biocontrol	Brazil (2); Israel (1-2); Mexico (2); US (1-2)
	Substrates	Canary Island (2-3)
	Organic Amendments (compost, etc.)	Universal (1-2)
	Crop Rotation/Fallow	Universal (3-4)
	Resistant Varieties	Developing countries (4); Japan (4); Spain (4); US (4)
	Grafting	Egypt (1); Japan (4); Jordan (1); Lebanon (1); Morocco (1); Spain (1); Tunisia (1); US (1)
	Biofumigation	Brazil (2); Mexico (2); US (1-2)
	Metam sodium	Australia (4); Brazil (4); Costa Rica (4); Egypt (4); Japan (3); Jordan (4); Lebanon (4); Mexico (4); Morocco (4) Spain (4); Tunisia (4); US (3); Zimbabwe (4)
	Dazomet	Brazil (2); Europe (3-4); Japan (3); Morocco (3); US (2)
	1,3-D	Costa Rica (3-4); Honduras (3-4); Italy (3-4); Japan (3); Mexico (3-4); Morocco (1-2); Spain (3-4); US (3-4)
	Chloropicrin	Costa Rica (3-4); Honduras (3-4); Japan (3-4); Mexico (3-4); US (3-4); Zimbabwe (3-4)
	Chloropicrin/methyl bromide mixtures	Australia (3); Japan (3)
TOBACCO SEEDLINGS		
	Dazomet	Brazil (3-4); India (2-3); Japan (3); Malawi (2-3); South Africa (2-3); Thailand (2-3); USA (3-4)
	Dazomet + EDB	Zimbabwe (2)
	Brush burning + 1,3-D	Malawi (3); Zambia (3); Zimbabwe (3)

	Treatment	Region
	Biocontrol (*Trichoderma*)	Malawi (4); Zambia (3); Zimbabwe (4)
	Biofumigation	Australia (2); South Africa (3); USA (3); Zimbabwe (3)
	Soil solarisation	Brazil (2); Zimbabwe (2)
	Soil-less culture	Brazil (3-4); South Africa (3-4); USA (3-4); Zimbabwe (2)
	Chloropicrin	Japan (4)
	Methyl isothiocyanate	Japan (3)
	Chloropicrin with 1,3-D or methyl bromide	Japan (3)

Footnotes:

a) Region. Examples of regions using the alternative in part or full replacement of the effect obtained by methyl bromide in production of the nominated crop. This list provides examples only and is not comprehensive. The alternative may or may not be economically competitive with methyl bromide use.

b) Numerals in brackets, e.g. (1) refer to the most advanced degree of development of the alternative in a region. Ratings correspond to the following levels:

(1) = under experimental investigation (laboratory)

(2) = under experimental investigation (field trials)

(3) = limited commercial use

(4) = widespread commercial use.

Annex 4.7 Major soil-borne pathogens (nematodes, insects, weeds and parasitic plants) for which MB is used in one or more countries in various regions of the world in 1998.

Table 4.4. Major soil-borne pathogens (nematodes, insects, weeds and parasitic plants) for which MB is used in one or more countries in various regions[1] of the world in 1998. (Listed are those which, if all other pests were excluded, MB would still be used)

	North America	Central and South America	Northern Europe	Mediterranean Region	Sub-Saharian Africa	Asia	Australasia
Nematodes							
Meloidogyne spp.	+	+	+	+	+	+	+
Rotylenchulus spp.	+	+	-	-	-	+	-
Xiphinema spp.	+	+	-	-	-	-	-
Nacobbus sp. (seedbeds only)	-	+	-	-	-	-	-
Fungi							
Armillaria spp/Rosellinia spp.	+	-	-	-	+	-	+
Fusarium spp.	+	+	+	+	+	+	+
Phytophthora spp.	+	+	+	+	+	+	+
Pythium spp.	+	+	+	+	+	+	+
Rhizoctonia spp.	+	+	+	+	+	+	+
Sclerotinia spp.	+	+	+	+	+	-	-
Sclerotium rolfsii	+	+	+	+	+	+	+
Verticillium spp.	+	+	+	+	+	+	+
Bacteria							
Clavibacter michiganensis	+	-	-	+	-	-	-
Insects							
Cutworms (*Agrotis* spp.)	+	-	-	-	-	-	-
Root weevils[2]	+	-	-	-	-	-	-
Rootworm (*Paria* spp.)Wireworms	+	-	-	-	-	-	-
Parasitic Plants/Weeds							
Orobanche spp.	-	+	+	+	+	-	-
Cyperus spp.	+	+	-	+	+	-	+
Replant Problems							
(Perennial Crops)	+	+	+	+	+	-	+

[1] May be important in one or more countries in the region.
[2] Root weevils include (*Otiorlynchus* spp., *Nemocestes* spp., *Asynonychus* spp.).

+ Methyl bromide considered necessary for this pest
- Methyl bromide not considered necessary for this pest

Note: Pests affecting specific uses (e.g. crop specific certification) have not been considered in the table. In the United States a range of nematodes are controlled with MB to assist certification of nursery stock and turf, also an additional 20 different pests, pathogens and weeds are still considered major targets for MB use in the US (eg. Florida and California).

Data Sources:

1. Survey data collected by MBTOC from Agricultural Ministeries and Departments of Environment.
2. Californian Department of Pesticide Regulation.
3. Florida Agricultural Statistics Service (1995). Vegetable Chemical Use.
4. USDA (1994) Agricultural Chemical Usage. USDA National Agricultural Statistics Service, Economic Research Service, Washington DC.
5. Australian National Methyl Bromide Response Strategy (1998). Environment Australia.
6. MBTOC Report (1994).
7. The Netherlands Policy Note, Lower House (1980).

Annex 4.8 Examples of alternatives to soil fumigation with methyl bromide used in major crops in MB-user countries since restrictions were enforced

Table 4.5 Non Article 5(1) countries which have phased out methyl bromide

Country	Crop	Proportion of Crop Treated with MB the Year Before Phase-out	Quantity of MB Used (t) the Year Before Phase-out	Main MB Formulation Used Prior to Restriction[1]	Estimated Proportion of Alternative Cropping Practice Adopted to Replace MB Use Since Phase-out	Key Research on Alternatives to MB
Holland[1]	Tomatoes	65%	1,200	MB (100) used in 1980	90% - Substrates 10% - Steam	Improvement and transfer of alternative methods
	Cucurbits	30%	300	" "	90% - Substrates 10% - Steam	
	Cut Flowers	25%	800	" "	60% - Substrates 30% - Steam 10% - Metam with 1,3-D	
	Flower bulbs (glasshouse)	90%	300	" "	70% - Metam with 1,3-D 25% - Crop rotation & Flooding 5% - Steam	
	Strawberries	75%	200	" "	90% - Substrates 10% - Metam	
	Total all crops		**3,000**			
Denmark[2]	Tomatoes, lettuce, cut flowers	NA	26	MB/Pic 98:2	99% - Substrates 1% - Steam	NA
	Total all crops		**26**			

[1] MB use shown for the year 1980 which represents levels in Holland before restrictions were imposed, total phase-out 1991.
[2] Total phase-out on 1 January, 1998.

Table 4.6 Non Article 5(1) countries with phase-out in 2005 or conforming to Montreal Protocol Restrictions

Country	Crop	Proportion of Crop Treated with MB in 1994	Quantity of MB Used (t) in 1994	Main MB Formulation Used Prior to 1994[1]	Estimated Proportion (since 1994) of Alternative Practice Adopted Commercially to Replace MB Use as of Jan 1997	Key Research on Alternatives to MB
USA e.g. California	Almond	NA	264	MB/Pic 98:2	NA	Fumigant/pesticide combinations
	Walnut	NA	130	98:2	NA	Solarisation, Biofumigation
	Grapes	NA	941	98:2	NA	Organic amendments
	Nurseries	NA	197	NA	Est. adoption of alternatives <1%	Rhizosphere organisms
	Strawberry nurseries	100%	174	57:43; 67:33	Est. adoption of alternatives <1%	Crop rotation, cover crops
	Strawberry fruit	98%	1,846	50:50 to 98:2	Est. adoption of alternatives <1%	Systemic acquired resistance
	Orchard (plum/peach)	NA	272	98:2	NA	Steam, Ohmic heating
	Sweet potato	53%	237	98:2	Est. adoption of alternatives <7%	Resistant varieties
	Tomatoes, Peppers (Fresh)	2%	349	67:33 85:15	Est. adoption of alternatives <2%	IPM
	Total all crops		**6,742**			
eg. Florida	Cucumber	100%	113	MB/Pic 98:2	Est. adoption of alternatives <1%	Cover crops, Organics
	Eggplant	100%	75	98:2		Biological Control Agents (BCAs) Crop rotation, IPM
	Melons	70%	67	98:2		Solarisation/biofumigation, Hot water/steam
	Peppers	100%	1,569	98:2 (80%) 67:33 (20%)		Mulches/emission reduction
	Strawberries	100%	501	98:2 (80%) 67:33 (20%)		Resistance, Biopesticides
	Tomatoes	100%	3,732	98:2 (60%) 67:33 (40%)		Fumigant/pesticide combinations, etc.
	Total all crops		**(Approx. 6,000)**			

Country	Crop	Proportion of Crop Treated with MB in 1994	Quantity of MB Used (t) in 1994	Main MB Formulation Used Prior to 1994[1]	Estimated Proportion (since 1994) of Alternative Practice Adopted Commercially to Replace MB Use as of Jan 1997	Key Research on Alternatives to MB
Spain	Cucurbits	0.4	175	MB/Pic 98:2	MB Rate reduction	Biofumigation
	Pepper	9.2	1,186		<40g/m^2 and PE or 20g/m^2 withVIF films (legislatory requirement)	Chemical control, Solarisation, Biofumigation
	Tomatoes	0.4	149			-
	Vegetables (General)	0.4	730		Use of other fumigant and non fumigant alternatives increased	Chemical control, Solarisation, Biofumigation, BCAs
	Ornamentals	29.9	470			Chemical control, Solarisation
	Strawberry fruit	39.1	972	MB/Pic (67:33)		Chemical control, Solarisation, Biofumigation, BCAs
	Strawberry nursery	100.0	432	MB/Pic (67:33)		
	Citrus (replants)	0.1	78	MB/Pic (98:2)		Chemical control, Solarisation
	Tobacco (seedbeds)	0.5	46	MB/Pic (98:2)	100% - substrates	
	Total all crops		**4,238**	**85% - (98:2) 15% - (67:33)**	**25% reduction (Legislatory requirement)**	
Japan	Melons	NA	741[1]	MB/Pic(98.5:1.5)	15% - Pic, 1,3-D or dazomet alone	Biological control, Pesticides
	Cucumber		526[1]	98.5:1.5	15% - Pic, 1,3-D or dazomet alone	Biological control, Pesticides
	Watermelons		963[1]	98.5:1.5	15% - Pic, 1,3-D or dazomet	Biological control, Pesticides
	Ginger		557	98.5:1.5	5% - Pic	Pesticides
	Ornamentals		225[1]	98.5:1.5	15% - Pic, 1,3-D or dazomet	Plant breeding, Grafting, Pesticides
	Pepper		273[1]	98.5:1.5	12.5% - Pic, 1,3-D or dazomet	Biological control, Pesticides
	Tomato		323[1]	98.5:1.5	12.5% - Pic, 1,3-D or dazomet	Biological control, Pesticides
	Strawberry fruit		326[1]	98.5:1.5	15% - Pic, 1,3-D or dazomet	Plant breeding, Pesticides
	Seedbeds		359[1]	98.5:1.5	15% - Pic or steaming	Chemical control
	Total all crops		**5,648**			

Country	Crop	Proportion of Crop Treated with MB in 1994	Quantity of MB Used (t) in 1994	Main MB Formulation Used Prior to 1994[1]	Estimated Proportion (since 1994) of Alternative Practice Adopted Commercially to Replace MB Use as of Jan 1997	Key Research on Alternatives to MB
Australia	Tomatoes (fresh) Pepper	50	290	MB/Pic (98:2)	50% -MB/Pic (70:30)	Wider Rotations, Prediction, Selective pesticides, IPM, Fumigants
	Flowers/Bulbs	15	140	98:2	70% - MB/Pic (70:30) 50% - IPM[2] (see Case History 5 - Annex 4.5)	Fumigant combinations, IPM, Biofumigants
	Strawberry fruit	65	130	70:30	10% - MB/Pic (50:50)	Fumigant combinations, IPM Biofumigants, Organics
	Strawberry nursery	98	30	70:30	No change	Fumigant/pesticide combinations, Biofumigants
	Protected crops	5	70	98:2 or 100%	5% - Steam	Steam, Fumigant combinations
	Orchard replants	2	7	98:2	70% - MB/Pic (70:30)	Nil
	Turf	10	8	98:2	No Change	Nil
	Total all crops		**679**			

[1] >90% of MB use is for treating soils for protected crops (ie. in greenhouses, polyhouses or glasshouses).
[2] Most bulb growers which use IPM still use MB.

Table 4.7 Article 5(1) countries which have implemented alternative practices to soil fumigation with methyl bromide

Country	Crop	Proportion of Crop Treated with MB in 1994	Quantity of MB Used (t), Prior to 1994	Main MB Formulation Used Prior to 1994	Estimated Proportion (since 1994) of Alternative Practice Adopted Commercially to Replace MB Use as of Jan 1997	Key Research on Alternatives to MB
Argentina	Tomato, pepper, eggplant (seedbeds)(Protected)	100%	7	MB/Pic (98:2)	20% - Substrates	Resistant varieties Solarisation (seedbeds) Substrates, Pesticides
	Tobacco (seedbeds)	100%	171	98:2	15% - Cultural, chemical	Pesticides, solarisation
	Ornamentals	5%	12	98:2	99% - Cultural/chemical	Substrates
	Strawberry	Nil	Nil	Nil	100% - MB/Pic (80:20)	Substrates
	Total all crops		**244**		**348t MB used in 1997**	
Morocco	Tomato, cucurbits, strawberry, beans, pepper, bananas, ornamentals	68%	1,025	MB/Pic (98:2)	Limited adoption Increased exports have led to existing and new growers increasing their use of MB, however some farmers use alternatives and have never used MB	Cultural practices (rotation) Plant resistance Resistant rootstocks Soil solarisation New substrates Pesticides (Timing, method, rate) Biofumigation, IPM
	Total all crops		**1,025**		**1,085t (Approx.)**	

Data sources for Tables 4.5, 4.6 and 4.7:

1. Survey data collected by MBTOC from Agricultural Ministeries and Departments of Environment.
2. Californian Department of Pesticide Regulation.
3. Florida Agricultural Statistics Service (1995). Vegetable Chemical Use.
4. USDA (1994) Agricultural Chemical Usage. USDA National Agricultural Statistics Service, Economic Research Service, Washington DC.
5. Australian National Methyl Bromide Response Strategy (1998). Environment Australia.
6. MBTOC Report (1994).
7. The Netherlands Policy Note, Lower House (1980).

Annex 4.9 Relative difficulty of finding alternatives for major uses of methyl bromide for soil disinfestation in one or more countries in various regions of the world in 1998.

Table 4.8 Relative difficulty of finding alternatives for major uses of methyl bromide for soil disinfestation in one or more countries in various regions[1] of the world in 1998. (* Least difficult; * Most difficult)**

Crops	North America (eg. California/Florida)	Northern Europe	Mediterranean Region	Asia (eg. Japan)	Australasia (eg. Australia)
Cucurbits:					
Field	(Florida ***)[1]	NA	NA	*	*
Protected	**	*	*	**[2]	**
Pepper					
Field	**	NA	NA	*	*
Protected	**	**	** (Spain***)[1]	**[2]	**
Tomatoes					
Field	**	NA	NA	*	*
Protected	**	**	** (Sicily ***)[1]	**	**
Orchard replants	***	NA	*	NA	***
Ornamentals					
Field	**	NA	NA	*	*
Protected	**	NA	**	*	**
Ornamental tree nursery	***	NA	*	NA	**
Strawberry fruit	**	**	**	**	**
Strawberry nursery	*** (Canada*)[1]	***	***	**	***
Tobacco (seedbeds)	*	NA	*	*	*
Turf	***	NA	NA	NA	**

NA - MB not applied in significant quantities. Protected crops include those grown in plastic houses and glasshouses.

[1] Indicates that a specific region has a greater/lesser need for which MB is used.
[2] Specific viruses in Japan (CGMMV, PMMV) for which no alternative other than MB is effective.

Footnote: In assigning rankings many factors have been considered including: crop value, difficulty of achieving acceptable pest levels, regulatory and certification requirements.

Chapter 5

Alternative treatments for durables, wood products and structures

5.1 Summary

Durables are commodities with a low moisture content that, in the absence of pest attack, can be safely stored for long periods. They include foods such as grains, dried fruits and beverage crops and non-foods such as wood products and tobacco. Wood products include: museum artefacts and other items of historical significance; unsawn timber, timber products and bamboo ware; and packaging materials and items of quarantine significance.

Structures include entire buildings and portions thereof which are being treated to control wood-destroying organisms and other pests in non-food facilities. Treatment of structures may also include food production and storage facilities for control of stored product insects and other pests. Transport vehicles, including ships, aircraft, freight containers and other vehicles, are treated to control stored product insects, rodents and other pests.

Currently, methyl bromide (MB) is primarily used: to disinfest bag stacks of grain; to disinfest food processing facilities such as mills; to treat durable commodities such as cocoa, grain, certain dried fruit and nuts, at time of export and post-entry; and for a variety of quarantine applications, notably treatment of unsawn logs.

MBTOC estimates that approximately 12% of the annual world non-feedstock usage of MB is for the disinfestation of durable commodities and about 3% for structures. Some of the MB uses for durables, wood products and structures fall within the quarantine and pre-shipment (QPS) exemption.

There is a variety of existing alternatives to MB for disinfestation of durable commodities and structures. The principal alternatives in use for durables are phosphine, heat, cold and contact pesticides; for wood products, they are sulphuryl fluoride, chemical wood preservatives and heat; for structures, they include sulphuryl fluoride and heat. The choice of appropriate alternatives is dependent on the commodity or structure to be treated, the situation in which the treatment is required, the accepted level of risk, the speed of action required and the cost. There has been considerable research and application activity in this area and 39% of the references quoted in this chapter have been added since the last report in 1994.

There are some current non-QPS uses of MB for which MBTOC did not identify any existing alternatives. For durables, these are: disinfestation of fresh chestnuts; disinfestation of fresh walnuts for immediate sale; elimination of seed-borne nematodes from alfalfa and

some other seeds for planting; and control of organophosphate-resistant mites in traditional cheese stores. In treatment of mills and food processing facilities where IPM systems have failed, it may be necessary to resort to occasional use of MB. Where hydrogen cyanide is not available as an alternative for disinfestation of aircraft, there are no proven alternatives to MB. The total of these uses is unlikely to exceed 50 tonnes per annum.

MBTOC also did not identify alternatives for a number of durable QPS uses of MB.

In many cases, an integrated program combining several different measures can effectively replace a particular use of MB. Some Integrated Pest Management (IPM) strategies require constant maintenance in order to succeed. Occasional full-site or curative treatments may be required to supplement IPM programs. These may involve fumigation, possibly with MB, or other processes.

Phosphine is the only available in-kind alternative extensively used, principally for stored cereals and similar products. It has the potential to act as a direct substitute for MB in many situations, but can also act as a component of an IPM process to avoid MB use. Its action against pests is much slower than MB, particularly at low temperatures. Insect populations are capable of developing resistance to phosphine relatively easily, therefore it is important to use correct exposure and application technology to avoid development of resistance and thus loss of this useful alternative. When used in structural situations, measures should be taken to avoid potential corrosive effects on certain metals.

There are several other fumigants which may have limited potential as alternatives for MB. Although hydrogen cyanide was once widely used for treatment of structures and durable commodities, its availability and limitations related to health and safety issues may prevent its immediate substitution for particular uses of MB. Ethyl formate, carbon bisulphide and ethylene oxide are useful in selected situations. Sulphuryl (sulfuryl) fluoride is mainly used for controlling wood-destroying pests in residences and other buildings. It is also used for disinfestation of wood products and research is in progress on its potential for use in empty food premises.

Treatment with controlled atmospheres, based on carbon dioxide or nitrogen, offers an alternative to fumigation for insect pest control, but not fungal pests. They are unlikely to be used where fast turn-around is necessary, unless the technique is combined with such measures as high pressure or raised temperature.

Physical methods of insect control, including mechanical measures, cold, heat and irradiation treatments, offer further potential as non-chemical alternatives in individual circumstances. Cold treatments are now used as part of IPM systems for stored products and artefacts. Heat treatment technologies are now used and match the speed of treatment afforded by MB and other fast-acting fumigants. Heating can also synergise the effects of other treatments, for example fumigants, controlled atmospheres and inert dusts.

Where registered for use, contact insecticides may provide persistent protection against reinfestation. In some situations, the use of dichlorvos offers a direct alternative to MB, for disinfestation of bulk grain during turning or loading at point of export. Contact insecticides are not normally registered for use on processed commodities or dried fruit, nuts and cocoa.

Biological agents are generally host specific and considered to be primarily preventive control measures. They are not directly comparable with MB fumigation because of their specificity, except in instances where only a few species of target pests are prevalent. Biological methods have potential to provide long-term protection for stored commodities in specific situations.

Botanical compounds, such as pyrethrum extract, have limited application as insecticides in non-Article 5(1) (developed) countries, but plant powders and oils are widely used in Article 5(1) (developing) countries. Inert dusts, such as those based on diatomaceous earth, can provide effective pest control in dry grain and as part of an IPM program in structures.

5.2 Introduction

This chapter summarises alternative treatments to methyl bromide (MB) for durables, wood products and wood structures and the control of food pests in structures and transport.

Durables are commodities with a low moisture content that, in the absence of pest attack, can be safely stored for long periods. Most durable commodities currently treated with MB are foodstuffs that are stored post-harvest, before being consumed, processed or transported in or out of a country between harvests, sometimes for long periods. Pest control in durables is usually to prevent damage to the commodity, but often the primary objective is to reduce insect populations to below a detectable level. Many pests can survive and proliferate on durables in storage. The risk of introducing and spreading infestation, either of field pests on the commodity at harvest or of storage pests further down the supply chain, is a major reason for treatment of durables which include artefacts, i.e. bamboo ware, museum and cultural artefacts; beverage crops, such as cocoa and coffee; cereal grains, e.g. wheat, rye, barley, rice, sorghum, maize; dried fish, dried meat and derived meals; dried fruit and nuts; grain products, including flour, noodles, semolina; herbs and spices; pulses, such as peas, beans and lentils; seeds, for planting; tobacco (post-harvest); and unsawn timber and timber products; packaging materials; and items of quarantine significance.

Generally, wood products which require treatment with MB can be classified into two categories, those items separate from buildings and structures and those forming an integral part of a structure.

Another area of concern involves structural treatments. Structural pest control is used to prevent or control pests in either an entire structure, or a portion of a structure. Many conditions and pests exist which require structural pest control, only some of these are treated primarily by MB fumigation. There are two main applications: (1) control of direct structural damage by drywood termites and wood-boring beetles found in domestic,

commercial and historic buildings; (2) control of pests, for example moths, beetles, cockroaches, mites, nematodes and rodents, in storage facilities and non-food facilities.

Structural fumigation for facilities with food pests is a pest management technique that provides broad spectrum control and the ability of the fumigant gas to penetrate to pests that are not on the surface and cannot be readily contacted by other types of pesticide applications. The ability to penetrate through packaging materials, walls and other areas to hidden infestations, is particularly valuable in structural fumigation. Structural treatments can involve empty buildings or those containing goods.

Treatment regimes for transport are often subject to stringent time constraints. Times-out-of-service for aircraft and ships can incur severe consequences for operators. Thus alternatives for MB fumigation need to provide a means for a rapid solution to pest problems.

There are a large number and variety of potential or existing alternatives to MB for disinfestation of durable commodities and structures. Some alternatives (e.g. some fumigants, heat treatment) may be implemented as stand alone treatments to replace MB in certain situations. In general, however, the level of risk may be brought to an acceptable level by combining two or more alternatives. A treatment based on combinations of measures (commonly called a "systems approach") may be mandatory in many situations.

Since it is unlikely that any single treatment or practice will replace MB for all uses in durable and structural uses, an IPM approach is often required. It aims to minimise pest infestation by employing a variety of tools and techniques to suppress pests effectively, economically and in an environmentally sound manner. It is described more fully in Section 5.4.15.

5.2.1 Target pests

Most of the target pests of durables and structures that are treated with MB are insects and, to a lesser extent, mites. Fungi and nematodes are not typically target organisms, except with unsawn timber and seeds for planting, respectively. MB is sometimes specified for quarantine purposes for control of other organisms (e.g. ticks, snails) that may be incidental contaminants of durable foodstuffs or timber, but are know to not normally infest and damage the commodity. The principal target pests are listed in the individual sections below.

5.2.2 Types of fumigation enclosures

For safety and efficient action, it is necessary to enclose the commodity to be treated with some form of system, the fumigation enclosure, which restricts loss of gas to a low level.

The most efficient method of fumigating bagged or cased commodities is in chambers equipped for applying the fumigant in a manner that will ensure its rapid and even distribution, typically, a recirculation system of some type (Bond 1984). Fumigation of commodities is also carried out:

- under gas-proof sheets of various thicknesses;
- in warehouses;

- in specially sealed transportable plastic enclosures ('bubbles');
- in freight containers;
- in silos;
- in railway box-cars;
- in barges and ships; and
- in specially designed and equipped vacuum chambers.

Many of these applications require some form of recirculation of the atmosphere within the treated enclosure, in order to achieve effective and rapid distribution of the added fumigant.

5.3 Existing Uses of Methyl Bromide

Of the estimated 9855 t of MB used on durables and wood products it was estimated that 4782 t (48%) were used on unsawn timber (logs); 472 t (5%) on dried fruit and nuts; and the remainder 4601 t (47%) used mainly on cereal grain and legumes with minor uses on other commodities.

MBTOC did not survey MB use in detail for durables and structures after 1994 as it considered there had been little change in the proportions used.

5.3.1 Uses for which MBTOC did not identify alternatives

There are some current non-QPS uses of MB for which MBTOC did not identify any existing alternatives. For durables, these were: disinfestation of fresh chestnuts; disinfestation of fresh walnuts for immediate sale; elimination of seed-borne nematodes from alfalfa and some other seeds for planting; and control of organophosphate-resistant mites in traditional cheese stores. In treatment of mills and food processing facilities where IPM systems have failed, it may be necessary to resort to occasional use of MB. Where hydrogen cyanide is not available as an alternative for disinfestation of aircraft, there are no proven alternatives to MB. The total of these uses is unlikely to exceed 50 tonnes per annum.

MBTOC also did not identify alternatives for a number of QPS uses of MB. These include: military equipment contaminated with soil; oak logs with oak wilt fungus; cotton against pink boll worm; empty ships where other methods have failed; and disinfestation of aircraft where hydrogen cyanide is not available.

5.3.2 Uses for durables

MB has been in widespread use as a fumigant for foodstuffs and other stored products for more than fifty years. As a result of MB's high toxicity to a wide range of insect pests (Annex 5.3, Table 5.16) excellent penetration and handling characteristics, it largely replaced hydrogen cyanide and ethylene oxide for many applications. In addition, it has been successfully utilised in the treatment of products in circumstances which were considered at one time not suited for fumigation.

MB has a rapid action on pests, with treatments of durables (preparation, fumigation and airing) completed within three days. In many cases, total treatment time can be less than 24h. The treatment time includes both the actual exposure period to the fumigant and the start point when the fumigant is distributed or is dispersed throughout the enclosure. It also includes the time at the end of the exposure, when residual gas is aired off from the treated commodity. The rapid speed of action makes MB fumigation a particularly convenient treatment, where the commodity cannot be held for long periods for logistical reasons, such as at ports during import and export. This speed of action is technically important in disinfesting semi-durable commodities such as fresh chestnuts and walnuts.

MB can be regarded as one of the tools used to disinfest and protect durables from damage by pests. There are a wide variety of other measures and a large number of publications which review and describe these measures as part of an integrated system of pest control. Most of these apply particularly to cereal grain storage, but the principles are applicable to the protection of durables in general. These publications include: Moulton (1988, textbook on storage of grain, pulses and oilseeds); Sauer (1992, textbook on grain storage); Bond (1984, textbook on fumigation); (Anon. 1989); Snelson (1987, review on insecticide use on grain); Jayas *et al.* (1994, reviews on techniques of pest control in stored grain); Highley *et al.* (1994, conference proceedings on advances in stored product protection); Bell (1996, discussion on issues in replacing MB); Donahaye *et al.* (1997, conference on fumigation and controlled atmosphere treatment of grain).

In general, MB plays a small, but significant, role in the overall disinfestation and protection of durables. Its rapid action and reliability have led to its continued use, as the treatment of choice or as a mandatory treatment in many countries, in several important situations. These are: disinfestation of bulk grain to phytosanitary or quarantine requirements at point of import or export; quarantine treatments against specific pests, particularly khapra beetle (*Trogoderma granarium*) the house longhorn beetle (*Hylotrupes bajulus*) and various snails; disinfestation of stacks of bagged grain, particularly in Africa and Singapore, including food aid grain at point of import; protection and disinfestation of dried vine fruit, some other dried fruit and nuts in storage and prior to sale.

In all these cases, though there may be alternative approaches, MB has a history of successful use. Up until recently, there has been no reason to change to less well tried measures, or ones which may involve significant changes to established practice.

MB is currently used as the major pest management process for several high value commodities in trade. In particular MBTOC estimates that about 80% of dried vine fruit (currants, sultanas and raisins) and about 90% of cocoa beans in global trade at some stage between production and processing, are currently disinfested with MB. There are also numerous low volume uses, such as disinfestation of particular kinds of dried herbs and spices and particular specialised cereal grains and products. Development of alternatives for these is hampered principally by the costs of registration, but also research, to permit their use. MB remains the only registered chemical that can be used. A dosage schedule for MB is appended as Annex 5.5, Table 5.18.

5.3.3 Uses for wood and wood products

In general, MB plays a significant, role in the overall treatment and protection of wood products and timber. Its rapid action and reliability have led to its continued use in several important situations. These are: disinfestation of museum objects and cultural relics (see Section 5.5.7); treatment of unsawn logs, traded internationally, against insect pests and some fungi; quarantine treatments against specific pests, particularly the house longhorn beetle (*Hylotrupes bajulus)* and certain snails; and treatment of dwellings and other buildings against structural pests.

Logs, timber and bark products, such as particle board and wood chips, as well as wooden products, containers, pallets, toys and sports goods, all come under either phytosanitary or quarantine regulations in international trade. Quarantine uses of MB also exist for bamboo ware.

MB has been in use for timber treatment within structures for many years, against wood-destroying insects such as powder post beetles, long-horned beetles, drywood termites and carpenter ants. Its continued successful use has tended to restrict possible development of alternatives, but other methods have been available for many years.

Treatments are normally carried out for logs, timber and bark materials either under gas-proof sheets or on board ships. A dose of 32 gm^{-3} at temperatures of 15°C or over is normally applied when fumigated under gas-proof sheets of 150 micron thickness for a 24 hour period. For in-ship fumigation a dose of 48 gm^{-3} is recommended for the same period of exposure. Treatments of timber may be carried out as part of a routine export system, or they may be ordered as a result of detection of pests on importation.

MB is absorbed significantly by woody materials and only slowly released at the end of a fumigation. It is estimated that about 88% of the MB applied to logs in ships' holds, is released to the atmosphere over a period of 1-2 weeks subsequent to treatment (see 'Emissions', Chapter 9).

MB is used for structural fumigation as indicated in Table 5.1. Detection of wood destroying insects in a building involves identifying and finding the specific location of pests so that control measures can be applied to the infested area when possible and practical. Monitoring pests is an on-going process of assessment of continuing pest presence where treatment procedures have been utilised. Several tools are used to supplement visual inspections to detect the presence of pests in wood, including specially trained dogs, optical devices, acoustic emission detectors and methane detectors. The ability to detect the locations of the pest population is critical to some of the techniques described below since several are effective only as spot treatments.

MB fumigation has long been used to eradicate drywood termites from structures. Current research indicates that termites are very heat and cold sensitive which offers the possibility of using heat and cold as alternatives to MB. When seasonal changes occur, drywood termite colonies move significantly within the structure. During warmer times, they move from exterior wall areas and attic spaces to other locations deeper into the structure where temperatures are cooler. Conversely when colder temperatures exist, the opposite

movement occurs. This may make detection and spot treatment of an entire colony more difficult to achieve. Additional research indicates that when an entire colony is not eradicated it will produce new reproductives and survive. Subsequently, eggs will be produced and a colony can recover and potentially continue to damage the structure.

Table 5.1 Types of buildings and structures fumigated against wood pests

Building/Structure	Pest
Dwellings including apartments, condominiums, trailer homes, historical buildings, commercial premises	Drywood termites, furniture beetles, powder post beetles, long horned beetles
Museums	Wood boring beetles, dermestid beetles, clothes moths, cigarette beetles, drugstore beetles
Structural elements before building in place, e.g. beams	Powder post beetles, long horned beetles
Antique vehicles	Powder post beetles

5.3.4 Uses for pests in structures

Pests which infest durable commodities and food products often become established in the fabric of the buildings or structures where food is stored. Table 5.2 describes the situations in which MB may be used as a space fumigant to disinfest premises, together with the pests concerned.

5.4 Description of Alternatives

Alternatives are provided based on the definition described in the Introduction, Section 5.2.

Many alternatives are measures designed to preclude the need for MB use, rather than direct replacements for existing uses. As with MB, use of alternatives may have human health and environmental consequences which must be taken into consideration. Regulatory actions within each country may affect their availability or applicability by for example, prescribing substantial exclusion zones around fumigation enclosures. Many of these potential alternatives have not been tested on large volumes of commodities, requiring rapid turn around for QPS purposes. The regulatory burden for some will be prohibitive if the use is to be confined to durable commodities or structures.

Aside from cost, the choice of an alternative is dependent upon the commodity or structure to be treated, the situation in which the treatment is to be carried out and the accepted risk of pest survival. Risk can be determined in relation to treatment failure, degradation of commodity value and human or environmental well-being.

Table 5.2 Uses and targets for structural fumigation to control urban and food pests

Description	Examples of Pests
Food Production and Storage Facilities	
Food processing plants	Stored product insects, rodents, cockroaches, psocids, mites, silverfish, beetles
Flour and feed mills	
Bulk commodity storage (e.g. silos)	
Warehouses	
Bakeries	
Ham smoke houses	
Cheese plants	
Refrigerated storage	
Restaurants	
Poultry houses	Lesser meal worm, mites, rodents
Mushroom houses	Mushroom flies, mites
Non-food Facilities	
Seed warehouses	Rodents, stored product insects
Museums	Dermestid beetles, clothes moths, cigarette beetles, drugstore beetles
Condemned housing or public health compliance	Rodents, cockroaches, venomous spiders
Transport Vehicles	
Trucks, truck trailers, vans (empty).	Beetles and moths
Ships, shipholds, galley and quarters (empty)	Insects and rodents
Railcars (freight or commodity).	Insects and rodents
Buses	Insects
Aircraft	Cockroaches, other insects, rodents, reptiles

5.4.1 Biological methods

Biological agents are generally host specific and considered to be primarily preventive control measures. They are not directly comparable with MB fumigation because of their specificity, except in instances where only a few species of target pests are prevalent. Biological methods have the potential to provide long-term protection for stored commodities in specific situations.

Arthropod parasitoids and predators are naturally occurring in stored commodities, but rarely suppress a storage pest before unacceptable damage occurs. Therefore, mass release or augmentative approaches will be needed to overwhelm pests before they can do harm. Some of the more effective parasitoids are *Bracon hebetor* which attacks larvae (Press *et al.* 1982); Brower and Press 1990; Cline and Press 1990) and *Trichogramma canescens*, which attacks eggs (Brower 1988a,b). Use of pathogens for insect control for durables appears more promising, though they are yet to be registered for stored product use. In some cases they have been shown to provide long term control.

The primary target pest species are flour moth and Indian meal moth larvae or eggs and various beetle larvae. *Bracon hebetor* has commercial use in South Africa for reducing the need for fumigation of stacks of bagged grain (Anon. 1991) and is used to control Indian meal moth in stored peanuts in the South-Eastern USA. Baker and Throne (1995) utilised an insecticide-resistant parasitoid with chemical treatment for control of weevils in wheat. Flinn

et al. (1996) reported effective control of the lesser grain borer in large-scale bulk wheat with a parasitoid.

The effectiveness of the predatory warehouse pirate bug, *Xylocoris flavipes*, has been evaluated in controlling stored product pest populations (Brower 1988a, 1988b; Brower and Mullen 1990; Brower and Press 1992; Press *et al.* 1975). After introduction of large numbers of the pirate bugs in storage premises, the populations of *Tribolium castaneum* can be suppressed in a short period of time (Press *et al.* 1975; Wen and Brower 1994).

Pathogens of insects include bacteria, viruses, protozoa, nematodes and fungi. Among these, the bacteria, viruses and protozoa have been most studied for their potential as control agents for stored product insects. Strains of *Bacillus thuringiensis* (Bt) have been tested for moth control on durables, but resistance by pests in stored products to Bt has been observed (McGaughey and Beeman 1988). Bt is exempt from a tolerance in the USA (but not in some other countries) for use as a stored product protectant. Residual activity against susceptible insects can last for more than a year (McGaughey 1986). Vail *et al.* (1991 1996) report the screening of several lines of transgenic walnut with high levels of the insecticidal crystal protein fragment that arrest development or kill larvae of codling moth, navel orangeworm and Indian meal moth, the principle targets for MB fumigation of stored walnuts.

Entomopathogenic viruses (primarily baculoviruses) have been studied for the control of post-harvest pests (Hunter *et al.* 1973; McGaughey 1982; Cowan *et al.* 1986; Kellen and Hoffmann 1987). Baculoviruses have been isolated from many of the important Lepidopterous pests of durable commodities (Hunter and Dexel 1970; Hunter and Hoffmann 1972) but are yet to be studied and developed further as control agents.

5.4.2 Botanicals

These compounds are derived from plants. At present, the only botanical in widespread use in developed countries for protection of durables is pyrethrum extract. Pyrethrum has toxic and repellent properties (Ndalut and Saggar 1996). Others, such as azadirachtin, an active principle from neem, are under continuing investigation. Botanicals may have limited application in developed countries because of concerns about transferring odours or off-flavours to milled or processed products. A wide variety of botanicals are still used by subsistence farmers in developing countries.

There is continued research on development of botanicals (Shaaya *et al.* 1997; Pemong *et al.* 1997; Huang *et al.* 1997). As natural products are not readily patented, there is little incentive for companies and other organisations, to pay for the toxicological testing required to gain registration for use. This may prove to be a stumbling block for their successful introduction for specific uses on durables as MB alternatives, except perhaps when data is already available to support registration as a food additive.

5.4.3 Carbon bisulphide

Application to large bulk storage is restricted by the potential fire hazard of the material and safe methods for large scale use have not been developed. Carbon bisulphide was once

widely used as a fumigant for bulk and bagged grain where it was typically applied as a 'liquid fumigant' in a mixture with carbon tetrachloride or alone. In most countries its use has been discontinued and registration has lapsed. There is some use in China and also in parts of Australia, where it is typically used for small lots of grain (c.50 tonnes) in farm storage.

5.4.4 Carbon dioxide at high pressure

High pressure carbon dioxide (about 25 bar) can potentially provide a rapid disinfestation system (a few hours or less) of commodities. Carbon dioxide under high pressure is in limited use in Germany to treat beverages, nuts and spices (Gerard *et al.* 1988; Prozell and Reichmuth 1991; Prozell *et al.* 1997). The high construction and operating costs of pressure chambers restrict their widespread use. The process is still under development (Le Torc'h and Fleurat-Lessard 1991; Nakakita and Kawashima 1994; Ulrichs 1994). The rate at which the pressure can be released affects the efficacy of action (Nakakita and Kawashima 1994; Ulrichs 1994) but in practice there are physical constraints on the rate at which pressures can be manipulated.

5.4.5 Carbonyl sulphide

Carbonyl sulphide is a promising fumigant under consideration for registration for durables, including timber, in Australia. It has a high penetration and mobility rate. Banks *et al.* (1993a) patented the gas as an insecticide. Carbonyl sulphide did not adversely affect the quality of malting barley, or wheat (Desmarchelier 1994). Sorption of carbonyl sulphide by wheat is very low. Wheat contains natural levels of this gas. Carbonyl sulphide does not appear to affect the seed viability of wheat (van S. Graver 1994).

Carbonyl sulphide also appears to be an effective fumigant for disinfesting non-perishable commodities such as timber and has been shown to be toxic to termites. It is active against durable commodity pests, including *Sitophilus granarius, Rhyzopertha dominica, Oryzaephilus surinamensis, Carpophilus hemipterus, Lasioderma serricorne* and *Tribolium confusum* (Plarre and Reichmuth 1996; Zettler *et al.* 1998).

5.4.6 Cold treatments

Cooling typically is used to prevent damage, pest multiplication and reinvasion. The technique is used for disinfestation in specific instances, such as for museum objects or small quantities of seed or products, where a mild non-chemical disinfestation is required. Under these circumstances, cooling can be an alternative to MB. Cold treatments are now used as part of IPM systems for stored products (including grains, cereals, oilseeds and seeds) and for structures where 'freezeouts' are used as space treatments in warehouses or grain storages (Fields and Muir 1995; Banks and Fields 1995). The technique is more commonly used in countries such as Canada with low ambient temperature after harvest (Worden 1987) but is also used where cold storage warehouses are part of a storage system (for example for prunes in USA and France).

Fields (1992) reviewed the effect of cold on insect and mite pests. Fields and White (1997) equate the rate of population development, rather than just the ability to survive cold temperatures, with the pest status of stored-product insects in Canada. Below about 10°C

insect reproduction ceases and infestation of populations of most pests of durables slowly decline. At 4°C adults of most species survive for many months, though immatures may be killed. Species of tropical origin, such as *Sitophilus oryzae*, *S. zeamais, Tenebroides mauritanicus* and *Lasioderma serricorne* tend to be cold sensitive, although some important pests including *Cryptolestes* spp., bruchids, mites and some Lepidoptera are very tolerant (Armitage 1987; Lasseran and Fleurat-Lessard 1991; Fields 1992).

Cooling typically requires very long periods to be effective. However, most pests require only a few days exposure at very low temperatures (-15°C or below) to ensure control (Chauvin and Vannier 1991; Fields 1992).

The stage of development of the pest is a factor contributing to its cold resistance. Eggs are more sensitive and adults and larvae are often the most cold tolerant (Banks and Fields 1995). Furthermore, some species of insects have the ability to acclimatise to cold and may become tolerant to otherwise lethal cold temperatures. For this reason, rapid cooling from harvest temperatures to cold temperatures should be part of any storage strategy to prevent cold acclimatisation and improve insect control.

5.4.7 Contact insecticides

Unlike fumigants, contact insecticides may provide persistent protection against reinfestation. These chemicals can be applied either directly to grain for protection against insect pests, or to storage buildings and to transport vehicles, in order to reduce the likelihood of cross-infestation or re-infestation of commodities. They are not normally registered for use on processed commodities.

Generally, fumigants such as MB have a somewhat different action on pests and role in stored product protection to contact insecticides. Differences, when used on stored grain, are summarised in Table 5.3. Despite these differences, where permitted by market preference and regulatory authorities, both techniques can result in pest-free end products.

Organophosphorus compounds are an important group of grain protectants in current use. The stability of deposits on grain vary widely, with particular material and ambient conditions. The rate of degradation increases both with temperature and water activity (moisture content). Furthermore, toxicity to insects increases with temperature. In consequence, persistence of the biological effectiveness will depend upon the insecticide used. For example, typically dichlorvos acts quickly and degrades within a few days, while malathion takes several weeks and pirimiphos methyl many months.

Dichlorvos is unique amongst the commonly used grain protectants, in its rapid action against pests and volatility on grain. In the absence of resistance and where approved, it can be sprayed onto bulk grain within a few days of export to disinfest a cargo. Subject to an adequate withholding period for the residues to decay to acceptable levels, such a treatment can provide a direct alternative to disinfestation with MB.

Most organophosphates have limited efficacy against bostrichids (*Rhyzopertha dominica* and *Prostephanus truncatus*). The principal materials used world-wide include: chlorpyrifos methyl, dichlorvos, fenitrothion, malathion and pirimiphos methyl. Currently, there are concerns

regarding possible regulatory control of organophosphates by the US EPA. Registrations vary between different countries, so there are potential problems with import/export regulations.

Table 5.3 The basic differences between contact insecticides and fumigants

Fumigants	Contact Insecticides
No lasting protection	Lasting protection possible
Grain can be treated *in situ*	Normally grain has to be moved in order to apply insecticide
Can be used for treating most commodities	In most countries, only permitted on commodities before processing
Disinfestation can be completed within 1-15 days, according to temperature	Disinfestation achieved over a longer period, since stages of those species which develop within the grain are not affected until they develop into adults
Skilled, certified personnel only can apply fumigants	Semi-skilled operators can apply contact insecticides
Effective generally against all insect species	Various compounds are selectively effective against different insect species
No incidence of substantial MB tolerance known, but development of resistance to phosphine a current concern	Most insect pests develop resistance to particular insecticides or groups of insecticides, with continued use
Good penetration of grain bulks	Poor penetration of grain bulks

Synthetic pyrethroids (SPs) are a group of insecticides with their chemical constituent based on the active ingredients of natural pyrethrum. Deposits are quite stable on grain and their insecticidal activities may persist up to 2 years (Snelson 1987). SP action is much less sensitive to temperature than organophosphorus insecticides. SPs are active against bostrichid beetles at a much lower dosage than for most other insect pests of durables. A disadvantage of these pesticides is their relatively high cost. In many situations pyrethroids are added in combination with a synergist such as piperonyl butoxide to increase effectiveness and reduce cost.

5.4.8 Controlled atmospheres

Treatment with controlled atmospheres (CAs) based on carbon dioxide and nitrogen, offers alternatives to fumigation for insect and vertebrate pest control in all durable commodities. They are ineffective against fungal pests. They are unlikely to be used for disinfestation where fast turn-around is necessary, unless combined with other factors such as high pressure (see Section 5.4.4) or raised temperature. The technology may require registration or other regulatory approval in some countries.

Structures for use with CA must be well sealed to achieve effective levels and keep gas usage and expense to acceptable levels (Mann *et al.* 1997). The use of a continuous flow of CA, such as that provided by combustion of propane, can allow somewhat less gas-tight enclosures to be used (Bell *et al.* 1993, 1997a).

Low oxygen atmospheres, created by adding the exhaust gas from a burner or nitrogen to a fumigation enclosure, need to reduce oxygen levels below 1% to effectively control pests. Carbon dioxide atmospheres typically are applied at about 60% CO_2 in air. At this level there is about 8% oxygen present, normally enough to support most stored product pests indefinitely. CO_2 thus is regarded as having a toxic effect on insect pests (Jay 1971) and not to act just as an inert gas that reduces the oxygen level to below that supporting life.

The effective use of CO_2 for grain storage was developed principally in Australia and the USA, although Australia for preference currently uses phosphine to treat bulk grain. However, the knowledge gained on CO_2 for grain storage is being used for stored rice and other bagged commodities in some ASEAN countries (Nataredja and Hodges 1990; Sukprakarn *et al.* 1990).

Until recently, the use of CO_2-based atmospheres was preferred over nitrogen-based ones for bulk grain for various technical reasons. Recent developments in the on-site generation of nitrogen-based atmospheres have made these atmospheres more competitive in price and convenience (Banks *et al.* 1991). Nitrogen-based CAs are in commercial use in Australia in an export grain terminal in bins originally designed and equipped for MB treatments (Cassells *et al.* 1994). CO_2-based atmospheres are now in experimental use in Canada for treatment of grain elevators (Marcotte 1995).

Data on exposure times for control are available for many species and stages of stored product pests under particular sets of conditions (Annis 1987; Bell and Armitage 1992; Bell 1996). Most species are completely controlled by exposures of 2 - 3 weeks at 25 - 30°C. As an extreme case, larvae of *Trogoderma granarium* in diapause require exposures longer than 17 days at 30°C or less, with CO_2 levels at or above 60% in air (Spratt *et al.* 1985).

5.4.9 Ethyl formate

Ethyl formate was formerly used as a fumigant for grain. Its use is now restricted to dried fruit and processed cereal products and registration has lapsed in most countries. Registration has been applied for in Australia for grain.

The action of ethyl formate against pests of durable foodstuffs is quite rapid with control being achievable after exposures of only a few hours (Hilton and Banks 1997). However, the gas is highly sorbed by commodities, especially at raised humidity and it is difficult to attain adequate distribution. Thus, in practice long exposure times may be needed to ensure adequate penetration of bulk commodities. Typical dosages on dried vine fruits are 3 to 6 ml per 15 kg. Ethyl formate can be corrosive to unpainted metals at high humidity.

5.4.10 Ethylene oxide

Ethylene oxide is used extensively to reduce microbial contamination in food commodities such as spices and some processed foods and coincidentally provides insect control. It was formerly widely used for insect control on grain (Cartox™ system) and dates. Its use in

these areas has been withdrawn in many countries, including the European Community, but it is still used in many other parts of the world, including China.

Because of its flammability, ethylene oxide is generally supplied in mixtures with inert diluents such as CO_2 or HCFCs. Ethylene oxide reacts with chemical constituents of some food commodities, producing potentially carcinogenic compounds. The detection of toxic reaction products, such as ethylene chlorohydrin, was reported by Wesley *et al.* (1965) and ethylene bromohydrin was found in flour and wheat, previously treated with MB followed by treatment with ethylene oxide (Heuser and Scudamore 1969).

Where health and environmental regulations permit, ethylene oxide may potentially replace MB in some non-food uses, notably treatment of some artefacts, manuscripts and other archive and museum materials.

5.4.11 Heat treatment

Heat treatment technologies are notable as a pest control option for durables that are capable of matching the speed of treatment afforded by MB and other fast-acting fumigants (Banks 1998). Commodities need to be heated to temperatures of 47 to 70°C and then rapidly cooled to avoid damage to heat-sensitive products. With very sensitive materials, humidity needs to be carefully controlled to prevent moisture content changes during both heating and cooling operations. The treatment time required is strongly dependent on the temperature reached and experienced by the target pest.

Stored product pest insects (all stages) can be eradicated in approximately one minute if they are exposed within the commodity to a temperature of 65°C. This high speed of action allows design of high throughput plants, such as those based on spouted or fluid beds (Claflin *et al.* 1984, 1986; Thorpe *et al.* 1984; Fleurat-Lessard 1984). Fluid-bed heating systems for bulk grain have been developed to a commercial prototype stage, with treatment rates of up to 150 th–1 (Evans *et al* 1983; Thorpe *et al* 1984; Fleurat-Lessard 1985) but installation of large-scale heat treatment facilities is likely to be capital intensive.

Pilot studies have been carried out on the use of rapid heating of grain by microwaves, radio frequency radiation or infrared radiation (Nelson 1972; Fleurat-Lessard 1987; Ingemanson 1997). Recent tests indicate that selective heating of the infesting insects in stored grain increases non-linearly at frequencies above 10.6 Ghz and that relaxation processes associated with free water in the insect and increased energy transfer at frequencies 24 Ghz would produce enhanced selective heating (Halverson, *et al.* 1996; Halverson *et al.* 1997). Halverson *et al.* (1997) report studies of both static (batch process) and dynamic (continuous process) applications that are being used to modify prototype equipment, to permit dynamic processing at a rate of 4.5 to 9 kgs-1. The target is to have a demonstration facility capable of processing at the rate required by a typical storage facility by 2000.

Heat for controlling the khapra beetle *Trogoderma granarium* is one aspect that has been recently examined as part of the review of the biology, distribution, monitoring and control of this important quarantine pest (Rees and Banks, in press).

Heat treatments are used to disinfest wood products either by kiln drying, or application of steam heat, to bulk shipments or to dunnage.

Heating above 50°C for 20-30 h has been used to control insects in flour mills for almost 100 years. It is increasingly used by a number of major food processors as an important part of their pest control programme (Heaps and Black 1994). Food plants that can be successfully heat treated rarely require fumigation. It is also advantageous in that there are no residues and treatments are just as quick to perform as with MB.

Heating can provide an alternative treatment method to using chemicals but also can synergise the effects of other treatments. For fumigants and CAs, heating does this in three ways: by increasing the diffusion and distribution of gases and hence their powers of penetration; by reducing physical sorption; and by increasing the toxicity or level of stress to target pests. Heat is particularly effective in increasing the efficacy of control using CO_2.

5.4.12 Hydrogen cyanide

Hydrogen cyanide was previously used widely as a fumigant for durable commodities, mills and other structures. Largely, it has been superseded by MB and phosphine, both of which are more convenient, less expensive and in many cases, more effective to use. Modern instructions for use of HCN are given in Anon (1989). These relate particularly to the ASEAN region, but are, in principle, suitable for most countries.

Hydrogen cyanide has received little research attention in recent years. Its availability and registration or re-registration difficulties may prevent its immediate substitution for particular uses of MB, should these be required. US-EPA may favourably reconsider HCN re-registration. Cylinders of liquid HCN are unstable and cannot be stored for long periods. However, HCN can be developed *in situ* from sodium cyanide (Anon. 1989). It is the fumigant of choice, where permitted, against rodents because of its rapid action. The Codex Alimentarius approved limits for HCN residues in grain and flour have lapsed due to lack of governmental support.

5.4.13 Inert dusts

Inert dusts may be: clays, sands, ashes or earths; diatomaceous earth (DE, fossilised remains of diatoms consisting mainly of silica with small amounts of other minerals); silica aerogels (very light, non-hygroscopic powders that are effective at lower dosages than diatomaceous earth formulations); and non-silica dusts, such as phosphate and lime. Inert dusts have a long history of use for grain protection (Ebeling 1971; Golob and Webley 1980; Quarles 1992a,b) and more recently have been evaluated as protectants for legumes (Giga and Chinwada 1994).

Several of these inert dusts are registered in some countries for treatment of grain and pulses against insect pests, reviewed by Banks and Fields (1995). They are particularly useful in dry conditions to control pests in storage structures (Fam *et al.* 1974). Inert dusts such as those based on DE can provide effective pest control in dry grain (Desmarchelier and Dines 1987). DE loses effectiveness at humidities above about 75% RH (Le Patourel 1986). Inert dusts are often useful as part of an IPM system.

DE products have also long been used as carriers for insecticides, but now they are being formulated for use alone. These new formulations are being designed to minimise their abrasive properties (to protect conveyancing machinery) and enhance their insecticidal action as desiccants by promoting their capacity to selectively absorb insect cuticular waxes. Dryacide, an activated DE, is in widespread use in Australia in the grain handling industry. In recent studies in Canada, Fields *et al.* (1997) combined an enhanced DE (Protect-It™) formulation with heat treatment, resulting in higher pest mortality at lower temperatures than DE use alone. DE was also added in a commercial trial during a plant's regular heat treatment. Korunic *et al.* (1996) summarised the uses and properties of new DE formulations that have helped overcome many of the problems associated with DE technology.

Inert dusts are rapid in their lethal action under favorable conditions for most pests. *Trogoderma* species do not appear to be effectively controlled. Some inert dusts are accepted as suitable for foods certified as 'organic' in some countries. DEs are widely used as food and processing additives.

Available data on responses of immature stages of grain pests are limited, although the success of inert dusts in suppressing population growth suggests that they are likely to have a strong effect on free living immature stages. It is not necessary for insects to be completely covered with the inert dust for it to be active (Maceljski and Korunic 1971).

The advantages of inert dusts is that they do not require capital equipment, they are relatively non-toxic and they provide continued protection without affecting baking quality (Desmarchelier and Dines 1987; Aldryhim 1990). Their disadvantages are decreased flowability of grain, visible residues that can affect grading and decrease in the bulk density of grain, although newer formulations alleviate these problems. They can cause excessive wear in handling machinery and may give rise to dust problems in the workspace. To alleviate dust problems, inert dusts can be applied as an aqueous slurry for surface treatment, though this can reduce their effectiveness (Maceljski and Korunic 1971). Research is on-going in relation to new methods of application (Fields *et al.* 1997).

5.4.14 Insect growth regulators

The term insect growth regulator (IGR) is used to describe compounds which interfere with the life-cycle of pests. The earliest of the IGRs developed were analogues of juvenile hormones and include methoprene and hydroprene. Some IGRs act against insects via ingestion or contact (e.g. methoprene) while others act only via ingestion (e.g. diflubenzuron). They tend to have low toxicity to vertebrates (Menn *et al.* 1989).

IGRs are generally used in a similar way to contact insecticides and are subject to similar constraints as replacements for MB. Additionally, they are relatively costly and are not normally directly toxic to adult pests which limit their effective uses. Generally, IGRs are more pest-specific than conventional contact insecticides which is a disadvantage for general disinfestation of commodities. IGRs persist on foodstuffs which may limit their use if residues are a problem.

There have been a number of recent studies on the use of IGRs (Edwards *et al.* 1991; Mkhize 1993; Silhacek *et al.* 1994; Dyby and Silhacek 1997; Oberlander *et al.* 1997).

Methoprene has been registered for use in the protection of a variety of stored commodities in a number of countries including the USA, Australia and the UK. It is effective against many stored product pests, including *Lasioderma serricorne*, *Rhyzopertha dominica, Ephestia cautella*, *Plodia interpunctella*, *Trogoderma granarium* and *Oryzaephilus surinamensis*, but not against *Sitophilus* spp. (Snelson 1987; Mkhize 1986). Diflubenzuron and fenoxycarb have been evaluated as grain protectants but not yet registered in the US. (Samson *et al.* 1990).

Recent studies with moths (Monconduit and Mauchamp 1998) indicate that very low level treatments in the parts per billion range with fenoxycarb, applied to the egg or larval stages just after hatching, causes lethal disruption of molting throughout the larval period. In these studies, virtually none of the insects survived to the pupal stage. Further studies are needed for development of effective protocols for commodity protection using IGR-based techniques.

5.4.15 Integrated pest management

IPM is often used to describe different combination treatments, particularly those departing from the regular use of chemicals. It must be emphasised that the components of the IPM system need to be closely defined for each pest control situation. IPM in itself is merely a loose, generic descriptor of a wide variety of multi-component control programmes and thus does not identify specific alternatives to specific uses of MB.

IPM involves understanding interactions between the stored product environment and insects associated with stored products and using this information to achieve effective pest control, thus moving away from a reliance on fumigation with MB.

Any IPM control strategy must begin with identification of existing and potential pests, the cause of their presence and their vulnerabilities. Thorough training of personnel is also needed to successfully introduce an IPM system, creating the opportunity to upgrade labour force skill levels.

IPM is dependent upon identifying action thresholds of insects and making appropriate decisions. This subject has been extensively reviewed by Subramanyam and Hagstrum (1996) who provide specific examples of the pests, their ecology, sampling procedures and physical, biological and chemical control and resistance management.

A major component of any IPM system for storage of durable commodities is sanitation which, in general, involves the application of a diverse range of measures designed to remove pests or prevent their access to the commodity or structure. These include cleaning and removal of harbourages for pests, regular monitoring for the incidence of pests, removing food residues in which pests can multiply and re-engineering machinery and buildings. Normal good warehousing practice such as stock rotation and where applicable, insect proof packaging, also reduce pest population pressure. Other measures include application of insecticidal sprays to control pest movement into the stored commodity (Banks and Fields 1995).

Monitoring devices and techniques are key components of an IPM system. Pheromones are used for detection or monitoring, mass trapping and mating disruption. Natural or synthetically-derived pheromones are chemicals that alter the behaviour of animals. The use of pheromones in the pest control industry has become more common over the past few years to detect a variety of insect pests (Canadian Pest Control Association 1997).

In the development of any IPM programme, consideration is given to all practical chemical and non-chemical controls and strategies. These will vary according to product and structure. Programmes will normally involve several techniques and products. Some IPM strategies require constant maintenance in order to succeed. Occasional full-site or curative treatments may be required to supplement IPM programs. These may involve fumigation, possibly with MB, or other processes.

5.4.16 Irradiation

Irradiation is similar to MB in that it is a broad spectrum method of controlling pests. Unlike MB, in most uses it is not immediately lethal, pests sometimes requiring several days or weeks to die, although they are sterile. The technique could be used as an alternative to MB for several durable commodities and is already in use commercially in some situations. The process involves the use of gamma energy, accelerated electrons or X-rays to penetrate the commodity. The most common radiation source is cobalt-60, which provides a constant field of ionising energy. The effectiveness of treatment for insect control and effect on food quality is related to the energy delivered. The capital investment for irradiation facilities is high and the infrastructure must be present to support a commercial radiation facility.

Disinfestation by irradiation has a long history (since 1912) and a sizeable research investment. Brower and Tilton (1985) and Tilton and Brower (1987) summarised the radio-sensitivity data on forty stored-product pest species, discussed the possible use of irradiation as a quarantine measure for these species and discussed irradiation disinfestation of grain and grain products. These data showed that pests vary in their sensitivity to radiation. Generally, the early developmental stages are more sensitive than later adult stages; females are more sensitive than males; and adults are more easily sterilised than killed. As a group, beetles are more sensitive than moths; and fruit flies are more sensitive than beetles. Mites have a range of sensitivity similar to that of beetles. The use of irradiation for quarantine is hampered by the fact that the insects are usually damaged and incapable of completing development, or sterilised and incapable of reproduction, but may remain alive in the commodity. Therefore, mechanisms are needed to identify treated commodities or insects.

Selection of the type of irradiation equipment to be used depends on whether the commodity is to be irradiated in packages or in bulk, the quantity of product to be treated and other factors. Gamma irradiators can treat packaged or bulk products; and accelerators can more effectively treat bulk products in thin layers (2-5 cm thickness). The International Consultative Group on Food Irradiation (ICGFI) under the aegis of the FAO/IAEA Joint Division, has published provisional guidelines for the irradiation of food stuffs for insect disinfestation as recommendations to be followed when using the technology (ICGFI 1988).

There are few agreements presently that allow movement of irradiated products in international trade. It is approved for at least one food use by 41 countries, although in less

than 25 of these the treatment is primarily for disinfestation purposes (Anon 1998). The regional members of the International Plant Protection Conventions (IPPC) including the North American Plant Protection Organisation (NAPPO) has recognised the effectiveness of irradiation as a broad spectrum phytosanitary treatment (Marcotte 1996; Griffin 1996).

Past concerns regarding public acceptance of irradiated foods appear to have diminished, especially in the light of increased public awareness of irradiation as a means of mitigating microbial contamination. There is no evidence of any enhancement of mycotoxin levels after irradiation, compared with those following fumigation (Borsa 1995).

5.4.17 Other fumigants

5.4.17.1 Cyanogen

Cyanogen is under consideration as an alternative grain fumigant and sterilant in Australia. It has been patented for this use.

5.4.17.2 Methyl iodide

Methyl iodide has properties similar to that of MB. However, methyl iodide is not registered nor is there a registrant. This compound is more expensive to synthesise than MB and it is unlikely that it would be registered solely for the relatively small market of post-harvest use. Some activity of methyl iodide against stored product pests has been reported in the literature (Soliman and Kashef 1962; Kostjukovsky *et al.* 1997).

5.4.17.3 Methyl isothiocyanate

Methyl isothiocyanate (MITC) was introduced in 1959 by Schering AG as a soil nematicide under the trade name Trapex™. This compound is being studied as a grain fumigant and protectant (Ducom 1994). Preliminary studies of biological efficiency showed that MITC is very active against *Sitophilus granarius* (all stages) at a very low *ct*-product of 8 ghm^{-3}. For optimal results, this compound has to be very well mixed with the grain because it is highly sorbed. Recent research indicates that it could be more useful as a treatment method for perishables (Ducom and Vinghes 1997).

5.4.17.4 Methyl phosphine

Methyl phosphine is under investigation in the UK primarily as a counter- measure to phosphine resistance, but also has the potential to replace some other MB applications. Methyl phosphine has specific action against phosphine resistant strains, being more toxic to these than to susceptible strains and thus could replace uses of MB in the combatting of resistance (Chaudhry *et al.* 1997). It is, however, an unstable compound and requires further research to evaluate its true potential.

5.4.17.5 Ozone

Ozone is also a capable of acting as a disinfestation agent. Apart from the sterilising action of ozone against bacteria and viruses, only limited information is known about the toxicity of

ozone to arthropods or storage fungi. It has been suggested as a replacement fumigant, but will require considerably more research to develop this technology to a stage where regulatory approval can be considered. Activity has been found against *Sitophilus oryzae* and *Oryzaephilus surinamensis* (Yoshida 1975); *Tribolium* spp. (Erdman 1979); *Ephestia elutella* (Mills 1992); and the moulds *Aspergillus flavus* and *Fusarium moniliforme* (Mason *et al.* 1997).

5.4.18 Pheromones

Pheromones are chemicals produced by one member of a species that are transmitted externally to and influence the behavior or physiology of, another member of the same species. The most fully studied of this class of semiochemicals are the sex pheromones. In most cases the female releases a chemical into the air that both attracts and sexually stimulates males. The sex pheromones of several storage-related pests, both Coleoptera and Lepidoptera, are among the earliest identified pheromone molecules (Mayer and McLaughlin 1990). The use of pheromones in the food industry has recently been reviewed (Phillips 1997).

Pheromones can be used as trap baits to monitor for stored product pests or they may be employed as direct control agents via mass trapping, pathogen dissemination or mating disruption (Burkholder 1985; Burkholder and Boush 1974; Shapas *et al.* 1977; Fleurat-Lessard 1986). Trematerra (1994a,b) summarises studies from 1986 to 1992 that describe mass-trapping, mating disruption and an attracticide method (combination of insecticide with attractant bait) to control Mediterranean flour moth in flour mills. Pierce (1994) describes the use of pheromone trapping to locate and suppress infestations in Hawaii. All of these techniques demonstrated suppression, but not total disinfestation. Effective results were obtained against a localised infestation of a warehouse moth in a cereal processing facility (Nickson *et al.* 1998).

The primary sex pheromone component of the phyticine moths is highly susceptible to degradation when exposed to light or air. Recently, Shin Etsu 'rope' formulations of this chemical have been used to disrupt mating of Indian meal moth in a warehouse. Indications are that mating disruption is useful as a control technique only with low or localised populations.

The registration procedures for control systems based on pheromones for stored commodities are lacking and need clarification.

5.4.19 Phosphine

Phosphine is the only fumigant other than MB which is widely registered for disinfestation of durable commodities. It is in fact the only available alternative extensively in use, principally for cereals and legumes. It has the potential to act as a direct substitute for MB in many situations, but can also act as a component of an IPM process to avoid MB use. It ranks as one of the most toxic fumigants known, but is used at low concentrations. Its action against pests tends to be much slower than MB, with long exposures required, particularly under low temperatures . There are many publications describing application of phosphine to stored grain and other durable commodities (e.g. Bond 1984; Banks 1986).

Phosphine penetrates well into commodities and can be removed rapidly by aeration after treatment. Phosphine has been questioned as having possible mutagenic and neurotoxic properties, the principal concern being human exposure of fumigation personnel. A study conducted in Australia found no effects on grain fumigation personnel when compared with other grain workers not encountering this fumigant (Barbosa and Bonin 1994).

Phosphine will form an explosive mixture with air when the concentration exceeds 1.8% by volume at normal atmospheric pressure. This level would not be reached in normal fumigation practice. This limit reduces at reduced pressure and care needs to be taken in designing recirculation and vacuum systems in chambers if phosphine is to be used (Green *et al.* 1984).

Phosphine reacts with copper, silver and gold and in some situations this may preclude its use. This is especially critical with regard to corrosion of electrical equipment and computers (Bond *et al.* 1984; Rislund 1996; Brigham 1997) but there are actions which can be taken to lessen these effects in many situations. For example sensitive items within the treatment enclosure have been protected by supplying positive pressure from an outside air or carbon dioxide source (Mueller 1996). Brigham (1998) has studied the corrosion of several metals at various phosphine concentrations at different temperatures and humidities.

Various proprietary formulations of phosphine are available world wide. Most contain aluminum phosphide or, less commonly, magnesium phosphide, formulated with ammonium carbamate or urea to lessen the risk of flammability. Phosphine is generated *in situ* by the reaction of atmospheric moisture with the metallic phosphide (Bond 1984).

There have been a number of studies to improve the delivery of phosphine within a commodity. New efficient fumigation techniques are presented by Taylor and Harris (1994) and new formulations of phosphine have been produced (Reichmuth 1994; Horn 1997). Phosphine generated from metallic phosphides is produced slowly and unevenly and the concentration produced is impossible to control with any precision. This should be improved in the future by the use of phosphine generators currently being developed in Chile, Japan and Australia (Horn 1997; Kawakami 1998).

Phosphine is available in pressurised gas cylinders as a non-flammable 2% mixture in carbon dioxide (SIROFLO®) and is widely used in Australia (Winks 1990, 1993). The product, undergoing the registration process as ECO_2FUME in the USA, elicited mortality against stored product insects comparable to that elicited by the traditional pellet formulation, but utilised nearly half as much active ingredient (Phillips *et al.* 1996; Noyes *et al.* 1997). Also, this treatment may be carried out using re-circulation in sealed bins and close electronic monitoring of gas concentrations (Chakrabarti 1997; Noyes, *et al.* 1997; Bell *et al.* 1997b).

The use of phosphine should follow these guidelines:

- The commodity temperature should be more than 15°C for most commodity treatments, but certain pests are susceptible to phosphine down to 5°C with long exposures.

- The exposure period often needs to be prolonged for effective action against all developmental stages of pests, typically 5 to 15 days, depending on the temperature and target species.
- Proven and well controlled techniques must be used to avoid the development of resistance.
- For aluminium phosphide formulations, the equilibrium relative humidity produced by the commodity should be more than 30% to ensure full evolution of phosphine from the formulation within the exposure period.

The toxicity of phosphine to arthropod pests is well researched and dosage schedules are available for the common stored product insects and mites (Annex 5.4, Table 5.17).

The period of exposure has a much more important role than concentration levels in the toxicity of phosphine. The use of *ct*-products as a measure of dosage for phosphine is not valid, unless the exposure period over which it applies is stated. All stages in the life cycle of stored-product insects have a broadly similar tolerance to MB (a factor of 3 times or so). However, there is a high degree of variation in tolerance to phosphine, with eggs and pupae being much more tolerant than larvae and adults. Mites are difficult to control with phosphine since the egg stage is highly tolerant.

To overcome some of the disadvantages of conventional phosphine treatments, a 'combination treatment' of heat, phosphine and carbon dioxide has been developed (McCarthy 1996; Mueller 1996). This approach is more costly than conventional MB treatments, but the amount of phosphine used is said to minimise corrosion levels. The risk of selecting insects for phosphine resistance using this method cannot be ignored.

High levels of resistance have been measured in the laboratory in several species of stored-product beetle pests originating from parts of Africa and the Indian subcontinent, following frequent use of phosphine in conditions of poor gas-tightness (Taylor 1989; Price and Mills 1988). There have been control failures attributable to this resistance. Insect populations are capable of developing resistance to phosphine relatively easily, therefore it is important to use correct exposure and application technology to avoid development of resistance and thus loss of this useful alternative. Short fumigation periods (e.g. less than 3 days) employing low concentrations of phosphine, provide the conditions in which insect resistance can develop. Repeated use of phosphine fumigation in flour mills in Hawaii has already led to suspected resistance in local flat grain beetle populations (*Cryptolestes* spp) (Pierce & Sorum 1998).

The considerable work on phosphine resistance and mode of action is reviewed by Chaudhry (1997). Resistance management is an important consideration when using phosphine. The effect of resistance to phosphine can at present be overcome provided that the gas concentration needed can be maintained for the longer exposure periods required by more tolerant strains. In leaky situations such as silos, insect control may be carried out by a continuous input of fumigant using a phosphine-carbon dioxide mixture from a pressurised cylinder (Winks 1990). However, for conventional dosing, the degree of gas-tightness of the enclosure should be improved as far as possible as described for enclosures around stacks of

bagged grain in Anon (1989) so that gas may be retained for a sufficient period. Multiple dosing may also assist.

5.4.20 Sulphuryl fluoride

Sulphuryl (sulfuryl) fluoride was developed in the late 1950s as a structural fumigant, mainly for termite control. It is applied to residences or other buildings which are covered with gas-proof sheets or otherwise sealed. Compared with MB it is less reactive and produces no objectionable colour or odour in treated materials. The efficacy of this product is well researched and understood. It provides good penetration, requires a short fumigation period of approximately 24 hours and has a 6 - 8 hour aeration period.

To kill the egg stage of many insects requires up to a 10 times increase in dosage when compared to the normal rate for control of adult termites. If good sealing techniques which enhance fumigant containment are achieved, lower dosages may be rendered more efficacious by extending the exposure period. The economics of the higher dosage or of plant down-time with prolonged exposure period must be considered.

Sulphuryl fluoride is similar to MB in its nonflammability and at least as effective in its powers of penetration and aeration. Sulphuryl fluoride is considered a practical alternative to MB for many uses, particularly for quarantine fumigation applications and for use in empty food processing facilities. It is toxic to post-embryonic stages of insects (Kenaga 1957; Bond and Monro 1961; Reichmuth *et al.* 1996) but the eggs of many species are very tolerant especially at low temperatures, requiring concentrations of over 50 g/m^3 and exposures of up to 3 days for complete kill (Bell *et al.* in press). Eggs of *Ephestia kuehniella* at 25°C required a *ct*-product of about 1000 ghm^{-3} to prevent hatch and 800 ghm^{-3} to prevent emergence (Bell and Savvidou 1998).

Sulphuryl fluoride is currently registered for use under the trade name Vikane™. It is used to control a wide range of pests including: drywood and Formosan subterranean termites; wood-destroying beetles; furniture and carpet beetles; clothes moths; cockroaches and rodents infesting buildings; furnishings; construction materials and vehicles (not including submarines and aircraft). The fumigant has been marketed since 1961 in the United States and the Caribbean. The fumigant has been manufactured and marketed in China under the trade name Xunmiejin™ since 1983, being used mostly on artefacts and wood or wood products. In 1994 it was licensed for use in Germany with an estimated 50 historic buildings (primarily churches) being treated per year. In 1995 registration was granted in Sweden. Dow AgroSciences is currently involved in efforts to increase current uses in two selected markets: (1) quarantine fumigation applications; and (2) use in empty food processing facilities (Chambers and Millard 1995).

Under current quarantine procedures (USDA-APHIS PPQ treatment Manual and the AQIS Cargo Container Quarantine Aspects and Procedures Manual) treatment rates for sulphuryl fluoride are provided for fumigation of non-food cargo against wood-infesting beetles. Efforts are underway to develop treatment schedules to fumigate timber being imported into the USA, Europe and Japan to control wood-destroying beetles or fungal pathogens (Chambers and Millard 1995).

5.5 Durables

5.5.1 Introduction

Durables are commodities with a low moisture content that, in the absence of pest attack, can be safely stored for long periods. Most durable commodities currently treated with MB are foodstuffs that are stored post-harvest, before being consumed, processed or transported in or out of a country between harvests, sometimes for long periods. Pest control in durables is usually necessary to prevent damage to the commodity, but often the primary objective is to reduce insect populations to below a detectable level. Many pests can survive and proliferate on durable commodities in storage. The risk of introducing and spreading infestation, either of field pests on the commodity at harvest or of storage pests further down the supply chain, is a major reason for treatment of durable commodities.

Generally, the commodities classified as durables have less than 15% moisture content. They include:

- Artefacts, including bamboo ware, museum and cultural artefacts.
- Beverage crops, including cocoa and coffee.
- Cereal grains, e.g. wheat, rye, barley, rice, sorghum, maize.
- Dried fish, meat and derived meals.
- Dried fruit and nuts.
- Grain products, including flour, noodles, semolina.
- Herbs and spices.
- Pulses, including peas, beans and lentils.
- Seeds, for planting.
- Tobacco (post-harvest).
- Unsawn timber and timber products.

5.5.2 Alternatives - grains and similar commodities

A wide variety of stored cereal grains and grain legumes (pulses) have been treated with MB. Examples are given in Table 5.4. Products made from cereals and legumes, including flour, pastas, semolina and compounded animal feed, have also been treated. This category also includes similar products such as sago and cassava chips. Fumigation of wheat flour or ground legumes with MB is becoming less common, since odours or taint may develop in bread or other products prepared from those finely divided commodities.

Oilseeds (e.g. sunflower seeds, soybeans) and oilseed expeller cake, are also sometimes treated with MB for control of insect and mite pests. These materials absorb MB strongly and generally other measures are used in preference (e.g. cooling, processing).

Table 5.4 Examples of cereal and legume crops which may be fumigated with MB

Common Name	Scientific Name
Barley	*Hordeum vulgare*
Beans	*Phaseolus* spp., *Vigna* spp.
Buckwheat	*Fagopyrum sagittatum*
Cassava	*Manihot esculenta*
Lentil	*Lens culinaris*
Maize	*Zea mais*
Millet	*Pennisetum* spp.
Oats	*Avena sativa*
Peanut	*Arachis hypogea*
Peas	*Pisum sativum*
Pigeon pea	*Cajanus* spp.
Rice	*Oryza sativa*
Rye	*Secale cerale*
Sorghum	*Sorghum bicolor*
Soybean	*Glycine max*
Wheat	*Triticum aestivum*

MB is effective against all stages of stored grain arthropod pests (Thompson 1970). The degree of susceptibility varies somewhat with developmental stage, with pupal stages of insects and the egg and hypopal stages of mites usually more tolerant. Typical pests and dosage rates required for control are given in Table 5.5 and Annex 5.3 respectively. Diapausing larvae of the khapra beetle (*Trogoderma granarium*) (Bell *et al.* 1985) and warehouse moth (*Ephestia elutella*) (Bell 1976) are highly tolerant of MB and dosage/exposure periods are increased to control these species. The dosages also vary with the temperature (Bond 1975) and the types of commodity being fumigated (Annex 5.5, Table 5.18). Psocids (*Liposcelis* spp.) can be controlled effectively using MB (Pike 1994).

Bagged grain, rice or legumes can be treated in fumigation chambers, containers or under gas-proof sheets. In many countries, however, grain and animal feedstuffs are stored either in silo bins or on floor storage. In such bulk storage conditions MB is unable to achieve adequate gas distribution without assistance. Infested bulk commodities can be treated with MB effectively by forced air recirculation in a completely closed system (Monro 1956; Storey 1967, 1971a,b). Procedures employing carbon dioxide as a carrier to assist the distribution of MB have also been used (e.g. Calderon and Carmi 1973).

Table 5.5 Principal pests of cereals and similar commodities

Common Name		Scientific Name
Dried bean beetle	*	*Acanthoscelides obtectus*
Flour mite		*Acarus siro*
Cowpea beetle	*	*Callosobruchus chinensis*
Cowpea beetle	*	*Callosobruchus maculatus*
Groundnut borer		*Caryedon serratus*
Rice moth		*Corcyra cephalonica*
Rust-red grain beetle		*Cryptolestes ferrugineus*
Tropical warehouse moth		*Ephestia cautella*
Tobacco moth		*Ephestia elutella*
Mediterranean flour moth	*	*Ephestia kuehniella*
Broad horned flour beetle		*Gnatocerus cornutus*
Booklice, psocids		*Liposcelis spp.*
European grain moth		*Nemapogon granellus*
Yellow spider beetle		*Niptus hololeucus*
Saw-toothed grain beetle	*	*Oryzaephilus surinamensis*
Indian meal moth	*	*Plodia interpunctella*
White-marked spider beetle		*Ptinus fur*
Australian spider beetle		*Ptinus tectus*
Lesser grain borer	*	*Rhyzopertha dominica*
Granary weevil	*	*Sitophilus granarius*
Rice weevil	*	*Sitophilus oryzae*
Maize weevil	*	*Sitophilus zeamais*
Angoumois grain moth	*	*Sitotroga cerealella*
Drug store beetle		*Stegobium paniceum*
Yellow mealworm		*Tenebrio molitor*
Cadelle		*Tenebroides mauretanicus*
Rust red flour beetle	*	*Tribolium castaneum*
Confused flour beetle	*	*Tribolium confusum*
Khapra beetle	*	*Trogoderma granarium*
Mexican bean beetle		*Zabrotes subfasciatus*

* Major pests

Although formerly used widely in developed countries for grain fumigation, MB is now largely limited to uses that meet official quarantine and phytosanitary regulations at time of export, or to disinfest imports in some countries.

5.5.2.1 Biological control methods

Biological control with predaceous insects or parasites has been studied in relation to use on stored grain, but cannot be regarded as a replacement for MB except as part of a wider IPM strategy. However, commercial formulations of *Bacillus thuringiensis* (Bt) provide control of almond moth and Indian meal moth when applied to grain as an aqueous suspension or as a dust. These are effective when all the grain is treated, or when just several centimeters of the surface layer are treated as Lepidopterous larvae usually live near the surface of the bulk. Potentially, Bt and other pathogens can form part of an IPM strategy, although some resistance has already been detected in stored grain moths (McGaughey and Beeman 1988). For further information, refer also to Section 5.4.1.

5.5.2.2 Cold treatments for grain

On a large scale, cold treatments are used as part of IPM systems and for disinfestation or management of grain pests, in stored grain or grain storage structures (Fields and Muir 1995; Banks and Fields 1995). The technique can involve aeration by ambient cold air, applied under the grain bulk or into the grain bin through specially designed aeration systems, or by the transfer of grain from one bin to another in cold weather, leaving it outside if possible for a few days before returning it to storage (Marcotte 1995). Aeration is a part of many grain pest management programs and plays a most important role in preventive control measures at a cost sometimes competitive with curative disinfestation processes such as fumigation with MB (Armitage *et al.* 1991).

Stores must be equipped with appropriate ventilation ducts and fans that are controlled to give optimum cooling performance for particular ambient conditions. The use of moderately low temperatures to control infestations by storage pests has long been recommended (Burgess and Burrell 1964; Navarro and Donahaye 1990). Cooling of grain with aeration is in widespread use in temperate climates. Aeration can also be practised in warmer climates or in the summer by utilising the time of day when cool temperatures prevail (Armitage 1987; Lasseran and Fleurat-Lessard 1991; Berhaut and Lasseran 1986).

Most of the immature stages of stored product pests die off if grain is held at less than 5°C for several months. However, some adult pests may still survive.

Where ambient conditions are unfavourable for normal aeration, i.e. high temperature or humidity, air dehumidified and chilled using a refrigeration unit may be used for the aeration. Many grain silos in the Mediterranean and subtropical regions use this process (Brunner 1987). The temperature of the grain soon after harvest is reduced in a few days below the developmental temperature threshold of the main insect pests. This process can be part of an overall pest management strategy which does not include fumigation with MB. A single refrigeration unit is used for several bins in a silo system, each bin being refrigerated in turn for a few days. The equipment is energy consuming and can be expensive.

All common stored grain insect pests can be controlled in grain exposed for two weeks to temperatures lower than -18°C, i.e. in an efficient freezer. This type of treatment is used preventatively for the disinfestation of high value grain, such as special seed stocks and

organically-grown rice, in some developed countries. This technique is efficient but only practicable for small quantities in batches.

It is important to note that the temperature to control the pests must be reached within the product to be protected and that many commodities such as grain are poor thermal conductors and provide some protection against the cold. It cannot be assumed that ambient temperature and commodity temperature are the same.

5.5.2.3 Contact insecticides (grain protectants)

Grain protectants, typically organophosphate and pyrethroid insecticides and IGRs, do not readily penetrate bagged or bulk grain. This restricts their utility substantially as normally they must be applied to the grain during handling, e.g. prior to bagging or on to grain on conveyors or elevators. They are also used as sprays on storage structures and the surfaces of bagged or bulk grain as part of a sanitation programme.

The use of grain protectants varies widely with country, market preference and local regulations. Where permitted and where pest resistance is not a problem, they can provide a useful means of avoiding the circumstances resulting in the need for fumigation.

Dichlorvos is unique amongst the commonly used grain protectants in its rapid action against pests and lability on grain. In the absence of resistance and, where approved, it can be sprayed onto bulk grain during handling within a few days of export to disinfest a cargo. Subject to an adequate withholding period for the residues to decay to acceptable levels, such a treatment can provide a direct alternative to disinfestation with MB.

While dichlorvos is currently approved under the Codex Alimentarius (1992) for application to raw cereal grains with a maximum residue level of 2 gt^{-1}, the registration is subject to debate in some countries and its long term future use is not assured.

5.5.2.4 Controlled atmospheres

Modified or CA treatments based on either nitrogen or CO_2 atmospheres, provide technical alternatives to MB-based disinfestations of bulk or bagged grain, provided adequate exposure periods (often more than 2 weeks) can be arranged logistically.

CAs require well sealed systems if they are to be effective and to avoid excessive usage of gas, to maintain the required atmospheric concentrations of O_2 and/or CO_2. Silo bins sealed to a standard suitable for recirculatory fumigation with MB are typically suitable for CA use. Application of CA may be constrained by the cost of the CO_2 or nitrogen required, particularly in developing countries. However, the technology of generating nitrogen from air on-site is progressing rapidly and cheap efficient systems can be expected to be available in the near future. Propane or LPG also offer an economically competitive method of continuously generating a low oxygen atmosphere on-site and has been successfully tested in France and the UK, where loaded grain bins of over 1000 tonnes capacity have been held under a less than 1% oxygen atmosphere for treatment periods long enough to kill all pests

(Fleurat-Lessard and Le Torc'h 1987; Bell *et al.* 1997a). However, France has discontinued this use.

Because of the slow speed of action compared with MB, CA is often not regarded as a potential substitute for its use. However, if CA is regarded as a tool in an integrated protection system, it may be suitable. Under Australian conditions, where a high level of pest control is achieved prior to moving grain to the export terminal, CA systems may then be used to maintain grain pest-free, until exported. One export terminal recently adopted this strategy in part of a facility converting a series of silo bins, including two equipped for MB fumigation, to nitrogen-based CA use (Cassells *et al.* 1994).

CO_2-based CA systems are used on a large scale in Indonesia for long term storage of bagged milled rice stocks (Nataredja and Hodges 1990; Sukprakarn *et al.* 1990). This system replaced a strategy of frequent MB fumigation and appears technically suitable for wherever bagged grain is stored in warehouses long term and CO_2 is available at reasonable cost. CO_2-based systems are now in experimental use in Canada for treatment of grain elevators (Marcotte 1995).

5.5.2.5 Heat treatment

Heat treatment is a process which can give complete mortality of insects in grain. It is one of the very few processes with the potential to meet the rapid treatment cycle, afforded by MB fumigation. The process still requires development for large scale use. There are currently no installations which meet the typical handling speeds of large modern grain terminals, often 500 th-1 or more on one belt, but a prototype fluid bed system has been built and successfully run at 150 th-1 (Sutherland *et al.* 1987).

Pilot and laboratory studies, reviewed by Sutherland *et al.* (1987) and Banks and Fields (1995) have typically used heated air at 90°C, or greater, as a heat transfer medium into the grain, with the objective of heating the grain briefly to above 65°C. Other heat sources, such as microwaves, infrared or radio-frequency irradiation can also be used (Boulanger *et al.* 1969; Banks and Fields 1995) but these have not yet been shown to be superior in practice to hot air-based systems.

Under good process control, there is no damage to the end use qualities of treated cereals at levels of heating required to eliminate insect pests. These include breadmaking quality of wheat, rice quality and malting quality of barley (Fleurat-Lessard 1985; Sutherland *et al.* 1987). However, the margin of error is small and only slightly excessive treatment can adversely affect the product (Fleurat-Lessard and Fuzeau 1991).

Heat disinfestation is one of the very few potential alternatives for disinfestation of bulk grain from live snails (*Cernuella* and *Cochlicella* spp.) (Cassells *et al.* 1994). Current recommendations against these quarantine pests involve high dosages of MB (Bond 1984). Heat also has the potential to replace MB treatments for some quarantine disinfestations targetted at *Trogoderma granarium*, an important quarantine pest of grain.

5.5.2.6 Inert dusts

Inert dusts (e.g. diatomaceous earth formulations) can provide a direct alternative to chemical protectants in dry grain where their adverse effects on grain characteristics and handling are acceptable. In particular, they provide good protection against insect infestation in dry grain stored long term for animal feed. They form a useful part of IPM strategies for grain protection in sprays applied to the storage fabric to minimise residual infestation and migration of pests into the bulks of stored grain. For further detail see Section 5.4.13.

5.5.2.7 IPM strategies

There are a wide range of processes available for control of pests in stored bulk and bagged grain. Alternative integrated control strategies incorporating sanitation measures, pest detection procedures, programmed spraying, stock rotation and environmental control, can be used to protect grain stocks from pest damage. Generally, except for specific circumstances, MB is little used in grain management in store and domestic trade as the alternative technologies already provide an effective solution. For further details see Section 5.4.15.

5.5.2.8 Irradiation

Irradiation of bulk grains may provide a technical alternative to MB in cases where the problems associated with the presence of live but sterile arthropod pests in the commodities can be tolerated. Extensive data exist on the irradiation of arthropod pests, as noted by Brower and Tilton (1985). Irradiation is effective at all temperatures with either bulk or bagged commodities. The dosage of irradiation which can be used is limited by effects on the quality of the commodity. Like MB, irradiation does not confer residual protection against pests, so packaging materials or post-treatment storage methods must prevent re-infestation. Otherwise, the irradiated grain combined with DE or CAs has been suggested as the most effective way to control re-infesting pests. Although irradiation is accepted by many regulatory authorities, there are retailer and consumer acceptance problems in some countries.

In Indonesia, commercial quantities of bagged rice have been irradiated as part of government rice storage for several years (300 t per week, since 1994). It is an effective treatment against *Sitophilus oryzae* (rice weevil) at a minimum dose of 0.40 kGy. The packaging materials are polyethylene liner with polypropylene outer bag sewn shut with polyester thread. A full scale commercial electron beam accelerator was formerly in use at Odessa, Ukraine, for the treatment of imported grain (Zakladnoi *et al.* 1982) but is no longer operational.

Logistics and quality assurance measures for the irradiation of bulk grain immediately before shipping have yet to be designed. They are important considerations because most exporting countries require grain to be pest free before it is exported. Irradiation does not immediately kill all life stages of the pests, so live (but sterile and not long living) pests may be present in irradiated grains. Irradiation at some doses may stop germination of grains and

seeds making it unsuitable, for instance, for malting barley. Thus far, irradiation has not been accepted as a quarantine treatment for grains.

5.5.2.9 Mechanical methods

Within an IPM system, mechanical methods offer the potential to reduce the need for MB (Banks and Fields 1995). Moving grain pneumatically or by screw auger has been shown to kill free living stored product insects and mites (White *et al.* 1997; Bahr 1991). Additionally some level of control of insects in flour milling is achieved through the removal of dockage and especially through the use of sieves and Entoleters.

5.5.2.10 Phosphine

Phosphine is widely used for treating infestation in bulk and bagged grain and grain products in many countries. Typically, aluminium phosphide preparations are added to the grain, or placed on the grain surface or near the product to be fumigated, within the fumigation enclosure. These release phosphine over a period of hours or days on contact with ambient moisture vapour. This process has superseded use of MB in many parts of the world. However, MB is still used, particularly at point of import or export (e.g. into Japan) or on stacks of bagged grain (e.g. parts of Africa, Singapore). In the first case, the speed of action and recognised effectiveness against pests of quarantine significance makes MB the preferred fumigant compared to phosphine, while in the second case, MB use has been developed into an efficient, effective and reliable system with no apparent need to change until recently.

Where regulations permit, in-transit fumigation of bulk and bagged grain on board ship can replace disinfestation with MB at point of export. Shipboard in-transit fumigation with phosphine is now a well developed technology (Leesch *et al.* 1978; 1986; Redlinger *et al.* 1979; Zettler, *et al.* 1982). It requires ships of appropriate design and stringent safety precautions (Snelson and Winks 1981; IMO 1996). Several grain-exporting countries, including Canada and Australia, require grain to be free of infestation at point of export and thus cannot use the system. However, technically it presents a method where the slow action of phosphine does not interfere substantially with the flow of trade through export ports and thus presents a feasible alternative to rapid MB treatments ashore.

Presently, there is no approved substitute to MB for treatment of khapra beetle (*Trogoderma granarium*) to quarantine standards in grain (and most other durable commodities). Phosphine is highly effective against all stages of this serious pest (Bell *et al.* 1984, 1985) including the tolerant diapausing larva, provided a sufficient exposure period can be used (5 - 10 days, depending on temperature) and the temperature is greater than 15°C (as is usual in regions where this pest occurs). Further studies are required to provide data for approval of phosphine treatments by quarantine authorities.

Recent developments in phosphine fumigation technology, including use of surface application in sealed systems and supply of non-flammable phosphine formulations in cylinders at about 2% w/w in CO_2 (Winks 1986; Chakrabarti *et al.* 1987; Chakrabarti 1994) have increased the competitiveness and effectiveness of phosphine use compared with MB. Discussion of recent advances in phosphine treatment of grain against infestation can be

found particularly in Navarro and Donahaye (1993), Highley *et al.* (1994) and Donahaye *et al.* (1997).

5.5.2.11 Other potential fumigants

Carbonyl sulphide, cyanogen, ethyl formate, methyl iodide, methyl isothiocyanate and methyl phosphine are under investigation as potential fumigant alternatives for MB on grain or grain products (see under Section 5.4 above).

5.5.3 Alternatives - dried fruit, nuts, coffee and cocoa

The commodities described in this section possess diverse physical and chemical characteristics. They may be stored for extended periods of time, both before and after processing. Quarantine treatments may be necessary in some cases. Many of these commodities, particularly coffee and cocoa, are typically produced in developing countries and shipped to developed countries that demand a high standard of quality and total absence of infestation by pests.

In many production areas storages are of inadequate quality to protect the commodities from invasion by pests and the ambient high temperatures and humidities may favour their rapid multiplication. Infestations can lead to severe economic losses unless effective control measures are applied. Losses result not only from direct damage and downgrading as a result of pest activity, but also from charges levied by importing countries where compulsory fumigations may be carried out at point of import, should infestations be detected. Infestations of commodities such as walnuts, apricots and cocoa may also emerge during storage at the final destination.

Dried fruit and nuts have particular quality characteristics which must be taken into account when considering application of technologies developed for pest control. Cool storage is used for long term protection and preservation of several types of dried fruit including dried pears, prunes and unprocessed sultanas and raisins. It is appropriate for nuts and beverage crops. However, it can lead to quality degradation with some specific grades of some dried vine fruit which are prone to crystallisation of fruit sugars, for instance, in processed sultanas. Sultanas may also change colour (increased brownness) and lose grade when subject to high temperatures for extended periods.

Walnuts, cocoa beans and some other products are susceptible to taint when treated with some chemicals. Some alternative technologies may be beneficial, e.g. nitrogen-based CA, in controlling rancidity as well as pests in some nuts.

Commodities covered in this section, at least sometimes treated with MB, are given in Table 5.6 below.

Most of these products are harvested over a relatively short period and at the same time - August to November in the northern hemisphere. Therefore, very large volumes have to be treated quickly. For instance, receiving stations in the USA can handle 26,000 tons per day of dried fruits and nuts at the peak of the season. Currently, most dried fruits and nuts are treated at least once with MB. The frequency depends on the time interval in storage prior

to processing (over one year, in some cases) and local conditions. Loss of MB is predicted to have a severe impact on the costs of pest control as currently used and secondary or indirect effects on storage, handling and processing for both domestic and foreign markets (Anon. 1993).

Table 5.6 Varieties of fruits and nuts sometimes treated with MB

Common Name	Scientific Name
Nuts and beans	
Almond	*Prunus amygdalus*
Beechnut	*Fagus* spp.
Betel nut	*Areca catechu*
Brazil nut	*Bertholletia excelsa*
Butternut	*Juglans cinera*
Cashew	*Anacardium occidentale*
Chestnut	*Castanea* spp.
Cocoa beans	*Theobroma* spp.
Coconut	*Cocos nucifera*
Coffee beans	*Coffea arabica*
Cola-nut	*Cola acuminata*
Hazelnut (filbert)	*Corylus* spp.
Hickory nut	*Carya* spp.
Macadamia nut	*Macadamia tenuifolia*
Pecan	*Carya illinoensis*
Pinenuts	*Pinus* spp.
Pistachio	*Pistacia vera*
Walnuts	*Juglans* spp.
Dried Fruits	
Apple	*Malus* spp.
Apricot	*Prunus armeniaca*
Banana	*Musa* spp.
Blueberry	*Vaccinium* spp.
Cherries	*Prunus cerasus*
Cranberry	*Vaccinium macrocarpon*
Date	*Phoenix dactylifera*
Fig	*Ficus carica*
Mango	*Mangifera indica*
Papaya	*Carica papaya*
Peach, nectarine	*Prunus persica*
Pear	*Pyrus* spp.
Pineapple	*Ananas comosus*
Prune	*Prunus domestica*
Raspberry	*Rubus idaeus*
Sultanas, currants and raisins	*Vitis* spp.
Tomato	*Lycopersicon esculentum*

Coffee and cocoa (Table 5.7) and dried fruit and nuts (Table 5.8) have pests typically associated with them. Some of the pests originate in the field and do not persist and reproduce in storage (e.g. codling moth (Dandekar 1989) and many bruchids); while others are general stored product pests (e.g. *Oryzaephilus* spp., *Tribolium* spp.) which may attack a wide range of commodities apart from dried fruit and nuts (e.g. grain). The field pests may require treatment to meet quarantine or phytosanitary requirements of producer or importing countries, while the stored product (storage) pests must be treated in order to avoid damage to the product as well as sometimes to meet market or regulatory standards. Reinfestation by storage pests may occur in local and importing country storage, during transit and subsequently in marketing channels and consumer storage.

Table 5.7 Target pests in coffee and cocoa

Common Name		Scientific Name
Coffee bean weevil	*	*Araecerus fasciculatus*
Foreign grain beetle		*Ahasverus advena*
Dried fruit beetle		*Carpophilus dimidiatus*
Rice moth		*Corcyra cephalonica*
Rust-red grain beetle		*Cryptolestes ferrugineus*
Tropical warehouse moth	*	*Ephestia cautella*
Warehouse (cocoa) moth	*	*Ephestia elutella*
Coffee berry borer		*Hypothenemus hampei*
Cigarette beetle		*Lasioderma serricorne*
Australian spider beetle		*Ptinus tectus*
Merchant grain beetle		*Oryzaephilus mercator*
Rust red flour beetle		*Tribolium castaneum*

* Major pests

5.5.3.1 Biological methods

Biological methods (predators, parasites, pheromone control and pathogens) in general, have not been developed to a commercial stage specifically for dried fruit, nuts and beverage crops. However, pathogens and parasitoids have been researched for various dried fruit (Vail *et al.* 1993a,b; Hunter *et al.* 1973; McGaughey 1986; Vail *et al.* 1991; Press *et al.* 1982; Cline and Press 1990). *Bracon hebetor* is used in South Africa as a parasitoid for reducing the need for fumigation against moth infestation in dried vine fruit.

5.5.3.2 Carbon dioxide at high pressure

For many years, CAs have been used to replace MB for disinfecting some dried fruit and beverage crops. A recent innovation combines carbon dioxide with high pressure of around 25 bar and controls all stages and species of pest insects in less than three hours. It requires a gas-tight chamber which can withstand pressure of this magnitude. It is currently in limited use in Germany (Prozell and Reichmuth 1991; Prozell *et al.* 1997).

Table 5.8 Target pests of dried fruits and nuts

Common Name		Scientific Name	Host[a]
Flour mite		*Acarus siro*	F
Black fungus beetle		*Alphitobius laevigatus*	N
Navel orange worm	*	*Amyelois transitella*	F, N
Peach twig borer		*Anarsia lineatella*	F, N
Coffee bean weevil		*Araecerus fasciculatus*	F
Raisin moth		*Cadra figulilella*	F, N
Dried fruit mite		*Carpoglyphus lactis*	F
Dried fruit beetles		*Carpophilus* spp.	F, N
Rust red flour beetle		*Cryptolestes ferrugineus*	N
Flat grain beetle		*Cryptolestes pusillus*	N
Pecan weevil		*Curculio carvae*	N
Curculio	*	*Curculio nasicus*	N
Hickory shuckworm		*Cydia caryana*	N
Codling moth	*	*Cydia pomonella*	F, N
Earwigs		Dermaptera	F
Dermestids		Dermestidae	N
Vinegar flies		*Drosophila* spp.	F
Almond moth	*	*Ephestia cautella*	F, N
Warehouse moth, tobacco moth		*Ephestia elutella*	F, N
Common earwig		*Forficula auricularia*	F
Ants		Formicidae	F, N
Cigarette beetle		*Lasioderma serricorne*	F, N
Merchant grain beetle		*Oryzaephilus mercator*	F, N
Saw-toothed grain beetle	*	*Oryzaephilus surinamensis*	F, N
Indian meal moth	*	*Plodia interpunctella*	F, N
Carob moth		*Spectrobate ceratoniae*	F
Drugstore beetle		*Stegobium paniceum*	N
Fruit flies	*	Tephritidae	F, N
Red flour beetle	*	*Tribolium castaneum*	N
Confused flour beetle		*Tribolium confusum*	F, N
Khapra beetle	*	*Trogoderma granarium*	F, N
Hairy fungus beetle		*Typhaea stercorea*	F
Dried fruit moth		*Vitula edmandsae serratilinella*	F

[a] F = principally dried fruit pest; N = principally pest of nuts * Major pests

5.5.3.3 Cold treatments

Cooling to very low temperatures (-10 to -18°C) is an established system of disinfestation of dates, replacing MB treatment. It is most effective when combined with a brief exposure to low pressure or 2.8% oxygen, which causes insects to leave the centre of the fruit (Donahaye *et al.* 1992) making them vulnerable to the cold treatment. A 10.5 hour exposure to minus 10°C, or 2.25 hour exposure to minus 18°C, killed all stages of the relevant insect pests (Donahaye *et al.* 1991). A similar treatment is increasingly replacing MB for disinfesting

dates in Israel. The utility of very low temperatures as disinfestants needs to be checked for other dried fruit and nuts.

Cool storage is used for long term protection and preservation of several types of dried fruit including dried pears, prunes and unprocessed sultanas and raisins. Cold storage is now use in parts of California to prevent pest attack of dehydrated raisins. The fruit is held for up to a year at -0.5 - 1°C, 90% r.h., in polythene-lined bins after drying to 11% m.c. However, it can lead to quality degradation with some specific grades of some dried fruit which are prone to crystallisation of fruit sugars, for instance, in processed sultanas.

It is used for some other dried fruits, for example prunes and dried pears and is appropriate for nuts and beverage crops.

Cooling, combined with nitrogen CA treatment in sealed, white-painted silo bins is in use in Australia for protection and disinfestation of in-shell almonds (Banks, H.J. pers. comm. 1998). Similar technologies may prove suitable for most bulk stored nuts, under appropriate climatic conditions, giving high quality storage without need for periodic MB treatments.

5.5.3.4 Controlled atmospheres

Modification of air space to suffocate insects (low O_2, high CO_2 or high N_2 or hyperbaric pressure) requires purging and displacing the atmosphere in the treatment enclosure (Soderstrom *et al.* 1984; Navarro and Donahaye 1990). Some further development of application technology and sealing methods and research on efficacy is required for the commodities in this section.

CAs have been used to some extent to replace MB for disinfesting dried fruits and nuts and there have been some recent trials on sealed stacks of sultanas in Australia (Tarr *et al.* 1994). Apart from the recent development of using CO_2 with high pressure of about 25 bar (Prozell and Reichmuth 1991; Prozell *et al.* 1997) other prospects lie in the use of continuous flow systems for low O_2 atmospheres to treat sheeted enclosures and the use of raised temperature to treat commodities in chambers.

Treatment of almonds in silos with CA has been successfully demonstrated under full scale commercial conditions (Soderstrom *et al.* 1984). Use of CO_2 as an alternative to MB has been successfully trialled for sultanas in cartons in stacks (Tarr *et al.* 1994) and in export freight containers (Banks *et al.* 1993b). Improvements in on-site generation of nitrogen (Navarro and Donahaye 1990; Banks *et al.* 1993b; Bell *et al.* 1993, 1997a; Banks and Annis 1997) and improved quality retention under CA, may make CA treatments an attractive alternative to MB. Some modification of sealing techniques, already developed for stored grain (e.g. Ripp *et al.* 1984; Annis and Graver 1990) will be required to suit the dried fruit and nut industries.

5.5.3.5 Ethyl formate

This compound is in use in some countries (e.g. Australia, South Africa) as a fumigant for packaged dried vine fruit at time of packing, directly substituting for the subsequent need for MB treatment soon after packing.

5.5.3.6 Heat treatments

Brief heat treatments have potential to disinfest cocoa, coffee and specific dried fruit and nuts. Techniques will need to be researched carefully before adoption to determine effects on quality of the treated product. It is already known that high temperature storage or treatment of many dried fruit and nuts can lead to detrimental colour change or rancidity.

5.5.3.7 IPM systems

Many of the processes and technologies given above may be better used in combination in an IPM system, rather than as 'stand-alone' measures for pest control. In this form, they may provide both an alternative to MB use and improved storage. Examples include use of permanent sheeting over carton stacks of dried vine fruit combined with hygiene and a disinfestation treatment, e.g. CO_2 or phosphine, or use of cooling and CA in a sealed system for nuts. Also, efficient sorting machines, removing damaged or infested nuts, could be used in combination with sanitation and packaging and beneficial insects (predators) to give an acceptable level of control. High-efficiency sorting machines may be used together with protectants and/or physical treatment, to provide acceptable control levels. Beneficial insects might be used for space treatments and sanitation.

Further research is required to substantiate and develop IPM options as alternatives. Many IPM strategies will require considerable engineering research in order to be applied efficiently. New methods of application, increased energy efficiency and sealing methods for existing or new structures, will have to be identified or developed. Specific facilities may need to be designed for use of multiple technologies. For further detail see Section 5.4.15.

5.5.3.8 Irradiation

Irradiation has been shown to control pests of cocoa or coffee beans, dried fruits and nuts (Appiah *et al.* 1981; Kader *et al.* 1984; Hoedaya *et al.* 1985, 1987; Rhodes 1986; Manoto *et al.* 1987) but the technique is not used commercially at present. Irradiation does cause off flavour in walnuts above 0.9 kGy and like MB fumigation, does not confer residual protection on commodities leaving treated products susceptible to reinfestation.

In some regions harvest volumes are considerable over a short period of time. Given the economic need of having continuing throughput in an irradiator, this technology may not be suitable to disinfest all incoming products in those regions. The most cost effective method for handling high volumes of incoming product might be to treat a thin stream of product with an electron beam irradiator. This might not be practical for dried fruits if it requires major changes in the way the product is normally handled, but might be more applicable for walnuts. Johnson (1995) found radiation potentially useful for quarantine treatment of walnuts.

Gamma irradiators provide better penetration and may be more practical than electron beam units for treating dried fruit in bins. However, given the minimum dose required for pest control (0.30 kGy) and the size of the storage bins used for dried fruit, the maximum dose would not be less than the current 1.0 kGy general maximum dose allowed for disinfestation in the United States. This may not be a problem in other countries since Codex permits re-irradiation when irradiation is used for disinfestation. In the USA, this would require a regulatory change.

For both walnuts and dried fruits, use of irradiation to disinfest packaged product holds more promise. Because the amount of product to be treated would be spread over a longer period of time, smaller on-site irradiators or remote contract irradiators could also be effectively used for outgoing packaged product. Irradiation also has promise for use as a phytosanitary treatment. Need for this treatment would be limited to product exported to certain countries. Processors would be unlikely to use on-site irradiators as irradiators located at ports would be more efficient.

Because of prolonged survival of insects after radiation treatment, a major consideration for its use as a quarantine treatment is the possibility of live insects being found during inspections by the importing country. Currently, there is no simple method to determine that an insect has been irradiated and is sterile. This issue is being addressed and needs to be resolved if quarantine irradiation treatments are to be viable.

5.5.3.9 Packaging

This involves use of insect-resistant packaging for bulk and consumer packed goods. This method may be used as a treatment by itself or after other treatments to prevent re-infestation, thereby reducing the need for subsequent MB treatments.

5.5.3.10 Phosphine

Phosphine is widely used to control insects in a wide range of commodities in storage (Nelson 1970; Clifford and Wilson 1985; Wood and Lass 1985; Hartsell *et al.* 1991) and further research is only needed to modify commercial practices. Phosphine has not been developed to a standard that could be approved as a quarantine treatment.

Most pests of dried fruit and nuts are highly susceptible to phosphine and shorter exposure times can be used than with stored grain. In the latter case, longer periods are needed to control *Sitophilus* species. These do not attack dried fruit or nuts. Walnuts are susceptible to taint and colour change when treated with phosphine. For more detail on phosphine see Section 5.4.19.

5.5.4 Alternatives - herbs and spices

The fruits, leaves, seeds and other parts of many dried plants are used for medical purposes or as seasonings, beverages and food additives. Many of these materials are subject to infestation by stored product pests and MB has been used routinely for their control (Table 5.9).

These high value products are usually grown in tropical regions. They may become infested prior to harvest, or in store in the country of production. These infestations can lead to severe economic losses if no control procedures are applied. Typically these commodities are either bagged or baled and fumigation is usually conducted under gas-proof sheets in warehouses, in specialist fumigation chambers, or in shipping containers. Dosages of MB vary between 15 to 30 gm^{-3} and exposure periods are in the range of 1 to 2 days. Residue of inorganic bromide can accumulate, particularly in products with high fat and protein content and multiple fumigations.

Table 5.9 Herbs and spices sometimes disinfested with MB

Common Name	Scientific Name
Basil	*Ocimum basilium*
Bay	*Laurus nobilis*
Chillies	*Capsicum* spp.
Cinnamon	*Cinnamonum zeylanicum*
Cloves	*Syzygium aromaticum*
Coriander	*Coriandrum sativum*
Fenugreek	*Trigonella foenum-graecum*
Ginger	*Zingiber officianale*
Marjoram	*Origanum marjorana*
Mint	*Mentha* spp.
Mustardseed	*Brassica juncae*
Nutmeg/mace	*Myristica fragrans*
Oregano	*Origanum vulgare*
Parsley	*Petroselinum crispum*
Pimento	*Pimenta dioica*
Rosemary	*Rosemarinus officianalis*
Saffron	*Crocus sativus*
Sage	*Salvia officianalis*
Sesame	*Sesamum indicum*
Tarragon	*Artemesia dracunculus*
Tea	*Camellia sinensis*
Thyme	*Thymus vulgaris*
Turmeric	*Curcuma domestica*
Vanilla	*Vanilla fragrans*

Many spices and herbs are produced under conditions where there may be excessive bacterial contamination for particular markets. Treatments with fumigants other than MB such as ethylene oxide (but see Section 5.5.4.2 below) have normally been used to sterilise herbs and spices. These treatments also controlled the commonly occurring pests (Table 5.10).

Table 5.10 Some target pests in herbs and spices

Common Name		Scientific Name
Coffee bean weevil		*Araecerus fasciculatus*
Rice moth		*Ephestia cautella*
Cigarette beetle	*	*Lasioderma serricorne*
Copra beetle		*Necrobia rufipes*
Grain beetles	*	*Oryzaephilus* spp.
Indian meal moth		*Plodia interpunctella*
Drugstore beetle	*	*Stegobium paniceum*
Flour beetles	*	*Tribolium* spp.

*Major pests

5.5.4.1 Carbon dioxide at high pressure

Carbon dioxide under high pressure is in limited use in Germany and elsewhere to treat plant products, including beverages and spices (Gerard *et al.* 1988; Prozell and Reichmuth 1991; Ulrich 1994; Prozell *et al.* 1997). Operating pressures are about 25 bar. The high construction and installation costs of pressure chambers restrict their widespread use.

5.5.4.2 Ethylene oxide

Some countries still allow the use of ethylene oxide for pest control. It is the fumigant of choice where sterilisation, as well as pest control, is required. This substance has been withdrawn widely due to its reaction with chloride and bromide in commodities that results in potentially carcinogenic compounds. Ethylene oxide is not usually recommended on herbs, vegetable seasonings or spice mixtures that include salt because of formation of these carcinogens. Apart from MB, phosphine and ethylene oxide, there are no other fumigant gases currently used for pest control in these products.

5.5.4.3 Extreme temperature treatments

Since herbs and spices contain volatile compounds which are responsible for their identity and quality, heat treatments are usually avoided. This may be achievable by cooling to a sub-zero temperature to preserve the quality while also serving as a control measure against insect pests. There is scope for further use of heat or cold as alternatives to MB for specific products, but research is needed to show they can eliminate pests while not adversely affecting quality.

5.5.4.4 Integrated pest management

For general information on IPM approaches, refer to Section 5.4.15

5.5.4.5 Irradiation

Spices, herbs and vegetable seasonings are commercially irradiated for control of bacterial contamination in many countries. The dosages necessary for this purpose are higher than

those required for disinfestation from insect pests (Marcotte 1994; Jategaonkar and Marcotte 1993; Katusin-Razem *et al.* 1985; Saint-Lebe *et al.* 1985). For most of these products, there are no significant changes in sensory evaluations as a result of irradiation in the dose range of 5.0 - 10.0 kGy, sufficient for sterilisation and thus no adverse effects can be expected at the much lower dosage required for insect pest control.

5.5.4.6 Controlled atmospheres

Carbon dioxide or nitrogen-based CAs are potentially useful alternatives for MB for pest control in herbs and spices. Since many of the processing factories already have gas-tight chambers, a change from MB to controlled atmospheres might not be too difficult. The main change would be the increase in the treatment period of about 2 to 6 weeks depending on the temperature and species of the insect to be controlled. Further details on CAs are given in Section 5.4.8.

In-transit or on-site treatment of containerised herbs or spices with CO_2 for pest control appears to be a feasible alternative to MB fumigation (Banks 1988).

5.5.4.7 Phosphine

Phosphine is often used to disinfest herbs and spices, particularly where there may be the possibility of excessive residues with MB. The longer exposure time required for effectiveness of phosphine compared with MB provides a disincentive to its use when pests are detected on importation in consignments of herbs or spices. There is also concern over possible taint with the use of phosphine.

5.5.5 Alternatives - tobacco

Tobacco is a high value commodity which is transported internationally either raw or as finished products (cigars, cigarettes). A small group of pest species are of importance in stored tobacco (Table 5.11). In the trade, a nil infestation is generally expected. MB was formerly used to control tobacco pests in many countries (Manzelli 1987) but this has largely been superseded by phosphine treatment and other measures. MB is still specified by some importers (e.g. Japan, Taiwan). Fumigation treatments generally rely on phosphine, coupled with an organised system of monitoring and localised action as necessary (Ryan 1995).

The main advantages of MB are that it can be used at atmospheric pressure, or under vacuum at low temperatures and it can rapidly kill all development stages of the insects. One disadvantage (Benezet 1989) is its adverse effects on the flavour of the tobacco product.

Table 5.11 Target pests in tobacco and related products

Common Name		Scientific Name
Warehouse moth, tobacco moth	*	*Ephestia elutella*
House mite		*Glycyphagus domesticus*
Potato tuber moth		*Phthorimaea operculella*
Cigarette beetle	*	*Lasioderma serricorne*

* Major pests

5.5.5.1 Heat and cold treatment

The tobacco industry has long practised pest control procedures based on heat or cold (Ryan 1995; Samfield and Brock 1958; Childs *et al.* 1968).

The lethal effects of a range of exposures of extreme temperature to adults, pupae, four-week-old larvae, two-week-old larvae and eggs of the cigarette beetle *Lasioderma serricorne*, have been investigated (Meyer 1980). At 50°C, the lethal exposure for larvae (the most tolerant stage) was 3 hours while at 55°C an exposure of 1 hour was lethal. All stages could survive 3 hours at minus 15°C. For cold treatment, exposure of cases for 5 days in a commercial draught-assisted freezer (minus 30°C) is recommended (Ryan 1995).

Heat is used in the redrying process for tobacco prior to storage, followed by steam to supply the exact amount of moisture required, but this process requires some additional action to kill all pest survivors (Tenhet and Bare 1946). Vacuum-steam conditioning is effective, a 'steamed' tobacco temperature of 60°C for three minutes being sufficient to kill all pests (Ryan 1995). All processes rely on the ability to limit the through-put of samples for treatment and are unsuited to deal with a sudden large outbreak of infestation.

5.5.5.2 Insect growth regulators

Methoprene, an IGR, is finding increasing use in stored tobacco against the principal pest, *Lasioderma serricorne*, removing the need for MB (or other) treatments in long-term storage.

5.5.5.3 IPM strategies

A comprehensive IPM strategy involving infestation detection, isolation, localised treatment and phosphine fumigation is in use for tobacco in many facilities (Ryan 1995). For further details, see Section 5.4.15.

5.5.5.4 Irradiation

Irradiation studies on cigarette beetle, *Lasioderma serricorne*, indicate that a dose in the range of 0.6 - 1.0 kGy can control all developmental stages. A dose of 5.0 kGy had no effect on nicotine content, volatile oil content, composition or pH of tobacco (Hoedaya *et al.* 1987). However, although research has been carried out, radiation techniques are not presently used in the tobacco industry.

5.5.5.5 Phosphine

Phosphine is very widely used for tobacco disinfestation. It is used at atmospheric pressure, has excellent penetration and is effective against all development stages of insects. The rate of use varies between 1 and 4 gm^{-3} and the duration of treatment from 5 - 15 days according to the temperature (Geneve 1972; Geneve *et al.* 1986). However, in recent years phosphine resistance in the cigarette beetle *Lasioderma serricorne* has been reported (Rajendran and Narasimhan 1994) and is becoming widespread. To combat resistance, exposure times for treatment need to be extended from the 5-7 days normally used.

5.5.6 Alternatives – seeds for planting

Several nematode genera are known to be seed-borne (Caubel 1983). The most important in agriculture are *Anguina, Aphelenchoides* and *Ditylenchus* (Bacci Del Bene and Cancellara 1973). Many crop species may be infested, including rice, wheat, leguminous plants and onions (Table 5.12 lists some of the nematodes transmitted on seeds). These nematodes may also be transmitted by propagules: bulbs, stolons and cuttings.

The increase in international exchange of seed increases the risk of dispersal of seed-borne nematodes. Regulations and certification schemes are required to minimise the risk of the dispersal of these important plant pests.

MB is a standard technique for destroying dormant nematodes in seed lots. There is usually little effect on seed germination after treatment under controlled conditions (Strong and Lindgren 1961). Fumigation of seeds is used as a routine prevention treatment and quarantine measure. Tests have been carried out with various combinations of concentrations and exposure times (Marre *et al.* 1983).

Developing countries are particularly dependent upon the use of MB for quarantine treatments of seed lots because imports are often only permitted if fumigated in the country of origin or at ports of entry.

At present, there is no single approved alternative to, or substitute for, MB for ridding seeds of seed-borne nematodes. However, there are substitute chemicals and alternative procedures for specific applications which could substantially reduce the use of MB.

5.5.6.1 Chemical soaking and fumigation

Promising results were obtained in the control of *A. besseyi* (Fortuner and Orton Williams 1975) by soaking rice in aqueous solution of systemic organophosphorus compounds. The compounds are not phytotoxic. Prasad (1992) eliminated *A. besseyi* in rice seeds by soaking them in a solution of mancozeb and monocrotophos, followed by fumigation with phosphine at a dose of 9.3 gm^{-3}.

Table 5.12 Some nematodes transmitted by seeds

Nematodes	Seed Species		Distribution
Aphelenchoides besseyi	Rice	*Oryza sativa*	Asia, America, Africa
A. ritzemabosi	Aster	*Callistephus sinensis*	Europe
A. blastophthorus	-	-	-
Anguina tritici	Wheat, rye	*Triticum* spp., *Secale* spp.	Europe, Asia
A. agrostis	Bentgrass	*Agrostis* spp., *Lolium* spp.	Europe, USA, Australia
A. funesta	Rye grass	*Lolium rigidum*	Australia
A. amsinckiae	-	*Amsincka* spp.	America
Subanguina chrysopogoni	Grass	*Chrysopogon fubus*	Asia
Ditylenchus angustus	Rice	*Oryza sativa*	Asia, Egypt
D. dipsaci	Oat	*Avena* spp.	Europe
	Onion	*Allium* spp.	Europe
	Shallot	-	Europe
	Beet	*Beta* spp.	Europe
	Fuller's teasel	*Dipsacus fullonum*	Europe, America
	Cat's ear	*Hypochaeris radicata*	America
	Lucerne	*Medicago* spp.	Europe, New Zealand
	Plantain	*Plantago* spp.	America
	Dandelion	*Taraxacum officinale*	America
	Clover	*Trifolium* spp.	Europe
	Field bean, Broad bean	*Vicia faba*	Europe, Africa, Middle East
	Carrot	*Daucus carota*	"
	Runner bean	*Phaseolus* spp.	"
	Pea	*Pisum sativum*	"
	Buckwheat	*Fagopyrum sagittatum*	"
	Spring vetch	*Vicia sativa*	"
D. destructor	Groundnut	*Arachis hypogea*	Africa
Heterodera schachtii	Beet	*Beta* spp.	Europe
Panagrolaimus spp.	Pearl Millet	*Pennisetum americanum*	Asia
Rhadinaphelenchus cocophilus	Coconut	*Cocos nucifera*	Tropical America

5.5.6.2 Cleaning

As some species are associated with plant debris, thorough cleaning reduces the chance of infestation. Measures such as seed cleaning and physical and chemical control help to limit the risks of infestation by seed-borne nematodes and reduce the need for MB curative treatments.

5.5.6.3 Cold treatment

Seeds, like cereal grains (see Section 5.5.2.2) can be held at cold temperatures to control pest populations.

5.5.6.4 Hot water treatment

Hot water treatment may be used to control *Anguina agrostis* in bent grass (*Agrostis stolonifera*) but a treatment of 15 minutes at 52.2°C reduces the germination rate.

Hot water treatment following pre-soaking the seeds provides the most effective control of white-tipped nematode *(A. besseyi)*. This may be a mandatory quarantine treatment. Pre-soaking activates their dormant state and subsequent soaking at 51°C for seven minutes controls the nematode. However, some injury to germination may be observed.

5.5.6.5 IPM strategies

For general information on IPM approaches, refer to Section 5.4.15.

5.5.6.6 Phosphine

Phosphine is not typically effective against seed-infesting nematodes. However, experimental applications of phosphine were effective in controlling nematodes in water suspension (Rout 1966). Phosphine may also be used in combination with soaking in chemicals (see Section 5.5.6.1).

5.5.7 Alternatives - artefacts

The preservation and protection of artefacts represent a broad area of interest including commercial interests (e.g. trade in artefacts) and artefacts of substantial value or of irreplaceable cultural and national significance. Many of the objects held in museums, libraries and similar repositories are subject to attack by rodent and insect pests and at high humidity by fungi. Damage can be extensive if pests become established (i.e. begin to reproduce, eat, excrete and die) in the museum collection. Infestable materials include those made of wood, paper, leather and skins, feathers and natural fibres (particularly wool). Artefacts and similar objects made of organic materials (e.g. natural history specimens) are objects of trade internationally and may carry pests of quarantine significance.

Pest insects hidden deeply in the material can be effectively and quickly treated with fumigants having high penetrability. MB was formerly the fumigant of choice for pest control in artefacts. Infested artefacts are fumigated in gas-tight chambers, sealed rooms or

under gas-proof plastic sheets. Duration of treatment, however, is not generally important. Therefore, alternatives which require extended periods of treatment are acceptable provided that they are effective and produce no adverse effects on the artefacts, or risks to health or the environment. Some of the pests attacking artefacts are listed in Table 5.13.

Since artefacts may be severely damaged by attack from a single insect. Museums, libraries and similar repositories try to avoid infestation and damage to their valuable and unique objects. Consequently, many museums, libraries and similar repositories have installed a quarantine system to ensure that only insect-free artefacts enter the location. Emphasis is thereafter focused on minimising the risk of introducing damaging pests.

If there is a risk that artefacts may harbour a pest of quarantine significance, notably *Trogoderma granarium*, many quarantine authorities will impose a mandatory MB treatment. In other cases the exporter carries out a treatment not required by regulatory authorities, but with the purpose of being able to certify that the artefacts are free from pests.

A number of countries are now including alternative treatments to MB fumigation in their trade regulations. Consequently alternative treatments are more frequently used than MB. The choices for museum artefacts have been discussed by Pinniger (1991); Newton *et al.* (1996); and Strang (1996). In many cases heat, cold and particularly modified atmospheres (Gilberg 1991; Rust 1996) are used as lethal treatments.

Table 5.13 Some common pests of artefacts made of wood, skin, feathers, wool and other organic materials

Common Name		Scientific Name
Furniture beetle	*	*Anobium punctatum*
Carpet beetles	*	*Anthrenus* spp.
Museum beetle		*Attagenus pellio*
Oriental silverfish		*Ctenolepsima villosa*
Larder beetle		*Dermestes lardarius*
Hide beetle		*Dermestes maculatus*
Smaller bamboo shot hole borer		*Dinoderus minutus*
Book borer		*Gastrallus immarginatus*
House longhorn beetle**		*Hylotrupes bajulus*
Cigarette beetle		*Lasioderma serricorne*
Book louse		*Liposcelis bostrichophila*
Powder-post beetles		*Lyctus* spp.
Drugstore beetle	*	*Stegobium paniceum*
Clothes moths		*Tinea* spp.
Clothes moth	*	*Tineola bisselliella*
Khapra beetle **		*Trogoderma granarium*

* Major pests; ** Quarantine pests

None of the above-mentioned pests are specific to artefacts in museums and can originate from other sources. In museums the requirements for a treatment are that it is effective

against the target pest and at the same time causes no damage to the artefact itself, or, in case of space fumigations, to the surrounding materials. Data on composition and pre-history of the material may be limited or unknown and experience about the effect of the treatment on the materials in the museum may be limited or absent. Artefacts often include a variety of different materials (e.g. wood with ornamentals, herbaria, different combinations of natural fibres, feathers and fur, leather and skins) which must be considered prior to the choice of treatment.

5.5.7.1 Contact insecticides

Contact insecticides are used as part of pest management strategies in museums and repositories. A variety of specific insecticides is used, depending on national regulation/approval, but contact insecticides based on pyrethroids (e.g. permethrin, cypermethrin, deltamethrin, cyhalothrin) or on organophosphates (e.g. dichlorvos, chlorpyrifos) are the most common.

In Japan, artefacts such as museum specimens, collections, books, antiques and art crafts are treated with cyphenothrin (applied as a 1% solution in liquid carbon dioxide) to control cigarette beetle, powder post beetle (*Lyctus brunneus*), black carpet beetle, book borer anobiid (*Gastrallus immarginatus*) oriental silverfish (*Ctenolepisma villosa*) and others. Phenothrin (applied as a 1% solution in liquid carbon dioxide) is also used to control cockroaches, fleas, bedbug and *Ornithonyssos* spp. (fowl and rat mites).

5.5.7.2 Heat and cold treatments

Heat and cold treatments can be used with care to disinfest artefacts, provided condensation and cracking of wood and other sensitive materials can be avoided by appropriate control of moisture. Exposure to -18°C can give disinfestation of woollen artefacts from clothes moths in a few days (Brokerhof *et al.* 1993).

A commercial technique employing heat and humidity to disinfest museum artefacts has been field tested in Germany, Austria and the UK. A Danish project (report in preparation, pers. comm. Michael Hostrasmassen 1998) has optimised heat and cold treatment of wood-boring beetles in wooden objects, reducing the temperature for heat treatments and increasing the temperature for freeze treatments without losing efficacy. Energy consumption can, under certain circumstances be reduced by 50%. Also, the degree of damage for wood, as well as for ornaments and paintings, was minimised. The project presents a treatment strategy including more precise determination of population viability. Heat and cold treatments for artefacts have been reviewed by Strang (1992).

5.5.7.3 Hydrogen cyanide

Hydrogen cyanide can also be effectively used for pest control in artefacts.

5.5.7.4 Integrated pest management

In Canada, the Canadian Conservation Institute (Strang 1996) has developed an IPM programme which has replaced the use of MB in museums, libraries and similar repositories.

A general framework, based on identification and assessment of the risks to a specific collection, is adjusted by taking into account nine conditions at the local site. The framework defines three levels at which control measures can be taken: the building; portable fittings; and 'Procedures' (actions that can be carried out by the staff). Control at the building or portable fittings level is further broken down into actions that are suitable for storage, display or transit situations.

Preservation of the various collections is continually optimised through long-term planning and review of the pest management program already in place, improving any shortcomings discovered in the 'avoid' through 'respond' control stages, together with recording of all costs incurred.

5.5.7.5 Irradiation

Irradiation has been used to control insect and fungal problems in historical artefacts, art objects, books and paper archives with good results in France, Czechoslovakia and China. Ornamental wood products are sometimes irradiated commercially against pests in Australia after importation from Indonesia (Marcotte 1994). The minimum recommended dose for pest control ranged between 0.50 kGy for insect control to 1.6 kGy (Ramière 1982; Fan *et al.* 1988).

5.5.7.6 Controlled atmospheres

CAs are being increasingly used for insect control in artefacts, although depending on the temperature, treatment may take two to eight weeks in gas-tight chambers (Newton 1993). There is limited but increasing use of CAs for artefacts in Germany (Reichmuth *et al.* 1992), the UK (Newton *et al.* 1996) and possibly elsewhere. CAs with humidified nitrogen in a carefully constructed gas-tight enclosure, can control all stages of museum insect pests after purging to bring oxygen levels down to about 1%. The introduction of a proprietary oxygen scavenger can bring oxygen levels down further to 0.05 % and hold them there for up to 30 days. CA fumigation with 0.1% oxygen content, or atmospheres with more than 60% carbon dioxide, are proving to be effective replacements for MB in museums (Strang 1996).

5.5.7.7 Phosphine

Phosphine is used to fumigate wooden objects, paper and other materials of vegetable origin. With some materials, e.g. furs and paper, phosphine may be preferred to MB because of the reduced risk of taint. Because the gas may adversely affect metals (copper, silver, gold) and pigments in paintings, it is rarely used for treating objects of this type. Fumigation with phosphine will require a longer exposure period than MB for complete control of insects.

5.5.7.8 Sulphuryl fluoride and other fumigants

Sulphuryl fluoride is widely used to control wood-destroying insects and has proven efficacy against some other pests that may infest museums. Sulphuryl fluoride has low reactivity which is an important factor for treatment of artefacts.

Ethylene oxide has also been used on artefacts but has been withdrawn from use in some countries. Ethyl formate and carbonyl sulphide may also be alternatives to MB, but no practical data are available on their use for this application.

5.5.8 Alternatives - other products

5.5.8.1 Cheeses

Currently no work in progress has been able to address the problem of replacing MB to control pesticide-resistant mites in traditional cheese stores.

5.5.8.2 Cotton

MB is still widely used in the US prior to shipment against pink boll worm, a quarantine pest. Treatments may also be carried out on products in contact with, or packed with, cotton. Approximately 40 tonnes per annum of MB is used for this purpose.

5.5.8.3 Dried fish, meat and seafood

Commodities damaged by pests include both saltwater and freshwater dried (cured) fish, dried meat and meat products. The common pests of animal products are listed in Table 5.14.

Table 5.14 Common pests in dried fish, meat and seafood

Common Name		Scientific Name
Flour mite		*Acarus siro*
Carpet beetle		*Attagenus* spp.
Hide beetle	*	*Dermestes* spp.
Red-necked bacon beetle		*Necrobia ruficollis*
Copra beetle	*	*Necrobia rufipes*
Khapra beetle, warehouse beetle		*Trogoderma* spp.
Cheese and bacon mite		*Tyrophagus* spp.

* Major pests

Dried fish is particularly prone to infestation by several species of dermestid beetles and to a lesser extent by *Necrobia* spp.. Damage caused by dermestids can be particularly severe and it has been reported from inland fisheries in Africa that, if infestation is not controlled, losses approaching 50% of the commodity can result (FAO 1981). Dried meat may also become infested by similar insect pests, but no information is readily available on economic losses caused to this product.

MB has been recommended for disinfesting dried fish in several African countries where experimental trials have been carried out, but little information is available to indicate the extent of its commercial use (Friendship 1990).

Disinfestation of dried fish using phosphine has been reported by Friendship (1990) and this fumigant would appear to provide effective control of the common insect pests, infesting this commodity.

Pyrethrins synergised with piperonyl butoxide have been recommended as an aqueous dip for protecting dried fish from insect infestation (Proctor 1972) and, more recently, pirimiphos methyl has been recommended for the same purpose (Golob *et al.* 1987). A maximum residue limit of 10 mg/kg was recommended for pirimiphos methyl by the FAO/WHO Committee on Pesticide Residues (FAO 1986).

Irradiation has been used to disinfest dried fish in Bangladesh and the Philippines (Matin and Bhuiya 1990; Manoto *et al.* 1985).

5.6 Wood Products and Wood in Structures

5.6.1 Introduction

Generally, wood products which require treatment with MB can be classified into two categories: those items separate from buildings and structures and those forming an integral part of a structure. The separate product category includes: artefacts, museum objects and other items of historical significance; unsawn timber, timber products and other wood products; bamboo ware, packaging materials and other items of quarantine significance.

Pest control in structures is used to prevent or control pests in either an entire structure, or a portion of a structure. Many conditions and pests exist which require structural pest control, only some of these are treated primarily by MB fumigation. There are two main applications: (1) control of direct structural damage by drywood termites and wood-boring beetles to domestic, commercial and historic buildings; (2) control of pests, for example moths, beetles, cockroaches, mites, nematodes and rodents, in storage facilities and non-food facilities (see Section 5.7 below).

Two major classes of pests require control: insects (Table 5.15) and fungi. Both classes of pests include species declared in some countries as specific objects of quarantine. In addition, the nematode *Bursaphelenchus xylophilus* is a major quarantine pest of timber.

Some wood inhabiting fungi which need to be controlled, usually for quarantine purposes, are: *Antroida carbonica, Ceratocystis fagacearum, Gloeophyllum sepiarium, Lentinus lepideus, Lenzites sepiaria, Lenzites trabea, Postia placenta* and *Serpula lacrimans*.

Table 5.15 Target insect pests in logs, timber and bark products

Common Name		Scientific Name
Pine bark borers		*Acanthocinus*
		Arixyleborus spp.
Longhorn beetle	*	*Cerambycidea scolytidea*
Book beetles	*	*Dentroctonus* spp.
Walnut pinhole borer		*Diapus pusillimus*
		Diapus quinquespiratus
Ambrosia beetle		*Gnathotrichus retsus*
Ambrosia beetle		*Gnathotrichus sulcatus*
Black pine bark beetle		*Hylastes ater*
Bark beetles		*Ips* spp.
Powder-post beetles	*	*Lyctus* spp.
Sawyer beetles	*	*Monochamus* spp.
Bark beetles		*Orthotomicus suturalis*
Ambrosia beetles		*Platypus* spp.
Bark beetle		*Polygraphus subopacus*
		Rhagium spp.
Bark beetles	*	*Scolytus* spp.
Eastern larch borer		*Tetropium cinnamopterum*
Striped ambrosia beetle		*Trypodendron lineatum*
Woodwasp, Sirex	*	*Sirex noctilio*
Ambrosia beetles		*Xyleborus* spp.

* Major pests

Timber, which is infested by the oak wilt fungus *Ceratocystis fagacearum*, is usually fumigated with MB, under gas-proof sheets or in chambers at the high rate of 240 gm^{-3}, prior to export to Europe (Liese and Ruetze 1985). This fungus is regarded as a particular quarantine problem in Europe. It should be noted that while there are a variety of potential substitutes, research is required to establish them as satisfactory treatments that meet the various standards, stipulated by different quarantine authorities.

5.6.2 Wood products

Wood products include raw material such as logs, sawn timber and products made of wood such as pallets. For pests that infest or infect wood or wood products, alternatives can be classified into two types of treatments, ones that are applied directly to the product, the other that utilises an enclosure for treatment in a confined space.

5.6.2.1 Contact insecticides

Contact insecticides, including dichlorvos, may be used as part of a pest management strategy. There is an approved quarantine treatment involving immersion of logs in water and treating the upper surface of the logs above the water level with an insecticide mixture

(see Section 5.6.2.10). In the USA and Japan, a dip-diffusion treatment in a solution of borate is registered for sawn timber. Australia allows pressure impregnation of insecticidal mixtures as an alternative to MB for treatment of wooden pallets for control of *Sirex noctilio* and other wood pests.

5.6.2.2 Controlled atmospheres

CAs have the potential for use in wood products but long exposure times are required for treatment at ambient temperatures. The efficacy of CAs at elevated temperatures for treatment of logs for export is being studied in New Zealand (Dentener *et al.* 1997).

5.6.2.3 Heat treatments

Heat treatment technologies are notable as one of the very few pest control options which are capable of matching the speed of treatment afforded by MB and other fast-acting fumigants. The time required is strongly dependent on the temperature reached and experienced by the target pest.

Dry heat treatment could be an alternative for small quantities of logs. However, it does not appear practical for large volumes. Heat treatments (steam or hot water dips) used to control fungi will presumably give complete disinfestation from insects, mites and snails. Steam heat or hot water dips are generally most suitable, but kiln drying or dry heat is suitable for sawn timber. Heat treatment by steam has been shown to eradicate all tested fungi when the wood centre temperature is held at 66°C for 1.25 hours (Chidester 1991; Miric and Willeitner 1990; Newbill and Morrell 1991). Further research is required to better define heat treatments for logs. Using microwave energy as a heat source is a possibility but more research is needed (Vijam 1983).

5.6.2.4 Integrated pest management strategies

For general information on IPM approaches, refer to Section 5.4.15.

5.6.2.5 Irradiation

There is very limited published data on the irradiation of timber and timber products. However, researchers in the USA have reported that a dose of 6 - 8 kGy will kill the nematode *Bursaphelenchus xylophilus*, an economic pest of timber (Eicholz *et al.* 1990).

Collaborative research has been conducted on irradiation in Russia with the United States to provide a quarantine treatment for logs transported from Siberia to the US. If successful, this would present an alternative to MB quarantine treatment.

Some wood products are commercially irradiated on arrival in Australia as a quarantine treatment.

5.6.2.6 Phosphine

Fumigation with phosphine will require a longer exposure period than MB for complete control of insects. Phosphine penetrates well into commodities and can be removed rapidly by aeration after treatment. It has a low degree of sorption by most commodities

Fumigation of logs using phosphine is effective in controlling bark beetles, wood-wasps, longhorn beetles and platypodids, at a dose of 1.2 gm^{-3} for 72 hours exposure at the temperature of 15°C or more. This schedule is registered only in the USA. The length of time required to complete treatments restricts its commercial acceptability.

New developments include phosphine to treat bamboo in transit to avoid MB quarantine treatments in Japan.

5.6.2.7 Other fumigants and gases

Carbonyl sulphide may be an alternative to MB for timber treatment. It has superior powers of penetration to MB, but has not been tested under full scale conditions. In Germany and Japan, a mixture of phosphine with sulphuryl fluoride has been investigated against forest insect pests, but results were not significantly different from those with phosphine alone (Soma *et al.* 1998).

5.6.2.8 Removal of bark

At present, removing bark from logs prior to export is practised to a very limited extent as a control measure against pests, particularly bark beetles. Debarking, together with conversion to sawn timber in country of origin, appears to have the potential to reduce a need for MB where bark-borne pests are the object of the treatment, including quarantine treatments.

5.6.2.9 Sulphuryl fluoride

Sulphuryl fluoride is widely used to control wood-destroying insects in structures This is effective against major insect pests of timber, including bark beetles, wood-wasps, longhorn beetles, powderpost beetles and dry wood termites. It is less effective against eggs of some ambrosia beetles (*Xyloborus* spp.) (Mizobuti *et al.* 1996). It is applied for log disinfestation and for fumigation of dwellings in the USA. Generally, the dose applied is 64 gm^{-3} for 16 hours exposure at a temperature of not less than 21°C. Advantages of this gas are that it penetrates very well and is very effective against all wood infesting adult insects. The disadvantages are that it will only control egg stages at very high dosages and is not registered in many countries. Research is ongoing to evaluate the potential of this chemical for timber treatment for plant quarantine purposes (Schmidt 1997).

5.6.2.10 Under water dipping

Under water dipping treatment of logs for plywood is a necessary process as it improves the quality of the products. However, it needs broad water area and a long exposure time. There is an approved treatment for logs to be kept immersed in water for more than 30 days in order to control pests. The upper surface of the logs above the water level is sprayed with

an insecticide mixture. In Japan, approximately 14% of the logs imported in 1992 were treated using this technique replacing MB treatment.

5.6.3 Wood in structures

For pests that attack wood, alternatives can be classified into two types of treatments, whole-structure or localised. Whole structure treatment is defined as the simultaneous treatment of all wooden members, whereas localised treatment is restricted to a group of boards or locations within boards (Scheffrahn and Su 1994). For localised treatments, accuracy in detection of and determining the extent of infestation is critical to optimising pest control service and providing effective treatment.

5.6.3.1 Construction/removal

New construction should be designed for pest exclusion and prevention as a priority so pests cannot gain access to a building and the structure does not provide inaccessible harbourage for pests. For example, in many situations constructing wooden structures in a manner which protects the wood from humidity, destroying the conditions necessary for pest development, can be substituted for the use of chemical wood preservatives and protect the wood against attacks.

Infested wood in dwellings can often be cut out and replaced. While this can be an effective spot treatment, it is labour-intensive. Where permitted, infested wood should be replaced with wood pre-treated against pest attack.

5.6.3.2 Contact insecticides/preservatives

Surface application/injection of liquid residuals is used for spot application to accessible wood. The products used for this application include organophosphates (e.g. chlorpyrifos) pyrethroids (e.g, permethrin) and borates (e.g. sodium octaborate tetrahydrate). These products are applied as sprays, fogs, brush-ons and/or injections for treating accessible components.

The efficacy of organophosphates and the pyrethroids against wood destroying insects is well documented. For some wood-destroying pests, sodium octaborate tetrahydrate has proven effective, when adequate penetration of the wood can be achieved. Tests undertaken on the efficacy of borates for drywood termites have shown limited efficacy (Scheffrahn *et al.* 1997).

Wood Preservative Treatment is a method of preventing wood destroying insect problems by applying a pesticide or preservative to wood pre-construction. Some materials used for wood impregnation have been discontinued because of environmental effects. Pentachlorophenol was broadly used at one time, but is only in use in a few countries now. A wide range of preservatives are available for vacuum or pressure treating wood, for example borates and copper-containing compounds. Preservative treated wood is widely used in new construction and renovations to prevent infestations.

Products such as boric acid, pyrethroids, silica gel, diatomaceous earth and sodium octaborate tetrahydrate, formulated as dusts, are applied as spot treatments or into cavities created by insects in the wood. Dusts are efficacious against some wood destroying pests, e.g. carpenter ants and termites and have long lasting residual activity when dry. Application of dusts can be labour-intensive and require boring into the wood in the structure. Further work is needed to determine the efficacy of these products for other wood destroying insects.

The use of arsenic and chromic compounds for pressure impregnation has several effects on the environment and human health and are regarded as unacceptable in some countries.

5.6.3.3 Heat treatments

Heating to greater than 44°C is reported to eradicate drywood termites. Higher temperatures are likely to give more rapid mortality, but the limiting factor with regard to treatment time is expected to be the rate at which lethal temperatures are attained throughout the treated structure. Further study is needed to determine what specific structural components and contents are affected by heat and how these may be protected and the quantity of energy required to attain eradication in practice.

Whole-structure heating for controlling drywood termites was first reported several decades ago (Ebeling 1975). However, laboratory and large-scale field validations have only recently been reported (Lewis and Haverty 1996a). Whole structure treatments with heat appear to be effective. However, unsuccessful control using heat can be due to heat sinks. Heat sinks are areas within a structure that absorb and disperse heat and are therefore more difficult to heat, for example, wood on concrete (Lewis and Haverty 1996b). Pre-treatment preparations to prevent and minimise structural and household item damage from heat treatment, have been reported (Ebeling 1994).

5.6.3.4 Hydrogen cyanide

Hydrogen cyanide has been used as a fumigant for almost a century and still has some uses in a few countries. Historically it has been used for long-horned beetles and other wood destroying insects.

5.6.3.5 Controlled atmospheres

Attempts to use carbon dioxide to treat structures have so far not been successful due to problems of gas retention.

5.6.3.6 Phosphine

Phosphine is often used in grain fumigation and can be used in some structural situations. There is limited efficacy data for wood destroying insects and thus phosphine requires further research or documentation to determine the feasibility of using it for disinfestation of dwellings. The use of phosphine in dwellings may be limited due to its corrosive properties, particularly on copper or gold and silver alloys under high humidity conditions. Phosphine may require an extended fumigation time of several days against most pests, especially at

lower temperatures (less than 20°C). Phosphine has been shown effective against wood-boring insects in Norwegian churches.

Phosphine was used annually as a structural fumigant in Mauritius, but this use has been discontinued due to corrosion problems.

Cylinder-supplied phosphine with carbon dioxide provides potential for lower dosages and more accurate application of phosphine than other phosphine producing methods. However, corrosion risk and potential for resistance development remain, but some of the risks may be reduced using this method. Currently this product requires registration in most countries and has not yet been used either commercially or in field trials against wood-destroying insects in structures.

5.6.3.7 Spot treatments by electrocution

High voltage electricity, or electrocution, is another localised option for controlling drywood termites. The device currently marketed uses high voltage (90,000 volts) but low current (less than 0.5 amps). Reported efficacy has been mixed and highly dependent on applicator technique (Lewis and Haverty 1996a). The administration of high levels of heat is the probable cause of mortality. For maximum effects, high voltage bursts of electricity are directed at galleries containing termites. Results can be enhanced by drilling holes and inserting metal pins into wood. Success also can vary depending on proximity to certain building materials. Drilling wall coverings and wood for inserting metal pins is a destructive treatment technique which may have limited support by home owners (Lewis and Haverty 1996a).

5.6.3.8 Spot treatments by liquid nitrogen

Cold can be used as a spot treatment by the injection of liquid nitrogen into confined spaces such as wall voids. Liquid nitrogen has primarily been limited to the control of drywood termites. It has been used in the USA for several years with limited success. It is confined to wall void treatments rather than full sites and is dependent on a thorough inspection of the pest location and the containment area. This technique cannot be used in inaccessible areas. Insulation in walls can affect cold distribution, causing warm spots in walls. Interior surfaces can be stained and warping of wooden structural components is possible. Some damage to water pipes has occurred. Deprivation of oxygen has been a concern for workers when leakage occurs. Relative efficacy of localised treatments with liquid nitrogen is highly dosage dependent and varies from ineffective to effective (Lewis and Haverty 1996a).

The limitations of this localised treatment include: many locations within structures are not treatable with this method; drilling holes damages wall coverings and wood; large amounts of liquid nitrogen may be needed; and accurately monitoring temperature changes is critical to success (Lewis and Haverty 1996a).

5.6.3.9 Spot treatments by microwaves

Microwave heating has been used as a spot treatment with very limited success. It destroys insects by heating the moisture in wood, but can damage wood by scorching it. The use of

microwaves has primarily been limited to the control of drywood termites. It has been used in the USA for several years with limited efficacy.

As a localised treatment, its success is dependent on a thorough inspection and the evenness of the microwaves to avoid hot and cold spots. There is concern about the health risks because of the difficulty of shielding microwaves. Some damage to properties has occurred because of overheating of the target area. Further research is needed before this technique is recommended and it may be only applicable to accessible wood.

5.6.3.10 Sulphuryl fluoride

Sulfphuryl fluoride is a substitute for MB in several countries where it is available and/or registered for use against dry wood termites and the efficacy for this use is well proven. In the USA (California) this substitution has led to virtually a 100% reduction in MB use in the fumigation of dwellings. It provides good penetration, requires a short fumigation period of approximately 24 hours and has a 6 - 8 hour aeration period. The egg stage of many insects requires up to a 10 times increase in dosage when compared to the normal rate for adult control because of sulphuryl fluoride's poor ovicidal properties. Sulphuryl fluoride is used for control of dry wood termites. If a good seal is obtained on the structure, lower dosages may be used over a longer exposure period.

5.6.3.11 Miscellaneous

Combinations:

- Fumigant + carbon dioxide
- Fumigant + heat
- Fumigant + carbon dioxide + heat
- Fumigant + fumigant
- Heat + carbon dioxide

The most significant advantage of using combinations of techniques is the reduced amount of fumigant required while still achieving an effective treatment. These treatments have the potential to reduce exposure and aeration time. The efficacy of reduced sulphuryl fluoride, or MB concentrations and carbon dioxide, has been demonstrated by Scheffrahn *et al.* (1995). This technology requires further study in operational settings.

5.7 Treatment of Structures for Food Pests

5.7.1 Introduction

The necessity of minimising pest infestation and eradicating pests in products is well documented. Infestations can migrate throughout the building from infested products. This can result in new infestations as insects move within the structure and infest other products. Therefore, structural treatments can involve empty buildings or those containing goods. This underscores the need for maintaining pest infestations at the lowest practical level.

The choice of treatment depends on the goal. Pest elimination, at least occasionally, may require full site treatment, which today usually includes use of a fumigant, while satisfactory pest control may be achieved in many cases by other treatments. New techniques being developed have the potential to achieve elimination without the use of a fumigation.

Structural fumigation is a pest management technique that provides broad spectrum control and the ability of the fumigant gas to penetrate to pests that are not on the surface and cannot be readily contacted by other types of pesticide applications. The ability to penetrate through packaging materials, walls and other areas to hidden infestations is particularly valuable in structural fumigation.

MB is registered for a wide variety of treatments. It is effective against all life stages of insects and vertebrates. It penetrates well and permits short fumigation times. MB can be used on an entire structure or a portion of a structure. Treatment duration is dependent upon the time taken to achieve a set *ct*-product. Ideally sufficient gas to kill the pests is released into the space and then maintained at the toxic level for a defined period of time. The current practice in many countries is to fumigate with MB during a three-day weekend when operations are typically suspended for preparation of the structure, a 24 h treatment exposure and up to 24 h airing period.

5.7.2 Alternatives for structures

5.7.2.1 Cold

Cold treatments are used as part of an IPM system for disinfestation of stored products and structures (Fields 1992; Fields and Muir 1995; Banks and Fields 1995). The technique is more commonly used in countries with low ambient winter temperatures (for example Canada) but is also used where cold storage warehouses are part of a storage system (for example, for some dried fruit in the USA and France).

Freeze-outs have been used as space treatments to kill pests in mills, warehouses or storages. This method is also used for seed warehouses. Water pipes, when present in the building, must first be drained and temperature sensitive equipment temporarily removed. As an alternative to whole site exposure, cold air directed to localised infested areas within a facility can provide local protection against infestation.

Most pests cannot develop or feed at temperatures below 10°C. Most pests require only a few days exposure at very low temperatures (-15°C or below) to ensure control (Chauvin and Vannier 1991; Fields 1992). The stage of development of the pest is a factor in its cold resistance - eggs are more sensitive and adults or larvae are the most cold tolerant (Banks and Fields 1995). Furthermore, if some species have had time to acclimatise to cold (temperatures of 10-20°C for some days or weeks) they will be more tolerant to otherwise lethal cold temperatures. For this reason, rapid cooling from harvest temperatures to cold temperatures can be part of IPM storage systems to prevent cold acclimatisation and population increase.

Tropical species, however, are quite cold sensitive. These include *Sitophilus oryzae*, *S. zeamais, Tenebroides mauritanicus* and *Lasioderma serricorne*. Some common stored product pests are cold

resistant, they include *Cryptolestes* spp. bruchids, mites and some Lepidoptera. Two common stored product pests (Indian meal moth, *Plodia interpunctella* and rusty grain beetle, *Cryptolestes ferrugineus*) are quite cold resistant. The diapausing moth larva is highly resistant requiring over 14 days at -10°C or one day at -15°C; while the adult rusty grain beetle requires two weeks at grain temperature of -15°C, six weeks at grain temperature of -10°C, or eight weeks at grain temperature of -5°C (Banks and Fields 1995).

It is important to note that the temperature to control the pests must be reached in the interior of the structure or stack of product to be protected. It cannot be assumed that ambient temperature and interior temperature are the same.

5.7.2.2 Contact pesticides

Surface application or space spraying (fogging, misting) of liquid residual pesticides is a part of most pest management programs in food production plants. Organophosphates, carbamates and pyrethroids are the classes of pesticides typically used. The target pests most often are stored grain insects, mites, psocids and cockroaches. When direct pesticide applications are made into the insect harbourage, infestations outside the product or raw commodity can be reduced. However, precise hand application is time consuming and expensive. Normally, residual applications are relatively easy to apply when compared to fumigation and can be effective for an extended period of time. Longevity of residual materials may be significantly influenced by surface composition, presence of other materials (such as dust, grease, food residues) ambient temperature and humidity. Some residual materials are repellent, causing insects to move to untreated surfaces.

Space sprays of contact insecticides usually involve dispersal of small particles below 50 microns in size, dispersed in the air at a rate of 0.5 to 1.0 gm^{-3}. The small particles stay suspended in the air for a period of time and contact and kill exposed insects. It can supplement other control methods as part of an IPM program, but is seldom a complete control itself, since space sprays do not have penetrating ability and therefore cannot move between stacked bags, or penetrate the bags where eggs and larvae are normally developing. Space sprays such as pyrethrins or dichlorvos have limited residual properties, which affects their ability to kill the insects not directly contacted (e.g. insects hidden in walls, floor drains and other protected areas) and commonly found in production machinery from which insect infestations can spread.

In the USA, the food additive tolerance for dichlorvos is under review, thus in the future it may not be permitted where processed or packaged food will be contacted. This effectively limits its use and its toxicity may lead to further restriction and unavailability.

5.7.2.3 Controlled atmospheres

CAs have has been used in field trials in buildings in the UK, Germany and the Netherlands. Application in most situations for control of pests requires that well sealed conditions are maintained for a long period. The technology required is commonly available but will require registration in some countries.

5.7.2.4 Heat

Heating above 50°C has been used to control insects in flour mills for almost 100 years. It is increasingly used by a number of major food processors as an important part of their pest control program (Heaps and Black 1994; Clarke 1996). Food plants that can be successfully heat treated rarely require fumigation. It is also advantageous in that there are no residues and treatments act as quickly as MB.

Although expansion of use of this technique is expected, there are some important considerations. For example, some structures cannot tolerate the stresses caused by extreme changes in temperature and differential expansion of structural components, e.g. of concrete and steel. In larger structures, the principal problem is one of achieving a uniform distribution of heat. Insects can sometimes migrate temporarily to outer walls or floor drains and successfully escape the effect of heat treatment. Some equipment must be modified or removed to avoid damage. Some greases may liquefy and must be reapplied after heat treatment. Some products cannot withstand the required temperatures and may have to be removed and treated separately to prevent the re-introduction of pests.

Three Scandinavian mills were treated with heat to control insects and the project concluded that: "…*heat treatment can be an efficient method of eradicating insect pests both in smaller, confined areas and in larger buildings and it will in many cases be a good alternative to Methyl Bromide.* (SFT 1997).

5.7.2.5 Hydrogen cyanide

Hydrogen cyanide has been used as a fumigant for almost a century and still has some uses in a few countries.

5.7.2.6 Inert dusts

Various forms of diatomaceous earths (DE) have long been used as stored product protectants with various effectiveness and product quality effects (Banks and Fields 1995; Ebeling 1971). Several DE formulations are being used to assist in controlling structural pests (Quarles and Winn 1996). Some of these are very effective at low concentrations (Korunic and Fields 1995; Fields *et al.* 1997).

Until recently, DE was not considered to be an important structural pest control treatment. Further research should be undertaken to determine the potential of inert dusts in providing residual control in cracks and crevices.

5.7.2.7 Integrated pest management

Any IPM programme for structures must begin with identification of existing and potential pests, the cause of their presence, their vulnerabilities and consideration of all practical chemical and non-chemical controls, with adequate consideration of materials present, worker safety and the environment. Some IPM strategies require constant maintenance in order to succeed. Occasional full-site or curative treatments may be required to supplement IPM programmes. These may involve fumigation, possibly with MB, or other processes.

With the above reservation, the IPM approach employing a variety of tools and techniques both chemical and non-chemical, will be the key strategy to replace the use of MB in structures. Assessment of the actual or potential pest problem will require continual inspection of the facility to determine the intensity and distribution of a pest problem. This will guide treatment schedules and determine the effectiveness of the overall strategy.

In developing an IPM plan, consideration may need to be given to building design improvements, the materials present, retrofitting of certain facilities and effects and exclusion practices aimed at reducing or eliminating infestations in incoming food and ingredients. The plan will also require implementation of good sanitation practices, with co-operation between cleaning crews, quality control officials and pest control contractors, as well as the development of a continuous inspection and monitoring programme. Pest minimisation must become the responsibility of everyone in the facility, in the same way that quality control is assured. Inherent in IPM systems is a long lead time needed to establish the full IPM structure.

It is important to identify the infested area within a facility, e.g. by using spatial analysis. A grid of traps is placed within the facility and is monitored. The trap catches are precisely plotted on a map over a set period of time. This allows the pest management professional to pin-point the infestation and target the treatment to the specified area.

Quantifying the data collected from the various traps used in facilities is a very effective method of pesticide reduction. Bar coding provides a tool to collect, decipher and report on the progress of the pest management programme. Pest activity, chemical usage, structural deficiencies, sanitation requirements and other pertinent information can be reported, reviewed and archived for comparison purposes. This information makes it much easier to determine the severity of the infestation and subsequently, the extent of the treatment.

In implementing the plan, physical and chemical controls will most likely be required. This IPM approach has proven effective for food and flour processing facilities in Australia, Canada and Denmark (Anon 1995a,b). Some have eliminated regular treatments with MB and other fumigants, while others have reported substantial reductions in their use of fumigants. The Canadian Methyl Bromide Industry Government Working Group (1998) has prepared an IPM strategy guideline for use in food processing facilities. Adoption of these practices in Canada is becoming common (McCarthy 1998; Stanbridge 1998). For further details see Section 5.4.15.

5.7.2.8 Pheromone trapping

Recent research has demonstrated that there is some potential for the use of pheromone trapping methods to eliminate insect infestation in food premises (Trematerra 1994a,b; Nickson *et al.* 1998). Identification of the area of infestation can be the first step of a control system using IPM.

5.7.2.9 Phosphine

Phosphine can be used in some structural situations. It provides good penetration and its efficacy against some pests is well researched and understood. It can cause corrosion

problems on copper, or gold and silver alloys. This is of particular concern in mills and food processing premises, where sensitive control equipment may be affected. Brigham (1998) described the conditions leading to corrosion as a basis of providing guidelines to limit this problem. The use of phosphine is generally not recommended below 15°C because it provides limited control at low temperatures. Depending on temperature and humidity, fumigation with phosphine may take five or more days for full effectiveness, in contrast with one day for MB (see Section 5.3.2).

New formulations of phosphine and phosphine used in combination with other gases and treatments as discussed in section 5.4.19, may reduce some of these problems.

5.7.2.10 Sulphuryl fluoride

Sulphuryl fluoride can be a substitute for MB in countries where it is available and registered. At the present time, sulphuryl fluoride is only registered or licensed for use in the United States, China, Germany, Japan, Sweden and the Caribbean (see Section 5.4.20). It is not registered for use where food and grain commodities are present because food residue tolerances have not been established. The American manufacturer (Dow AgroSciences, communication to MBTOC) has recently decided to pursue further work for empty food processing facilities.

5.7.2.11 Treatment combinations

The most significant advantage of using combinations is the reduced amount of fumigant required for effective treatment. These procedures have the potential to reduce the risk of human and environmental exposure and reduce treatment time.

Phosphine (0.09 - 0.14 gm^{-3}) combined with heat at 32 - 37°C and carbon dioxide (4 - 6%) is claimed to provide good penetration and a rapid treatment time, similar to that for MB (Mueller 1996). This combination is currently being used in the USA and Canada in full-scale trials. Tests to date show it to be efficient against the main mill pests, but further data are required to measure efficacy under a wider range of conditions and against a full range of mill pests. Registration requirements and additional insurance requirements in some countries will affect commercial uptake. Recent work in Canada has demonstrated the efficacy of this process in Canadian conditions (Anon 1996).

Recently, the effectiveness of diatomaceous earth (DE) in combination with heat, has been proven in controlling structural pests in Canada (Fields *et al.* 1997). In a commercial field trial, dry application of Protect-It™, an enhanced DE, gave 100% mortality of the confused flour beetle adults after 13-22 hours and 41°C compared to untreated insects that required 32-38 hours at 46-47°C (Fields *et al.* 1997). The results of this field trial are now in commercial application in a Canadian flour mill with good results (Bergen 1997).

Additional data are needed on efficacy and the advantages and limitations of these techniques better defined in other countries (Bell 1997). See Section 5.4.19 for further information on phosphine.

5.7.3 Alternatives for transport

Treatment regimes for transport are often subject to stringent time constraints. Times out of service for aircraft and ships can incur severe consequences for operators. Thus alternatives for MB fumigation need to provide a means for a rapid solution to problems. MB is currently used for ship fumigation usually as a last resort, for the disinfestation or deratting of empty ships.

MB is currently the only fumigant allowed for many quarantine treatments on ships in many countries, but is no longer allowed for in-transit fumigation in ship holds (IMO 1996). Cargo may be treated after loading and prior to sailing, either with ventilation before sailing or during the voyage.

The alternatives currently available are: HCN, used against rodents in Singapore and France; phosphine, used against both insects and rodents elsewhere; and rodenticides and traps. HCN could be used in empty vessels alone where there is no water in the bilges. HCN has some advantages in controlling rats because it rapidly kills them and their ectoparasites, principally fleas. Availability of HCN may be limited by its extreme acute toxicity and regulations on its transportation and handling.

Phosphine may be suitable as an alternative to MB for treatment of empty ships and barges for rodent and insect control prior to loading commodity. Some developing countries currently use MB for this purpose. While phosphine is rapidly lethal to rodents, its slow action against insect pests and consequent demurrage costs may limit its usefulness. Where ships contain cargo and where regulations permit, in-transit fumigation with phosphine or modified atmosphere treatments may be feasible.

Rodenticides and traps could be used more widely if maintained carefully and consistently, or where the infestation is low and time is not a constraint. This approach is recommended in a recent report to the Nordic Council of Ministers (Kristensen 1997).

5.7.3.1 Aircraft

Currently, MB is sometimes used to fumigate aircraft, usually for rodent control, but occasionally against insects. For insect control, residual or aerosol insecticide applications are usually used. MB provides a rapid and guaranteed kill which is essential in the context of the cost of grounding aircraft and the risks to the aircraft if the rodents are not killed.

Hydrogen cyanide is used for rodent control in France, but not against insects. Phosphine is not recommended because of the corrosion risk.

CAs have been shown to be promising for rodent control, but require research.

5.7.3.2 Freight containers

Fumigation of freight containers can be carried out either before (pre-shipment) or after transport (post-shipment). MB is not allowed for in-transit fumigation under the current International Maritime Organisation recommendations (IMO 1996). All containers under fumigation are classified as 'Dangerous Goods' under the International Maritime

Organisation Dangerous Goods Code, the provisions of which allow phosphine fumigation in transit, which may replace some pre and post shipment fumigations with MB. Sulphuryl fluoride is also permitted for containers when locally available.

Methods for treating containerised cargo in transit with CO_2 have been described (Banks 1988). This is in use as an alternative to MB before shipment for some exports from Australia.

5.7.3.3 Other vehicles

Vehicles such as catering trucks or railway coaches are sometimes fumigated with MB for general pest control purposes. Commercial vehicles and railway cars may require treatment to meet quarantine legislation when empty and prior to loading. In some countries MB treatment is currently mandatory.

Phosphine could be an alternative treatment to MB. Nitrogen-based CA treatments are being considered for quarantine rodent control between Barrow Island and mainland Australia for treatment of trucks and containers.

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Annex 5.1 Case History 1 : Rice irradiation in Indonesia

1. **Commodity:** Rice

2. **Pest:** *Sitophilus oryzae*

3. **History:**

The Indonesian government, through its National Logistics Agency, BULOG, protects its general populace and its rice farmers against the effects of drought, floods and other natural disasters. Since an average Indonesian consumes 149 kg of raw rice per annum, BULOG buys locally produced rice to maintain the stability of rice prices and to control the market through storage of the rice for later sale and distribution.

The quantity of rice stored, upwards of 2.0 million tonnes, is also sufficient to help ensure food security in an emergency. The rice is stored in 50 kg bags (6 - 9 mil polyethylene - polyester co-polymer, sewn shut). The bags are stacked seven meters high in large storage sheds. Currently the Indonesian government uses several methods to disinfest the rice: fumigation with MB, phosphine and CA (CO_2). With concerns about the use of chemical fumigants and cost difficulties with CA, the government indicated an interest in developing another treatment.

4. **Description of the alternative:**

Pt. Perkasa SteriGenics, a joint Indonesian and American commercial venture, operates a commercial contract irradiator in Jakarta. The facility is a modified tote/carrier - product overlap irradiator, suitable for the irradiation of a wide variety of products. A commercial efficacy test irradiation of 50 kg bags irradiated at 0.40 kGy minimum dose was conducted in 1993 and the rice was evaluated over several months for quality, the presence of weevils and other pests.

5. **Regulatory agency acceptance:**

The irradiation of rice has been well researched and approved by the Codex Alimentarius and many other food regulatory agencies worldwide. Following the successful completion of the rice irradiation studies in Indonesia and demonstration of the scale up logistics required to commercially irradiate rice, the project was approved by the Chairman of BULOG on a limited basis.

6. **Current commercial use:**

Commercial rice irradiation will begin in August, 1994 with 3 - 5,000 tonnes per month with the figure increasing after the 1994 harvest to 8 - 10,000 tonnes per month. Irradiation is carried out by Pt. Perkasa SteriGenics under contract to BULOG with rice storage in BULOG facilities.

7. **Was the treatment difficult to develop?**

Although weevils are more difficult to kill than some other pests, the dose delivered (0.40 kGy minimum) resulted in complete control of the pest at all life stages. While there was concern that the packaging material used may allow for re-infestation, it performed reasonably well in tests.

8. **Was the treatment difficult to implement?**

Yes. Processing substantial commercial amounts of packaged rice required sophisticated synchronisation of multiple disciplines and departments within BULOG with Pt. Perkasa Sterigenics. The success of the packaging system will continue to be evaluated and amended as required. As the projected volumes increase, the fine tuning of shipping/delivery schedules will determine the success of the facility to meet the total needs of BULOG.

9. **Is the effect of this treatment on other crops being determined?**

The Indonesian government through their radiation research organisation, Centre for the Application of Isotopes and Radiation, BATAN, conducts research to assess the effect of irradiation on a wide variety of products. Currently the irradiation of mangoes, strawberries and frozen shellfish are under review.

Annex 5.2 Case History 2 : Development of integrated pest management manual for Canadian food processing facilities

1. **Commodity:** Food Processing Facilities

2. **Pest:** Stored grain pests

3. **History:**

The Canadian Methyl Bromide Industry Government Working Group, a consultative forum, was set up to provide direction on effective implementation of Canada's programme for the control of MB. In Canada, progress has been made using demonstration projects, research trials and joint initiatives with other countries.

In late 1996, representatives of the food processing sector indicated a need to further develop alternatives to MB specific to that sector. In response, the Methyl Bromide Industry Government Working Group set up a sub-committee to identify and help implement alternatives for the food processing sector, with a focus on an integrated pest management (IPM) approach. The Subcommittee included members from the Canadian Pasta Manufacturers' Association, the Food and Consumer Products Manufacturers of Canada, the Canadian Spice Association, the Canadian National Millers Association, the Canadian Pest Control Association, Agriculture and Agri-food Canada, Environment Canada and Industry Canada, as well as suppliers of pest control products. The Pest Management Regulatory Agency provided chair and secretariat functions.

4. **Description of the alternative:**

IPM is a process for planning and managing sites to prevent pest problems and for making decisions about when and how to intervene when pest problems do occur. It is a sustainable approach, combining biological, cultural, physical and chemical tools to manage pests so that the benefits of pest control are maximised and the health and environmental risks are minimised.

5. **Regulatory agency acceptance:**

The approach taken was built upon a series of successful projects conducted by the Pest Management Regulatory Agency, in partnership with stakeholders, to develop IPM approaches for various crops. The key to these projects has been the involvement and partnership with user groups to ensure that recommendations are practical and implementable. In the case of the Food Processing IPM project, research scientists and pest control applicators and suppliers provided up to date information on available techniques.

6. **Current commercial use:**

The Sub-committee has prepared a document and brochure that provides a guideline of practices to facilitate the use of IPM in food processing facilities. The documents were developed by the Sub-committee and benefitted from review and comment by a wider audience of companies, associations and government officials involved in food processing and pest control.

7. **Was the treatment difficult to develop?**

Yes. The documents outline the steps in IPM for food processing including assessment; development of pest management plan; plan implementation; evaluation of plan; adjustments) and briefly describe the elements of a pest management plan (building and materials design and retrofitting; exclusion practices; good sanitation practices; building maintenance; inspections and monitoring; pest identification; physical and chemical controls.

8. **Reference and further reading:**

Integrated Pest Management in Food Processing: Working Without Methyl Bromide was published in October, 1998. Copies of the document are available on the web at http://www.hc-sc.gc.ca/pmra-arla/ or from the Publications Co-ordinator, Pest Management Regulatory Agency, 2250 Riverside Drive, A.L. 6606D1, Ottawa, Ontario K1A 0K9. A summary of the project and some examples of 'Success Stories' were published in *Pest Management News* (Vol. 10, No. 1, Spring 1988: Integrated Pest Management (IPM) for the food processing sector).

Annex 5.3 Estimates of the minimum *ct*-product (ghm^{-3}) of methyl bromide for a 99.9 per cent kill of various stages of a number of insect species

Table 5.16 Estimates of the minimum *ct*-product (ghm^{-3}) of methyl bromide for a 99.9 per cent kill of various stages of a number of insect species at 10, 15, 25 and 30°C and 70% RH. (Heseltine and Thompson 1974)

Species	Stage	Temperature (°C)			
		10	15	25	30
Callosobruchus chinensis	pre-adult stages	175	85	40	-
Cryptolestes minutus	cocoons	170	145	125	-
Ephestia cautella	pupae	-	70	55	-
Ephestia elutella	diapausing larvae	360	360	205	180
Ephestia kuehniella	pupae	-	75	60	-
Lasioderma serricorne	cocoons	-	180	100	-
Oryzaephilus surinamensis	adults	85	85	50	40
Plodia interpunctella	diapausing larvae	300	250	105	-
Ptinus tectus	cocoons	170	155	100	-
Ptinus tectus	adults	155	125	85	-
Rhyzopertha dominica	early pre-adult stages	-	40	40	-
Rhyzopertha dominica	later pre-adult stages	-	75	45	-
Rhyzopertha dominica	adults	80	65	40	-
Sitophilus granarius	early pre-adult stages	115	75	50	50
Sitophilus granarius	later pre-adult stages	200	115	65	65
Sitophilus granarius	adults	55	55	35	-
Sitophilus oryzae	pre-adult stages	-	105	85	-
Sitophilus oryzae	adults	50	30	30	15
Tribolium castaneum	pupae	-	-	125	100
Tribolium castaneum	adults	125	80	60	50
Tribolium confusum	pupae	230	180	90	-
Tribolium confusum	adults	115	85	60	45
Trogoderma granarium	larvae	290	190	110	70

(A dash in the table indicates that no test was carried out).

Annex 5.4 Minimum exposure periods (days) required for control of all stages of the stored product pests listed, based on a phosphine concentration of 1.0 gm^{-3}

Table 5.17 Minimum exposure periods (days) required for control of all stages of the stored product pests listed, based on a phosphine concentration of 1.0 gm^{-3}. This dosage is as recommended for good conditions and the dosage applied will usually need to be increased considerably in leaky situations (EPPO 1984)

Species	Common names	Temperature (°C)	
		10 - 20	20 - 30*
Oryzaephilus surinamensis	Saw-toothed grain beetle	3	3
Cryptolestes pusillus	Flat grain beetle	5	4
Oryzaephilus mercator	Merchant grain beetle		
Tribolium castaneum	Rust-red flour beetle		
Lasioderma serricorne	Cigarette beetle	5	5
Acanthoscelides obtectus	Dried bean beetle	8	5
Corcyra cephalonica	Rice moth		
Cryptolestes ferrugineus	Rust-red grain beetle		
Plodia interpunctella	Indian-meal moth		
Ptinus tectus	Australian spider beetle		
Rhyzopertha dominica	Lesser grain borer		
Sitotroga cerealella	Angoumois grain moth		
Tribolium confusum	Confused flour beetle		
Ephestia cautella	Tropical warehouse moth	10	5
Ephestia elutella	Warehouse moth		
Ephestia kuehniella	Mediterranean flour moth		
Caryedon serratus	Groundnut borer	10	8
Sitophilus granarius	Grain/granary weevil	16	8
Sitophilus oryzae	Rice weevil		
Sitophilus zeamais	Maize weevil		
Trogoderma granarium	Khapra beetle		

* All species listed succumb to a 4-day exposure at this dosage level at 30°C or above.

For certain commodities in long-term storage where it is necessary to control a mite infestation two fumigations may be carried out separately by an interval dependent on ambient temperature, allowing eggs surviving the first fumigation to hatch. This interval varies from 2 weeks at 20°C to 6 weeks at 10°C (Bowley and Bell 1981).

Annex 5.5 Methyl bromide dosage table

Table 5.18 Methyl bromide dosage table. European Plant Protection Organization (1993)

Group	Commodities	Dosage (gm^{-3}) <10°C	10-20°C	>20°C	Exposure period (h)
1	Rice, peas, beans, cocoa beans, dried vine fruits	25	15	10	24
2	Wheat, barley, oats, maize, lentils	50	35	25	24
3	Pollards, rice bran	70	45	30	48
4a	Sorghum, nuts, figs	75	50	35	24
4b	Groundnuts, oilseeds, dates, empty sacks	75	50	35	48
5	Oilseeds, cakes and meals	120	85	60	48
6	Fishmeal, dried blood etc.	140	100	65	48
7	Flour	50	50	40	48

Notes:

1. These dosage rates apply to fumigations under gas-proof sheets and in freight containers which are usually fully loaded. If this method is to be used for mites, dosage rates should be doubled accordingly.
2. Penetration of MB into commodities in Groups 5 and 6 is poor and fumigation may be uneconomic using the recommended dosage rates. In such cases the use of phosphine should be considered and this is the preferred fumigant for Group 7 (flour).
3. To reduce the possibility of taint the dose for flour should never exceed 50 gm^{-3}.
4. Diapausing larvae of *Trogoderma granarium* (khapra beetle) and *Ephestia elutella* (warehouse moth) are highly tolerant of MB. In this case, these dosages should be increased by one half and, where applicable, exposure periods increased to 48 h in order to achieve the requisite *ct*-products.

Chapter 6

Alternatives to methyl bromide for perishable commodities

6.1 Summary

Perishable commodities include fresh fruit and vegetables, cut flowers, ornamental plants, fresh root crops and bulbs. Perishable exports are an important source of revenue for many countries and are required to be free of quarantine pests or diseases. Methyl bromide (MB) used for quarantine treatments is currently exempt from control under the Montreal Protocol.

If one or more pests are detected, MB fumigation is by far the most predominant treatment to meet importing country phytosanitary requirements. Mandatory treatments in the exporting country may be required if pests are difficult to detect or if the pest is of extreme concern to the importing country. Quarantine pests detected in a country or region previously free of them can result in considerable cost caused by suspension of exports, eradication measures and implementation of a disinfestation treatment if eradication is not achievable.

About 9% of MB global consumption is used for disinfestation of perishable commodities, with about half used for disinfestation of fruit for quarantine purposes. Although global consumption for disinfestation is relatively low in volume, this amount of MB is nevertheless very significant as, in the absence of site-specific alternatives, it allows import and export of high-value perishable commodities. One of the major uses of MB in this category is to disinfest consignments intercepted on arrival with pests deemed unacceptable to the importing country. These disinfestation treatments are crucial for minimising the risk of plant pests becoming established in new regions. In addition, a minor quantity of MB is used to prevent the spread of exotic pests domestically.

There are at least thirteen different categories of alternative treatments e.g. heat, cold, irradiation, that are approved by regulatory agencies in one or more countries for disinfestation of perishable commodities, but only for very specific applications. Only a small proportion of commodities in commercial trade are treated in the export country using these alternatives as most countries have specific requirements for proving the efficacy for each commodity-pest combination. Post-entry alternative treatments used by the importing country are particularly problematical because many alternatives have neither been approved for treating a specific product on arrival, nor would they be easy to implement. To solve this problem, a range of alternatives are urgently needed to cope with a large and highly varied

volume of produce entering via multiple air and sea ports. Such treatments would need to be able to treat perishable commodities quickly in order to avoid congestion at busy ports.

In the future if MB for quarantine treatments is not permitted and if no alternatives to MB are available to disinfest consignments intercepted with pests of quarantine concern, infested consignments may be prohibited until satisfactory on-arrival treatments are developed and approved, or the consignments may be re-shipped or destroyed. Alternatively, import of consignments considered high risk for pest infestation may be prohibited until an alternative treatment has been implemented in the exporting country to reduce pest contamination to a level acceptable to the importing country.

Alternatives to MB for perishable commodities include those based on: (1) pre-harvest practices and inspection procedures; (2) non-chemical treatments; and (3) chemical treatments.

Those based on pre-harvest practices include: a description of cultural techniques leading to pest reduction; agreement on pest-free zones; and inspection certification. In these cases, regulatory approval depends on a number of factors including: knowledge of the pest-host biology; evidence of commodity resistance to the pest; trapping and field treatment results; surveillance for pests and diseases; and careful documentation.

Non-chemical treatments kill pests by exposure to changes in temperature and/or atmospheric conditions, or high energy processes such as irradiation and microwaves, or physical removal using air or water jets. Often a combination of treatments is required to kill pests because they can be tolerant to treatments applied singularly. A greater understanding of the physiological changes occurring in both pests and commodities will be essential to expedite the development of disinfestation treatments based on these non-chemical alternatives.

Chemical fumigation treatments are feasible, but the number of chemicals is limited at present mainly because companies are reluctant to make submissions for registration, due to the high costs of demonstrating compliance with health and safety standards. However, for cut-flower exports without alternatives to MB, chemical dips can be a practical and efficacious method to control pests, particularly if occupational standards for their safe use and disposal are implemented and the treatment is approved by the importing country.

For each category of alternative to MB, MBTOC noted country-specific regulatory agency approval for specific commodities or several commodities within a class (e.g. citrus): *heat* treatments for at least eleven commodities including citrus, mango, papaya, bell pepper, eggplant, pineapple, squash, tomato and zucchini; *chemical* treatments for citrus, vegetables, cut flowers and bulbs; *cold* treatments for apples, pears, citrus, grapes, kiwifruit, carambola and avocado; *pest-free zones* for apples, berryfruit, some vegetables, cucurbits, avocado and papaya; the *systems approach* for citrus, apples and melons; and *irradiation* for papaya, litchi and carambola. Currently, there are no approved alternatives for economically important exports such as apple, pear and stonefruit hosts to codling moth; for berryfruit; for grapes infested with, for example mites, exported to some countries; and many root crops exported by countries if soil is present or pests of concern are detected on arrival.

MBTOC identified where alternative research was possible within each category. Commercialisation of any of these treatments as replacements for MB will depend on a number of factors that include: proven treatment efficacy; commodity tolerance; equipment design and commercial availability; cost competitiveness; regulatory approval; logistical capability; availability and agreement on the scientific research required for regulatory approval; and technology transfer. Given all of these considerations, the time from conception to implementation of an alternative disinfestation treatment for perishable commodities can vary from 2 to 15 years.

6.2 Introduction

Perishable commodities include fresh fruit and vegetables, cut flowers, ornamental plants, fresh root crops and bulbs. The majority of these commodities decay quickly when not stored under conditions such as cool storage to extend their shelf-life. Marketability is therefore enhanced by minimising the period between harvest and consumption.

6.2.1 Treatment on arrival

For those countries that export some or most of their production, perishable commodities can be a significant source of external revenue. Pesticides are typically applied to produce commodities for export free of insect damage. As a consequence of pesticide application, most commodities are substantially free of pest contamination when presented for export. However, the detection of a single pest in a consignment can result in a disinfestation treatment being ordered by quarantine authorities. Any disinfestation treatment applied will have been officially approved by the regulatory agency operating in each country for the commodity-pest combination, based on extensive scientific data generated to ensure a very high level of confidence in treatment efficacy.

Once accidentally imported, many insect pests can have high reproduction rates if temperature and host availability are favourable. Because climate exerts such a profound influence on the distribution and abundance of insects, quantification of climate influences is of considerable interest to quarantine scientists for assessment of potential establishment and spread of exotic pests (for more detail, refer Worner 1994). In addition, many insects have short generation cycles, for example, the Oriental fruit fly produces 3-18 generations per year depending on temperature (Paull and Armstrong 1994).

It is natural for insects to be closely associated with commodities such as fruit which as maturity advances advertise their readiness for consumption (and seed distribution) by releasing volatile chemicals attractive to insects (Greany 1994). This association can result in insects being included in the final export package, even after the commodity is graded and

checked. Their small size relative to the commodity and ability to have life stages hidden inside the commodity, make them difficult to detect by quarantine inspectors.

As history shows, insects have become very adept at moving into new ecological niches, adapting to new conditions, multiplying rapidly and even expanding their host range. The costs of *accidentally* importing a pest can result in a significant loss of trade if the insect is a quarantine pest and exports are based on area or country freedom. Exotic pests can result in additional pest control or eradication costs totalling from US$5m to more than US$100m over successive years.

For these reasons, a large number of exotic pests are of concern to quarantine authorities in importing countries. Importing countries often require a mandatory disinfestation treatment prior to export for several of the most important pest species. This is called country of origin treatment. On the other hand, most commodities are shipped subject to inspection on arrival. If live pests are detected by official inspection on arrival most importing countries require an immediate disinfestation treatment on entry, or the commodity is ordered to be re-shipped or destroyed. Treatments on entry are considered essential to prevent the introduction of exotic pests. The frequency of treatments on entry far exceeds the frequency of Country of Origin treatments.

6.2.2 Country of origin treatments

In the overwhelming majority of cases, disinfestation in the country of origin or on arrival has relied on MB. For the past 40 years and until the early 1990 s, there has been little need to consider alternatives to MB for these uses. During this period, however, many disinfestation treatments were developed but none of them have been found suitable for ship-side treatment of a large range of commodities. Ideally, alternatives that replace MB for on entry applications should be of short duration and capable of being carried out on-site. On entry treatment remains one of the most important areas where substitution of MB will be difficult.

6.2.3 Quarantine and pre-shipment

In recognition that there are few alternatives available to MB for ship-side or Country of Origin disinfestation and that trade would be disrupted if MB were not permitted, the Montreal Protocol has exempted Quarantine and Pre-shipment (QPS) from control. That is, under the current control scenario, when MB is phased out in developed countries under the Protocol by 2005 and in developing countries by 2015, QPS uses of MB will still be permitted after this phase-out date. Further detail on QPS, the likely impact on consumption of MB and the implications of the current controls for countries are provided in Chapter 8.

The volume of MB used for QPS treatments of perishables is estimated to be about 9% of total global consumption (MBTOC 1994; TEAP 1995; TEAP 1997). Most MB fumigations are carried out in fixed structures such as fumigation facilities or shipping containers, generally for about 3-4 hours including aeration. About 90% of the MB is released to the atmosphere from these fumigations as, in contrast to durable commodities such as wheat and rice, perishable commodities absorb less than 15% of the MB used in a fumigation

treatment. Large-scale equipment exists to capture and re-use MB released from perishable commodities (refer Chapter 9) but to date none have been approved for commercial application.

6.2.4 Development of alternatives to MB

Treatments for perishable commodities are generally time-consuming as they must demonstrate treatment efficacy against pests to rigorous standards demanded by quarantine authorities (see section 6.7). Few alternative treatments have been developed for commercial use. They are more pest and commodity specific than MB and none have all the attributes of the ideal disinfestation treatment. Alternative treatments may require modification to adapt them to effectively control pests without damaging the commodity. Modification of post-harvest handling and packing may be required. Alternative quarantine treatments typically require 3-7 years for adaptation under non-urgent conditions in order to complete the technical requirements. Possibly 10 or more years are needed under non-urgent conditions if an entirely new quarantine treatment is to be developed.

This period could be longer if specialised equipment must be designed and built before research can commence. Neven (1994) and Petry and McDonald (1995) reported on the construction of experimental equipment capable of delivering heated, controlled atmospheres (CAs) uniformly distributed throughout a chamber. This equipment was constructed to test the insecticidal nature of heated CA treatments on codling moth in apples and cherries and their impact on fruit quality. Sometimes development of a quarantine treatment depends firstly on developing a system to rear the test species as year-round supply of sufficient pest numbers may be required (Carpenter *et al.* 1995).

There is often very little treatment differential between killing the pest and not damaging the commodity. The development of deleterious responses by plant tissues is influenced by a number of factors including the treatment duration, the type of treatment, its concentration, its physical range (moderate versus high temperature) pre-harvest handling, post-harvest treatments and the innate resistance of the commodity. In general, low temperatures less than 10-12°C for tropical commodities and less than 7°C for subtropical commodities cannot be used for disinfestation treatments (Paull and McDonald 1994). To make treatment development and implementation even more difficult, commodities often vary in response from variety to variety and there may even be seasonal differences in response within a variety (Houck and Jenner 1997). Therefore, in order to minimise any detrimental effects on the quality and market life of perishable commodities, treatments implemented commercially are typically of short duration. The physiological responses of horticultural produce to a range of physical insect disinfestation treatments including irradiation, heat, cold, controlled atmospheres, reduced pressure and washing has been reviewed by Paull (1994).

Quarantine authorities may also have a policy of requiring new treatments to be tested prior to approval even if the treatment is in current use in another country. This ensures that no assumptions have been made on the effects of the treatment on pest efficacy and commodity quality as for example, pest and commodity responses to the treatment may vary between regions and countries.

6.2.5 Alternatives development

Despite the constraints discussed above, there are several reasons for continued and strong interest in the development of alternatives to MB for disinfestation of perishable commodities:

- Some countries propose to ban MB earlier than the phase out date scheduled under the Protocol. This will accelerate the need for alternative treatments for QPS if this use is not exempt under individual country legislation.
- All quarantine authorities are charged with protecting their own agriculture through exclusion of exotic pests and therefore agricultural protection is focused on monitoring imported produce for pest and disease. If an alternative treatment is not available, smuggling of commodities could increase which, as the commodities are not being checked when entering the country, increases the risk of exotic pests entering commercial agricultural production.
- MB treatment can be damaging, often to a specific variety e.g, Ohrin apples and not to another variety e.g. Gala apples, when used under identical treatment conditions and equivalent apple maturity. There is therefore interest in developing treatments that are less detrimental on the quality and/or shelf-life of commodities than MB.
- Most countries are investing in research on chemical and non-chemical alternatives to MB to avoid dependency on an ozone-depleting chemical that may not always qualify for exemption under the Montreal Protocol.

Discussed in this Chapter are examples of disinfestation treatments reported in the 1994 Assessment (MBTOC 1995), examples of those that have been investigated and commercialised since the last Assessment and those with potential for implementation within the next 2-5 years. While most examples are new treatments rather than replacements for existing MB treatments, they serve to illustrate the investment in a range of commercial options that will avoid further dependency on MB.

There are a number of relevant references that provide a useful overview. Cox (1997) provides a general overview of post-harvest treatments with particular reference to their effect on consumer acceptability. Johnson and Heather (1994) provide a review of post-harvest disease and pest control in tropical fruit, including a useful outline of the steps required for approval by quarantine agencies when developing treatments based on chemical and non-chemical methods. Hallman and Quinlan (1996) summarise the key issues and challenges facing post-harvest quarantine treatment research. Aluja (1996) argued that integration of alternative biorational fruit fly management strategies will result in better management of fruit flies than alternatives that rely on just one or two strategies.

6.3 Alternatives to Methyl Bromide

This section describes eleven categories (e.g. heat, cold) of existing or potential alternatives to MB for meeting quarantine security.

Although this section lists a large number of potential alternative treatments, the potential for success of each treatment depends on the physiological responses of the commodity and the pests associated with each commodity. With this in mind, for each commodity grouping there are relatively few alternatives currently in use because each is developed to control one or more pests on a specific commodity, although with further research a number of potential alternatives will be developed and implemented.

6.4 Pre-harvest Practices and Inspection Procedures

The presence of pests *post-harvest* indicates insufficient *pre-harvest* control to comply with strict phytosanitary standards and therefore considerable attention needs to be paid to controlling them before harvest. Inspection can be carried out to determine the effectiveness of the pre-harvest treatments and if through sampling a proportion of the packed consignment the pest incidence is determined to be nil or very low, the product may be exported without a post-harvest treatment. However, field control of a pest has rarely provided quarantine security. As a general rule, 90% of the pesticide applied does not hit the target pests (Luckmann and Metcalf 1982). This results in field levels of control rarely exceeding 90% pest mortality which is an insufficient level of control for the present concept of greater than 99.9% mortality for quarantine security (Baker 1939; Couey and Chew 1986).

Historically, the mutual acceptance of a new QPS protocol by trading partners has taken 2-15 years because of extensive data requirements to Probit 9 security level (equivalent to 99.9968% mortality) demonstrating minimal risk of accidentally importing a quarantine pest. The USA is considering accepting a new approach to replace Probit 9. This would involve a sliding scale based on pest risk combined with packing, distribution and inspection activities to mitigate against pest infestation of the commodity (Anon 1997). Reducing the treatment acceptance criterion while still maintaining quarantine security increases the opportunity for researchers to identify treatments less harmful to the commodity as alternatives to MB.

6.4.1 Cultural practices leading to pest reduction

The Systems Approach is the implementation of multiple safeguard actions in the country of export that result in a commodity meeting the phytosanitary standards of the importing country (Shannon 1994). These actions have a scientifically derived basis and can be quantified at key points in the production-to-export system (hence the term Systems Approach). The Systems Approach to achieving quarantine security is described in detail by Jang and Moffitt (1994).

The Systems Approach includes the following steps: (1) consistent and effective management for reducing pest populations in the field and monitoring this management; (2) prevention of contamination after harvest; (3) culling in the packhouse; (4) inspection and certification of the critical parts of the system based on effective trace-back procedures; and (5) shipping using methods that prevent re-infestation. The Systems Approach is highly dependent on a knowledge of the pest-host biology and phenology. Using pest risk analyses, the probability of accidentally exporting the pest is often shown to be minimal and in some cases exceeds the level of quarantine security achieved by fumigation alone (Moffitt 1990). Provided there is no pest breeding in storage, the Systems Approach can achieve or exceed the level of quarantine security acceptable to an importing country and in some situations, without any further actions

needed (Vail *et al.* 1993). Whiting (1995) proposed integrating pre- and post-harvest pest control practices to reduce the incidence and viability of quarantine pests on export commodities. To date, there are very few approvals by a quarantine authority for using the systems approach as a disinfestation treatment.

Reduction in insect populations can be achieved by cultural practices such as: planting commodities that are no longer the preferred host of the insect (host plant resistance); harvesting when the commodity is not susceptible to attack (e.g. papaya which is harvested immature and ripened later); harvesting when the pest is not active (e.g. diapausing or over-wintering stage of the pest); improved harvesting practices that remove 'hitchhiker pests' in the field or orchard; the addition of biological agents such as parasitoids and predators; releasing sterile insects; using pheromones; using microbial agents as pest pathogens; or in some Asian countries by wrapping commodities such as pears, apples and peaches on the tree with pesticide-impregnated paper. However, in some cases the presence of biological and microbial agents on the commodity after harvest may cause quarantine concern.

Commodity resistance to pest attack has allowed many commodities to enter trade without the need for a quarantine treatment. Drawing on mainly tropical commodities as examples, commodity resistance based on known susceptibility to pests, cultivar variability, stage of maturity and growing periods has been summarised by Armstrong (1994a).

Some commodities are naturally resistant to the pest. For example, Hennessey *et al.* (1992) found no Caribbean fruit fly (CFF) infestations in more than 100,000 Tahiti limes collected and examined from 184 groves in Florida over 60 harvest dates, effectively presenting a case for no disinfestation treatment required for this pest/commodity. Grapefruit also increase their oil content in the skin which results in resistance to CFF attack. This oil increase is correlated with a colour change which, in the future, may allow skin colour to be used as an indicator of shipments free of this pest (Greany 1994).

Commercially there are few examples of the Systems Approach used for quarantine. Japan has accepted a Systems Approach for citrus exported from Florida (Anon 1990a). Brazil has accepted a Systems Approach for apples exported from the United States (J. Thaw, USDA-APHIS, pers. comm. 1997).

Avocados exported from Mexico to 19 Northeastern states in the USA are certified free of avocado seed weevil, avocado seed moth, avocado stem weevil, fruit fly and other hitchhikers based on field surveys, trapping and field treatments, field sanitation, host resistance, post-harvest safeguards (e.g. tarpaulins on trucks, screened packhouses) packhouse inspection and fruit cutting, winter shipping only and port of arrival inspection (Firko 1995; Miller *et al.* 1995).

The systems approach for control of major quarantine pests often exceeds the security level required by some countries and could become more prevalent as a substitute for MB in the future. To date, inter-governmental agreements on accepting the Systems Approach as a disinfestation treatment are rare because the pre- and post-harvest measures are time-consuming to establish and document and difficult to regulate. However, both exporting and importing countries need to be involved in the development of mutually-agreed measures

required for phytosanitary security if this methodology is to gain greater acceptance internationally.

6.4.2 Pest-free zones and periods

A pest-free zone is the establishment of a certified area where a regulated quarantine pest does not exist, even though it may be established in another area within the same country (Shannon 1994). Based on survey technology and data that confirm the area is free of the organism of concern, the exporting country establishes formal, specific regulatory measures to protect the area and an ongoing surveillance system that ensures early detection of any infestations in the area. These systems are dependent on scientific information, judgements about organisms behaviour and survey technologies and methods.

Pest-free zones have been established by many countries and consist of geographic areas where commodities may be produced and exported because of the absence of pests of quarantine importance. For example, Japan accepts: melons from the Hsingchang Uighur Autonomous Region in China based on this area being a melon fly free zone (Anon 1988a); capsicum, egg plant and tomatoes produced in Tasmania (Australia) as free from Tobacco Blue Mold *Peronospora tabacina* (Anon 1996a) Mediterranean fruit fly (Medfly, *C. capitata*) and Queensland fruit fly (*Bactrocera tryoni*) (Anon 1989a); strawberry, cucumber, pepper, tomato, egg plant, grapes, squash and melon from the Netherlands as free of Mediterranean fruit fly (Anon 1993a); and grapes, kiwifruit and other produce from southern Chile as free from Mediterranean fruit fly (Anon 1996b). In the future, it may also be possible to establish pest-free periods provided quarantine authorities can be assured of times during the growing season when it is not possible for the pest to infest the commodity. Further examples of pest-free zones are provided by Riherd *et al.* (1994).

An advantage of the Pest-free Zone is that no treatment need be applied post-harvest and therefore marketability of the commodity is not reduced which is sometimes the case when a disinfestation treatment is applied. However, these zones are often restricted to geographically isolated areas with buffer zones that exclude host plants and residential areas where possible, require continuous enforcement, monitoring and reporting, are based on extensive knowledge of the pest and commodity biology and are generally expensive because of all these factors.

6.4.3 Inspection and certification

Some countries inspect a sample of the produce prior to export (termed pre-shipment inspection) and certify each consignment based on levels of acceptability for pests of quarantine importance. For example, Japanese quarantine officials inspect cut flowers in the Netherlands and Colombia which reduces the need for inspection and disinfestation on arrival in Japan. However, this usually does not preclude further inspection on arrival. Some commodities are accepted only after inspection of the packed commodity and endorsement of the procedures used by the importing country to kill any live pests (e.g. Japan, United States, New Zealand) or that live pests are within permissible limits (e.g. New Zealand) (Baker *et al.* 1990).

Inspection is environmentally acceptable but labour intensive. The costs of inspection are typically borne by growers and packers in the exporting country for pre-shipment certification and by the government from the importing country for inspection on arrival. These costs may

be reduced in the future using automatic inspection systems under development such as low-dose X-rays to see pests, or detection systems to smell pests when they release pest-specific chemicals.

6.5 Non-chemical Post-harvest Treatments

Non-chemical alternative treatments to MB are generally environmentally sound and leave commodities free of chemical residues. However, compared with MB fumigation, they require more technical expertise in their development, implementation and operation in order to kill pests without damaging the commodity.

Those treatments used commercially, or with potential for commercial use in the near future, are discussed first. Few have been accepted for quarantine use. Only heat and cold treatments for fruit fly control on papaya, mango and citrus have been commercialised to date and extensive research is needed in most cases to commercialise other non-chemical treatments.

6.5.1 Cold

Cold storage can be used as a quarantine treatment to ship perishable commodities to areas where the fruit would otherwise not be permitted. It is most useful as a treatment when it is used as part of the normal handling, distribution and marketing procedures. Cold treatments cannot be applied to commodities that exhibit cold injury, a physiological disorder that affects many tropical commodities.

Cold treatment is generally applied to fruit potentially infested with tropical pests which have relatively little tolerance to cold conditions compared to temperate pests. The temperature range acceptable for the use of cold treatment is typically very narrow and in addition the treatment must be documented in detail to satisfy the importing authorities. The duration and temperature of the treatment (typically -1°C to +2°C) depend on pest susceptibility and fruit tolerance to cold conditions. Cold treatment is particularly suitable for controlling pests found in or on some subtropical (e.g. citrus) and tropical (e.g. mangosteen) commodities provided a treatment period, usually of at least 10 days, can be accurately maintained and documented. Cold treatment is carried out in-transit or in land-based facilities. Some chilling damage can occur during treatment for some chilling-sensitive commodities. Chilling injury can be reduced if the commodity is conditioned to relatively low temperatures prior to cold storage (Houck *et al.* 1990b).

Following approval of exposure to cold conditions as a quarantine treatment for 4 species of fruit flies (Mediterranean, Queensland, Oriental and Melon) Japan accepts grapes, kiwifruit and citrus from Australia, Chile, China, Hawaii, Israel, Philippines, South Africa, Spain, Swaziland and Taiwan (Kawakami 1996).

A summary of the uses of cold treatment and further examples has been provided by Gould (1994). Cold treatments identified by MBTOC for a range of perishable commodities are provided in Table 6.2 in this chapter.

6.5.2 Controlled atmosphere

Fruit shelf-life can be extended by altering the normal atmosphere of 21% oxygen and 0.03% carbon dioxide to about 0.5 - 3% oxygen and 2 - 5% carbon dioxide and *controlling* it at these levels. Typically the treatments are carried out at optimum storage temperatures and times for the commodity which may be too short for acceptance as a quarantine treatment. The use of CAs in the trade of perishable commodities has been summarised by Carpenter and Potter (1994).

CA is an environmentally sound treatment that is particularly suitable for controlling some pests on perishable products that store well such as apples (Batchelor *et al.* 1985; Whiting *et al.* 1991 for control of Lepidoptera under low and high temperature CA; Dickler *et al.* 1975 for low temperature control of scale insects). Most commodities exhibit low oxygen and/or high CO_2 injury and off-flavour development when exposed to insecticidal CA conditions outside of their tolerance range (Kader and Ke 1994) which limits successful disinfestation treatments using CA to relatively few.

Commodities show great varibility in their ability to tolerate CAs which limits the development of a generalised CA treatment. Vegetables tolerate a minimum of 0.5% oxygen; some cultivars of apples and pears, brocolli, mushroom, garlic, onion 1%; most cultivars of apples and pears, kiwifruit, apricot, cherry, nectarine, peach, plum, strawberry, pineapple, olive, cantaloupe, sweetcorn, green bean, celery, lettuce, cabbage, cauliflower and brussel sprouts 2%; avocado, persimmons, tomato, pepper, cucumber, artichoke 4%; citrus, green peas, asparagus, potato 5% (Kader and Ke 1994). Carbon dioxide maximum tolerance shows similar variation by commodity from 2% to 15%.

Although CAs have been widely used for at least 30 years for prolonging the storage life of apples and pears, there are few commercial uses of CA for disinfestation of fresh products because lengthy periods in standard CA cool storage are required to achieve high pest mortality which can result in an unacceptable reduction in commodity quality (Meheriuk *et al.* 1994). More recently CAs have proven effective on a laboratory scale for quarantine control of temperate and tropical pests (not tested inside the commodity) particularly when combined for short durations with temperatures above 30°C (Whiting *et al.* 1991; Jessup 1995). Unfortunately, in some cases the requirements for insect control damage the commodity (Smilanick and Fouse 1989). CA treatment is not known to be approved for quarantine use by any country (Anon 1998b).

Other factors limiting widespread adoption of this technology are inadequate data on the responses of pests and commodities to high-temperature CA, the difficulty of designing large high-temperature CA disinfestation facilities with adequate gas retention and regional variation in the cost of gases for CA (Whiting *et al.* 1991; Benshoter 1987). Carpenter *et al.* (1995) reported that the problems likely to be associated with the implementation of CA treatments at elevated temperatures (60% CO_2 + 40% N_2 at 35°C for 2, 4, or 8 hours) were variability in produce and pest responses and the limited ability to extrapolate laboratory data to commercial conditions for a variety of pests and produce.

6.5.3 Heat

Heat is an environmentally acceptable but energy intensive alternative that is particularly suitable for controlling pests found in or on most tropical and some subtropical commodities. Costs of heat treatment are reported as 6 - 7 times more expensive than MB fumigation (US-EPA Case Study December 1996). The temperature, duration and application method must be precise to kill pests without damaging the commodity. However, heat is unsuitable for many highly perishable products such as asparagus, cherries or leafy vegetables as their shelf-life and marketability is significantly reduced by the treatment. Currently heat treatment facilities capable of handling large volumes of commodities are limited in size and number and limited data are available for Regulatory Approval of any commodity-heat-pest combinations (Anon 1998b).

Numerous heat schedules have been published by USDA-APHIS attesting to its value as a disinfestation treatment for viruses, nematodes, insects, mites, fungi, bacteria and snails. Summaries describing the quarantine uses of heated water and air have been produced (Sharp 1994a for hot water treatments; Hallman and Armstrong 1994 for heated air treatments).

Heat treatments include those using moist (>90% Relative Humidity (RH) also called vapour heat) or dry air (<90% RH) and immersion in hot water (Armstrong 1994b; Paull and McDonald 1994). In general, heat treatments are carried out for 10 minutes to eight hours (Anon 1992a) at temperatures that range from 40 - 50°C depending on the specific temperature and duration known to be lethal to the pest. For more heat-sensitive commodities, it may only be possible to control surface pests.

Commercial shipments of tropical fruit such as mango are immersed in warm water at 46.1°C and above for 65 - 90 minutes to kill any pests that might be present (Anon 1992a). The water temperature and immersion period are precisely maintained so that the pest tolerance to heat is exceeded without damaging the commodity. Papaya exposed to fruit centre temperatures of 47.2°C is commercially shipped from Hawaii to the mainland USA after 4 - 7 hours dry-heat (Armstrong *et al.* 1989) or to Japan after the same exposure time to *vapour heat* (Anon 1972). This treatment kills all stages of 3 species of fruit fly potentially infesting this commodity. Laboratory tests are being conducted to determine the potential of water dips and vapour heat treatments to kill temperate pests associated with apples, stonefruit, kiwifruit and citrus and the effect of these treatments on their storage life.

Vapour heat is used commercially for control of oriental, melon, Queensland and Mediterranean fruit flies potentially infesting litchi, papaya and mango exports from Australia, China, Hawaii, Philippines, Taiwan and Thailand to Japan (Kawakami 1996); as a quarantine treatment for oriental fruit fly potentially infesting papaya, mango and bell pepper; for melon fly potentially infesting netted melon and bitter cucumber; and for sweet potato weevil, west Indian potato weevil and sweet potato vine borer potentially infesting Japanese sweet potatoes shipped to the mainland from the southern islands of Japan (Kawakami 1996).

The infrared equivalent of microwave technology has recently been reported as effective in controlling *Tilletia indica* teliospores (Karnal bunt of wheat) in 10 seconds compared to 96 hours using MB. Ingemanson (1997) speculated that this technology which uses specific infrared

species targeted at the molecular level could be used for disinfestation of pests in fruits and vegetables.

Hallman and Mangan (1997) expressed a number of problems with quarantine treatment research based on temperature that should be considered by researchers. These problems were the methods and criteria used to assess pest mortality after treatment, potential differences in heat tolerance between laboratory and wild insects of the same species, temperature profiles achieved commercially compared to those tested, variability in the commodity that allows for survival of the pest and the ability of laboratory conditions to simulate those used commercially. Pest mortality can vary with previous temperature exposure. For example, Phillips *et al.* (1997) reported that the mortality of Mediterranean fruit fly in litchi is lower than for carambola when exposed to the same temperature regime suggesting that host fruit may influence the mortality of fruit flies exposed to cold treatments.

Certain cut flowers were more susceptible to heat injury during cool, rainy seasons (Hara 1997). Conditioning flowers in hot air at 39 - 40°C for 2 - 4 h before hot water treatment eliminated seasonal phytoxicity, but increased survival of mealybug cut flower pests. The increase in tolerance to heat by pests induced by a conditioning treatment needs to be carefully evaluated prior to commercialisation of the disinfestation treatment.

Houck and Jenner (1997) showed that, using a number of controlled-temperature glass houses, the pre-harvest environment affected the response of lemon fruit to cold, heat and fumigation treatments. Fruit pre-conditioned on the tree to cool temperatures were tolerant after harvest to cold treatment but not heat and the converse was true for lemons grown in a warm environment. Therefore the environment in which the fruit was grown is one of the factors that determines the type of disinfestation treatment that could be successfully applied.

A review of heat-based treatments for disinfestation of perishable commodities has been published (Anon 1996c). A more specific review of potential controls for *Anastrepha* species of fruit flies describes a number of heat-based treatments as well as those using irradiation, refrigeration, modified atmospheres and combinations of these treatments (Wolfenbarger 1995b).

6.5.4 Irradiation

Irradiation is the process of treating commodities with ionising energy and includes radio waves, radar, microwaves, infrared, visible rays, ultraviolet rays, x-rays and gamma rays. Gamma rays and x-rays are efficient ionising energies for quarantine purposes as they easily penetrate the commodity. A summary of irradiation is provided by Burditt (1994). Irradiation is an environmentally sound alternative, with over 36 countries approving its use on more than 40 foodstuffs including vegetables and fresh fruit (Anon 1987a). The commercial status, regulatory progress and the role of irradiation has been summarised (Marcotte 1996; Borsa 1996).

Irradiation can control many pest species and has additional advantages of allowing the commodity to be treated in the final packaging with no appreciable increase in temperature. Successful use of low dosage irradiation from isotope or electron beam sources depends on breaking the life cycle of the pest, usually resulting in sterility but sometimes mortality, without reducing the value of the commodity. Shelf-life extension should not be expected at low

disinfestation doses (less than 1000 Gy) but often occurs. Considerable research on changes to commodity quality indicates irradiation is suitable for some fruits, vegetables and cut flowers (Anon 1986a; Kader 1986; Hayashi and Todoriki 1996).

The internationally accepted dose limit for food irradiation is 10,000 Gy (IAEA 1991); the United States allows disinfestation of fresh foods up to 1000 Gy (Anon 1986a) which has encouraged use in commodity disinfestation. United Nations agencies have recognised the similarity in response of fruit fly species. In order to avoid unnecessary disinfestation experiments, they have recommended a minimum dose of 150 Gy which is considered effective regardless of the fruit fly species. Similarly, the International Atomic Energy Agency s (IAEA) International Group on Food Irradiation (ICGFI) has produced several reports on the use of irradiation as a disinfestation treatment for fresh fruits and vegetables (ICGFI 1991ab, ICGFI 1994).

USDA-APHIS reviewed the IAEA data and proposed a minimum generic dose of 250 Gy for fruit fly disinfestation (Griffin 1996). Disinfestation by irradiation for fruit flies was approved for exports of Hawaiian papaya (minimum of 250 Gy) litchi and carambola to the US mainland (Anon 1996d).

Smittle (1997) has suggested that the 250 Gy level is higher than necessary now that dosimetry methods can be calibrated to national (in the USA) and international standards. Phillips *et al.* (1997) reported 150 Gy achieved a Probit 9 level of security for *Bactrocera latifrons* infested in green peppers in Hawaii. A minimum of 300 Gy was recommended for insects other than fruit fly and mites (ICGFI 1989).

Among the factors currently influencing the adoption of irradiation for disinfestation are widespread consumer, industry and regulatory acceptance. Other factors are insufficient commercial-scale assessments of cost-benefit, verification of live but sterile pests and perceived public concern with the safety of isotope transport, long-term storage and facility location. There is also the potential for irradiation-sterilised insects to be imported with live viruses as the sterilisation dose for insects is much less than the disinfestation dose for viruses.

To address some of these issues USDA-APHIS permitted test shipments of Hawaiian produce to the Chicago region for irradiation to control pests potentially infesting a range of tropical commodities. Shipments have increased each year starting with 6 shipments in 1995, 16 in 1996 and 37 in 1997 (Wong 1998). The product shipped (and shipment weight in pounds) for the period 1995 to February 1998 was: atemoya (11,516); banana (380); litchi (25,620); melon (40); orange (200); papaya (81,000); rambutan (65,982); and starfruit (2,264). The number of stores selling irradiated food and the quantity sold on the mainland USA continue to increase. The construction of an irradiator in Hawaii is in the planning stage (E. Jang USDA-Hilo pers. comm. 1998).

USDA-APHIS has approved a regulation on the use of irradiation as a quarantine treatment (Anon 1996e). Concurrently, the North American Plant Protection Organisation (NAPPO) produced a position statement in support of irradiation as a quarantine treatment, but this statement is not currently supported by Mexico or Canada. The USDA also held a plant quarantine workshop for regulatory personnel and intends to accelerate the work toward

identifying the data and research needed for additional dose recommendations, particularly for generic doses (Griffin 1996).

New designs for improved irradiation facilities that treat pallets or small batches on-site at agricultural packing facilities are being marketed (Anon 1995c). To date, only the equipment designed by SteriGenics has been approved and is commercially operational (Anon 1997b).

Tests to identify irradiated insects have been developed based on changes to the supraoesophageal ganglion (Rahman *et al.* 1990) and melanisation and changes in phenoloxidase levels (Smittle and Nation 1995). Irradiated insects did not retain sufficient phenoloxidase activity to cause a colour change on transparency film impregnated with 2-methyl-DOPA which differentiated them from untreated insects that did cause a colour change.

Several areas have been suggested as considerations for future research that examine the impact of irradiation on commodities including pre- and post-harvest treatments, harvest maturity, time between harvest and treatment, post-treatment storage conditions, the physiological basis of tolerance and the potential for conditioning treatments and objective measurements for recording damage and relating these to biochemical indices (McDonald and Miller 1995). Examples of objective measurements for mango, carambola and grapefruit have been provided by McDonald and Miller (1994).

6.5.5 Modified atmosphere

The shelf-life of fruit can also be extended by allowing fruit respiration to modify the atmosphere, reducing oxygen and elevating carbon dioxide. The final atmosphere and the time to establish equilibrium is not easily controlled or predictable as it depends on the biological process of fruit respiration which, for example, increases with increasing temperature. Modified atmospheres (MAs) are typically generated by wrapping various types of *polyfilms* around the commodity (Shetty *et al.* 1989). In some cases, the commodity is palletised and wrapped and then flushed with gases to establish the desired atmosphere. Film permeability varies with film type and temperature, making MA control difficult under the changing temperatures commodities may experience in transit. Consumers, however, may eventually limit the widespread use of this technology due to concerns with excessive use of packaging materials.

More recently, applying specialised *coatings* made of wax or cellulose to citrus has proven effective in the laboratory for killing Caribbean fruit fly (Greeney and McDonald 1993; Sharp 1990). Wax treatment of a commodity may not be acceptable to the consumer.

MA is an environmentally sound treatment that is particularly suitable for controlling pests on perishable products that can be stored for at least 7 days such as strawberries. However, there are currently no commercial examples of using MA for disinfestation of perishable commodities mainly because the atmospheres are, by definition, not controllable and repeatable. Regulatory agencies use controllability and repeatability as (implicit) criteria for acceptance of a quarantine treament.

Specialised films for maintaining commodity quality using atmosphere-absorbing compounds impregnated into the film are becoming available. Such films are called 'active packaging' and are sometimes temperature activated. They are likely to be important in the future, particularly

if they have a disinfestation role rather than just their current focus of increasing shelf-life mainly by ethylene absorption.

6.5.6 Microwaves

Pest control using microwaves is in the early stages of investigation. Microwave technologies and applications currently used by the military may eventually find use as quarantine treatments (Armstrong 1994b). Microwaves may be useful to control pests that are in the seed of commodities such as mango and avocado.

Sharp (1996) reported that increasing microwave power reduced the time to reach the target temperature but reduced the efficacy of the treatment in controlling Caribbean fruit fly larvae.

Microwave technology may also allow on-site treatment of commodities which could be advantageous for quarantine treatment of small shipments.

Further research is required to determine the potential of microwaves to kill pests without reducing commodity quality.

6.5.7 Physical removal

Water under high pressure has been shown experimentally to remove large numbers of pests from the fruit surface (Honiball *et al.* 1979 for scale insects; Yokoyama and Miller 1988 for codling moth eggs). Air under positive or negative pressure has also been used experimentally to remove pests, but not in sufficient numbers to be acceptable as a disinfestation treatment. These treatments are only suitable for removing pests on the surface of fruit such as accidental contaminants (hitch-hikers) scale insects and mealybugs. The choice of air or water depends on the tolerance of the commodity to the treatment or convenience of use in the packing operation.

6.5.8 Combination

Treatments may be combined to achieve required efficacy levels. This is necessitated by an inability to achieve required efficacy levels using a single treatment, or when a single treatment causes phytotoxicity at doses required for pest control (Moffitt *et al.* 1988, 1994). For example, MB fumigation combined with a short period of cold storage kills codling moth eggs on apples more effectively than either treatment alone (Waddell 1993). The *combination treatment* of 18 days *cold treatment* at 0°C (± 0.5°C) followed by 12 gm^{-3} MB *fumigation* for 2 hours at 15°C for control of fifth instar diapause larvae of peach fruit moth potentially infesting apples for export to the USA was more effective than MB fumigation alone (Kawakami *et al.* 1994). A combination of *vapour heat* followed by *cold storage* is used to kill oriental fruit flies on litchi imported by Japan from Taiwan (Anon 1980) and China (Anon 1994a).

Inspection combined with a heat treatment is an accepted treatment for litchi exported from Hawaii to the mainland USA. Litchis must be thoroughly examined in the packhouse and found free of *Cryptophlebia* spp. and other plant pests. Fruit must be submerged at least four inches below the surface of the water which must be kept at 120.2°F and above for 20 minutes (Anon 1998b). Hyrdocooling is recommended after treatment to avoid damage.

A mixture of MB, phosphine and carbon dioxide was registered for use in Japan for controlling arthropods intercepted on cut flowers (Anon 1995a). The MB dose was two-thirds less with the gas mixture than when used alone (Kawakami *et al.* 1996). No injury was observed on chrysanthemums and orchids which are sensitive to MB fumigation.

The four combination treatments cited above are the only known commercially available ones accepted by regulatory agencies. The rarity of combination treatments compared with single treatment applications is probably due to extensive technical documentation required to demonstrate treatment efficacy for regulatory agencies.

6.6 Chemical Post-harvest Treatments

Chemical treatments consist of using fumigants or immersing commodities in dilute insecticides (chemical dips).

6.6.1 Fumigation

This is the act of releasing and dispersing a pesticidal chemical so that it reaches a pest completely or partially while in the gaseous state. Yokoyama (1994) summarised fumigation treatments in use, treatments under development, methods of developing disinfestation treatments and fumigant residues.

Fumigation treatments are usually carried out under very specific parameters to achieve complete pest mortality without damaging the commodity. For example, phosphine, carbon monoxide, sulphur dioxide and hydrogen cyanide require minimal chemical concentrations, temperatures and exposure periods to kill pests within the conditions known to be tolerated by the commodity. Fruit injury when used outside of the tolerance range for methyl bromide fumigation include browning, softening and scald (Meheriuk and Gaunce 1994). Methods for avoiding injury using carbon absorbers (Kawakami and Soma 1991) and DPA treatment (Sproul et al. 1976) have been well documented. Bond (1984) provides details of fumigant properties and methods of application.

Many fumigants must be used cautiously due to their inherent physico-chemical properties and threats to human safety. Carbon monoxide is explosive and generally phytotoxic at concentrations required to kill pests and therefore has little commercial application.

Hydrogen cyanide is commonly used on fresh commodities for control of pests such as thrips, white flies, scale and aphids (Bond 1984). However, not all countries allow hydrogen cyanide to be used as there are concerns for human safety with this highly toxic fumigant.

Carbon disulphide (CS_2) has been used in the past for fumigating durable commodities. Because it is extremely hazardous due to its flammability and explosiveness, it is usually mixed with non-flammable products (Stark 1994). It has limited use on fresh products, but it has been used to fumigate some fruit in the past (Osburn and Lipp 1935).

Sulphur dioxide is used mainly for fungus control in cool stored grapes and recent research has shown a potential to control mealybug and Lepidopteran insects (Vail *et al.* 1991).

Phosphine fumigation for 24 hours at 15°C is proving effective in controlling two-spotted spider mites without injuring apples and grapes (Soma *et al.* 1997a,b).

Carbon sulphide (CAS 463-58-1) has been under patent application since July 1993. CSIRO (Australia) categorises this fumigant as potentially suitable for controlling pests in soil as well as those infesting durable and perishable commodities (CSIRO 1993). Research is currently underway to determine its effect on perishable commodities and to quantify any residues that are formed (EPA 1997 Case Studies Vol 3).

There is an interest in the use of plant volatiles such as separate applications of ethyl or methyl formate and acetaldehyde (Aharoni *et al.* 1979; Stewart and Mon 1984) but none are currently registered as fumigation treatments. Ethyl and methyl formate are inflammable and explosive when mixed with air at concentrations required to kill pests. Ethyl formate is less pesticidal than methyl formate. Acetaldehyde is more effective as a fungicide than an insecticide and its safety to humans has been questioned (Woutersen *et al.* 1984).

Aerosol formulations using natural plant products e.g. pyrethroids, or dichlorvos insecticide, are used to meet phytosanitary requirements for cut flower exports from some countries such as New Zealand (Carpenter and Stocker 1992), Australia and Malaysia.

Fumigants generally penetrate well and are particularly suitable for killing pests that could be inside the commodity. However, they are not favoured by a segment of consumers that seek food with no pesticide residues. Registration of new chemical fumigants is also costly and time consuming as many countries now require extensive safety tests.

6.6.2 Dips

Commodities can be dipped in a very dilute pesticide solution after harvest to kill targeted pests that might be present in or on the commodity or plant. An insecticidal dip must be cost effective and not phytotoxic to commodities or plants. It must be able to reach pests often well-hidden within the leaves and flower parts of plants. Operators must be well-protected with gloves, breathing equipment that protects against insecticide inhalation and work in a well-ventilated area. Insecticide disposal after treatment must be carried out in a way that minimises any environmental problems.

Some countries discourage the use of chemical dips because of consumer concern for chemical residues, or because disposal of the pesticide solution after treatment is often environmentally unacceptable. For these reasons, a chemical dip is usually restricted to non-edible commodities such as ornamental plants, bulbs, nursery plants and cut flowers. Other countries such as New Zealand and Singapore accept chemical dips providing the maximum residue limits in edible commodities are not exceeded.

Australian tomatoes exported to New Zealand are dipped in dimethoate insecticide to control Queensland fruit fly (*Bactrocera tryoni*) (Heather *et al.* 1987) potentially infesting the commodity. Insecticidal dip is one of the most common post-harvest treatments for cut flowers (Hara 1994) and likely to become even more widespread as an alternative to MB in the future. Fluvalinate, a synthetic pyrethroid, is registered for use on cut flowers in the USA and its use

has been recommended as a dip for tropical foliage plants imported into the USA (Osborne 1986).

6.7 Constraints to Acceptance of Alternatives

Economic, logistical and engineering considerations are key factors in deciding the acceptability of a disinfestation treatment. Developing effective disinfestation treatments that do not significantly reduce commodity marketability is the most important priority. MB may reduce the quality of many perishable commodities. Depending on the future availability of MB, the potential for acceptance of an alternative treatment should be determined by comparing the effect of MB on the commodity with the alternative, as well as the no treatment evaluation. Treatment damage thresholds should be determined, particularly for sensitive commodities.

If an alternative treatment to MB is to be adopted by industry, it must be practical to apply, capable of being documented to prove that the treatment has been carried out satisfactorily, cost effective (determined mainly by equipment and operating costs) and result in an acceptable level of residues. Government approval by the importing country often requires extensive technical documentation. This step is often the major impediment to final approval of quarantine treatments.

Apart from regulatory constraints, the almost universal application and acceptance of MB for post-harvest disinfestation has stifled the search for alternative treatments. For example, most regulatory agencies have a policy of only accepting 99.9968% mortality (called Probit 9, Baker 1939) whereas other agencies accept lower levels of mortality based on pest risk analysis (PRA) methodology (Heather 1994a).

Some scientists have suggested that Probit 9 mortality may not be necessary to achieve quarantine security as it may be too severe, impractical and unnecessary for commodities that are rarely or poorly infested (Landolt *et al.* 1984, Baker *et al.* 1990, Vail *et al.* 1993; Liquido *et al.* 1996). Harte *et al.* (1992) developed a probability model to quantify the quarantine risk from importing fruit fly hosts, based on pre-determined and known infestation levels in the host, lot size imported and the tolerance level permitted. An alternative approach that has been proposed is to measure the risk as the probability of survival of one or more reproductive units in a shipment. The use of Probit 9 security may be based largely on policy considerations rather than technical justification. Delegates to the December 1993 Codex meeting supported PRA as a method for making phytosanitary decisions (Codex 1993). Most recently, the Food and Agricultural Organisation (FAO) has developed Principles of Plant Quarantine as related to International Trade which seeks to harmonise quarantine policies between countries and these principles will influence the development and use of alternative treatments in the future.

Alternative treatments are developed and implemented by integrating many technical, environmental and regulatory factors. Mamat and Husain (1994) have proposed a standard quarantine treatment protocol design to be considered by researchers when embarking on a treatment that will be evaluated by a regulatory agency. A useful summary of the regulatory factors affecting international trade has been provided by Ganapathi (1994) in which harmonisation of phytosanitary principles, plant quarantine procedures and pest risk assessment are discussed. Shannon (1994) also discusses the principles of international trade and outlines the system of pest risk analysis used by the United States Animal and Plant Health Inspection

Service (US-APHIS). Most recently, the Japan Plant Quarantine Association has published the theory and practice of fumigation and thermal disinfestation techniques, including procedures for undertaking and confirming treatments (Anon 1998a).

In order to avoid loss of exports or restriction on imports due to the unavailability of a commercial alternative to methyl bromide, it is imperative that treatment acceptance criteria for disinfestation treatments are reviewed by scientists, industry and regulatory agencies in order to streamline the process to develop and implement alternatives as rapidly as possible. To this end, USDA-APHIS are continuing to design regulatory mechanisms that will allow treatments to become available more quickly (Griffin 1996).

6.8 Current Research Examples

Examples of current research that seek to minimise interceptions of pests on arrival are:

- Disinfestation of a range of pests intercepted on 17 species of cut flowers imported by Japan such as lily, orchid and carnation at an absorbed dose of 0.4 kGy (Hayashi and Todoriki 1996) using electron beam irradiation.
- Radiation-based disinfestation of litchi, orchids, mango, fresh herbs and ornamental plants of insects and mites of quarantine importance (Anon 1996f).
- In-transit, controlled atmosphere (CA) (high CO_2, low oxygen) combined with cool storage disinfestation of table grapes exported from the USA to Australia (Mitcham *et al.* 1995, 1996).
- Heat treatment of apples, pears and cherries using forced hot air for disinfestation of codling moth, combined with a controlled atmosphere and post-harvest cool storage to reduce the duration of the heat treatment (Neven 1995).
- A low-oxygen treatment developed by the United States Navy to preserve the quality of leafy vegetables uses a CA in shipping containers while in transit to Guam (Gay *et al.* 1994). Although not yet supported by entomological research and therefore not a recognised quarantine treament, these CA procedures have substantially reduced the number of occasions when dockside treatment was required for quarantine pests.
- CA mixtures of oxygen, nitrogen and carbon dioxide gases applied in-transit for controlling fruit flies in citrus, mango, avocado and other fresh fruit shipped from California and Texas to other parts of the USA (Anon 1996g).

6.9 Examples of Alternatives for Pest Control on Major Commodities

Within each commodity group, alternative treatments discussed in Section 6.8 have been *italicised* in order to highlight their use with particular commodities.

6.9.1 Apples and pears

Apple and pear exports are economically important for: Argentina, Australia, Belgium, Chile, China, France, Hungary, Italy, the Netherlands, New Zealand, South Africa and the United States.

Although apples and pears are infested by a large number of pests, for most countries codling moth, fruit fly, mites, scale insects and fire blight bacterial disease are the major pests and diseases of quarantine concern.

Methyl bromide has been rarely used for apples and pears, but greater amounts may be used in the near future to control codling moth on apple exports to Japan by New Zealand, the United States, France and Australia (Tasmania).

6.9.1.1 Existing alternatives

There are few commercial treatments for apples and pears to control pests. *Pre-shipment certification* is carried out successfully by several countries exporting to the United States including New Zealand and Chile. *Controlled Atmospheres (CAs)* combined with cold storage have been used to kill scale insects on apples exported from Canada to California (Dickler *et al.* 1975). USDA-APHIS approves a *cold* treatment to control fruit fly in apples or pears imported into the United States from Chile, France, Israel, Italy, Jordan, Mexico, South Africa, Spain and Uraguay (Anon 1992a). *Irradiation* is used to increase the shelf-life of apples on a small scale in China (Xu *et al.* 1993). A *systems approach* has been accepted by Taiwan for New Zealand and Australian apples (Tom Batchelor pers. comm. 1998); and for Brazilian apples to the United States (John Thaw, USDA-APHIS, pers. comm. 1998).

6.9.1.2 Potential alternatives

CA at low temperature kills some Lepidopterous species, but short duration and therefore less costly treatments may be achievable by combining CAs with heat, or by using heat alone.

Packham Triumph pears exposed to heated CA atmosphere of <1 kPa O_2 for 30 hours at 30°C followed by one month of cold storage in air gained 100% mortality of major Australian apple and pear pests *Epiphyas postvitanna*, *Cydia pomonella* and *Grapholitha molesta* (Chervin *et al.* 1997). Implementation of such treatments was not considered to be costly for fruit industries already equipped with CA facilities.

There is an urgent need to gain a better understanding of pest and fruit physiology under CA/heat or heat alone in order to optimise treatment parameters.

A codling moth *pest-free zone* is feasible in Western Australia since this pest is absent in apple and pear production areas. Sterile codling moths are currently being released in the Okanagan Valley region in Canada to establish a pest-free zone (Proverbs *et al.* 1982).

A *systems approach* may be feasible for some commodities in the USA and Canada where, for example, a reduction in codling moth populations in apples has been documented for some packhouse operations in Washington State (Hansen *et al.* 1997). This study showed that only 71 codling moths were found in over 160,000,000 fruit fruit surveyed in three years. Thus, the

combination of pest control in the field and culling in the packhouse has reduced the risk of contamination for apple exports to levels that meet and often exceed current levels of quarantine security in international trade.

New Zealand reported that their Regulatory agency was allocating resources to investigate appropriate methods for quantifying the efficacy of field control programmes for a number of exports including apples as these are considered at least equivalent by New Zealand to fumigation with methyl bromide (Ivess 1995).

The response of all stages of codling moth to *irradiation* has been defined (Burditt and Moffitt 1985). Similarly, *Ctenopseustis obliquana* leafroller eggs and larvae were prevented from completing further generations when exposed to only 70.1 Gy, a dose that is unlikey to damage apples (Lester and Barrington 1997). 'Red Delicious' apples irradiated up to 1000 Gy were marketable even after 11 months storage (Olsen *et al.* 1989). Apples irradiated at 600 Gy followed by regular or *CA* (1.5% O_2; 1.5% CO_2) cool storage were not damaged but San José scale (*Quadraspidiotus perniciosus*) mortality was inconsistent from year to year (Angerilli and Fitzgibbon 1990).

Hallman and Thomas (1997) confirmed that apples and blueberries could readily tolerate 300 Gy if a disinfestation-effective dose of <100 Gy was applied to control apple maggot, blueberry maggot and plum curculio.

A *combination fumigation* treatment consisting of MB (10 gm^{-3}) and phosphine (3 gm^{-3}) at 15°C for 4 hours killed the most tolerant stage (the egg) of Kanazawa spider mite, a pest potentially present on apple exports from Japan to the USA (Mizobuchi *et al.* 1997).

Ohrin , Kinsei and Fuji apples were undamaged by phosphine *fumigation* (3 gm^{-3} for 18 - 24 hours at 15°C) suggesting that this could be a disinfestation treatment for mites in the future (Soma *et al.* 1997b).

New Zealand apples were exposed to an insecticidal *heat* treatment of 40°C for 17 or 20 hours in an atmosphere of 1.2% O_2, 1% CO_2 followed by cool storage in air. No significant damage was observed in Royal Gala apples but Granny Smith showed some damage (Lay-Yee *et al.* 1996). Both varieties were firmer when heat-treated under CA rather than air suggesting their shelf-life may have been improved. Granny Smith apples immersed in 45°C water for up to 40 minutes were not damaged by the treatment (Spooner and Lay-Yee 1995). These apples also tolerated exposure to higher temperatures or for longer periods provided they were first exposed to air at 38°C.

Neven and Drake (1997a) listed 12 *heat* treatments for codling moth control in apples and pears that varied in: (1) the rate at which the target temperature was achieved (4 - 12°C per hour); (2) the target temperature (44 - 46°C) and the duration of the treatment at the target temperature (2 - 18 hours). All 12 treatments provided control of codling moth and resulted in acceptable quality of Red Delicious , Golden Delicious , Fuji , Granny Smith apples; and d Anjou and Bosc pears. Further research is required to test the most promising treatments using sufficiently large numbers of insects acceptable to quarantine authorities.

Pears were considered likely to tolerate a disinfestation *CA* treatment for the two-spotted spider mite (*Tetranychus urticae*) consisting of 5.5 days under 95% CO_2 in air at 0°C and a *combination treatment* consisting of a 1 day shock treatment in 95% CO_2 or 0.125% O_2 at 20°C followed by 18 days in air at 0°C (Zhou and Micham 1997).

6.9.2 Berryfruit

Berryfruit includes strawberry, raspberry, blueberry and blackberry. Exports are economically important for: Australia, Brazil, Canada, Colombia, Israel, New Zealand, South Africa, the United States and Zimbabwe.

The main pests of quarantine concern are blueberry maggot and other fruit flies, thrips, aphids and mites.

Many countries require a mandatory MB fumigation for berryfruit imported from countries with fruit flies. If fruit flies are not of quarantine concern, berryfruit are imported upon inspection. Imports of blueberries into regions in Canada that do not grow blueberries are permitted.

6.9.2.1 Existing alternatives

Japan accepts strawberries from the Netherlands as free of Mediterranean fruit fly (*host freedom*) (Anon 1993a). There are no other alternatives currently available for control of internal pests. However, *irradiation* shows potential for controlling blueberry maggot (*Rhagoletis mendax*) in blueberries (Miller *et al.* 1994).

6.9.2.2 Potential alternatives

Strawberries under MA of about 10% CO_2 are commercially irradiated in Florida (Marcotte 1992) which may also allow phytosanitary control if required. Currently, strawberries are gassed with 15 - 20% carbon dioxide atmospheres (a *modified atmosphere*) for *Botrytis* control in-transit from California to other parts of the United States, a treatment that might also kill thrips and aphids. *Fumigation* with separate applications of *sulphur dioxide*, *carbon monoxide* or *hydrogen cyanide* may be tolerated by some berryfruit crops, but the cost of commercial implementation of three consecutive treatments may be prohibitive. *Heat* treatments may be suitable for controlling heat sensitive pests such as thrips (Lay-Yee *et al.* 1993) and *cold* treatments for control of tropical insects providing the exposure period is not detrimental to the shelf-life of the commodity. Because of the relatively short life of berryfruit, *CA* will not be of sufficient duration to kill pests.

6.9.3 Bulbs

Bulbs include tulip, narcissus, lily, gladiolus and garlic. Bulb exports are economically important from: The Republic of China, the Netherlands, New Zealand, Taiwan and the United States.

Some bulbs e.g. narcissi, are infested by dry bulb mite, bulb mite and tulip bulb aphid, although these are often difficult to detect.

Most bulbs are currently fumigated in the United States and other countries with MB, the rate depending on whether the pest is an internal or a surface feeder. The USDA-APHIS accepts a 1 hour 43.3 - 43.9°C hot water immersion of narcissus bulbs to control *Steneotarsonemus laticeps* mite providing this is carried out within 1 month of the normal harvest date to avoid bud injury (Anon 1992a).

6.9.3.1 Existing alternatives

In Japan, bulbs infested with aphids and thrips are fumigated with hydrogen cyanide. Narcissi infested with narcissus bulb fly and thrips are dipped in hot water for 1.5 - 2 hours at 44°C.

6.9.3.2 Potential alternatives

Lillies infested with nematodes may be dipped in a dilute *insecticide dip* (e.g. methomyl) or for tulips infested with tulip bulb mite, in an emulsion of pirimiphos-methyl. Two-spotted spider mites and aphids are killed with dichlorvos insecticide in a aerosol formulation.

6.9.4 Citrus

Citrus includes oranges, grapefruit, lemons, limes, tangeloes, tangerines and pummelos. Exports are economically important for: Australia, Brazil, Israel, Japan, South Africa, United States and some other Mediterranean countries.

Although citrus are infested by a large number of pests, for most countries fruit flies, scale insects and Fullers rose weevil are the main pests of quarantine importance.

MB often damages citrus at concentrations required to kill fruit fly, limiting its use.

6.9.4.1 Existing alternatives

Japan accepts: citrus from Florida exposed for 17 - 24 days to *cold* treatment at 2.2°C to control Caribbean fruit fly (*Anastraepha suspensa*) (Anon 1990a); citrus from South Africa after 12 days *cold treatment* at -0.6°C to control Mediterranean fruit fly (*C. capitata*); citrus from South Africa and Swaziland after 12 days cold treatment at -0.6°C to control Mediterranean fruit fly (Anon 1973); citrus from Israel after 13 - 16 days *cold treatment* at 0.5 1.5°C (Anon 1990b); citrus from Spain after 16 days cold treatment at 2.0°C to control Mediterranean fruit fly (Anon 1988b); citrus from Australia after 14 - 16 days cold treatment at 1°C to control Mediterranean fruit fly and Queensland fruit fly (*B. tryoni*) (Anon 1992b); citrus from Taiwan after 14 days at 1°C to control Oriental fruit fly (*B. dorsalis*) (Anon 1980); grapes from Chile after 12 days at 0°C to control Mediterranean fruit fly (Anon 1990c); and kiwifruit from Chile after 14 days at 0°C (Anon 1991) to control Medfly.

USDA-APHIS accepts *cold treatment* for 11 - 22 days depending on the temperature for control of fruit fly species in some varieties of citrus from 23 countries (Anon 1992a). Included in these treatments is storage at 0.6 - 1.7°C for 18 - 22 days as a quarantine treatment against Mexican fruit fly for citrus imported into the USA from Mexico or Central America. However, this treatment is not used commercially because of problems with chilling injury (Shellie *et al.* 1997).

Sometimes conditioning at warm temperatures is necessary for citrus fruit to tolerate cold treatment (Houck *et al.* 1990a,b; Houck and Jenner 1995; Kitagawa *et al.* 1988). For example, in work with Arizona-grown desert lemons, curing fruits at 15°C and 95% relative humidity for one week significantly reduced phytotoxicity of fruit stored at 1°C for 2 - 6 weeks. Recently, pre-conditioning lemons in air at 15°C for several days or in water at 55°C for 5 minutes induced biochemical changes which may be related to stress tolerance by citrus (Aung *et al.* 1997).

Hydrogen cyanide fumigation is used to kill scale insects on citrus.

Heated dry air that increases the fruit centre of grapefruit to 47.8°C over at least a 3 hour period is an approved quarantine treatment to control Mexican fruit fly (*Anastraepha ludens*) (Anon 1992a). Heated *moist* air to a fruit centre temperature of 43.3°C and held for 6 hours is approved for control of this pest in grapefruit, orange and tangerine from Mexico (Anon 1992a) and pineapple imported from areas infested with Medfly, Oriential fruit fly and Melon fly (Anon 1992a).

6.9.4.2 Potential alternatives

These include *irradiation* for some varieties of oranges, grapefruit and lemons (Thomas 1986; Johnson *et al.* 1990). Limes exhibit significant radiation injury (Maxie *et al.* 1969). Some citrus is individually wrapped with fungicidal film and the *modified atmosphere* generated may also kill pests if insects inside the fruit do not break the film. Some MA treatments damage citrus (Houck and Snider 1969) limiting its widespread use.

Shellie and Mangan (1997) reported that grapefruit *heated* at 10°C in 1 kPa oxygen required 30% less exposure time than fruit heated in air to obtain 100% mortality of the Mexican fruit fly, *Anastrepha ludens*. Further research on the same species showed that heating Rio Red grapefruit at 44°C under 1% O_2 atmosphere for 2 hours shortened the treatment time by 30% to achieve 100% larval mortality than when the treatment was carried out in air enriched with 20% CO_2 (Shellie *et al.* 1997). Inconsistent fruit quality results warranted further tests.

Results from these experiments suggest that treatment in heated atmospheres low in oxygen has potential for disinfesting grapefruit of Mexican fruit fly, particularly if further work is based on thermal kinetics of fruit fly mortality and an understanding of plant physiological responses to stress at the cellular level. For example, based on a large set of mortality data generated from heat treatments for this fruit fly species, a kinetic model was shown to be the best predictor of the thermal death point likely to meet quarantine security levels (Thomas and Mangan 1997). In addition, developing storage practices that allow produce to adapt to disinfestation treatments and anaerobiosis conditions may be the key to implementing these treatments in commercial practice (refer to Chervin *et al.* 1996 for studies on cellular responses to low oxygen conditions). Brown *et al.* (1995) suggested using thermodynamic principles for predicting the final temperature of navel oranges dipped, flooded or sprayed with heated water to control mites, mealybug and lightbrown apple moth species.

The USDA is currently testing the response of lemons to fumigation with *carbon disulphide* (CS_2) (Jang pers comm 1998).

Phosphine fumigation was predicted to kill all stages of Mexican fruit fly larvae and pupae in Ruby Red grapefruit after 4 - 7 days exposure at 0.125 gm^{-3} at 8 - 48°C and > 50% RH (Wolfenbarger 1995a). This variety tolerated 4 days fumigation with phosphine at 0.5 gm^{-3} under the similar environmental conditions indicating potential for a commercial disinfestation treatment.

California red scale *Aonidiella aurantii* infesting grapefruit were killed by separate *fumigations* of 1.5 or 3% acetaldehyde, ethyl formate and methyl formate (Aharoni *et al.* 1987). No phytotoxicity or off-flavours were detected in the fruit. These three plant volatiles have potential to control this insect pest on citrus.

Immersion of oranges intended for export to Japan from Australia in water at 50°C for 2 and 10 minutes and 52°C for 2 and 7 minutes, reduced egg hatch in the weevil *Asynonychus cervinus* by up to 66% with no fruit damage detectable (Jessup *et al.* 1993). Further research is required to achieve 100% inhibition of egg hatch.

Heat treatments for control of different species of fruit fly are under development for grapefruit (Sharp 1993 in Florida; Mangan and Ingle 1994 in Texas) and for grapefruit and 'Valencia' oranges (J.W. Armstrong, USDA-ARS Hilo pers. comm. 1993 in Hawaii). Citrus phytotoxicity as a result of heat treatment has been previously reported (Houck 1967).

There may also be opportunities for pest control by: genetically *inducing resistance* in citrus to pests; adding *coatings* to the surface of the fruit (in combination with dimethoate insecticide or heat) which reduce the ability of the internal atmosphere of the fruit to sustain pests (J.D. Hansen, USDA-ARS Miami, pers. comm. 1993); demonstrating *pest-free zones* and *pest-free periods*; or documenting pest reduction due to a series of control measures applied in the production of the commodity (*systems approach*).

Previous research at the University of California (Riverside) showed *high pressure water* washes scale insects and Fuller's rose weevil eggs off citrus, but the treatment is unlikely to be acceptable to regulatory agencies as a quarantine treatment. Petracek and Kelsey (1995) measured a wound ethylene response to excessive water pressure, suggesting that there may be a loss of shelf-life of citrus if the recommended pressures are exceeded.

6.9.5 Cucurbits

Cucurbits include different varieties of cucumbers, melons and squash. Exports are economically important to: Australia, Chile, Israel, Mexico, the Netherlands, New Zealand, South Africa and the United States. For some developing countries, cucurbit production is very important for the national economy.

Cucurbits are infested by a wide range of pests particularly fruit fly, Lepidoptera, aphids and thrips.

Most cucurbits are not fumigated with MB but are imported after inspection and certification. However, watermelon exported from Tonga to New Zealand is the only example of an inter-governmental agreement on *systems approach*, based on culling infested fruit in the field followed by fumigation with MB.

6.9.5.1 Existing alternatives

Some countries such as the United States and Japan accept imports of cucurbits only from pest-free zones. Japan accepts melon from Hsingchiang region in China as this is a *pest-free zone* for melon fly (Anon 1988a) and squash from Tasmania as this is a *pest-free zone* for Queensland and Mediterranean fruit flies (Anon 1989a). *Moist heated air* sufficient to raise the fruit centre temperature to 44.4°C and held at this temperature for 8.75 hours is an approved quarantine treatment for controlling *Ceratitis capitata*, *Bactrocera dorsalis* and *B. cucurbitae* in eggplant, squash and zucchini (Anon 1992a). Japan accepts squash, melon and cucumber from the Netherlands as free of Mediterranean fruit fly (*host freedom*) (Anon 1993a). Bitter cucumber and netted melon shipments from Okinawa to mainland Japan are acceptable after vapour heat treatment for 30 minutes at 43 - 46°C to control melon fly (Anon 1987b; Anon 1989b).

Fiji developed a forced hot-air quarantine treatment for eggplant that was approved by New Zealand in 1997 New Zealand MAF has approved a forced hot-air quarantine treatment for control of fruit flies in papaya, eggplant and mango exported from Fiji to New Zealand (Anon 1997c).

6.9.5.2 Potential alternatives

Some cucurbits such as cucumber and squash are tolerant to heat (water or moist air) particularly if pre-conditioned to a temperature slightly less than the final temperature and therefore this treatment offers potential for controlling fruit fly and Lepidoptera. Chilling injury may limit the commercial potential for fruit fly disinfestation of zucchini exposed to 45°C for 30 minutes followed by storage at 7 - 8°C for up to 11 days (Jacobi *et al.* 1996). The commercialisation of heat treatments may also be limited by the ability of insects to increase thermo-tolerance when exposed to pre-treatment heat or cold conditions. For example, Lester and Greenwood (1997) reported that 8 hours exposure to 35°C almost doubled the time for 99% mortality in *Epiphyas postvittana* leafroller larvae compared to no pre-treatment and that synthesis of heat shock proteins was associated with this increase in thermo-tolerance. In the future, the conditions necessary to induce thermo-tolerance is essential to optimise heat treatments used for insect disinfestation and disease control (Paull and McDonald 1994).

Heat treatments are under consideration for development in Hawaii for eggplant and zucchini (J.W. Armstrong, USDA-Hilo, pers. comm. 1998). It may be possible to develop a *systems approach* since some cucurbits are not hosts to some fruit fly species and *pest-free zones* may be possible for cucurbits potentially infested by melon fly in South American produce imported by the United States. The shelf-life of cucumber is extended by *shrink wrap films* and the potential for controlling insects using this method requires further investigation (Shetty *et al.* 1989; Jang 1990).

6.9.6 Cut flowers and ornamentals

Cut flowers such as roses, carnations, chrysanthemums, bird-of-paradise and orchids are economically important as exports from: Australia, Colombia, Kenya, Malaysia, the Netherlands, New Zealand, Singapore, South Africa, Thailand, the United States (especially Hawaii) and Zimbabwe. Ornamental exports include deciduous woody plants, evergreens and cycads and are also economically important as exports from these countries.

Cut flowers and ornamentals are infested by a wide range of pests including external feeders, Lepidoptera, thrips, aphids, mites and scale insects. Live pests intercepted on cut flowers and ornamentals on arrival are typically fumigated with MB (Anon 1992a). The dosage varies with temperature, target pest and in the case of ornamentals the physiological state of the plant e.g. dormancy.

6.9.6.1 Existing alternatives

MB is damaging to many types of cut flowers and the most common alternative to MB is *pre-clearance inspection*. A treatment is only required if pests are detected, or if no treatment is available the consigment is prevented from being exported.

Some flowers and ornamentals are fumigated with *hydrogen cyanide* to control aphids, thrips and whitefly, but the treatment can be detrimental to some flowers such as gerbera that have a high moisture content. *Hydrogen cyanide* fumigation is no longer registered by the US-EPA as an insecticide fumigant, despite it being suitable for disinfestation of some pests from cut flowers and foliage from Hawaii (Hansen *et al.* 1991).

Insecticidal dip is one of the most common post-harvest treatments for cut flowers (Hara 1994) and likely to become even more widespread as an alternative to MB in the future. Hawaii and Thailand dip cut flowers in a dilute insecticide solution such as malathion to control thrips and other pests. The USDA-APHIS approves the use of chemical dips (for about a 30 second immersion) in lieu of fumigation for those plants known to be intolerant of fumigants (Anon 1992a).

USDA-APHIS has approved a high-pressure water spray for *Succinea horticola* snails followed by a dilute carbaryl insecticide dip, or hand-removal of the pests where practical followed by immersion in a malathion-carbaryl dip if necessary (Anon 1992a).

Aerosol formulations of insecticide chemicals (e.g. Hortigas® containing dichlorvos) and natural products (e.g. Permigas® containing permethrin) are used on cut flower exports from New Zealand to Japan and from Hawaii to the mainland USA. They are not as effective as fumigants in penetrating flowers and relatively longer exposure periods of 3 - 16 hours are often required to obtain efficacious results (Hara 1994).

Fluvalinate (a synthetic pyrethroid) is registered for use on cut flowers in the USA and its use has been recommended for tropical foliage plants imported into the USA (Osborne 1986).

Advantages and disadvantages of disinfestation treatments and procedures for quarantine security of floriculture crops are summarised by Hara (1994).

6.9.6.2 Potential alternatives

Irradiation is being investigated further for cut flowers and their pests in several countries including the Netherlands, New Zealand, Japan, Malaysia, Philippines and Thailand. This process has the advantage of being rapid and completely effective by arresting the development of pests and preventing reproduction. Sealed packages can be treated effectively under packed conditions with irradiation, in contrast to fumigants that are typically applied to unpacked product to improve penetration. A recent review of cut flower irradiation (Hayashi *et al.* 1998) listed carnation, Alstromeria, Gladiolus, tulip, statice, stock, Dendrobium, prairie gentian, Oncidium, Campanula, Gloriosa, fern, Gypsophila, freesia, Lobelia, Triteleia and Gerbera as tolerant to electron beam irradiation at 400 Gy while Chrysanthemum, rose, lily, calla, Antherium, sweet pea and iris were intolerant.

Irradiation at 400 Gy inhibited hatching, larval growth, pupation, adult emergence and/or oviposition and sterilised adults of: two-spotted spider mites, leaf-miners, mealybugs, cutworms and thrips. Although the disinfestation dose is lower than the tolerance of cut flowers, the difference between the two doses is not large enough to permit commercial, low penetration irradiation as the Maximum-Minimum ratio would exceed the cut flower tolerance. X-rays would be preferable as they have better penetration than electron beam, but technology to irradiate products with X-rays for long periods of time has yet to be proven.

Aerosol formulations of insecticide chemicals and natural products are under investigation in Thailand and other countries. Results to date show the formulations lack penetration into the commodity and therefore do not always kill leaf-miners and mites.

Controlled atmospheres using for example CO_2 at 0 - 1°C for one week is promising for protea flowers, but the requirement for relatively long treatment times makes CA more suited to sea transport and many tropical flowers are subject to chilling injury (Hara 1994).

Fumigation with *phosphine* shows potential for quarantine treatment of live plants as Chrysanthemum and poinsettia cuttings were not damaged by concentrations and exposure periods that are known to be insecticidal to some plant pests (McDonald and Mills 1995).

A *combination fumigation* treatment of carbon dioxide (5%) MB ($10gm^{-3}$) and phosphine ($3\ gm^{-3}$) at 15°C for 4 hours was 100% effective in killing 7 species of pests (Kanazawa spider mite, two-spotted spider mite, *Thrips palmi*, greenhouse whitefly, greenhouse peach aphid, cotton aphid, Japanese mealybug and cabbage moth) on cut flowers (Kawakami *et al.* 1996). Fumigation using chlorpyrifos-impregnated bags has been shown to kill ants and thrips on flowers (Hara 1994) but this use has not been registered in the USA.

Fumigation using 2.6% phosphine by volume in CO_2 (called ECO_2FUME) can be used on a wide variety of products including plant cuttings (Slone Group 1996; McDonald and Mills 1995; Mueller 1996; Mueller *et al.* 1997). ECO_2FUME gas can be used at cool (<3 - 5°C) temperatures which is an advantage over MB that requires warm temperatures for activation and loss of shelf-life for perishable commodities (Mueller 1997). Regulatory data sufficient to support US-EPA registration of ECO_2FUME is underway to allow its potential to be evaluated as a disinfestation treatment for citrus, vegetables and other products that are routinely cool stored. On-site generation of phosphine in CO_2 using a Turbo Horn Generator (Anon 1996i)

has also been developed as an alternative to pre-mixed cylinders of ECO_2FUME at a cost that is only marginally more than MB fumigation (EPA 1997).

Some essential oils extracted from plants were recently found to have *fumigant* activity at low concentrations causing 100% mortality of cut flower pests such as thrips and whitfly (Shaaya *et al.* 1997). Further research is required to determine the commercial potential of these extracts as quarantine disinfestation treatments.

Moist air *heat* treatment shows promise as a disinfestation treatment for tropical cut flowers and foliage (Hansen *et al.* 1992). A proposal to control magnolia white scale *Pseudolaucaspis cockerelli* on Bird of Paradise using 49°C water immersion for 10 minutes has been submitted to the California Department of Food and Agriculture (A.H. Hara, University of Hawaii, pers. comm. 1998). Previous heat treatment research has been accepted by CDFA as efficacious against this scale species.

Commercial shippers in Hawaii have adopted the hot air and hot water treatments for producing pest-free, high quality flowers for export (Hara 1997).

Warm water immersion of Cape jasmine, a popular conservatory plant from Hawaii exported to the mainland USA, for 10 minutes at 49°C disinfested all stages of green scale (*Coccus viridis*) (Hara *et al.* 1994). This treatment has not been accepted by USDA-APHIS as the Probit 9 quarantine security has not been demonstrated. However, the very low incidence of any live pests as a result of the treatment has avoided the need for treatment on arrival and is therefore commercially justified. Cape jasmine, *Anthurium* sp., *Cordyline* sp., *Dracaena* sp., *Gardenia* sp. and *Plumeria* sp. root and shoot development was stimulated when 0.8% IBA growth stimulant was added to this *heat* treatment. The vase life and quality of most species of *Heliconia* were not detrimental or improved by hot water at 49°C for 12 minutes. Immersion of red ginger flowers (*Alpinia purpurata*) in 6-benzylamino purine after treatment further extended the vase life.

A double *insecticide dip* for 3 minutes each time with a 2 hour wait period between immersions in the dilute insecticide solution proved more effective in killing thrips species on orchids in Hawaii than a single immersion (Hata *et al.* 1993). The first dip caused pest excitability, restlessness and withdrawal from cracks and crevices on the flowers. Thrips then became more directly exposed to the second immersion. This is particularly important for chemical dips as their efficacy depends on contact with the pest which can be difficult when certain pests occur in tight cracks. Another benefit of using insecticidal dips was reduced pesticide use in the field which is important for growers controlling pests that show resistance to a range of chemicals. Insecticides used post-harvest should differ from those used pre-harvest as a safeguard for minimising survival of pests after insecticide dipping. Some chemicals are phytotoxic to flowers and foliage leading to reduced shelf-life and therefore care must be exercised in selection of the disinfestation materials.

Synthetic pyrethroids which have repellant activity as *fumigants* act as protectants of flowers and foliage and are especially effective in combination with insecticidal soap (Hara 1994).

A *systems approach* consisting of field management combined with post-harvest insecticide dip reduced the interception incidence of aphids, mealybug, thrips, earwigs and ants on red ginger exported from Hawaii to the mainland USA (Hara 1994). Cut flowers exported to Japan

following the same procedures also show a similar reduction in interceptions of pests. This may lead MAFF-Japan to classify such consignments as low risk once the very low incidence of live pests has been verified for an acceptable period of time. However, effective and consistent field pest management procedures are required to obtain this level of quarantine security.

Similarly, a post-harvest *insecticidal dip* was only 100% effective if pre-harvest pesticides reduced mealybug field populations to <6%; banana aphid infestations to <33%; and cotton aphid infestations to <70% (Hata *et al.* 1992).

Cut flowers were considered likely to tolerate a disinfestation *CA* treatment for two-spotted spider mite (*Tetranychus urticae*) consisting of 5.5 days under 95% CO_2 in air at 0°C and a *combination treatment* consisting of a 1 day shock treatment in 95% CO_2 or 0.125% O_2 at 20°C followed by 18 days in air at 0°C (Zhou and Micham 1997).

6.9.7 Grapes

Grape exports are economically important for: Australia, Brazil, Chile, Israel, South Africa, the United States and many European countries.

The main pests of quarantine concern on grapes are fruit flies, Lepidoptera, mealybug and mites.

The USDA-APHIS accepts cold treatment from 30 countries for control of vine moth *Lobesia botrana* and other insects in grapes providing the treatment is combined with MB fumigation. Grape exports to the United States from Chile are accepted from a Mediterranean fruit fly free zone provided they are also fumigated with MB to control the mite *Brevipalpis chilensis*.

Currently the USA requires that all grapes from Chile are fumigated with MB as a condition of entry. Alternatives to MB for treatment of grapes remains a very high priority for grapes imported from Chile into the USA. The USA also exports 264,550 tonnes of grapes in calendar year 1997 out of a total production of almost 800,000 tonnes. US grape exports are only treated with MB on entry to other countries if pests of concern are intercepted (Pers. comm., Ms Amy Philpott, Director International Marketing California Table Grape Commission 1998).

6.9.7.1 Existing alternatives

Japan accepts 12 days *cold treatment* at 0.5°C for control of Mediterranean fruit fly on grapes exported from Chile (Anon 1990c). Japan also accepts that grapes from the Netherlands are free from Mediterranean fruit fly (*host freedom*) (Anon 1993a).

6.9.7.2 Potential alternatives

In-storage fumigation with *sulphur dioxide* (routinely applied for fungal control) alone or combined with carbon dioxide or carbon monoxide (Vota 1957) may provide pest control, although this has received little study. Vail *et al.* (1992) reported sulphur dioxide concentrations comparable to those used in routine fumigation of grapes killed a key insect pest in the United States. This suggests sulphur dioxide has the potential to control both fungi and insects. However, the presence of sulphur residues from sulphites, typically about 10 ppm, may limit

widespread use of sulphur dioxide for disinfestation. The United States requires mandatory labelling of products containing ≥ 10 ppm sulphites to warn sulphite-sensitive people of their presence.

Kyoho grapes tolerated 24 hours *fumigation* with 3 gm^{-3} phosphine at 15°C which is an effective treatment for killing all stages of the two-spotted spider mite (Soma *et al.* 1997a). Further research is required to determine the effects of phosphine against other pests of grapes before the commercial potential of this treatment can be evaluated. For commercial application, a safe and efficient phosphine generator has been designed and tested by Teijin Chemicals Company (Tokyo). It produces 3 kg of gaseous phosphine in < 75 minutes and uses carbon dioxide gas as the carrier (F. Kawakami MAFF-Japan pers comm. 1998).

Recent tests on Californian Thompson seedless table grapes, potentially an export to Australia, showed that 6 days exposure to 45% CO_2 in air at 5°C had a minor effect on grape quality and provided effective control of the omnivorous leafroller (*Platynota stultana*), western flower thrips (*Frankliniella occidentalis*) and Pacific spider mite (*Tetranychus pacificus*) (Mitcham *et al.* 1995). Further large scale tests for longer exposure periods of up to 15 days at 0°C were planned to determine the commercial applicability of this treatment.

Gamma *radiation* using less than 1000 Gy shows potential for disinfestation of grapes which are damaged by greater than 1000 Gy (Bramlage and Couey 1965; Maxie *et al.* 1971). In general the response of grapes to gamma irradiation is variable (Josephson and Peterson 1983). Other potential alternatives requiring investigation are *heat* treatments and *CAs*.

6.9.8 Root crops

Root crops include yams, potato, sweet potato, cassava, carrot, taro, onion, ginger and garlic. Exports are economically important for a large number of countries and particularly important to the national economies of many of the developing countries.

Root crops are infested by a wide range of pests including weevils, scale, beetles, thrips, mites and nematodes. Because most of these pests can be carried in soil attached to root crops, their entry without treatment is permissible only if soil is not present. Many countries permit imports of root crops, provided the soil has been removed. Currently MB is the only registered treatment for a number of these pests on shipments of garlic and yams imported into the United States and other countries.

6.9.8.1 Existing alternatives

Sweet potatoes from Okinawa were shipped to other parts of Japan after vapour heat treatment at 47 - 48°C for 3 hours and 10 minutes to control sweet potato weevil, west Indian potato weevil and sweet potato vine borer (Anon 1995b).

6.9.8.2 Potential alternatives

Irradiation is being investigated for control of the sweet potato weevil *Cylas formicarius eleganthus* in Florida and in Malaysia for control of nematodes and scale (*Aspidiella hartii*) in ginger (Sidam *et al.* 1994). Irradiation, currently used in many countries to inhibit sprouting of many root

crops, could also be considered to prevent adult pest emergence. *Irradiation* is currently used for disinfestation of garlic in South Africa (Mr Du Plessis, Managing Director Gammatron, South Africa, pers. comm. 1994). *Heat* treatment of sweet potato is also being evaluated in Florida for control of the sweet potato weevil and the banana moth *Opogona sacchari* (Sharp 1994).

Exposure to *heat* in a water dip or moist air requires evaluation because the tolerance of many root crops is unknown. *Pre-shipment inspection* may be possible for some root crops that are free of soil, but this will not be feasible for internal pests such as nematodes. Many of these crops can be stored for relatively long periods of time which suggests *CA* or *cold* treatments have potential for pest control. *Dipping* in dilute insecticide and planting pest *resistant varieties* may also be feasible.

6.9.9 Stonefruit

Stonefruit include peaches, plums, cherries, apricots and nectarines. Exports are economically important for: Canada, Chile, France, Mexico, New Zealand, United States and some South American and Mediterranean countries.

Although stonefruit are infested by a large number of pests, for most countries codling moth, fruit flies, oriental fruit moth, walnut husk fly, mites and thrips are the major pests of quarantine concern.

Some countries, e.g. United States (Yokoyama *et al.* 1987) New Zealand and Canada, have developed a mandatory MB fumigation treatment for exports of cherries and nectarines to Japan. The USDA-APHIS accepts a *cold* treatment alone for some stonefruit including cherries imported from Chile, plums from Israel and apricots, peaches and plums from Morocco (Anon 1992a).

6.9.9.1 Existing alternatives

Australia has set maximum pest levels and accepts *pre-shipment certification* from New Zealand that these are not exceeded on nectarine and apricot exports. About 14 tonnes of fresh plums imported by South Africa from France were *irradiated* at 2 kGy for insect disinfestation (Mr Du Plessis, Managing Director Gammatron, South Africa, pers. comm. 1994).

6.9.9.2 Potential alternatives

Stonefruit tolerate low oxygen *CAs* (0.25 - 0.5% oxygen) (Kader 1985; Ke et al. 1994) for 8 - 40 days depending on the commodity and the temperature. *CA* combined with *heat* may damage the quality of stonefruit (Smilanick and Fouse 1989). The potential for controlling pests under CA at a range of temperatures is currently being determined.

Previous research has shown some varieties of nectarines tolerate 24 hours exposure to *heat* using 41°C moist air to kill some thrips species (Lay-Yee and Rose 1993). Immersion of apricots in water heated from 25 45°C for 10 - 30 minutes damaged fruit quality, probably due to the inoculum in the water being carried into the core cavity of the fruit (Lay-Yee and Rose 1993). Californian nectarines also appear to be tolerant of heat at 4 hours heating to

47.2°C and holding at this temperature for 10 minutes followed by cool storage. In general, nectarines showed few differences from unheated fruit and therefore this treatment shows potential as a Mediterranean fruit fly disinfestation treatment (Obenland 1997).

'Bing' cherries heated in moist air at 47°C for 35 minutes and then stored at 0 ± 1°C for less than 14 days tolerated the treatment (E. Mitcham University of California (Davis) pers. comm. 1993) which may also control codling moth (Neven 1994).

New Zealand, Brazil, Colombia and Ecuador accept a *pest-free period* for walnut husk fly on peach and nectarine exports from the United States (Yokoyama *et al.* 1992; V. Yokoyama USDA-Fresno pers. comm. 1998).

Cherries, nectarines and peaches are the most tolerant of all the stonefruit to *irradiation* and therefore this treatment offers potential for insect control. For example, irradiation could be used up to a dose of 300 Gy on cherries, apricots and peaches as a quarantine treatment with little loss in quality (Drake and Neven 1998). However, some of the irradiated larvae lived for 2 months following treatment (Neven and Drake 1997b) which, if intercepted, would cause concern to many regulatory agencies.

Cherries are particularly tolerant of high carbon dioxide levels generated by a *modified atmosphere* treatment which may be effective for controlling pests. Van cherries, stored in 38 micrometer LDPE bags for 2 days at 38°C, tolerated MAs of about 9% CO_2, 3% O_2 at 98% RH (Brown *et al.* 1998). This treatment holds promise for control of codling moth, medfly and Queensland fruit fly in Australian cherry exports.

Stonefruit were considered likely to tolerate a disinfestation *CA* treatment for the two-spotted spider mite (*Tetranychus urticae*) consisting of 5.5 days under 95% CO_2 in air at 0°C and a *combination treatment* consisting of a 1 day shock treatment in 95% CO_2 or 0.125% O_2 at 20°C followed by 18 days in air at 0°C (Zhou and Micham 1997). *Heated CA* may also provide an effective disinfestation treatment. Neven and Drake (1997b) report that fruit quality was acceptable for up to 2 weeks following treatment of cherries at 45 or 47°C under 1% O_2/15% CO_2 for 45 or 25 minutes respectively. Both treatments achieved 100% mortality of codling moth.

Cherries and nectarines are largely *host-resistant* to codling moth (Vail *et al.* 1993; Curtis *et al.* 1991). Over the past 19 years in the USA, only 8 codling moth larvae in more than 700,000,000 cherries were detected by domestic USDA-APHIS inspectors (Hansen *et al.* 1997). If the pest is present, pesticides applied in the orchard together with sorting in the packhouse (*systems approach*) can achieve a level of security which should meet the requirements of most countries. Nectarine varieties vary in their susceptibility to field infestation levels of codling moth which suggests *commodity resistance* has potential (Curtis *et al.* 1991).

6.9.10 Subtropical fruit

Subtropical fruit include avocado, cherimoya, kiwifruit, feijoa, tamarillo and persimmon, that are economically important exports from: New Zealand (kiwifruit, persimmon, tamarillo); Chile (kiwifruit); France (kiwifruit); and Italy (kiwifruit).

Subtropicals can be infested with a wide range of pests, particularly the two-spotted spider mite on kiwfruit exports to Japan from New Zealand. Mites intercepted on kiwifruit in Japan are typically fumigated with MB on arrival.

6.9.10.1 Existing alternatives

Japan accepts kiwifruit exported from Chile after 14 days *cold treatment* at 0°C to control Mediterranean fruit fly (Anon 1991). Avocado are commercially treated with cold treatment for fruit fly disinfestation when exported from Hawaii to the mainland USA.

Physical removal of pests from feijoa exports from New Zealand is carried out using hand-held air jets (T.A. Batchelor pers. comm. 1998).

Cherimoya (*Annona cherimolla*) can be treated with soapy water (20 seconds in one part soap to 3000 parts water) and wax (e.g. Johnsons Wax PrimaFresh® 31 Kosher fruit coating) to control the mite species *Brevipalpus chilensis* (Anon 1998b). Although the treatment was also effective on limes it was not effective on citrus as the wax was unable to penetrate all regions of the fruit and stalk joints to suffocate mites in these areas (Gonzalez 1997).

States in Australia accept that avocados from Western Australia are free of medfly (*host freedom*) provided they are packed within three days of harvest and stored at less than or equal to 10°C (De Lima 1995).

6.9.10.2 Potential alternatives

Physical removal using an automated system that would orientate air jets toward the stem region of feijoa exports. *Heat treatment* of persimmons up to 54°C for less than 5 minutes, or 3.8 hours at 50°C, may be potential quarantine treatments to control diapausing and non-diapausing two-spotted spider mites (Lester *et al.* 1997); leafroller Lepidoptera and mealybugs (Dentener *et al.* 1996); when the impact of these or similar treatments is not detrimental to persimmon quality.

Freshly-harvested Fuyu persimmons treated in insecticidal atmospheres at 20°C for 3, 5, or 7 days showed slight injury but not sufficient to prevent further consideration of these as a quarantine treatment (Mitcham *et al.* 1997). The insecticidal atmospheres were 0.25% O_2; 0.25% O_2 + 40% CO_2; or air + 40% CO_2.

The LT99s for diapause and non-diapause two-spotted spider mites (*Tetranychus urticae*) on Hayward kiwifruit were 5.4+/-0.1 hours and 8.1+/-0.3 hours respectively when exposed to 0.4% O_2 + 20% CO_2 at 40°C (Lay-Yee and Whiting 1996). The kiwifruit, subjected to 10 hours of these conditions, hydrocooled immediately after treatment and then stored for 8 weeks at 0°C, showed no significant damage.

6.9.11 Tropical fruit

Tropical fruit include avocado, papaya, mango, banana, litchi, pineapple, guava, longan, durian, rambutan, cherimoya, carambola, passionfruit and sapodilla. Exports are economically important to: The Americas, Australia, the Caribbean, India, Indonesia, Malaysia, Mexico,

Philippines, Taiwan and Thailand. For some developing countries, the sale and supply of tropical fruit is very important for the national economy.

Tropical fruit are infested by a wide range of pests including internal and external feeders, Lepidoptera, mites and weevils, but fruit fly is the most predominant. MB is not widely used on tropical commodities because the concentrations required to kill fruit fly typically exceed the tolerance of the commodity (Arpaia *et al.* 1992, 1993).

6.9.11.1 Existing alternatives

Mango exports to Japan potentially infested with *B. dorsalis and B. curcurbitae* are treated by *moist heated* air to raise the pulp temperature to 46.5°C for 30 minutes when exported from Taiwan (Anon 1982a); to 46°C for 10 minutes when exported from the Philippines (Anon 1975); and to 46.5 47°C for 10 - 20 minutes when exported from Thailand (Anon 1993b). Mango exports from Australia to Japan potentially infested with Queensland fruit fly or Mediterranean fruit fly must achieve a pulp temperature of 47°C for 15 minutes (Anon 1996h). *Hot-water* immersion is a USDA-APHIS approved treatment for mangoes potentially infested with Mediterranean fruit fly imported from Mexico, the Caribbean and Central and South America (Anon 1998b). Japan accepts 15 days *cold* treatment at 1.1°C for control of Caribbean fruit fly on carambola exported from Florida (Anon 1990a). Carambola can be *cold treated* at 1.1- 0.6°C for 12 days as a disinfestation treatment for fruit flies when exported from Hawaii to the mainland USA (Armstrong *et al.* 1995).

Papaya exported from Hawaii to Japan is treated with moist *heated air* to raise the pulp temperature to 47.2°C to control Medfly, Melon and Oriental fruit flies (Anon 1972); to 46°C for 70 minutes to control Oriental fruit fly potentially infesting papaya from the Philippines (Anon 1994b); to 45 - 46°C for 30 minutes for papaya (Anon 1986b); and to 43 - 44°C for 3 hours for mango (Anon 1987b) to control Oriental fruit fly shipped to the mainland from the southern islands of Japan.

The duration and temperature requirements for mango immersed in *water* at 46.1°C varies from 65 - 90 minutes depending on the shape and weight of each variety. USDA-APHIS have approved treatments of papaya with dry air to a final seed cavity temperature of 47.2°C achieved over a minimum of 2 hours (Anon 1992a). This treatment for papaya is presented as a Case History at the end of this chapter (Annex 6.1) which summarises the development of an alternative treatment through to commercial implementation.

The *systems approach* based on *pest-free zones* and *periods*, *host resistance* and *host status* has been approved by USDA-APHIS for avocados imported from Mexico to 19 North-eastern states in the USA. Imported avocados are certified free of avocado seed weevil, avocado seed moth, avocado stem weevil, fruit fly and other hitchhikers based on field surveys, trapping and field treatments, field sanitation, host resistance, post-harvest safeguards (e.g. tarpaulins on trucks, screened packhouses) packhouse inspection and fruit cutting, winter shipping only and port of arrival inspection (Firko 1995; Miller *et al.* 1995).

New Zealand requires bananas from Australia to be immersed in a *dimethoate* solution at 500 ppm active ingredient (ai) for 30 seconds at a minimum flesh temperature of 18°C; and

bananas from the Philippines in *fenthion* solution at 100 g ai in 100 litres of water (Armstrong 1994b).

Papaya are treated when slightly immature, but capable of ripening later, because research has shown they are not susceptible to fruit fly infestation at this stage (*commodity resistance*). Pineapple is not a host to fruit fly allowing most exports to occur after pre-shipment inspection. Immature banana is accepted by Japan as free from fruit flies because even though the adults will lay eggs in them, the eggs will not hatch to form mature larvae (Umeya and Yamamoto 1971). Avocado may be resistant to fruit fly attack when grown under well-irrigated conditions and harvested with the stems attached to the commodity (Armstrong *et al.* 1983).

The USDA-APHIS approval (Anon 1995d) of Hawaiian-grown papaya *irradiated* at a minimal dose of 150 Gy as a quarantine treatment has since been superceded by a further regulation (Anon 1997) allowing treatment of papaya, carambola and litchi in Hawaii, or in some northern USA states. Other crops are under consideration. Doses for Hawaiian pests may be as high as 250 Gy. This regulation is limited to the movement of Hawaiian products to the US mainland. Currently, no other country has adopted irradiation as a quarantine treatment.

Control of mango seed weevil (*Sternochaetus mangiferae*) is achieved with 300 Gy of *irradiation* (ICGFI 1994).

Waxing of cherimoya for pest control is accepted for imports by the United States from Chile.

A treatment of 1.1°C for 15 days has been used as a *cold* treatment allowing carambola to be shipped routinely from Florida to California (Gould 1996) and a similar schedule is being examined for carambola exported from Hawaii to the mainland USA.

Litchi imported by Japan from Taiwan (Anon 1980) and China (Anon 1994a) are commercially treated with a *combination* of *vapour heat* and *cold treatment* to control oriental fruit fly.

6.9.11.2 Potential alternatives

Non-chemical options for disinfestation of tropical fruits has been summarised by Heather (1994b) and Shellie and Mangan (1994).

Heat (as immersion in water) has been considered for controlling some species of fruit flies in banana, guava (Gould and Sharp 1992); carambola (Sharp and Hallman 1992); mango (Sharp 1992); and papaya (for the Papaya fruit fly *Toxotrypana curvicauda* found from Mexico to Brazil; Gould 1995).

Heat treatments are under development in Hawaii for mango and litchi (E. Jang, USDA-ARS Hilo, pers. comm. 1998) and for rambutan in combination with 3% SO_2 for 60 minutes prior to heat treatment for red colour retention (R.E. Paull, University of Hawaii, pers. comm. 1993). For litchi, a confirmatory test using 100,000 medfly larvae, the most resistant stage and species of fruit fly found on litchi in Hawaii, showed that, at the holding temperature of 1.1°C, quarantine security (equivalent to Probit 9) was only possible after 16 days at this temperature, but 99.8564% mortality was achievable after only 12 days (Phillips *et al.* 1997). If a level of

security less than Probit 9 was acceptable for tephritids in litchi, a suitable cold treatment could be developed that was not damaging to litchi fruit quality.

Research has been completed at USDA Hilo and submitted for consideration to APHIS on rambutan based on a forced hot-air quarantine treatment against fruit flies (Armstrong, pers. comm. 1998).

The germ plasm of avocado has been screened for resistance to the Caribbean fruit fly using caged adults on fruit and observing the development of eggs (J.D. Hansen, USDA-ARS Miami, pers. comm. 1993) with a view to using *commodity resistance* as a phytosanitary measure.

Film wraps to control fruit fly may be feasible for papaya and other tropical fruit exports (Jang 1990). A *film wrap* treatment for mangoes is under investigation. Recent experiments in Florida have shown Caribbean fruit fly are killed in grapefruit coated with NatureSeal® prior to *heat* treatments for 60 minutes at 48°C (Hallman pers. comm. 1993) and experiments are continuing on other fruit (guava, carambola and mango) and other treatments such as *cold* storage, *irradiation* and *insecticides* (Hallman *et al.* 1994).

6.9.12 Vegetables

Vegetables include green pod (e.g. long beans, french beans, peas) asparagus, broccoli, brussels sprouts; fruit-vegetables such as tomatoes; peppers; and leafy vegetables such as cabbage, cauliflower, lettuce and spinach. Exports are economically important for a large number of countries and particularly important to the national economies of most of the developing countries.

Vegetables are infested by a wide range of pests including fruit fly, weevils, beetles, Lepidoptera, thrips, aphids and bugs. MB fumigation is the predominant treatment when a number of these pests are detected alive on shipments imported into many countries. Some vegetables are sensitive to MB fumigation (Spitler *et al.* 1985).

6.9.12.1 Existing alternatives

Most imports currently rely on *inspection* and release to the market if no live pests are intercepted. Asparagus is fumigated with MB in Japan for control of Lepidoptera and mites and with *hydrogen cyanide* when live thrips and aphids are intercepted. Bell peppers from Okinawa were shipped to other parts of Japan after a *vapour heat treatment* to control melon fly which used to infest this island (Anon 1982b). Tomatoes exported from Australia to New Zealand are immersed in a dimethoate *chemical dip* for control of Queensland fruit fly prior to export (Heather *et al.* 1987). Moist heated air sufficient to raise the fruit centre temperature to 44.4°C for 8.75 hours is an approved quarantine treatment for controlling *Ceratitis capitata*, *Bactrocera dorsalis* and *B. cucurbitae* in bell pepper, eggplant, zucchini, squash and tomato imported into the United States (Anon 1992a). Japan accepts green peppers, tomatoes and eggplant from the Netherlands as free of Mediterranean fruit fly (*host freedom*) (Anon 1993a).

6.9.12.2 Potential alternatives

Methyl or ethyl formate *fumigants* may control pests on leafy vegetables (Spitler *et al.* 1985). Unfortunately, effective concentrations are close to their flashpoints (Aharoni *et al.* 1979; Stewart and Mon 1984). Further research is required to define the tolerance of the pests and commodities to these natural plant products. Environmental and/or health considerations may restrict registration of these and other biocides.

Heat treatment (vapour or dip) may be feasible for some vegetables (e.g. tomato, green pod vegetables) and pests (e.g. thrips); research is required to determine the commodity and pest tolerance.

Tomatoes are currently treated commercially with *irradiation* (Corrigan 1993) a treatment that also appears feasible for asparagus (Markakis and Nicholas 1972). Most leafy vegetables undergo tissue damage at doses of irradiation less than those required to kill pests (Markakis and Nicholas 1972).

Cold treatment may control tropical pests such as fruit fly in tomatoes, particularly if they are picked immature (but capable of ripening under the specific conditions) when they are more tolerant to cold storage.

Cabbages are exported to Japan from New Zealand under in-transit *CA* conditions to maintain quality and this treatment may have potential for controlling pests. Similarly, *CA* cold storage conditions developed to maintain the quality of vegetables transported in containers from the mainland United States to Guam by the United States military were observed to kill aphids and thrips (Gay *et al.* 1994).

6.10 Existing and Potential Alternatives to Methyl Bromide

The range of alternative treatments identified by MBTOC for perishable commodities is summarised in Tables 6.1, 6.2 and 6.3.

Table 6.1 Alternative quarantine techniques, with examples of approved applications for fresh fruit, vegetables and cut flowers

Procedure or teatment	Examples of approved quarantine applications
Cold treatments	Many approved cases see Table 6.2 for examples.
Heat treatments	Mangoes from Australia, Philippines, Taiwan and Thailand to Japan. Papaya from Hawaii to Japan. Tomato, bell pepper, zucchini, eggplant, squash, mango, pineapple, papaya and mountain papaya to USA. Orange, grapefruit, clementine, mango from Mexico to USA Mountain papaya from Chile to USA Citrus, papaya, lychee, from Hawaii to mainland USA. Papaya from Belize to USA. Mango from Taiwan to USA. Ear corn to USA Orchids, plants and cuttings to USA. Chrysanthemum cuttings to USA. Plant material unable to tolerate MB fumigation to USA. Banana roots for propagation to USA. Many bulbs and tubers to USA. Narcissus bulbs to Japan.
Certified pest-free zones or pest-free periods	Melons from a region of China and from the Netherlands to Japan. Squash, tomatoes, green pepper, eggplant from Tasmania (Australia) to Japan Cucurbits to Japan and USA. Nectarines from USA to New Zealand.
Systems Approach	Immature banana to Japan. Avocado. Citrus from Florida to Japan.
Pre-shipment inspection and certification	Certain cut flowers from Netherlands and Colombia to Japan. Apples from Chile and New Zealand to USA. Garlic from Italy and Spain to USA. Nectarines from New Zealand to Australia. Green vegetables to many countries.
Inspection on arrival	Small batches of seeds for propagation to USA.
Physical removal of pests.	Root crops are accepted by many countries if all soil removed. Hand removal of certain pests from cut flowers to USA. Propagative plant materials (unable to tolerate MB fumigation) to USA.
Controlled atmospheres	Apples from Canada to California.
Pesticides, fumigants and aerosols	Cut Flowers from New Zealand to Japan. Asparagus to Japan. Cut flowers from Thailand and Hawaii to Japan. Bulbs to Japan. Tomatoes from Australia to New Zealand. Propagative plant material to USA. Certain ornamental plants to USA.
Irradiation	Plums. Garlic.
Combination treatments	Soapy water and wax coating for cherimoya and limes from Chile to USA. Warm soapy water + brushing for durian and other large fruit to USA. Vapour heat and cold treatment for litchi from China and Taiwan to Japan. Pressure water spray and insecticide for certain cut flowers to USA. Hand removal + pesticide for certain ornamental plants, Christmas trees and propagative plant materials to USA. Heat treatment + removal of pulp from seeds for propagation to USA.

Sources: Compiled from this chapter and USDA-APHIS (Anon 1998b)

Table 6.2 Examples of cold treatments approved for quarantine purposes

Perishable commodity	Examples of cold treatments approved for quarantine
Apple	• From Mexico, Chile, South Africa, Israel, Argentina, Brazil, Italy, France, Spain, Portugal, Jordan, Lebanon, Australia, Hungary, Uruguay, Ecuador, Guyana and Zimbabwe to USA
Cherry	• From Mexico, Chile and Argentina to USA
Grape	• From Chile to Japan. • From South Africa, Brazil, Colombia, Dominican Republic, Ecuador, Peru, Uruguay, Venezuela and India to USA
Citrus	• From Australia, Florida (USA), Israel, South Africa, Spain, Swaziland and Taiwan shipped to Japan • From South Africa (Western Cape) and 23 countries to USA
Orange	• From Israel, Mexico, Spain, Morocco, Costa Rica, Colombia, Bolivia, Honduras, El Salvador, Nicaragua, Panama, Guatemala, Venezuela, Guyana, Belize, Trinidad & Tobago, Suriname, Bermuda, Italy, Greece, Turkey, Egypt, Algeria, Tunisia and Australia to USA • Interstate USA
Clementine	• From Israel, Spain, Morocco, Costa Rica, Colombia, Guatemala, Honduras, Ecuador, El Salvador, Nicaragua, Panama, Venezuela, Suriname, Trinidad & Tobago, Algeria, Tunisia, Greece, Cyprus and Italy to USA • Interstate USA
Tangerine	• From Mexico, Australia and Belize to USA • Interstate USA
Grapefruit	• From Israel, Mexico, Costa Rica, Guatemala, Honduras, El Salvador, Nicaragua, Panama, Colombia, Bolivia, Venezuela, Italy, Spain, Tunisia, Australia, Suriname, Trinidad & Tobago, Belize, Bermuda, Cyprus, Algeria and Morocco to USA • Interstate USA
Peach	• From Mexico, Israel, Morocco, South Africa, Tunisia, Zimbabwe, Uruguay and Argentina to USA
Nectarine	• From Israel, Argentina, Uruguay, Zimbabwe and South Africa to USA
Apricot	• From Mexico, Israel, Morocco, Zimbabwe, Haiti and Argentina to USA
Plum	• From Mexico, Israel, Morocco, Colombia, Argentina, Uruguay, Guatemala, Algeria, Tunisia, Zimbabwe and South Africa to USA
Plumcot	• From Chile to USA
Kiwifruit	• From Chile to Japan • From Chile, Italy, France, Greece, Zimbabwe and Australia to USA
Pear	• From Israel, Chile, South Africa, Morocco, Italy, France, Spain, Portugal, Egypt, Tunisia, Algeria, Uruguay, Argentina, Zimbabwe and Australia to USA
Persimmon	• From Israel, Italy and Jordan to USA
Pomegranate	• From Israel, Colombia, Argentina, Haiti and Greece to USA
Litchi	• From China, Israel and Taiwan to USA
Loquat	• From Chile, Israel and Spain to USA
Quince	• From Chile and Argentina to USA
Carambola	• From Hawaii, Belize and Taiwan to USA
Pummelo	• From Israel to USA
Papaya	• From Chile to USA
Ya pear	• From China to USA
Ethrog	• From Israel, Costa Rica, Ecuador, El Salvador, Guatemala, Honduras, Nicaragua, Panama, Morocco, Spain, Italy, France, Greece, Portugal, Tunisia, Syria, Turkey, Albania, Algeria, Belize, Bosnia, Macedonia, Croatia, Libya, Corsica and Cyprus to USA
Durian	• To USA
Avocado (Sharwill)	• From Hawaii to mainland USA

Sources: Compiled from this chapter and USDA-APHIS (Anon 1998b).

Table 6.3 Number of known cases where countries have approved an alternative quarantine technique for perishable commodities (or groups of similar commodities).

Alternative procedure or technique	Identified cases where a country has approved an alternative quarantine treatment
Systems Approach	4
Pest-free zones or periods	9
Pre-shipment inspection	Many
Cold treatments	210
Heat treatments	34
Controlled atmospheres	1
Modified atmospheres	nil
Physical removal of pests	Many
Pesticides, aerosols, fumigants	8
Combined treatments	11
Total identified to date	> 277

6.11 Commodities Without Approved Non-MB Quarantine Treatments

Although there are many potential alternatives, currently there are no approved post-harvest quarantine treatments to replace MB for the following commodities that have mainly internal feeding pests. In rare cases, however, export of these crops is carried out without MB treatment under agreements that allow pre-shipment certification. If a pest is detected, MB is currently the only approved treatment.

- ***Apple*** exports potentially infested with codling moth to countries free of codling moth. This is important for New Zealand and the United States exports to Japan.
- ***Stonefruit*** (peaches, plums, cherries, apricots, nectarines) exports potentially infested with codling moth to countries free of codling moth.
- ***Grapes*** from Chile potentially infested with *Brevipalpis chilensis* mite on exports to the United States; and grape exports from the USA to countries that currently require MB fumigation.
- ***Berryfruit*** (strawberry, raspberry, blueberry and blackberry). Exports are economically important for the United States, New Zealand, Colombia, Australia, Israel, Brazil, South Africa, Canada and Zimbabwe.
- ***Root crops*** (carrot, cassava, garlic, ginger, onion, potato, sweet potato, taro and yam). Some of these crops are exported in minor volumes (but often economically significant) from developing countries to ethnic groups in developed countries.

6.12 Opportunities to Reduce Emissions

Post-harvest disinfestation of perishable commodities using MB is carried out in fixed-wall structures such as a fumigation chambers, or under tarpaulins.

Controlled conditions allow manipulation of the key fumigation parameters: dose, temperature and time. Greater control is potentially more achievable in an enclosed structure. The dose can be reduced by increasing either the temperature or the time, or both. Forced air circulation could also allow reduction of the dose. MB could be conserved by developing high temperature schedules with or without longer fumigation durations, providing the marketability of the produce is acceptable.

Improving the gas-tightness of fumigation facilities will prevent unwarranted leakage of MB into the atmosphere. Simple test criteria have been provided to the industry for determining the gas tightness of chambers (Bond 1984).

More accurate measuring equipment (weighing scales and measuring cylinder with dispenser) will minimise excessive use of MB. This equipment could also be attached for fumigation from small cylinders (e.g. 5 kg) which would avoid the use of small cans (about 1 kg).

A combination of gases e.g. MB with carbon dioxide and phosphine, allows a reduction in MB, is less phytotoxic to cut flowers and ornamentals than MB or phosphine alone and has the same insecticidal activity (Kawakami *et al.* 1994).

Currently, most fumigation chambers release MB into the atmosphere at the end of the fumigation period. Commercial equipment used to recover MB could be attached to the fumigation chamber, making up to about 80% of the gas available for the next fumigation depending on commodity adsorption and losses to the facility (further detail is provided in Chapter 9: Reducing Methyl Bromide Emissions). However, the use of such systems will depend mainly upon the level of emission reduction required, on the cost-benefit of MB recovery and recycling and regulatory approval for recycling chemicals for use on food that may contain contaminants.

6.13 Research Priorities

The research priorities for alternatives to MB are different for developing and developed countries because each has different market requirements and economic constraints.

6.13.1 Developing countries

Developing countries are largely dependent on technology tested and available in other countries. Assistance should be provided by developed countries for the implementation of specific alternatives. For example, a heat treatment for papaya was developed in the United States (Armstrong *et al.* 1989) and modified by New Zealand for use in the South Pacific (Waddell *et al.* 1993). This process is now used on Cook Island papaya exports, replacing ethylene dibromide which was banned. The project was financed by a consortium of government and private organisations.

The choice of alternatives will be determined largely by the commodity tolerance, the target pest, the potential for success based on previous research and capital and operational costs. Most research in developing countries currently involves heat treatments. There is also some research on irradiation for high value fruit exports because most tropical commodities have been shown to tolerate these treatments.

Currently, grapes exported from Chile to the USA and cut flowers (roses, carnations and statice) exported to Europe, USA, Scandinavia and Japan are the only examples of commodities from a developing country with no alternative treatment.

6.13.2 Developed countries

Most research involves the development of heat, cold, CA, MA and combinations of these alternatives in the short term because these have shown the most potential for many commodities. Treatments based on pre-harvest procedures (inspection, pest-free zones and periods and the systems approach) are also high priority, but are longer term since considerable documentation on pest security is required by regulatory agencies. Irradiation research is usually given medium priority as scientific information on the effects on the commodity and the pest is generally recognised as sufficient, although high priority is given if other alternatives are less promising.

Those commodities with no potential alternative treatment currently available are apples and stonefruit exports to Japan and rootcrops with unacceptable pest levels upon importation into many countries. Therefore these commodities should have a high priority for research.

6.14 Technology Transfer and Training

Funds are required for key personnel to attend conferences, workshops and training courses. Information on post-harvest alternatives must be written in the appropriate technical language and published in scientific journals and bulletins.

Developing countries should request clear guidelines for the development of disinfestation treatments. A technical expert from a developed country may be necessary to assist with experimental design (including equipment, lifestages, commodity quality) and report documentation necessary for demonstrating quarantine security. Ongoing exchange visits to developing countries by scientists and technicians are essential for effective collaboration in projects that test and implement alternatives.

To ensure continuity of skilled personnel, quarantine officers and students should be encouraged to undertake courses essential to the development and implementation of alternatives, particularly those related to plant physiology, entomology, engineering and related areas. International companies with facilities in developing countries should be encouraged to increase their technology transfer expenditures.

6.15 Developing Country Issues

Post-harvest treatments using MB are more common for perishable commodities exported from Asian and Latin American countries than Africa which, apart from South Africa and Zimbabwe, has relatively few exports. MB is mainly used to disinfest cut flowers, vegetables and fruit in Asia and Latin America.

Despite this varying usage, developing countries have similar requirements that include:

- Obtaining the appropriate disinfestation technology.
- Transferring this technology to the local environment.
- Training personnel to carry out new disinfestation treatments.
- Obtaining sufficient funds to allow completion of the research to demonstrate efficacy.
- Training in the commercial use of alternatives.

Ideally, any alternative treatment to MB must be appropriate to the local conditions, i.e., cost-effective, safe to apply, environmentally sound, simple to use and require minimal maintenance. Promising technologies must be tested in the developing countries. Highly skilled personnel are required to adapt the technology to the local conditions, train local staff in its effective use and develop treatment and operational manuals in collaboration with technical staff.

The first priority must be to replace MB with an alternative treatment. However, if this is not possible, an interim strategy must be to reduce the amount of MB released to the atmosphere. This could be achieved by fitting fumigation facilities with recovery equipment as soon as it becomes commercially available. Equipment for recovering and recycling MB requires further technological development before it can be adopted widely and it is likely to be expensive.

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Annex 6.1 Case History : Heat disinfestation treatments for papaya in Hawaii

1. **Commodity:** Papaya, *Carica papaya* L.
2. **Pests:** Mediterranean fruit fly, *Ceratitis capitata* (Widemann)

   Melon fly, *Bactrocera cucurbitae* (Coquillett)

   Oriental fruit fly, *Bactrocera dorsalis* (Hendel)
3. **History:**

Quarantine disinfestation treatments are required for the export of papaya from Hawaii because of the presence of tephritid fruit flies. When ethylene dibromide was banned in the USA in 1984, interest in heat treatments resulted in the development of hot-water immersion, vapor heat (VH) and high-temperature forced-air (HTFA) treatments. The hot-water immersion treatment is no longer used, but the HTFA and VH treatments are still in use today. HTFA and VH treatments are essentially the same treatment except that humidity is held low or the dew point of the air is held below the dew point of the fruit to preclude condensation on the fruit surface during HTFA treatment. The fruit surface is wet during VH treatment and dry during HTFA treatment.

4. **Description of the alternative:**

Methyl bromide (MB) fumigation was tested as an alternative quarantine treatment, but it caused excessive damage (phytotoxicity) to the fruit at ambient temperatures. Further research found that if papayas were heated to 30°C, the fruit would tolerate MB fumigation. Furthermore, high-temperature fumigation permitted reductions in both MB concentration and fumigation time while still providing quarantine security. However, with the availability of HTFA and VH treatments, high-temperature MB fumigation was never used commercially.

5. **Regulatory agency acceptance:**

VH treatment of papaya in Hawaii was accepted by the USA Department of Agriculture, Animal and Plant Health Inspection Service during the 1970s and by Japan Ministry of Agriculture, Fisheries and Forestry in the mid-1980s. HTFA treatment was accepted by USDA-APHIS in 1988. The hot-water immersion treatment was accepted by USDA-APHIS in 1985, then rescinded in 1991 because of regulatory difficulties with the treatment.

6. **Current commercial use:**

Tropical Hawaiian Products, Inc.; Pacific Tropical Products, Inc.; and Diamond Head Papaya Co. Inc., of Hilo, Hawaii, treat all export papayas with either HTFA or VH. In the past three years papaya exports in excess of approximately 60,000 tons were treated with either HTFA or VH.

7. **Was the treatment difficult to develop?**

Yes. The time and temperature combinations required to kill fruit fly eggs and larvae to provide quarantine security are close to the conditions that will cause heat-induced damage to the fruit.

8. **Was the treatment difficult to implement?**

Yes. Engineering problems were encountered when scaling up from laboratory research to the commercial situation; and the regulatory certification and monitoring of commercial equipment presented difficulties.

9. **Is the effect of this treatment on other crops being determined?**

Yes. HTFA and/or VH disinfestation treatments are in use or being researched for atemoya, avocado, carambola, capsicums, citrus, cucumber, eggplant, green beans, guava, mango and zucchini. Hot-water immersion treatments are in use or being researched for carambola, guava, litchi, mango and sapote.

Contributor: Dr Jack Armstrong, USDA-Hilo Tropical Laboratory, Hawaii.

Chapter 7

Developing country perspective

7.1 Summary

Based on official data, MBTOC estimates Article 5(1) countries consume 15,350 - 17,500 tonnes of methyl bromide (MB) per annum which is equivalent to 23-26% of global consumption. MB is used in developing countries mainly as a pre-plant soil fumigant for producing certain high value exports such as tobacco, cut flowers, strawberries, bananas, melons; and tomatoes, peppers and some other vegetables. MB s other significant use in developing countries is for disinfestation of durable commodities. About 70% of MB is used for pre-plant fumigation and about 20% for durable commodities. MB is not used in the production of staple foodstuffs.

The quantity of MB used in developing countries varies widely. Some countries have officially phased out or greatly reduced their consumption over the past four years. Decrease in MB may be due to the use of alternatives such as: (1) non-chemicals (crop rotation, soil amendments and compost, resistant varieties, grafting, cultural practices, soil-less culture, solarisation) and chemicals (metam sodium, dazomet, chloropicrin and others) for soil-borne pests; (2) phosphine (alone or in combination with carbon dioxide) for grain treatment; (3) heat treatments for perishable commodities; and (4) sulphuryl fluoride for structures and non-food commodities.

In contrast, some countries have substantially increased their usage and in some cases production and may increase MB use still further unless alternatives are adopted. Increase in MB use may be due to a combination of factors including: lack of national strategies for phasing out MB; the slow transfer of alternative technologies; marketing of MB by suppliers; and concern regarding pest resistance to phosphine. It is also possible that some countries are importing MB to stockpile as a hedge against price increases.

Developing countries are concerned that MB use may shift from developed to developing countries in the future as a result of earlier phase out in the developed country. In view of the changing pattern of MB consumption in Article 5(1) countries, it would be prudent to monitor both the policies and practices that encourage or discourage the use of MB and its alternatives, in order to avoid developing countries being left with outdated pest control technology.

Alternatives to MB in developing countries are similar to those in developed countries. At present there is no single in-kind alternative for all uses of MB in developing countries. The adaptation of alternatives is often constrained by socio-economic conditions, level of infrastructure and other conditions found in many of these countries. These constraints can

be overcome by actions such as early recognition of problems, a national-international focus on seeking solutions and mechanisms for providing technical and financial assistance.

There are a number of crop protection methods that can, together, address the pest problems for which MB is now used. Potential chemical alternatives to MB can be hazardous to humans and the environment and may require registration, regulation and specific training to promote safe and effective use. It should be noted that MB is also potentially hazardous to humans and the environment, requires skilled application and substantial precautions for safe and effective use. Lack of appropriate skills can be a constraint to use of both MB and alternatives in many developing countries.

While it is possible to use alternative materials and methods to substitute for most MB uses, the conditions prevailing in developing countries require that the alternatives to MB be appropriately adapted to specific climatic conditions, cropping techniques, resource availability and target pests. Some replacements to MB may involve significant effort in areas such as research and field testing to adapt alternatives to local conditions, on-farm demonstrations, technology transfer, user education, institutional capacity building, information exchange and training. Among other agencies, UNEP-IE continues to conduct workshops promoting alternatives to MB in developing countries.

Concern has been expressed regarding future trade restrictions which may be imposed by importing entities upon developing countries that use MB in the production or treatment of export commodities. Such a situation may render the 10-year grace period, currently up to 2015, ineffective. This could be unfavourable to Parties whose growers do not have access to viable alternatives. Furthermore, some Article 5(1) countries report slow progress on implementation of demonstration projects and other conditions necessary to provide growers with the proper pest control strategies to grow, store and export food without MB.

The Executive Committee of the Multilateral Fund under the Montreal Protocol has provided strategy and guidelines for MB projects which will be eligible for funding. A number of projects have already been approved. MBTOC noted that it would be helpful to monitor these projects as part of an overall effort to focus future strategies for the successful adoption of alternatives. Strategies include support for implementation of successful demonstration projects, review of lessons learned from these projects and the need for policy measures and training.

7.2 Introduction

This chapter presents an overview of the current uses of MB in Article 5(1) countries and also discusses the potential and existing alternatives to MB with regard to feasibility, potential problems (including user safety and environmental concerns) as well as other country-specific concerns. In the light of current and future restrictions on MB, this chapter describes Article 5(1) country-specific issues associated with the implementation of alternatives.

Resources such as technological capacity and infrastructure tend to be less in Article 5(1) than in non-Article 5(1) countries. These countries may have social needs which may be more dependent on the agricultural sector than non-Article 5(1) countries. However, it should be noted that in some cases the users of MB in Article 5(1) countries are multi-national corporations.

Several Article 5(1) countries currently use MB for some important aspects of their economies. Issues such as short-term agricultural development, poverty, global inequalities and external debts are often closely linked to the revenue generated by the export of crops which have become dependent on MB.

In addition, in many Article 5(1) countries government regulatory and advisory staff are usually few, with technical assistance for pesticide use often provided by representatives of pesticide manufacturers and distributors. Furthermore, the implementation of chemical alternatives to MB will need to include provision for local extension services and training of local pest control personnel so as to ensure safe and effective use. Implementation of non-chemical alternatives, some of which may require considerable skills, will also require training and good local extension services.

7.3 Methyl Bromide Use in Article 5(1) Countries

MB is a broad-spectrum pesticide that is used as a fumigant in the control of insects, nematodes, weeds, pathogens and rodents. Data on the volumes of MB used for these purposes in Article 5(1) in this Chapter were obtained from a number of sources: the Ozone Secretariat, the 1998 MBTOC survey, UNEP/IE 1998 survey, UNDP 1995 and 1997 surveys, Multilateral Fund project documents, interviews and discussions with National Ozone Officers and MBTOC members. The most recent data and best estimates were used in the preparation of this Chapter.

Various sources have provided estimates of total MB consumption in Article 5(1) countries, varying from about 15,350 tonnes to 17,500 tonnes in 1996. MBTOC s best estimate, based on a review of official sources of data, is 17,323 tonnes in 1996. This figure represents gross consumption because it includes quarantine and pre-shipment uses.

MB consumption in Article 5(1) countries is increasing. In 1992, gross consumption of MB in Article 5(1) countries was about 14,510 tonnes. Official data (see Table 7.7, Annex 7.4) indicate that this figure increased to about 16,356 tonnes in 1995 and to 17,323 tonnes in 1996. This represents an increase of about 19% between 1992 and 1996.

In 1992, MB consumption in Article 5(1) countries accounted for about 20% of global consumption, but by 1996 it had increased to about 25% of global consumption.

Official data for 1996 (Annex 7.4) provide the following gross consumption figures for Article 5(1) regions:

Region	MB consumption (tonnes)	
Latin America and the Caribbean	6,616	38%
Africa (both north and south)	4,269	25%
Asia and Pacific	4,177	24%
Middle East	2,120	12%
CEIT Article 5(1) countries	141	1%
Total for Article 5(1) regions	**17,323**	**100%**

The amount of MB consumed varies widely among Article 5(1) countries. Of the 83 countries reporting data for 1995/6, 30 (36%) consumed less than 50 tonnes of MB; 18 (22%) consumed between 50 and 500 tonnes; 11 countries (13%) consumed more than 500 tonnes; while 24 countries (29%) reported zero consumption of MB (Refer Annex 7.4 - Table 7.7, official consumption data).

MB is used under diverse geographical conditions found in Article 5(1) countries because of its relatively low price and because of its physical and chemical properties. The chemical is used primarily for soil treatments (70%, or probably slightly more); fumigation of durable and perishable commodities (up to 27%); and structures (up to 3%). Quarantine and pre-shipment (QPS) uses are estimated to account for about 21% of the MB consumed in Article 5(1) countries.

The most critical use of MB is on cash-crop exports (e.g. tobacco, cut flower, strawberry, banana and vegetable crops) which are important to the economies of a number of Article 5(1) countries. In addition, some MB is used for QPS as a condition of entry by the importing country, usually a non-Article 5(1) country. It is essential that alternatives to the use of MB for perishable commodities will not only control the target pest effectively but also be accepted by the importing country. The Committee noted that agricultural systems which rely on MB are currently being developed and expanded in some Article 5(1) countries as one method of producing certain high value crops for export. Important uses of MB are shown in Table 7.1

Table 7.1 Important uses of MB in Article 5 (1) countries

Category	Use
Soil treatments e.g. strawberries, tomatoes, peppers, cucurbits, cut flowers, bananas, tobacco	For production of certain high-value export crops to non-Article 5(1) country markets and other high-value uses: • open field crops • glass and plastic houses • nurseries and seed-beds (e.g. tobacco, tomatoes) • re-planting (e.g. deciduous trees) • non-crop uses (e.g. golf courses)
Durable commodities e.g. grains, timber, wood products, dried fruits	• Disinfestation of in-country food stocks, particularly cereal grains held in long-term storage (e.g. Africa for the control of larger grain borer) • Export commodities QPS and commercial treatments required by importing countries and companies, including specific quarantine treatments (e.g. Khapra beetle, larger grain borer) • Disinfestation of imported grain, including food aid, which may be in transit
Perishable commodities e.g. some fresh fruit, vegetables, cut flowers	• Primarily quarantine treatments to meet the requirements of certain importing countries
Transport	• Disinfestation of ships, aircraft and other transport vehicles for rodent control or to prevent the cross-contamination of exports

7.3.1 Trends in methyl bromide use

Analysis of information gathered on MB use in Article 5(1) countries in recent years (Annex 7.4) shows that a number of countries have decreased overall MB usage and an increase in the use of alternatives has been noted. Specifically, between 1994 and 1996, consumption of MB (ie. officially reported gross consumption estimates) decreased in countries such as Iran, Jordan, Kuwait, Malaysia, Malta, Mexico, Mozambique, Panama, Peru, the Philippines and Uruguay. In the same period, MB gross consumption increased in countries such as Algeria, Argentina, Chile, Costa Rica, Dominican Republic, Morocco, South Africa, Vietnam and Zimbabwe. Uganda re-introduced the use of MB in 1995. In view of the changing pattern of MB consumption, continued monitoring of MB and the alternatives used in Article 5(1) is a critical aspect.

Factors which have contributed to an increase in MB use in a particular country should be identified and addressed. In Morocco, the increase of MB usage from 1993 to 1998 is due to increased acreage of some economically important protected crops for export (vegetables, cut flowers and strawberries) and for local consumption (bananas). In China, MB consumption has increased in soil applications partly because MB is now available in small cans and has increased for stored grains due to the development of insect resistance to phosphine.

However, strategies to overcome or avoid insect resistance are well documented and in use. In general, MB use in other Article 5(1) countries is decreasing for grain disinfestation as phosphine is a cost-effective replacement. Improved formulations of diatomaceous earth,

combined with other pesticides as an IPM strategy, have proved to be effective for grain protection in China and may be used to reduce or avoid the need for fumigation in some parts of China.

Since 1994, some programmes for education, information and public awareness on issues relating to MB and alternatives have been held in most Article 5(1) countries. For example, UNEP-IE has conducted regional workshops in Africa, Latin America and Southeast Asia and the Pacific concerning the adoption of alternatives to MB. In addition, the National Ozone Offices, governmental and non-governmental organisations and bilateral and multilateral agencies have held workshops and public awareness programmes regarding MB issues and alternatives. The MB industry has also held promotional seminars for government officials and farmers in a number of Article 5(1) countries. These seminars and public awareness endeavours may have contributed to the MB consumption trends and alternatives noted in this chapter.

An area of concern is the potential of some MB use in non-Article 5(1) countries for agricultural production to move to Article 5(1) countries in the future. This may occur when MB is phased out in a non-Article 5(1) country and some production of the agricultural crop dependent upon MB is transferred to an Article 5(1) country where MB is available and use still permitted. Where such a transfer occurs, it is possible that the quantity of MB used in that Article 5(1) country may increase.

It has been confirmed that some joint ventures involving a non-Article 5(1) and an Article 5(1) country have facilitated transfer of MB-related technologies. For example in China, Israel has introduced the technology for filling of small cans with MB. Another example involves a fumigation company from the United States providing increased amounts and types of formulations of MB to Mexico.

7.3.2 Evaluation and adoption of alternatives to methyl bromide

Presently, there is no single in-kind alternative that can substitute for MB in all of its applications. IPM, a series of procedures combining chemical and non-chemical alternatives, may substitute for the pest control uses of MB in some situations.

Potential and existing alternatives in specific areas of MB are described in other sections of this report. These include IPM systems, cultural practices, other pesticides, heat or cold treatments, controlled atmospheres and irradiation. The choice of alternatives is determined by target pest, crop, soil type and commodity. The potential success of the alternative is usually based upon research findings or experience elsewhere. Since some exported commodities are perishable, it is essential that an effective treatment be accomplished within a short period prior to shipment.

Research alternatives need to focus on specific cash-crop exports for each particular situation, commodity and pest. Country-specific infrastructure limitations and needs (such as training the required policy framework) should be defined early to assure sustainable technology transfer.

7.3.2.1 Alternatives to methyl bromide currently in use in Article 5(1) countries

Annexes 7.1, 7.2 and 7.3 of this document contain several Case Studies on MB alternative materials and methods which are currently being utilised by Article 5(1) countries. These alternatives are not intended to be replacements for all uses of MB. They illustrate some of the tools available to farmers which are effective on the pests that are currently controlled by this pesticide. These Case Studies were chosen to provide a brief sample of the available pest control materials and methods and should not in any way be construed to be the only alternatives to MB.

Annexes 7.5, 7.6, 7.7 and 7.8 of this document contain tables of alternatives now in use or undergoing testing in Article 5(1) countries. The reader should note that each alternative that replaces the current use of MB must be adapted to the specific climatic conditions, crop and pest complex in a given Article 5(1) region. By providing this information, MBTOC does not imply an endorsement or recommendation of either the pesticide or the crop protection system listed in these Annexes. Further, the absence of any pest control material or method should not be interpreted as MBTOC disapproval. In addition, the reader should understand that the information contained in Annexes 7.5 - 7.8 was obtained from a number of different sources, some anecdotal and is considered to be the most recent and best information possible.

7.3.3 Country specific information

The information presented in this section is intended to provide the reader with an overview of the specific uses of MB in several Article 5(1) countries. Where possible, annual use amounts, use trends, specific MB uses, potential alternatives and active alternative research programmes are included in the following sub-sections. MB use data and estimates were obtained from a number of sources and are considered to be the best available at the time this report was drafted. The Committee endeavoured to include the most recent estimates possible. In order to qualify information that may be anecdotal, such data where used, will be categorised as follows:

1. Data from the 1996 Ozone Secretariat documentation.
2. Data from the 1998 MBTOC survey.
3. Data from UNEP/IE 1998 survey.
4. Data from UNDP 1995 and 1997 surveys.
5. Quantity information from various Multilateral Fund Project Documents.
6. Anecdotal information from interviews and discussions with National Ozone Officers.
7. Anecdotal information from MBTOC members.
8. Data in correspondence from Parties.

7.3.3.1 Algeria

The vast majority of MB in Algeria (about 20 tonnes {5}) is used as a post-harvest treatment on dates prior to export where the primary pest is the carob moth (*Ectomyelois ceratanaiae* Zell). Phosphine and carbon dioxide are considered to be the best alternatives to the use of MB

and trials are underway to determine application procedures, fumigation duration and dosages. Both phosphine and carbon dioxide are already in use in Algeria for cereals and appear able to achieve infestation control at a similar level to that provided by MB. Logistical changes brought about by time constraints imposed by the use of phosphine do not appear to be an obstacle to the replacement of MB in Algeria.

7.3.3.2 Argentina

In general, MB in Argentina (434 tonnes in 1995, 498 tonnes in 1997 {7}) is used as a soil fumigant for seed-bed and greenhouse production of tobacco, peppers, cucumber, egg plant, citrus, flowers, tomatoes and strawberries. It is also used to fumigate durable commodities such as grain and wood products and perishable commodities such as fruit. Regional seminars are being held to assist users with the transition from MB and to alternatives.

7.3.3.3 Botswana

According to recent information {5}, Botswana used about 0.6 tonnes of MB in 1997, primarily for soil fumigation in the production of high value export crops such as tomatoes and cut flowers.

7.3.3.4 Brazil

Brazil used about 1,500 tonnes in 1997 {7}, most of which (97%) was used for soil fumigation of seed-beds and nurseries. Tobacco seed-beds used most MB, followed by seed-beds/nurseries for strawberries, cut flowers, cucurbits, peppers. Smaller amounts were used for banana, citrus, coffee and forest tree nurseries. It was also used for the treatment of soil for field strawberry production and greenhouse production of strawberries, tomatoes, peppers, cucumbers, melons and cut flowers.

Alternatives to MB include substrates in seed trays, steam and combinations of crop rotation, solarisation, bio-fumigation and plant breeding. Brazil is investigating alternatives for raised bed tobacco seedling production, including: solarisation, bio-fumigation, dazomet and metam sodium. For low tunnel tobacco seedling production: seed trays with commercial substrate (floating) and paper-pot seed trays with virgin forest soil are used. For plastic house production, raised seed trays with commercial substrate, alone or in combination with solarisation, virgin forest soil in paper pots and commercial substrate (in floating trays) are used. Brazil aims to phase out use of MB in tobacco seed-beds within 5 years.

7.3.3.5 Cameroon

According to recent information, Cameroon used about 25 tonnes of MB in 1996 {5} for QPS, treatment of commodities in storage and for soil fumigation. Most of the MB used both for commodity fumigation and soil treatments was related to the production and export of tobacco. Since tobacco cultivation and export are expected to expand in the future, Cameroon will need alternatives specifically developed for this crop.

7.3.3.6 China

China used about 1,200 1,600 tonnes of MB in 1996 and 2,260 tonnes in 1997 {1, 6,7,8}. Compared with the 659 810 tonnes used in 1995, these were significant increases and were primarily due to increases in soil fumigation of seed beds, greenhouses and open fields. The recent availability of MB in small cans has permitted considerably more farmers to use this material. This factor is expected to result in a significant increase in the use of MB in the near future. About 500 tonnes of the above listed amounts were used for QPS, durable and structural treatments.

The intensive production of fruits, vegetables and tobacco has increased over the past 10 years with market demand and agricultural soil disease problems have increased as well. In 1987, MB began to be used in the production of market vegetables, tobacco, strawberries, flowers and medicinal herbs. After several years of small-scale use, it is now widely accepted by farmers and use is increasing.

Alternatives include grafting, burning of tobacco stalks for soil fumigation, phosphine (alone or combined with carbon dioxide) and sulphuryl fluoride for QPS, durable and structural uses. Demonstration projects for replacing MB used for soil and grain fumigation have been carried out. There are several factories producing MB in China.

The construction of new MB factories was prohibited in 1997.

7.3.3.7 Croatia

According to recent information, about 30 tonnes of MB were used in 1997 {5}, primarily for soil fumigation in the production of tobacco.

7.3.3.8 Egypt

In 1996, Egypt consumed 450 tonnes of MB {1}. The 1995 UNDP Regional Survey indicated that Egypt continues to be the largest consumer of MB for commodity (cereals) disinfestation in Africa.

7.3.3.9 India

In 1997, a total of 170 tonnes of MB was used {1, 7}, but the consumption is showing a downward trend possibly due to a recent decrease in exports. Only very small quantities (21.866 tonnes) for durables and (3.224 tonnes) for structures (aircraft) were used in 1996. On the other hand, the pre-shipment use of MB for a variety of articles like grains (rice), coffee and cocoa beans, dried fruits and nuts, dried herbs and spices, logs, timber, cotton yarn, packaging material and cut flowers has increased recently.

In India, MB is used only for QPS purposes. This use is strictly controlled by the Directorate of Plant Protection, Quarantine and Storage of the Ministry of Agriculture (PPQ&S), Government of India. Only government organisations (quarantine) and government undertakings (Food Corporation of India; Central Ware Housing Organisation) are permitted to use MB under their expert supervision. Private pest control operators, functioning mostly in pre-shipment fumigation, are licenced by the Plant Protection Adviser

after ascertaining their expertise. All other users of MB require permission from the Directorate of PPQ&S.

Instead of MB, which is not used for soil disinfestation in India, the following control methods are recommended for nematode control (Table 7.2).

Table 7.2 Alternative treatments to MB for soil fumigation in India

Crop	Nematodes	Recommendations
Banana	*M. incognita* *Helicotylenchus* sp. *Radopholus similis*	1. Hot water treatment of corms (55^0C for 2 minutes) 2. Carbofuran (0.6g a.i/plant) with Neemcake (1.0 kg/plant)
Chili	Root knot nematodes *M. incognita*	1. Resistant varieties 2. Carbofuran @ 0.6 g ai m^{-2} in nursery beds at sowing time.
Vegetable Crops	*Rotylenchus reniformis*	1. Carbofuran @ 0.6 g m^{-2} in nursery beds at sowing time 2. Resistant varieties 3. Bthoprop @ 0.3 g ai m^{-2}
Ginger	*Pratylenchus delateri* *Nothangnina cesidoplastes* *Rotylenchus reniformis*	1. Neemcake @ 1 ton/ha before planting and carbofuran 45 days after planting @ 1 kg ai/ha 2. Treatment of rhizomes with hot water (45^0C for 2 hr)
Groundnut	*M. javanica*	1. Resistant varieties 2. Castor/mustard/neemcake @ 1 ton/ha 3. Carbofuran @ 4 kg ai/ha
Citrus	*Tylenchulus semipenetrans*	1. Phorate @ 3 kg ai /ha at inflorescence stage

Source: AICRP report on plant parasitic nematodes with integrated approach for their control (1989-94)

7.3.3.10 Iran

In 1996, Iran consumed about 70 tonnes of MB {5}. Most of the uses were for QPS treatments. Soil fumigation use was limited. Alternatives to MB for high-value, perishable exports such as cut flowers, fruits and vegetables are likely to be required in the future.

7.3.3.11 Jordan

In 1996, Jordan consumed about 300 tonnes of MB {5} which was mostly used for soil fumigation in the production of cucumbers and tomatoes.

7.3.3.12 Kenya

In 1996, Kenya consumed about 395 tonnes of MB {1,6,7}, mainly for soil fumigation in the production of high-value crops such as cut flowers.

There appears to be an upward trend in the importation of MB by Kenya despite significant reduction in use by major multi-national flower-growing and exporting countries. This reduction is possibly linked to:

- Parent companies of multinational subsidiaries adopting policies to phase-out the use of MB in conformity with control schedules operating in non-Article 5(1) countries.
- Market forces linked to Codes of Conduct on Flower Production and Trade in non-Article 5(1) countries, which discourage the use of banned/controlled pesticides.

This upward trend in MB use may be as a result of a gradual build-up of soil-borne pests over the last seven years due to the production of flowers on the same land, whereas previously sufficient land was available to allow production from virgin soils. In addition, there have been increases in MB imports as a stockpile to hedge against further price increases.

Alternatives to MB use in Kenya include dazomet for soil fumigation and phosphine for fumigation of durable commodities. Potential alternatives currently being tested include: solarisation for soil-borne diseases and pests, biological control of *Fusarium oxysporum* f.sp. *dianthi* using *Trichoderma* spp.; 1,3,D alone or in combination with captan, metam sodium for the treatment of soil; biopesticides e.g. *Tagetes* spp. for soil treatment; pyrethroids as repellants for storage pests; IPM systems including crop rotation and grafting of roses with resistant root stocks; soil substitutes like vermiculite, volcanic pumice and sand; and raised beds for planting flowers. Large multi-national companies have adopted steam sterilisation for treating soil-borne pests/disease.

In addition, legislation is being strengthened and there is a draft environmental management bill which proposes to control import and export of ODS including MB. Current regulations state that MB can only be used by farmers with technical know-how and therefore imports can only be done on behalf of these licenced farmers.

Some demonstration projects have been identified and are being carried out with assistance from the Multilateral Fund. These include:

- The use of carbon dioxide and phosphine as applied to commodities, grain storage in transit, grain in outdoor storage and grain sealed in bag stacks (Australian government).
- Alternatives to the use of MB for soil fumigation in cut flowers (UNIDO).

In addition, public awareness workshops directed at stakeholders have been held by NGOs and the Ozone Unit of the Kenya government to encourage adoption of alternatives.

7.3.3.13 Lebanon

In 1996, Lebanon consumed 299 tonnes of MB {5}, most of which was used in greenhouses for soil pest control in the production of cucumbers, tomatoes, strawberries and melons.

7.3.3.14 Malaysia

Use trends in Malaysia showed that MB imports from 1995 to 1996 reduced from 56 tonnes to 42 tonnes, but increased slightly in 1997 to 46 tonnes {1,7}. This slight increase was due to increased usage for QPS treatments of agricultural exports and imports.

The use of MB in 1996 was divided as follows: soil 5%; durable commodity 63%; structural 26%; and QPS 6%. Demonstration projects are underway regarding alternatives to MB on timber products. Importation of MB into Malaysia is controlled by permits issued by the Department of Agriculture and application is controlled by a fumigation licence issued by the Ministry of Health.

7.3.3.15 Mexico

Mexico reported gross MB consumption in 1996 to be about 2084 tonnes {1,5}. This was mainly used for soil fumigation in the production of high-value export crops. Approximately 10 million tonnes of grain were fumigated annually in Mexico, 25% of this was treated with MB and 75% was treated with phosphine.

The total quantity of MB used by the official organisations ANDSA (national stores) and BORUCONSA (rural stores) to fumigate grain was reported to be approximately 100 tonnes per year. This quantity has not varied substantially in the last five years. It was also reported that no reductions in the usage of MB for commodity disinfestation were currently taking place.

An additional use of MB was for the fumigation of imported grain in ships. The large grain importation in recent years, varying from 4 to 6 million tonnes per year due to poor harvests, has increased the number of quarantine treatments conducted. This has had a significant effect on the total MB usage. Application of MB for quarantine fumigation conducted on ships is reported to be at the relatively high rate of 57 to 60 gm^{-3} . However, information on the exact quantity of MB used for this purpose was not currently available. MB is a restricted-use chemical and users need a special licence from the Agriculture Ministry to buy the product.

7.3.3.16 Morocco

Morocco had an annual average consumption of MB of about 1085 tonnes {1,7}, most of which was used for soil fumigation (usually in combination with chloropicrin 98:2). The pre-plant rates of MB used for soil treatments varied from 70 gm^{-2} to 100 gm^{-2}, primarily for greenhouse soil used in the production of vegetables, strawberries and bananas with about 2,300 hectares fumigated in 1995. Strip fumigation, as opposed to whole field fumigation, could reduce MB use by two-thirds.

7.3.3.17 Philippines

MB imports into the Philippines fell from 107.5 tonnes in 1993 to 63.4 tonnes in 1994 {7}, largely due to the change in use pattern among the institutional users. Soil uses in banana plantations and golf courses accounted for 54.2% (34.36 tonnes) of the total amount

imported in 1994. In banana plantations, MB is important as a curative control of *Pseudomonas* sp., the causal organism of Moko disease. This disease can destroy a plantation in a few weeks if left unchecked - a critical factor as banana exportation is the main income-generating industry in the Philippines.

MB imports declined partly because dazomet was registered to replace some of the MB usage in banana plantations and golf courses. However, the performance of the pesticide is not fully proven in this situation and it costs almost three times more than MB. The production area for export banana in the Philippines is increasing and a recent study shows that MB consumption will increase as a result. The Philippines is planning a project for banana growers, to demonstrate several alternatives from other countries, aiming to halt and reverse the increase in MB consumption.

For the golf and turf industries, disease and weed control are important factors and while MB has been used, alternatives can replace such uses without a significant economic problem. Quarantine treatments accounted for 37.9% (24.08 tonnes) of MB consumed in 1994, a use largely dictated by importing countries such as Australia and New Zealand. Exported commodities include banana, nuts, furniture, baskets, abaca fibers and glassware in wooden crates. Since the income generated from such exports is critical to the Philippine economy, quarantine requirements bind this sector to dependence on MB. Commodity fumigation accounted for 7.7% (4.9 tonnes) and post-harvest treatments accounted for 0.13% (80 kg) of the total volume of MB imported in 1994.

For commodity fumigation, phosphine is the most likely replacement, especially for wood products where quarantine regulations allow. Controlled atmospheres combined with phosphine have been used successfully in grain storage facilities where grain is stored for a long period of time as food reserves.

In regard to regulatory issues, it should be noted that MB is a restricted use pesticide and can only be used by certified fumigators. Adequate time for aeration is required after a MB treatment before commodities are processed into food or feed. The Committee on Environment and Natural Resources of the Philippine Senate has conducted public hearings on the environmental impact of MB use on golf courses.

7.3.3.18 South Africa

In 1996, South Africa imported 1,265 tonnes of MB {1}. There were no exact figures on how much of the imported MB was used for which crops or commodities or where it was used. The greater proportion of MB was used for soil fumigation in the replant of fruit trees, perennial trees and tobacco nurseries, as well as tomato and strawberry crops.

Phosphine is the preferred grain fumigant and very little, if any, MB is used for this purpose. MB use for quarantine is estimated as less than 40 tonnes {7}.

The South African crops that depend upon MB protection are generally regarded as high value crops. In certain instances, e.g. the fruit industry, MB is used for replant problems of deciduous fruit trees.

The National Department of Agriculture (NDA) promulgates the following regulations to control the use of MB:

- No MB may be sold to, or applied by, any person who is not a qualified fumigator.
- Where soil fumigation requires that the soil be covered for MB containment, only VIF (Virtual Impermeable Film) may be used instead of the ordinary polyethylene sheeting previously allowed.
- Small 2 lb containers are banned.

Research to identify replacements for MB has been limited and uncoordinated.

Of prime concern at the moment is the lack of precise use data on how much, for what crop, where and under which specific conditions and for what pests/problem MB is used. This information is considered to be essential for setting priorities and planning research.

7.3.3.19 Syria

Syria has an annual average consumption of MB of 280 tonnes {5,1} with most of this used for post-harvest, storage and quarantine treatments. The use of MB for soil fumigation is limited.

7.3.3.20 Thailand

Imports of MB into Thailand were as follows: 1994 - 590 tonnes {2,8}; 1995 - 567 tonnes {2,8}; 1996 - 642 tonnes {2,8}; and 1997 - 602 tonnes {2,8}. The recent decrease was due to increasing use of phosphine for commodity fumigation. Soil and structural fumigations are no longer conducted.

Over 95% of MB consumption in Thailand is for pre-shipment, phytosanitary requirements for the export of rice and corn. A small quantity is also used for fumigating perishable commodities, such as cut flowers (orchids) and asparagus exports.

A demonstration project involving the use of phosphine mixed with carbon dioxide, carbon dioxide alone and integrated commodity management is being conducted by UNIDO. The Ministry of Defence regulates the importation of MB and the Ministry of Agriculture regulates the application for agricultural commodity disinfestation.

7.3.3.21 Turkey

Turkey used about 841 tonnes {5} of MB in 1997, about 60% of which is used for soil fumigation, 30% for commodity and structural treatments and 10% for QPS uses. Most of the soil fumigation occured in the Mediterranean regions of the country for production of high value export vegetables and ornamental crops.

7.3.3.22 Uruguay

In 1997, Uruguay used about 27 tonnes {5} of MB, primarily for soil fumigation for crops such as tomatoes, cucumbers and peppers under plastic cover. Alternatives such as solarisation, bio-fumigation, other pesticides, cultural practices and other pest control techniques are being examined as part of an integrated pest management system.

7.3.3.23 Vietnam

In Vietnam, use of MB has increased progressively in recent years (1990 and 1997). It is used only for the control of insects in commodities intended for export, particularly rice. None is used for soil fumigation.

The rapid increase in MB use was associated almost entirely with a substantial increase in rice exports, with Vietnam currently being reported as the world s third largest exporter. In 1997, rice exports were of the order of 3.5 million tonnes, most of this being treated with MB before shipment and usually as a condition of the purchase contract.

Other commodities, including coffee, cocoa beans and timber are increasingly exported from Vietnam and also require pre-shipment fumigation. Minimal MB for disinfestation of perishable commodities was reported.

The Ozone Office in Vietnam notes that, because of increasing commodity exports, there is expected to be at least a three-fold increase in the use of MB in the next eight years.

Main uses for methyl bromide by sector (tonnes in 1996):

Soil	Durable commodities excluding QPS	Structures excluding QPS	Quarantine and pre-shipment (QPS)
Nil	34.0	nil	280.0

Data source: Ozone Office, Vietnam

Trends in use of methyl bromide (tonnes):

1990	1991	1992	1993	1994	1995	1996	1997
50	50	74	85	108	310	314	350

Data source: Ozone Secretariat, Vietnam and UNDP Survey 1995

7.4 Fumigation of Soil

7.4.1 Current uses of methyl bromide

In Article 5(1) countries, about 70% of the total imported MB is used for pre-plant soil fumigation to control soil-borne pests. This pesticide is used for fumigation of seed-beds, nurseries and fields (open and covered) for certain crops such as tobacco, flowers, vegetables, bananas, strawberry and forest tree production. The chemical is also used to a limited extent to fumigate soil when perennial fruit trees are replanted such as apples, pears, citrus and guava, among others, as well as for turf production and golf courses.

In most Article 5(1) countries, MB use on soils is related to production of high-value export crops with very little (less than 2%) being used for the production of food for in-country consumption. The Committee was not aware of any MB used in the production of staple foodstuffs such as rice, maize, wheat and beans.

7.4.2 Alternatives to methyl bromide

The current status of the use of alternatives to MB on crops grown in Article 5(1) countries is shown in Annex 7.5. Some alternative soil pest control methods have been developed and adopted commercially for the major crop uses in Article 5(1) countries including cut flowers, tomatoes, strawberries, bananas, tobacco seed-beds, peppers, cucurbits and nursery crops. Some of these alternatives have now been adapted to a variety of soil types, climates and regions. However, some of the alternatives are still undergoing adaptation, development and field evaluation prior to their general acceptance.

The various alternatives and techniques for soil uses consist of chemical and non-chemical technologies. Commonly used non-chemical techniques include IPM practices such as soil amendments, sanitation, cover crops, resistant varieties, composting, soil-less culture and soil solarisation. Chemical alternatives include dazomet, 1,3-dichloropropene and metam sodium.

These alternative materials or technologies may require additional research and development and demonstrations of cost-effectiveness, availability and applicability to the special needs of Article 5(1) countries, for ease of adoption. In many cases combinations of measures are required to control the range of pests now managed using MB. Examples of alternatives already in use include conventional seed trays for tobacco seed-beds in countries such as Zimbabwe and Brazil; solarisation for cucurbits in Brazil, Jordan and Morocco; steam for cut flower production in Brazil and Columbia; and soil-less cultures for strawberries in Indonesia and Singapore and for vegetables in Morocco.

Field trials on a number of alternative methods are currently being conducted in some Article 5(1) countries including steam in Kenya, biofumigation, use of antagonistic plants and soil amendments in Morocco. A low-cost method that shows promise is bio-fumigation, the tilling in of brassica crops and/or seed cakes (neem or mustard) that give off volatile chemicals that suppress soil-borne pathogens.

Solarisation is another alternative to MB which is already used in a number of Article (5)1 countries for controlling soil pests. This pest control method has been widely adopted where climatic and soil conditions are suitable and can be used in combination with other pest control methods in an IPM system such as in Morocco. This method has been evaluated in tropical areas with success, proving effective in controlling pests and giving yields similar to those in fields treated with MB.

IPM strategies employing a combination of pest control techniques have also been successfully adopted for various crops in certain regions in Article 5(1) countries. Examples of IPM systems which involve the use of cultivation practices and selected pesticides can be seen for strawberries grown in Zimbabwe and Guatemala and for protected vegetables in

Morocco. Mixed cropping with *Tagetes* spp. controls nematodes on vegetable fields in India, Kenya, Vietnam, Uganda and Morocco.

It is important to recognise that many of the pest management practices that are being used in one Article 5(1) country or region can be applied or modified for use on other crops or in other Article 5(1) countries or regions. Information sharing between Article 5(1) countries, technology transfer and farmer education and training workshops are important in promoting the adoption of alternatives in other countries and regions.

It is apparent that significant work still needs to be done to enhance confidence in and promote the adoption of alternatives to MB in some Article 5(1) countries. In particular, it is critical that future efforts continue to focus on field testing (on-farm demonstrations) the evaluation of efficacy, as well as the essential elements of technology transfer programme which will ensure the adoption of alternatives. Field demonstrations, farmer education and training are integral components of these technology transfer endeavours. Significant technical assistance and financial support, under the provisions of the Montreal Protocol, are critical to achieve these goals.

Although some demonstration projects have already been funded and are being implemented under the Multilateral Fund, it is important that the success factors leading to the widespread adoption and use of these alternatives are defined.

7.5 Fumigation of Durable Commodities and Structures

7.5.1 Current uses of methyl bromide

MB continues to be used in some situations in Article 5(1) countries to fumigate commodities such as grains, beans, dried spices, wood, timber and wood products, bamboo ware and tapioca; and structures such as silos, warehouses and containers. Commodities are also frequently fumigated with MB prior to import or export because of QPS requirements.

In parts of eastern and southern Africa, MB is used to fumigate some durable commodities such as dried spices, timber and wood products, coffee and grain. In some Latin American countries MB is used for the fumigation of durables such as coffee, rice, cotton, maize, wheat, beans, peanuts, soya bean, sorghum and timber. On an annual basis, of the total quantity of MB used in Article 5(1) countries, about 20% (19.5%) is estimated to be used for the fumigation of durables. Although the total quantities of MB used by Article 5(1) countries for fumigating durable commodities is generally small, its use is economically important for some countries. For example, in Thailand and Vietnam, a large proportion of the exported rice crop is treated with MB.

In some Article 5(1) countries, particularly those exporting large quantities of cereals such as rice, the major use of MB is the disinfestation of these commodities prior to export. These treatments are mostly conducted as a condition of the purchase contract, with buyers usually specifying both the fumigant to be used and the rate at which it must be applied.

Past experience of incomplete control of insects because of unsatisfactory fumigation in exporting countries has meant that purchasers contracts frequently specify very high rates of

MB application. Under these circumstances, exporting countries have little choice other than to follow the contract requirements. Although purchase contracts increasingly specify the use of phosphine for pre-shipment fumigation, the proportion of these is small in comparison to those specifying MB. Where no fumigant is specified in contracts, MB is generally used because of the much shorter time period in which treatments can be completed. However, some markets are now specifically requesting that MB should not be used, in which case it is critical that alternatives are made available.

Small quantities of MB (less than 3% of Article 5(1) country consumption) are used for empty structures, including warehouses, flour mills, ships, aircraft and other transport vehicles. Fumigation of ships and aircraft is usually conducted to satisfy quarantine requirements.

7.5.2 Alternatives for durables and structures

Phosphine is registered in most Article 5(1) countries and remains the major alternative to MB for disinfesting commodities. However, MB is still used, especially where treatment has to be completed rapidly because of time constraints (which in some cases can be overcome by changes to logistical management).

Phosphine is an effective alternative fumigant which, when used and properly applied, can directly substitute for MB in many durable commodity applications. In most Article 5(1) countries, as in the rest of the world, it is the fumigant of choice for protection of most stored products. In some situations (grains stored in bag-stacks) which are neither quarantine nor pre-shipment, MB continues to be used largely because of habit rather than the specific advantages of the material.

Whilst phosphine can be used as an alternative to existing uses of MB, there are constraints which need to be considered. However, a new method for rapid on-site generation of phosphine gas (the Horn Generator) may overcome some of the constraints listed below.

- Phosphine requires a longer fumigation period than MB for full effectiveness. This may delay importation or exportation processes to such an extent that it may be difficult to accommodate logistically. Use of phosphine with carbon dioxide and heat can reduce the period for fumigating structures compared to using phosphine alone.
- There is a potential of fire hazard during application if solid phosphide formulations get wet or are handled improperly or carelessly.
- Currently available solid formulations generating phosphine gas are not suitable for very dry conditions because of the long time period required for gas release. Due to this constraint, fumigation with phosphine is generally not recommended where grain moisture content is less than 9%.
- Insect pest resistance to phosphine has been identified in several Article 5(1) countries.

The major concern arising from the improper use of phosphine is the emergence of strains of pests resistant to this fumigant. However, this can be prevented or overcome if good management strategies and practices are observed when using phosphine.

Phosphine is the principal alternative chemical that is available for structural fumigation. However, the disadvantage of phosphine in structural fumigation is that it reacts with and corrodes copper-containing materials and chemically similar metals that may be found in machinery and ancillary electrical equipment.

The potential use of CO_2 as an alternative to MB has been successfully demonstrated for stored grains in bag stacks in Zimbabwe. In Indonesia, this technique has been routinely used under some circumstances for approximately ten years. Additional trials have been conducted on the use of CO_2 in vertical grain silos in Kenya. The local availability of the gas in Kenya from a volcanic source was found to be a major factor in the cost-effectiveness of this method. Carbon dioxide and phosphine are used in the Philippines and Brazil to protect grain reserves from stored product pests.

Timber exported from Indonesia that currently requires MB treatment is mostly shipped as whole logs. These are de-barked, sawn, dried and worked into valuable forest products in the importing country. However, logs could be debarked and cut in Indonesia and treated with either heat or pesticides as necessary, prior to export.

Other potential chemical alternatives for pest control in structures include fumigants such as sulphuryl fluoride (not recommended for structures containing foodstuffs) and hydrogen cyanide (not very penetrative and a fire hazard). While sulphuryl fluoride is registered and available in China, it is not currently registered in other Article 5(1) countries. Surface spray pesticides such as chlorpyrifos-methyl, pirimiphos-methyl, fenitrothion, malathion and other contact insecticides can be utilised where approved. A new technique under evaluation is the use of heat in combination with diatomaceous earth.

A systems approach or single technologies are currently used in many Article 5(1) countries for disinfestation of durables where MB could be used. For example, in Indonesia, rice stocks are routinely fumigated with carbon dioxide on a large scale in years when there are stocks to be carried over from one season to the next. It has also been used experimentally in Papua New Guinea for protection of stored coffee.

Alternative technologies available for treatment of durable commodities include sulphuryl fluoride (for timber), carbon dioxide, heat treatments, hermetically sealed storage, controlled atmospheres, irradiation and combined treatments such as protein coating with steam (for spices) and vacuum steam flow processes (for leaf tobacco). However, these technologies may be appropriate for some commodities only and may require additional research and capital investment to adequately replace MB where rapid disinfestation is needed. Chemicals generally need local registration before they can be introduced.

7.6 Fumigation of Perishable Commodities

7.6.1 Current uses of methyl bromide

MB is sometimes used to fumigate perishable agricultural products such as cut flowers, stem cuttings, bud-wood, rooted plants, bulbs, corms, rhizomes, fresh fruits, including grapes, bananas and vegetables prior to export. This can be an important use of the chemical in some Article 5(1) countries and is estimated to account for about 8% of MB consumption.

The majority of this usage is because of the quarantine and other phytosanitary requirements of importing countries.

Examples of perishable commodities, some of which are currently treated with MB and their economic importance include:

- Cut flowers in Kenya account for 13% of the total foreign exchange earnings (US$42 million in 1992).
- In 1997, cut flowers exports for Thailand had a value of US$20 million.
- Grapes exported from Chile to USA had a value of about US$300 million.

It should be noted that the treatment of perishables is usually driven by the requirements of the importing country and the prevalence of quarantine pests and often falls within the QPS exemption. For example, all grapes from Chile exported to USA are currently treated with MB as a quarantine requirement.

7.6.2 Alternatives for perishable commodities

Alternative quarantine treatments or procedures already approved by certain countries include pre-shipment inspection, pest-free zones or periods, systems approach, cold and/or heat treatments, controlled atmospheres and physical removal of pests or soil. For example, cold treatments are used for apples exported from Chile, Jordan, Mexico and Uruguay to the USA; for plums and apricots from Morocco to the USA; and for kiwifruit from Chile to Japan. Heat treatments are used to disinfest papaya, mango, citrus, eggplant, zucchini, squash and bell pepper and could be developed for a wide range of perishables. In many situations, combined treatments are necessary, such as soapy water with wax for cherimoya exported from Chile and vapour heat with cold treatment for litchi exported from Taiwan.

Each treatment is dependent upon the commodity, the target pest and the geographical area of origin, as well as the requirements of the importing country. Some of the treatments listed above are already used to a limited extent in specific countries. Limitations and constraints include: capital and operational costs; lack of country-specific research; lack of technical know-how; incorrect application; and in particular, the need for quarantine acceptance by the importing countries. However, some alternative treatments give improved retention of quality in transport and storage compared to fumigation with MB.

7.7 Quarantine and Pre-shipment Uses

For a full discussion of this issue and an explanation of the definitions used by the Montreal Protocol, as well as further information relevant to QPS, please refer to Chapter 8.

7.7.1 Relevance of QPS to Article 5(1) countries

Some Article 5(1) countries that import and export large quantities of cereal commodities are heavily dependent on fumigation to satisfy their own or other countries quarantine regulations, or because purchase contracts specify the need for a treatment. Examples of countries in which pre-shipment fumigation is of major significance are Thailand and

Vietnam. Both of these countries export large quantities of rice, almost all of which is fumigated with MB immediately prior to shipment. Treatments are completed in 24-48 hours. A change to another method of disinfestation such as phosphine would require a much longer treatment period and would severely disrupt the present storage and export system, particularly where fumigation has to be conducted at short notice.

Fumigation is equally important in some countries in connection with imported commodities. On inspection at destination ports, durable commodities such as grains are often found to be infested on board ship. The plant protection authorities of many countries will not allow unloading to commence until the commodity has been disinfested, irrespective of whether or not the infestation is due to a quarantine pest. In order to avoid demurrage or other port charges it will be necessary to fumigate the ship as quickly as possible and for this reason MB is almost always used.

Until local plant protection authorities relax their requirement allowing greater use of on-board fumigation of infested commodities the present system will continue to operate. However, where the infestation is due to common pest(s) known to exist in the importing country and where warehousing space is available, it may be difficult to justify why a ship containing such an infestation should not be unloaded and the fumigation conducted on shore using phosphine.

7.8 Replacement of Methyl Bromide

Now that a phase-out schedule has been agreed by the Parties to the Montreal Protocol for Article 5(1) countries, the complete replacement of MB takes on greater importance involving not only site-specific agricultural trials and demonstrations, but also changes in agricultural practices, including relevant economic and social processes. Examples include:

- The creation of awareness about the Montreal Protocol, ensuring that adequate technical information is made available at all relevant levels.
- The determination of the capacity of various Article 5(1) countries in terms of technological capabilities, manpower resource base and the availability of funds to implement alternative pest control methods.
- The development and production of training and public information materials for distribution to the relevant authorities and personnel such as technical staff, local farmers and the public sector.
- The implementation of reliable programmes to ensure a quick field adoption of alternatives.
- The need for an overall policy at a national level to support the adoption of alternatives, and retard potential growth of MB use.
- The need to explore the possibility of market measures and commercial initiatives to support MB phase-out.

Among the technical strategies necessary for Article 5(1) alternatives to MB use, there is a need for the following specific research priorities:

- Implementation of IPM practices, which include non-chemical technologies (e.g. using healthy stocks for propagation, crop rotation, biological control) and chemical pesticides when needed.
- Research to identify, adapt and implement alternatives that are effective, environmentally sound, easy to apply, safe to users and affordable and specific to local conditions, crops and target pests.
- Technology transfer to enable Article 5(1) countries to evaluate and implement the use of alternatives.
- Training of local technical staff as part of the process of technology transfer.
- Alternatives possibly through farmer exchange programmes between countries.

7.8.1 Technology transfer issues

Technology transfer is one of the major issues relevant to Article 5(1) countries in the replacement of MB. In order to facilitate increased adoption of existing alternatives, a number of factors need to be considered which have proved to be useful in the successful transfer of know-how and technology. Large and small-scale IPM training and technology transfer programmes have been successfully implemented in diverse regions of the world, including many Article 5(1) countries. These programmes have identified the following critical components:

- Precise definition of target groups and their plant protection problems.
- Creation of a legislative and agricultural policy framework at a national level to promote alternatives, including reviewing and/or amending pesticide regulations and farm subsidies.
- Establishment or improvement of locally-based agricultural extension services.
- Participation and co-operation of all stakeholders in the design of IPM systems including: farmers; extension agents; government agencies; agricultural researchers; agricultural institutions; farmers who already use successful alternative techniques; companies supplying alternative equipment and services; NGOs; and buyers.
- On-farm development and training conducted by farmers who will provide leadership for future initiatives.
- Information programmes for rural students.
- Farmer training on pest monitoring skills, including appropriate IPM system practices.
- Establishing farmer groups, with extension agents and/or researchers where possible, to allow sharing of experiences, discussion of field problems and exchange of information.

It is also important that such technology transfer be supported by activities that would ensure the sustainability of the adoption of these alternatives (Table 7.3).

Table 7.3 Support activities needed to ensure alternatives are adopted in developing countries

Extent of programme	Necessary support activities
Global	• Information materials • Inter-agency co-operation • Initiatives with companies that purchase crops and commodities (e.g. tobacco companies, auction houses, supermarkets and food processing companies)
Regional	• Awareness/motivational workshops • For specific crops: farmer to farmer exchanges
National	• National phase-out strategy including a broader policy and institutional framework • Sector-specific workshops and demonstration projects • For specific crops: farmer to farmer exchanges • Training for farmers and extension agents including the preparation of necessary training materials • Public information programmes and information exchange

7.9 Technical Issues Related to the Multilateral Fund

Decisions on MB made during the 9th Meeting of the Parties to the Montreal Protocol in September 1997 include a provision of US$25 million per year in 1998 and 1999 for the purpose of identifying, evaluating, adapting and demonstrating MB alternatives and substitutes for Article 5(1) countries. This will facilitate compliance with the control measures on MB.

7.9.1 Multilateral Fund guidelines for projects

The 24th Meeting of the Executive Committee of the Multilateral Fund held in Montreal in March 1998 approved a Strategy and Guidelines for MB projects. The Strategy is intended to assist the Executive Committee in allocating resources to the MB sector, as a response to the decision of the Meeting of the Parties. These do not cover QPS uses of MB because they are exempted from Montreal Protocol controls.

The guidelines categorised users of MB into three groups, namely:

- Countries that traditionally use MB for more than QPS.
- Countries that are new users of MB and/or are increasing their use.
- Countries that use little or no MB.

It was agreed that the provisions on MB under the Montreal Protocol are applicable only to those countries that have ratified the Copenhagen Amendment. This also applies to funding support for MB phase-out projects under the Multilateral Fund. However, projects on information exchange and policy development can be made available to Article 5(1) countries that have not yet ratified the Copenhagen Amendment on the condition that they give a firm commitment to ratification.

Three main project categories open for funding under the Multilateral Fund are:

- Demonstration projects.
- Investment projects.
- Non-investment projects.

Demonstration projects are those whose prime objective is to demonstrate the efficacy of alternatives to facilitate the broader implementation of investment projects with a view to phasing out MB use. These projects are expected to have strong evaluation and information dissemination components so that the results of such projects can be widely distributed both within the country and also to other countries that will benefit from the results. Some commitment is also expected regarding the development of successful demonstration projects into full investment projects where suitable.

Investment projects are projects whose primary objective is the reduction of MB consumption by putting in place clearly effective and available alternatives. The incremental costs for these projects will be calculated based on the Multilateral Fund s existing policies and guidelines. In addition, such projects will need to be supported by a package of policy measures in the country in order to ensure that the phase-out will be sustained.

Non-investment projects are those that focus on creating and disseminating information and/or educating MB users and other interested parties. This project category also includes the provision of policy support to Article 5(1) countries as needed, as well as training support.

The main priority for funding support will be demonstration and investment projects that have wide global benefits, which should also focus on crops and processes that represent significant use and on alternatives that have global applicability. Non-investment projects will also prioritise dissemination of information materials, hold targeted and structured workshops and provide assistance for creating policy instruments for Article 5(1) countries.

7.9.2 Ongoing and planned demonstration projects

In accordance with the strategy and guidelines adopted for MB projects, a number of demonstration projects are being implemented under the Multilateral Fund of the Montreal Protocol in Article 5(1) countries. Likewise, project preparation funds have also been approved, which would eventually result in the identification and development of new MB demonstration projects (Table 7.4).

Table 7.4 Countries where MB demonstration projects are being prepared or implemented (as of July 1998)

Country	Crops or commodities	Agency
Algeria	Demonstration projects	UNIDO (project preparation)
Argentina	Tobacco	UNDP (project preparation)
Argentina	Tomatoes, cut flowers and strawberries	UNIDO
Argentina	Citrus and Cotton	World Bank (project preparation)
Botswana	Grain	UNIDO (project preparation)
Botswana	Tomatoes, cucurbits	UNIDO
Brazil	Tobacco	UNIDO
Brazil	Flowers, tomatoes, cucumbers, strawberries	UNDP (project preparation)
Cameroon	Tobacco	UNIDO
Chile	Tomatoes and peppers	World Bank (project preparation)
Chile	Nurseries and seed-beds for apples/kiwis	UNDP (project preparation)
China	Cucumbers, tomatoes, tobacco, strawberries and medicinal herbs	UNIDO
China	* sectoral policy plan	UNEP
China	Grain storage	Canada
Colombia	Project formulation for investment projects	UNIDO
Croatia	Tobacco, tomatoes	UNIDO
Cuba	Tobacco	UNIDO (project preparation)
Dominican Republic	Tobacco, cucurbits, flowers, tomatoes	UNIDO (project preparation)
Ecuador	Cut flowers and tobacco	World Bank (project preparation)
Egypt	Strawberries, tomatoes and cucurbits	UNDP (project preparation)
Guatemala	Broccoli, melon, tobacco and tomatoes	UNIDO
Indonesia	Demonstration project	UNIDO (project preparation)
Indonesia	Tobacco, tomatoes, peppers	UNIDO (project preparation)
Iran	Demonstration project	UNIDO (project preparation)
Jamaica	Tobacco	UNIDO (project preparation)
Jordan	Cucumber and tomatoes	UNIDO
Kenya	Grain storage	Australia/UK
Kenya	Cut flowers	UNIDO
Korea	Demonstration project	UNIDO
Korea	Rice and maize	UNIDO (non-investment project to promote transfer of alternatives)
Lebanon		UNDP (project preparation)
Macedonia	Tobacco, pepper and tomatoes	UNIDO
Malawi	Tobacco	UNDP
Malaysia	Timber	UNDP (project preparation)
Mexico	Flowers and crop storage	UNDP (project preparation)
Mexico	Tomatoes, strawberries, tobacco, melons, cut flowers	UNIDO
Morocco	Horticulture	UNIDO
Pakistan	Tobacco, tomatoes and cucurbits	UNIDO
Peru	Demonstration Project	UNDP (project preparation)
Philippines		UNDP (project preparation)
Romania	Demonstration Project	UNIDO (project preparation)
Senegal	Tobacco and peanuts	UNIDO (project preparation)
Sri Lanka		UNDP (project preparation)
Syria	Grain and cut flowers	UNIDO
Thailand	Grain storage	UNIDO
Tunisia	Post-harvest disinfestation of palm dates	UNIDO
Turkey		World Bank (project preparation) IBRD
Turkey	Tomatoes, cucumbers, carnations	UNIDO
Uruguay	Cucumbers, peppers, seed-beds and nurseries	UNIDO
Vietnam	Stacked bags of rice, grain in silos, timber in warehouses	UNIDO
Zimbabwe	Project preparation for MB demonstration	UNDP
Zimbabwe	Tobacco seedlings	UNIDO

7.10 Conclusions

MB is currently used in Article 5(1) countries for soil fumigation and for disinfesting commodities. Its use is most often related to the production and treatment of high-value export crops and commodities and not for the production of staple food stuffs.

Some countries have reduced their consumption of MB over the past five years, while others have substantially increased usage (and in some cases production). Such variation is likely to continue until Article 5(1) consumption is frozen in 2002.

Significant progress has been made in the adoption of alternatives in some areas of use. For example, natural substrates, solarisation and IPM are now accepted alternatives for controlling soil pests and are already in use in a number of countries. For commodity treatment, phosphine is now accepted as the standard fumigant for controlling stored grain pests where time is not a constraint.

While alternatives to MB in Article 5(1) countries are similar to those in non-Article 5(1) countries, it is the adaptation of alternatives that can be significantly constrained by conditions typical in many Article 5(1) countries. Due to this aspect, alternatives to MB may not be used in Article 5(1) countries unless appropriately adapted to specific climatic conditions, cropping techniques, resource availability and target pests. This may involve significant effort in areas such as field testing to adapt alternatives to local conditions, on-farm demonstrations, technology transfer, user education, institutional capacity building, information exchange and training.

It is important that applied research, field demonstration projects, capital investment projects, information exchange, public awareness campaigns and training programmes on alternatives, continue in order to allow Article 5(1) countries to decrease reliance on MB. To address these issues, a follow-up programme is a priority to those Article 5(1) countries that are evaluating and/or adopting alternatives. Further assistance in the form of training information exchange and other support activities will be required to implement available alternative pest control methods which are cost-effective, environmentally sound and safe to users.

7.11 Case Histories

Three example Case Histories on methyl bromide (MB) alternatives and methods which are currently being used by Article 5(1) countries can be found in Annexes 7.1, 7.2 and 7.3. While these alternatives are not intended to be complete replacements for MB, they are tools farmers can use which are effective on the pests that are currently controlled by this pesticide. The Case Histories were chosen to provide a brief overview of the available pest control materials and methods and should not be construed as the only alternatives to MB.

Alternatives that replace the current uses of methyl bromide must often be adapted to the specific location, climatic conditions, crop and pest complex in a given Article 5(1) country. By providing this information, MBTOC does not imply an endorsement of the pesticides, systems or products; while the absence of a pest control tool, material or method should not be interpreted as MBTOC disapproval.

Annex 7.1 Case History 1 : Sulphuryl fluoride on stored product pests in China

1. **Commodity:** Ancient articles, papers, structures and wooden products, imported timber and the empty freight containers

2. **Location:** China

3. **Pest:** Wood-boring insects or stored product pests, termites and other structural or stored product pests

4. **Overview of alternative:**

Sulphuryl fluoride was developed as a structural fumigant in the late 1950s by Dow Chemical. Its characteristics include a low boiling point, non-flammability, non-corrosion, low solubility in water, high penetrative ability and wide spectrum pest control. This material was chosen by Chinese experts as an effective way to protect ancient Chinese art-crafts, papers, clothes, structures and imported wood products. A number of laboratory and field tests were conducted in China from 1976 to 1983 relating to pest control effectiveness, toxicity, residue analysis and monitoring, chemical synthesis and production. This fumigant was first available in the Chinese market in 1983 under the trade name Xunmiejin . Currently, there are two factories to produce this fumigant, each with about 100 tons/year production capability.

Tests on commodities have shown that the treatment of seeds with sulphuryl fluoride was safer than that treated by methyl bromide. For example, 50g/m^3 and 72 hrs fumigation of rice seed did not significantly affect its germination ability, but using methyl bromide with the same dosage, the safe fumigation duration was only 24 hrs. Tests also demonstrated that sulphuryl fluoride had stronger penetration capability than methyl bromide in some wood products, where 8g/m^3 of sulphuryl fluoride and methyl bromide were used to fumigate sawdust for 16 hrs at 26.7°C . In this case, 100% mortality was noted for larval *Trogoderma granarium* to 23 cm under the surface treated with sulphuryl fluoride. However, with the methyl bromide treated sawdust, mortality was found only to 3 cm under the surface. Even though eggs of many insect species can be more tolerant to sulphuryl fluoride, normally 30-60 times higher than tolerance of larvae or adults, they can also be successfully controlled in 72 hrs at a reasonable higher dosage. The absorption of sulphuryl fluoride to commodities was noted to be less than that of methyl bromide, especially in cereals and grains.

5. **Description of alternative in use:**

This is an example of sulphuryl fluoride structural fumigation in China. The structure was a historic building called Huanglou in Xi'an which had been attacked by termites. In addition, much of the furniture and carpet inside the building were also infested with insects. This particular building is very large, almost 80 m long, 30 m wide and 6 m high. Before fumigation, 12 electric fans were installed to insure good dispersion of sulphuryl fluoride and all holes, crevices, windows and doors were closed and thoroughly sealed using plastic sheets, tape and glue as necessary. After the building had been sealed, 48 g/m^3 of

sulphuryl fluoride was injected into the building for a 48 hour fumigation. At the time of fumigation, the temperature was 22-28°C and wind was 3-5 m/s. During the fumigation, gas concentrations were checked several times. After the building had been ventilated, the results of the fumigation were investigated and complete kill of the target insect was noted.

6. **Cost issues:**

The price of this material is about US$5000/ton, which is about two times the cost of methyl bromide in Chinese market.

7. **Source of information:**

This case history was written by Dr. Wang Yuejin, a MBTOC member and plant quarantine expert with the Institute of Plant Quarantine, Ministry of Agriculture, China.

Annex 7.2 Case History 2 : Coconut substrate mixture as a soil fumigation alternative

Editor s Note: At the time this report was in press, the Article 5(1) sub-committee of MBTOC replaced the Case History on Coconut substrate mixture as a soil fumigation alternative with the following Case History from Brazil:

Case History 2: Floating as a soil fumigation alternative in tobacco seed beds

1. **Commodity:** Tobacco

2. **Location:** Brazil

3. **Pests:** Nematodes, fungi and weeds

4. **Overview:**

Methyl Bromide (MB) is primarily used in Brazil for soil treatment (97%). Its major use is in tobacco seed bed preparation (95.8%), mainly in the southern part of Brazil.

Brazil grows about 450,000 t of tobacco a year and is the third largest tobacco producer in the world and the largest exporter. The Southern region of Brazil (Rio Grande do Sul, Santa Catarina and Paraná) produces about 90% of the domestic tobacco which is used mainly for cigarettes while the remainder in the north-eastern Brazil (in Bahia and Alagoas States) grows tobacco that is air-cured and twisted for cigars and cigarillos.

Tobacco is produced in more than 600 municipalities in the Southern States by approximately 150,000 small farmers whose farm acreage averages less than 20 ha of which only 2 ha are dedicated to tobacco.

Conventional seedling production consists of cultivating seedlings in seed beds previously treated with MB. For each plot (2 x 25 m) two 1.5-pound cans of MB are used. Later on the bare-rooted seedlings are transplanted. Despite the use of MB, seedling development is generally uneven. This increases the risk of non-establishment of plants due to both bare-rooted seedlings and lack of systematic irrigation.

5. **Description of alternative being used:**

A Demonstration Project on alternatives to MB for tobacco seedling production using the Floating system is being carried out under the auspices of the United Nations Industrial Development Organization (UNIDO). In this system, seedlings are placed in styrofoam trays, filled with commercial substrate (usually composted pine bark, peat and vermiculite added to fertilizer) and kept floating on a small pool of water (10.50 x 1.4 m or 5.25 x 1.4 m and 10 cm high). A low tunnel (transparent plastic cover) is placed over the pool as a means of managing temperature, rainfall and strong winds.

In Santa Catarina State this system is being well-accepted as a substitute for MB. Besides eliminating MB this system has the advantage of reducing the seedling production period, of

producing even seedlings, of reducing the risk of non-establishment of seedling in transplanting (carries entire clod roots plus substrate) and of improving yield and quality of harvested tobacco leaves.

6. **Production costs:**

The production cost of 1000 seedlings using the floating system is approximately US$ 9.09, but using MB it is US$ 2.73. Although the floating system requires a higher direct cost, it tends to be more profitable in the end as yields are greater and leaf quality is better than when MB is used.

7. **Source of information:**

This case history was prepared by Juarez Müller, a MBTOC member and researcher of Empresa de Pesquisa Agropecuária e Extensão Rural-EPAGRI (Agricultural Research and Extension Agency of Santa Catarina State).

Annex 7.3 Case History 3 : Integrated pest management for crops in Morocco

Editor s Note: At the time this report was in press, the Article 5(1) sub-committee of MBTOC replaced the Case History on Integrated pest management for crops in Morocco (including Tables 7.5 and 7.6) with the following Case History from Kenya.

Case History 3: The use of phosphine and carbon dioxide for grain disinfestation in Kenya

1. **Commodities:** Wheat and maize

2. **Location:** Kenya

3. **Pests:** Coleopterous beetles including *Sitophilus* spp, *Tribolium castaneum*, *Rhyzopertha dominica* and *Oryzaephilus surinamensis*, and moths such as *Ephestia cautella*.

4. **History:**

Wheat and maize are grown on a large scale in Kenya and form part of the staple diet. In large and medium-scale storage, both crops are subject to damage by insect pests which infest grain either before harvest or during storage and cause significant damage and loss if remedial action such as fumigation is unavailable. Methyl bromide was formerly used by marketing boards and the larger pest control servicing companies to fumigate grain stored in warehouses and silos.

3. **Alternatives:**

Where time is not a constraint methyl bromide has now been largely replaced by phosphine. Another alternative, carbon dioxide, has been successfully demonstrated for the disinfestation of grain stored in silos and in sealed bag stacks in Kenya.

Phosphine is a direct alternative to methyl bromide for disinfesting durable commodities and has been in world-wide use for at least 25 years. It is commonly applied as a solid preparation such as tablets, the gas being evolved from these over a period of about 24 hours depending upon the temperature and grain moisture. Compared to methyl bromide, phosphine is easy to apply and because of the delay in gas evolution, it is safer to use.

The chief disadvantage of phosphine is the long exposure period required, at least five days being recommended.

Carbon dioxide is only weakly insecticidal compared to methyl bromide or phosphine and for this reason high concentrations and long exposure periods are essential for effective disinfestation of grain. Recommendations are that initial concentration of the gas should be at least 80% and this should not fall below 40% in the first 10 days of the treatment. At 25°C the total treatment period should be at least 15 days. Very well-sealed enclosures are necessary for effective fumigation with carbon dioxide and large quantities of gas are

required. For example, in the treatment of individual silo cells in Kenya, each containing 2000 tonnes of grain, 10 tonnes of carbon dioxide were needed.

4. **Regulatory agency acceptance:**

Phosphine is already in widespread use and registered by the Kenyan authorities. The registration of carbon dioxide as a fumigant is under review.

5. **Current commercial use:**

Phosphine has been used commercially as a fumigant in Kenya for several decades, but carbon dioxide has only been used experimentally.

6. **Time to commercialise use:**

Phosphine could be used more widely almost immediately.

For the treatment of bag stacks, carbon dioxide could be introduced in approximately six months, providing sufficient funds were available.

For the treatment of bulk grain in silos, a much longer period would be needed both to install the application system and then to evaluate the gas-tightness of individual silo cells. A realistic time period for this might be 1-2 years.

7. **Testing of alternatives in other areas:**

For the treatment of bag stacks, testing with both phosphine and carbon dioxide should not present a problem. For silo systems, however, this would depend on the type and age of the installation. If the silos are very old it may not be economic to consider upgrading them to a standard that would permit carbon dioxide to be maintained in sufficient concentration for the required time period.

Annex 7.4 Officially reported methyl bromide consumption by Article 5(1) countries

- Gross consumption in metric tonnes.
- Official import figures reported to Ozone Secretariat and MBTOC survey 1998.
- The global and regional totals are incomplete because there are no data for some countries.

Table 7.7 Officially reported methyl bromide consumption by Article 5(1) countries

KEY: Shaded areas indicate data extrapolated from previous years (to estimate totals)
'Net' indicates imports + production - exports for countries that produce MB

Region and Country	1991	1992	1993	1994	1995	1996	Notes
ASIA & PACIFIC							
Bangladesh	0.0		0.0		0.0	0.0	
China - net (estimates)		851.4	766.0	882.0	810.0	1600.0	estimates
India - net (estimates)	124.0			135.0	200.0	185.0	estimates
Indonesia	133.3				50.0	50.0	
Korea, Republic of	1412.0		1439.0	1123.0	1245.0	1211.0	
Malaysia			30.0	89.0	55.8	41.5	
Myanmar				64.3	16.0	79.2	
Pakistan	0.0				0.0	0.0	
Papua New Guinea	0.0				1.2	1.0	
Philippines	34.8		107.5	63.4	68.3	53.7	
Sri Lanka	0.0				6.0	13.8	
Thailand				590.0	567.0	642.0	
Vietnam	460.0			140.0	310.0	300.0	
Sub Total					3329.3	4177.2	

Region and Country	1991	1992	1993	1994	1995	1996	Notes
AFRICA							
Algeria	0.0		1.0	1.0	1.0	10.0	
Benin		15.1	28.3	22.8	3.2		
Botswana				0.0	0.0	0.0	
Burkino Faso	0.0			0.0	0.0	0.0	
Burundi	0.0	0.0	0.0	0.0	0.0	0.0	
Cameroon	0.0		23.7	23.7	25.2		
Central African Rep	0.0		0.0	0.0	0.0	0.0	
Chad	0.0	0.0	0.0	0.0	0.0	0.0	
Comoros						0.0	
Congo	0.0			0.0	0.0	0.0	
Cote D'Ivoire	26.5	26.5	26.5	26.5	26.5	26.5	
Egypt	92.0	90.0	80.0	150.0	450.0	450.0	
Ethiopia	21.0				30.0	30.0	
Gambia	0.0	0.0	0.0	0.0	0.0	0.0	
Ghana			0.0			0.0	
Kenya	330.0	350.0	340.0	400.0	225.0	394.5	
Lesotho	0.5			0.3	0.5	0.3	
Malawi	114.0		190.0	203.0	163.7	208.0	
Mali					0.0	0.0	
Mauritania	0.0			0.0	0.0	0.0	
Mauritius	0.0		0.0	0.0	0.0	0.0	
Morocco	221.0	437.0	376.0	884.0	1298.0	1085.0	
Mozambique	7.2			9.5	8.0	4.5	
Namibia					0.0	0.0	
Niger	0.0			0.0	0.0	0.0	
Senegal	0.8	0.0	0.0	0.9	1.2	1.2	
Seychelles	0.0				0.0	0.0	
South Africa	1265.0	716.7	1074.0	1002.0	1007.0	1265.0	
Sudan	10.0		15.0	20.0	10.0	10.0	
Swaziland	0.0		1.3	0.2	0.7	0.8	
Tanzania	7.2		8.7	9.0	0.0	10.8	
Tunisia			4.7	9.7	20.0	8.0	
Uganda					2.5	3.0	
Zambia	7.0	8.5	40.0	40.0	54.0	54.0	
Zimbabwe	628.0		600.0	628.0	675.0	707.0	
Sub Total					4001.5	4268.6	

Region and Country	1991	1992	1993	1994	1995	1996	Notes
MIDDLE EAST							
Bahrain	0.0	0.0	0.0	0.0	0.0	0.0	
Brunei/Darussalam	0.0		0.0	0.0	0.0	0.0	
Iran	100.0	150.0	120.0	122.0	25.0	70.0	
Jordan	112.0		30.0	333.0	300.0	300.0	
Kuwait	0.0			20.0	0.0	0.0	
Lebanon				227.0	252.0	299.0	
Qatar	0.0				0.0	0.0	
Saudi Arabia	0.0	0.0	0.0		0.0	0.0	
Syria	120.0	210.0	285.0	225.0	225.0	487.0	
Turkey	495.0				702.0	964.0	
Sub Total					1504.0	2120.0	
LATIN AMERICA AND CARIBBEAN							
Argentina			99.2	282.0	443.0	530.0	
Bahamas	0.0		0.0	0.0	0.0	0.0	
Barbados				0.0	0.0	0.0	
Bolivia	0.0			0.0	0.0	0.0	
Brazil	940.5	1146.9	1144.3	388.1	953.2	1778.4	
Chile	256.3	319.5	282.7	199.0	294.7	393.7	
Colombia	218.0			72.0	343.0	391.0	
Costa Rica	460.0	450.0		500.0	550.0	600.0	
Cuba	109.5	146.0		125.0	125.0	125.0	
Dominican Republic	56.5	4.5	78.0	82.0	115.0	169.8	
Ecuador	205.0			124.0	65.7	65.7	
El Salvador	3.8	3.8	4.3	3.3	4.2	4.2	
Guatemala	0.0			95.0	418.0	418.0	
Guyana	4.2				4.7	4.7	
Jamaica	0.0		0.0	0.0	0.0	0.0	
Mexico	660.7	1297.4	3523.2	5421.5	3995.4	2084.0	
Nicaragua	0.0	0.0	0.0	0.2	0.3	2.8	
Panama	8.5	16.3	6.2	1.3	0.2	0.2	
Paraguay					1.3	1.3	
Peru	1.2		0.5	2.2	1.3	0.2	
Saint Lucia			0.0	0.0	0.0	0.0	
Trinidad and Tobago	0.0				19.7	19.7	
Uruguay	5.5	10.3	9.7	18.1	25.0	10.1	
Venezuela			22.5	3.3	17.0	17.0	
Sub Total					7376.7	6615.8	

Region and Country	1991	1992	1993	1994	1995	1996	Notes
EUROPE							
Croatia	31.0	26.0	24.0	27.0	28.0	29.0	
Georgia							
Macedonia former Yugoslav	20.0				20.0	42.0	
Malta	40.0	30.0		112.0	62.0	39.0	
Moldova					0.0	0.0	
Romania - net			4.3	20.0	33.7	31.0	
Slovenia	0.0		5.5	0.3	1.0	0.0	
Sub Total					144.7	141.0	
TOTAL Article 5(1)					16,356.2	17,322.6	

Sources of data: Ozone Secretariat and government responses to survey.

Annex 7.5 Use of alternatives for soil-borne pests in Article (5)1 countries

Crops	Alternatives	Countries	Comments
Banana	Carbofuran (0.6g a.i/plant) with neemcake (1.0 kg/plant)	India	For nematodes e.g. *M. incognita, Helicotylenchus* sp*, Radopholus similis.*
Banana	Hot water treatment of corms (55^0C for 2 minutes)	India	*For nematodes e.g.* M. incognita*,* Helicotylenchus sp, Radopholus similis
Banana	Soil amendments	Many countries	Commercial use
Banana	Natural substrates	Canary Islands	Widespread commercial use
Banana	1,3-D	Costa Rica	Commercial use
Broccoli	Cultural practices and pesticides	Guatemala	Widely used
Cabbage, Cauliflower	Composts	India	Widely used in some regions
Chilli	Resistant varieties Carbofuran @ 0.6 g a.i/m^2 in nursery beds	India	For root knot nematodes, *M. incognita*
Citrus	Phorate at inflorescence stage	India	*Tylenchus semipenetrans*
Cumin	Solarisation	India	Limited use due to cost constraints and degradation of plastic tarp material
Cumin	Soil amendments	India	Widely used for soil improvement
Cucurbits	Soil solarisation	Morocco, Jordan	Limited use based on nematode populations
Cucurbits	Solarisation of soil & agricultural material	Brazil	Recently introduced in greenhouses
Cucurbits	Grafting onto resistant rootstock	Morocco, Lebanon, Egypt, Jordan and many other Article 5(1) countries	Widely used for melons China uses grafting for cucumber to control diseases such as *Fusarium* spp. wilt
Cucurbits	Metam sodium, dazomet, 1,3-D, carbofuran	Morocco	Widely used

Crops	Alternatives	Countries	Comments
Cucurbits	Soil-less culture (volcanic stones, rock wool, perlite)	Morocco	Used on limited acreage due to cost
Cucurbits	Resistant varieties	Many countries	Widespread use
Cucurbits	Steam	Brazil	Field trials for protected cultivation
Cucurbits	Crop rotation	Many countries	Widespread use
Cut flower seed beds	Steam	Brazil	Limited use because of cost issues
Cut flowers	Compost, steam, IPM and soil substitutes (grain hulls, waste coal slag)	Colombia	Widely used, cost effective
Cut flowers (protected)	Substrates	Brazil	Limited commercial use
Cut flowers	Steam	Brazil, China, Kenya, Thailand	Limited use because of cost issues, in an experimental state
Cut flowers	*Tagetes* spp. extract	Kenya	Limited use
Cut flowers	Crop rotation	Kenya	Limited use
Cut flowers	Tissue culture to produce pathogen-free plants	Kenya	Limited use due to cost and expertise required - used for Statice, chrysanthemum
Cut flowers	Dazomet	Kenya	Registered for use, limited but increasing use
Cut flowers	Metam sodium and dazomet	Brazil	Widely used
Cut flowers (protected)	Solarisation	Lebanon	Commercial use
Cut flowers	Dazomet	Malaysia	Registered for use, widely used
Cut flowers (protected and open field)	Resistant varieties	Many countries	Commercial use

Crops	Alternatives	Countries	Comments
Cut flowers (protected and open field)	Organic amendments (compost etc.)	Many countries	Widespread commercial use
Eggplant	Composts	India	Widespread use in some regions
Eggplant	Resistant or tolerant cultivars	Malaysia	Commonly used against bacterial blight
Fruit tree nurseries	Solarisation	Egypt	Used only during hot season
Ginger	Neemcake @ 1 ton/ha before planting and carbofuran 45 days after planting @ 1 kg a.i/ha Treatment of rhizomes with hot water (45^0C for 2 hr)	India	For nematode control: *Pratylenchus delateri* *Nothangnina cesidoplastes* *Rotylenchus reniformis*
Groundnut	Resistant varieties Castor/mustard/neemcake @ 1 ton/ha Carbofuran @ 4 kg/ a.i/ha	India	*M. javanica* nematode
Lettuce	Soil substitutes (grain hulls)	Chile	Limited use
Nurseries	Steam	Zimbabwe	Used commercially
Nurseries	Substrates (e.g. composted pine bark, mixtures of other materials)	Zimbabwe, Brazil	Used commercially
Nursery crops Fruit & vegetables	Steam	Many countries	Widespread commercial use
Nursery crops Fruit & vegetables	Solarisation	Some Article 5(1) countries	Commercial use
Nursery crops Fruit & vegetables	Biocontrols	Mauritius	Limited commercial use
Nursery crops Fruit & vegetables	Soil amendments (compost etc.)	Many countries	Widespread commercial use

Crops	Alternatives	Countries	Comments
Nursery crops Fruit & vegetables	Biofumigation	Mexico, Brazil	Limited commercial use
Nursery crops (protected fruit & vegetables)	Substrates	Mexico, Chile, Brazil, Morocco, Zimbabwe	Widespread commercial use
Okra	Composts	India	Used in some regions
Paprika	Seed trays + substrates	Zimbabwe	Limited use
Paprika	Directing sowing	Zimbabwe	Limited use, but expected to increase
Paprika	Dazomet	Chile	Widely used
Pulses	Deep summer ploughing 2-3 times at 15-20 days gap in the months of May-June	India	For control of *Pratylenchus* spp
Peppers	Dazomet	Chile	Widely used
Peppers	Substrates	Malaysia, Indonesia	Used commercially
Peppers (bell)	Rice straw or plastic mulch	Taiwan	Used commercially for weed control
Peppers (hot)	Resistant or tolerant cultivars	Malaysia	Used against bacterial blight
Potatoes	Composts	India	Used in some regions
Rice paddy	Paddy seed soaking with carbofuran 25 EC (0.1%) Resistant varieties	India	For nematode control *M. graminicola* *Ditylenchus angustus*
Roses	Biocontrol of *Agrobacterium tumefascens* with *A. radiobacter*	Morocco	Used for the production for grafted rose plants in nurseries
Roses	Resistant varieties, grafting	Many countries	Commercial use

Crops	Alternatives	Countries	Comments
Roses	1,3-D, metam sodium	Egypt, Jordan, Lebanon, Morocco, Tunisia	Field trials and limited commercial use
Salad vegetables	Substrates	Singapore	Used commercially
Snow peas	IPM system (cultural practices) and pesticides	Guatemala	Widely used
Strawberries	Straw mulch with solarisation	Philippines	Widely used
Strawberries	Resistant varieties	Morocco	Used on large scale for some soil-borne pathogens
Strawberries	Soil solarisation	Morocco	Used on a limited scale for soil-borne pathogens
Strawberries	IPM system (cultural practices and pesticides)	Guatemala	Widely used
Strawberries	IPM system (soil amendments and selected pesticides)	Zimbabwe	Limited use, accepted by growers
Strawberries	Metam sodium, dazomet	Egypt, Jordan, Lebanon, Morocco, Tunisia	Limited commercial use
Strawberries	Soil & agricultural material solarisation	Brazil	Recently introduced
Strawberries	Substrates	Malaysia	Used commercially
Strawberries	Organic amendments (composts etc.) crop rotation	Many countries	Widespread commercial use
Strawberry seed beds	Solarisation	Egypt	Hot season only
Sugarcane	Biocontrol: fungal pathogen, *Beauveria* spp.	Mauritius	Experimental
Tobacco seed beds	Solarisation	Brazil, Zimbabwe	Experimental
Tobacco seed beds	Floating seed trays	Brazil	Recently introduced, use is expected to increase
Tobacco seed beds	Substrate of pine bark, rice hulls, vermiculite & manure	Brazil	Recently introduced, use is expected to increase

Crops	Alternatives	Countries	Comments
Tobacco seed beds	Dazomet, metam sodium	Brazil	Recently introduced
Tobacco seed beds	Composting with locally available materials	China	Limited use
Tobacco seed beds	Dazomet	Malaysia, Thailand	Registered for use, widely used
Tobacco seed beds	Steam	Thailand	Limited use due to cost issues
Tobacco seed beds	Seed trays + substrates	Zimbabwe	Experimental, but use is expected to increase
Tobacco seed beds	Rotation with selected cover crops	Zimbabwe	Widely used
Tobacco seed beds	Pine bark substrate	Zimbabwe	Experimental
Tobacco seed beds	1,3-D + brush burning	Zimbabwe, Malawi, Zambia	Limited commercial use
Tobacco seed beds	Resistant cultivars	Zimbabwe	Used for root knot nematode
Tobacco seed beds	Biofumigation	South Africa, Zimbabwe	Limited commercial use
Tobacco seed beds	Biocontrol: *Trichoderma harzianum*	Philippines, Malawi Zimbabwe, Zambia	Used as part of an IPM programme for control of *Fusarium* spp. and *Rhizoctonia* spp.
Tomatoes	Soil & agricultural material solarisation	Brazil	Recently introduced
Tomatoes	Soil substitutes (grain hulls)	Chile	Limited use in field greenhouses
Tomatoes	IPM system (cultural practices and pesticides)	Guatemala	Widely used

Crops	Alternatives	Countries	Comments
Tomatoes	Resistant varieties Biological control *with Paecilomyces lilacinus* 10^6 spores/g soil Polymulch and carbofuran @ 2kg/ha Phorate @ 3 kg/ha	India	Root knot nematodes (*M. incognita*)
Tomatoes	Composts	India	Widely used in some regions
Tomatoes	Soil solarisation	Jordan	Used
Tomatoes	Substrates	Malaysia, Indonesia,	Used commercially
Tomatoes	Resistant cultivars	Mexico and many Article 5(1) countries	Widely used
Tomatoes	Resistant or tolerant cultivars	Malaysia	Used against bacterial blight
Tomatoes	Soil-less culture (volcanic stones, rock wool, perlite)	Morocco	Used on limited acreage due to cost
Tomatoes	Solarisation of soil & tomato stakes	Morocco	For the control of *Fusarium* spp. and *Verticillium* spp. wilt and *Didymella* spp. stem canker
Tomatoes	Grafting	Morocco	Widely used for soil-borne pathogens
Tomatoes	Resistant varieties	Many Article 5(1) Countries	Widely used
Tomatoes	Rice straw or plastic mulch	Taiwan	Used for weed control
Tomatoes, Peppers	Substrates	Zimbabwe	Trials being conducted
Tomatoes, peppers (open field)	Metam sodium	Costa Rica, Brazil, Egypt, Jordan, Lebanon, Mexico, Morocco, Tunisia, Zimbabwe	Widespread commercial use
Tomatoes, peppers (protected)	Metam sodium, dazomet	Egypt, Jordan, Lebanon, Morocco, Tunisia	Limited commercial use

Crops	Alternatives	Countries	Comments
Tomatoes, Cucurbits (greenhouse)	Integrated disease management of soil-borne pathogens	Many Article 5(1) Countries	Widely used
Tree nurseries	Crop rotation	South Africa	Widely used
Turf	Dazomet	Philippines, Malaysia, Egypt	Widely used - related to commercial landscaping and golf courses
Vegetable seedbeds	Burning of waste material (e.g. dry leaves) on soil surface	India	Used to reduce nematodes and weed seeds
Vegetable crops	Substrates	Indonesia	Used commercially for high-value crops
Vegetable crops	Carbofuran @ 0.6 g/m^2 in nursery beds at sowing time Resistant varieties Ethoprop @ 0.3 g.a.i/m^2	India	*Rotilenchus reniformis*

Annex 7.6 Use of alternatives for durable commodities in Article (5)1 countries

Commodity	Alternative	Countries	Comments
Black pepper	Phosphine	Malaysia	Registered for use and widely used - storage
Coconut products	Phosphine	Philippines	Registered for use; mostly used for exports
Coffee	Phosphine	Vietnam	Registered for use - widely used for exports
Grain (rice)	Carbon dioxide	Indonesia	Long term storage for carryover stocks
Grain (rice)	Carbon dioxide plus phosphine	Philippines	Long term storage for security reserve stocks
Grain (rice)	Carbon dioxide	Vietnam	Use increasing
Grain (barley)	Pre-mixed CO_2 & phosphine	Cyprus	Used
Grain	Controlled atmospheres	China	Adopted and use expected to increase
Grain	Diatomaceous earth	China	Experimental - used to avoid fumigation
Grain	Phosphine	Article 5(1) Countries	Use continues to increase
Grain (rice and barley)	Hermetic sealing/storage	Philippines (rice) Cyprus (barley)	Technology available for adoption
Peanuts	Nitrogen	India	Commercial - retail packages
Rice	Irradiation	Indonesia, Thailand	Indonesia - limited commercial use Thailand - experimental use
Rice	Carbon dioxide	Thailand	Commercial - retail packages
Timber	Heat	China	Limited use
Timber	Sulphuryl fluoride	China	Use increasing, but trials still needed
Tobacco	Phosphine	Many Article 5(1) Countries	Widely used
Wheat	Carbon dioxide	Kenya	Experimental in silos

Annex 7.7 Use of alternatives for perishable commodities in Article (5)1 countries

Commodity	Alternative	Country	Comments
Apples	Wax coating	Chile	Widely used
Apples	Pre-shipment inspection & certification	Chile	Approved for exports to USA
Apples	Cold treatment	Mexico, Chile, South Africa	Approved for exports to USA
Cherries	Cold treatment	Chile	Approved for exports to USA
Cherimoya	Soapy water + wax coating	Chile	Approved for exports to USA
Citrus	Wax coating	Chile	Widely used
Citrus	Cold treatment	South Africa	Approved for exports to Japan
Citrus	Cold treatment	Many countries	Approved for exports to USA
Cut flowers (orchids)	Chemical dips	Thailand	Experimental
Cut flowers	Pressure water spray + insecticide	Several countries	Approved for exports to USA
Garlic	Phosphine	China	Widely used
Guava	Hot water dipping	Vietnam	Experimental
Lychees	Vapour heat + cold treatment	Taiwan	Approved for exports to Japan
Mangoes	Heat treatment	Taiwan	Approved for exports to Japan
Melons	Certified pest-free zones or periods	China (one region)	Approved for exports to Japan
Orange	Irradiation	China	Experimental - for imported fruit
Stone fruit peaches, plums, apricots	Cold treatments	Morocco	Approved for exports to USA
Stone fruit	Double inspections	Chile	Widely used

Annex 7.8 Use of alternatives for structural pests in Article (5)1 countries

Structure	Alternative	Country	Comments
Grain mills	Cold CO_2 + phosphine	Argentina	Experimental
Grain mills	Hot CO_2 + phosphine	Chile	Commercially used
Empty containers buildings	Sulphuryl fluoride	China	Widely used

Chapter 8

Quarantine and pre-shipment

8.1 Summary

Quarantine applications, as defined under Decision VII/5 of the Montreal Protocol, are treatments that aim to prevent the introduction, establishment and/or spread of quarantine pests, or to ensure their official control, where official control is that performed by, or authorised by, a national plant, animal or environmental protection or health authority.

Pre-shipment applications, defined under the same Decision, are those 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 use of methyl bromide (MB) for quarantine and pre-shipment (QPS) is a remaining emissive use which is unregulated under the Montreal Protocol. Although there are some limited essential use exemptions agreed by the Parties for other ODS such as CFCs these only apply after phase-out. Under present controls QPS uses remain exempt from the freeze, reductions and phase-out schedules.

QPS use currently accounts for about 22% of world-wide MB consumption. Preliminary data from four countries indicate that MB used for QPS is increasing for both developing and developed countries.

MBTOC noted that there may be some inconsistency in the interpretation of the terms quarantine and pre-shipment. For example, treatment of commodities with MB required contractually, rather than officially, does not qualify as QPS but some Parties appear to be incorrectly exempting this use. This inconsistency would result in an understatement of an individual country s calculated annual controlled consumption in a particular year.

MBTOC noted that there may be also be inconsistencies in the interpretation of pre-shipment treatment defined as directly preceding export . The interpretation may result in multiple applications, when a single application of MB just prior to shipment would fully satisfy the sanitary or phytosanitary requirements of the importing or exporting country. In order to be clear for practical implementation of this measure, Parties may wish to define pre-shipment applications as those carried out within 14 days prior to shipment, in addition to meeting the phytosanitary and sanitary requirements of the importing or exporting countries.

From current use world-wide, MBTOC provided examples it considered complied with the QPS definition and those which did not. MBTOC also designed a logic diagram to assist in differentiating between Q and PS uses.

Further data collection is required to assess the volume and uses of MB under QPS, the extent of the development of alternatives, the likely operation of exemptions in the future once MB is phased-out and the regulations governing the use of QPS treatments.

8.2 Introduction

Decisions VI/11 and VII/5 of the Montreal Protocol relating to the use of methyl bromide (MB) for QPS treatments, define the conditions under which MB is exempt from control measures. Interpretation of the terms under QPS is currently quite broad, particularly for pre-shipment treatments, leading to inconsistencies in understanding the scope of the exemption and in reporting MB consumption.

Parties may seek further clarification on the scope of this exemption to allow consistent application and consistent reporting of quantities used. Furthermore, individual Parties may wish to set up internal procedures for improving collection of data on QPS use. This is particularly important where there are concerns that MB stocks that are attributed to uses under the QPS exemption are being diverted to other (non-exempt) uses. It should be noted that some increase in usage under the QPS exemption is to be expected given the ongoing expansion of trade.

A consistent interpretation of the scope of the QPS exemption under Article 2H of the Montreal Protocol is directly relevant to the funding of projects through the Multilateral Fund facility as set out in Article 10 of the Protocol. Since the Fund can only cover costs related to projects aimed at replacing uses of MB which fall within the Protocol s control measures, project proposals for the replacement of MB for particular uses which fall within the QPS exemption are not eligible for support.

The term pre-shipment and the area it covers is capable of a broad range of interpretation. The scope of treatments that may fall under quarantine is much narrower and more strictly defined.

There has been considerable discussion on the scope of the QPS exemption. TEAP suggests that application of a well defined exemption would promote implementation of alternatives in non-exempt areas in accordance with the objectives of the Protocol. In their 1998 report, TEAP suggests MBTOC further considers the scope of QPS exemptions and gives examples of where these exemptions may or may not apply.

To assist the Parties, MBTOC provides in this chapter:

- Information on the status of QPS under the Montreal Protocol.
- Criteria under which MB is exempt from control.
- Comparisons of Montreal Protocol definitions with those of the International Plant Protection Convention.
- Suggested interpretation of the definitions.
- Examples that may assist in the interpretation of the definition.
- A logic diagram to assist in categorising MB applications as Q or PS.

8.3 Status of QPS Under the Montreal Protocol

The use of MB for QPS is a remaining emissive use which is unregulated under the Montreal Protocol. Although there are some limited essential use exemptions agreed by the Parties for other ODS such as CFCs these only apply after phase-out. QPS comprises approximately 22% of consumption and is exempt from freeze, reductions and phase-out under Article 2H of the Protocol.

8.4 Definitions

8.4.1 Montreal Protocol

Decision VI/11 defined the terms quarantine and pre-shipment with regard to implementing the controls under Article 2H of the Protocol. These terms were further defined under Decision VII/5, which reads, in part:

(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.

8.4.2 International Plant Protection Convention

Article VI of the New Revised Text of the IPPC Convention states that *Parties may require phytosanitary measures for quarantine pests and regulated non-quarantine pests and shall not require phytosanitary measures for non-regulated pests.* (Anon 1997).

A regulated pest is defined as *a quarantine pest or a regulated non-quarantine pest* . The definition of a quarantine pest is the same as that defined under the Montreal Protocol and shown in Section 8.4.1 (a) except the IPPC definition refers to *a pest of* economic *importance* whereas the Protocol excludes *economic* .

A regulated non-quarantine pest is *a non-quarantine pest whose presence in plants for planting affects the intended use of those plants with an economically unacceptable impact and which is therefore regulated within the territory of the importing contracting party.*

8.4.3 General comparison of MP and IPPC

MBTOC notes that although there are general similarities between the IPPC definition of quarantine and that adopted by the Parties to the Montreal Protocol, there are some significant differences that may affect implementation by some quarantine authorities. Note that Decision VII/5 of the Protocol *precedes* the revision by the IPPC.

The IPPC focuses on securing common and effective action to prevent the spread and introduction of damaging pests of plants and plant products. In contrast, the definition agreed under the Protocol is broader as it encompasses not only the activities covered by IPPC but also covers human health and wider environmental considerations. From a human health perspective, the jurisdiction of health authorities includes preventing the spread of disease from rodents which are found in ships, aircraft and other vehicles; and controlling particular micro-organisms such as bacteria or other disease-carrying organisms which are harmful or even fatal to humans and that may be prevalent in an imported food product.

The IPPC has recently introduced a separate category of pests called regulated non-quarantine pests which have the potential to be detrimental to plants for planting . Since the Montreal Protocol definition preceded this IPPC definition, there is now no equivalent pest category within the Montreal Protocol definition and therefore implementation by quarantine officials in each country may vary.

Further information is required to develop a better understanding of the implications of the scope of the IPPC definition and to clarify their relevance to the uses of MB under the Montreal Protocol.

8.4.4 Quarantine

Based on the definitions provided in Section 8.4.1, a treatment must be applied or authorised by a national plant, animal or environmental protection or health authority against officially recognised quarantine pests, in order to be categorised as a quarantine treatment.

8.4.5 Pre-shipment

The time prior to shipment for a country to apply a pre-shipment treatment has been loosely defined by the Parties as *directly preceding export* .

Technically, MB treatments can take up to 4 days to complete including preparation, application, exposure and airing. MBTOC considers that 10 days would typically be required

to accumulate a volume of commodities required for treatment. Therefore, in order to be clear for practical implementation of this measure, Parties may wish to consider pre-shipment applications as those carried out within 14 days prior to export.

In addition to the criterion of *immediately preceding export*, PS treatments must also be carried out to meet either an *official* import requirement or an *official* export requirement. Contractual or credit agent requests are not official and therefore would not be categorised as PS. For non-Article 5(1) countries, the official export regulation must have been in force before 7 October 1994 (when the Decision was made at the sixth meeting of the Parties); and for Article 5(1) countries, the official export regulation must have been in force before 7 December 1995 (when the Decision was made at the seventh meeting of the Parties).

8.5 Implications of Inconsistent Interpretation of QPS for the Parties

MBTOC noted that there is some inconsistency in the interpretation of the terms quarantine and pre-shipment. For example, treatment of commodities with MB required contractually rather than officially does not qualify as QPS but some Parties appear to be incorrectly exempting this use.

This inconsistency would result in an understatement of an individual country s calculated annual controlled consumption in a particular year and for developed countries, could lead to additional efforts to meet agreed controls. Similarly, for Article 5(1) countries, this could result in a possible miscalculation of an individual country s base-line MB consumption, resulting in some countries having to make greater reductions than originally envisaged in order to meet the freeze in 2002.

8.6 TEAP Interim Explanatory Note

The Technology and Economic Assessment Panel (TEAP 1998) provided the following interim explanatory note to assist Parties to apply QPS terms more consistently:

There appears to be a wide variation between Parties and also methyl bromide users as to the interpretation of the terms quarantine and pre-shipment application :

(2) The term quarantine may have different connotations to methyl bromide users and officials in some countries. For example, in some cases treatments regarded locally as quarantine are applied to kill non-quarantine pests, such as species of insects (e.g. cosmopolitan grain pests) already present in the country. Detection by inspection authorities of live insects in an incoming shipment may be sufficient to require authorisation of a treatment regarded locally as quarantine. However, the definition adopted by the Montreal Protocol of quarantine treatments is narrower than this and conforms to the international concepts of quarantine agreed by FAO and IPPC, where the pest for which treatment is authorised must be a declared object of quarantine.

(In IPPC/FAO language, quarantine applications are limited to regulated quarantine pests and exclude applications for regulated non-quarantine pests.)

(3) *The definition of pre-shipment application is restricted by the terms phytosanitary or sanitary to officially authorised but non-quarantine treatments, fulfilling official requirements of the importing or exporting country at time of export. It was not intended to cover informal or purely contractual or commercial arrangements not required under official regulations.*

(Applying IPPC/FAO terms, pre-shipment applications are limited to applications for regulated pests .)

(4) *The definition in Decision VII/5 is silent on quarantine application in intra-country trade. However at the time of crafting the definition of QPS it was not intended to exclude official intra-country quarantine treatments from exemption, although the text of Decision VII/5 could be interpreted to restrict exempt quarantine treatments to those conducted or authorised by national, not state authorities.*

(5) *The intention of the definition of pre-shipment applications was to limit exemptions to those treatments carried out at time of export under official requirements, either of the importing country or regulations in force in exporting countries at the time of the Decision (December 1995). This excludes arrangements which are contractual only.*

(6) *It is clear that a pre-shipment application is applied to export trade between countries and that the application must be made shortly before export to qualify for exemption. With a methyl bromide treatment, including airing, taking from a few hours to three or four days depending on circumstances the term directly preceding in (b) suggests a treatment applied, at most, within a few days prior to export.*

MBTOC notes that inconsistency in the interpretation of the terms quarantine and pre-shipment may lead to some officially required treatments which are not applied to quarantine pests and would be more appropriately categorised as pre-shipment treatments. Similarly, there may be instances where treatment of commodities with MB is required contractually rather than officially and should not be categorised as pre-shipment treatments.

In order to assist Parties in a consistent application of these terms, MBTOC provides the following explanatory notes and a diagram.

8.7 Examples that May Assist in the Interpretation of QPS

8.7.1 Uses considered by MBTOC to be QPS treatments

8.7.1.1 Official quarantine treatment in country of origin

A MB treatment required by officials in an importing country against a quarantine pest known to infest a particular commodity.

- ***Example:*** Treatment of packed commodities subject to infestation such as rice, spices and expeller cake or materials packed in straw and wooden crates from a country known to have khapra beetle as an established pest.
- ***Reasoning:*** This is covered by the QPS exemption. It is a quarantine treatment because khapra beetle is an officially recognised quarantine pest in a number of countries. Typically MB is specified for its control.

- ***Example:*** MB treatment in the USA of oak logs to control oak wilt fungus. The logs are destined for Europe.
- ***Reasoning:*** This is covered by the QPS exemption because oak wilt fungus is a declared object of quarantine in the European Union.

8.7.1.2 Official quarantine treatment on arrival

Official treatment of imported consignment where a pest, declared as an object of quarantine, is detected.

- ***Example:*** MB treatment of grapefruit from Florida found to be infested with Caribbean fruit fly on arrival in Japan.
- ***Reasoning:*** This is covered by the QPS exemption. It is a quarantine treatment because Caribbean fruit fly is not present in Japan and MB is specified as a control measure.

Official treatment of a commodity transported within a country where there is potential for transfer of a quarantine pest into an area declared free of that pest, or when the pest is under official containment.

- ***Example:*** MB treatment of rice shipped into Western Australia as a precaution against *Trogoderma variabile*, a pest established in the rice growing area of New South Wales.
- ***Reasoning:*** This is covered by the QPS exemption. It is a quarantine treatment because the pest is under official containment in Western Australia and is a declared object of State quarantine (although known to be present in a restricted area of Western Australia) and under official control.

8.7.1.3 Eradication of a quarantine pest from an area

MB may be required to control or possibly eradicate quarantine pests in limited and well-defined geographical areas. Pests may be recently established or under long term control.

Treatment of an established quarantine pest with a view to its control and eventual eradication from a country.

- ***Example:*** MB treatment of dry wood termites in houses and in other structures in Southern Queensland.
- ***Reasoning:*** This can be categorised under QPS as a quarantine treatment because dry wood termites are quarantine pests established in a few small regions of Australia and subject to official control. Treatment of quarantine pests established in a limited area is an example of a post-entry quarantine treatment.

8.7.1.4 Official pre-shipment treatment in country of origin in relation to exports

Treatment of a cargo prior to shipment to meet an importing country s official phytosanitary requirements.

- ***Example:*** MB treatment of wheat shipments destined for Kenya. The treatments against cosmopolitan grain pests are carried out in the seven day period prior to export.

- ***Reasoning:*** This is categorised under QPS as a pre-shipment application because treatment with MB is an official phytosanitary requirement of the Kenyan Government for wheat imported into Kenya.

Treatment of a cargo preceding export to meet a country s export regulatory requirements which were in force before 7 October 1994 (for non-Article 5(1) countries) or before 7 December 1995 (for Article 5(1) countries).

- ***Example:*** MB fumigation of wheat at the point of export (seaboard terminal) within a few days prior to shipment from Australia to meet officially required nil tolerance levels for insect infestation in export grain.
- ***Reasoning:*** This can be categorised under QPS as a pre-shipment treatment as it was applied at the time of export to meet the official requirements of the Grain, Plant and Plant Protection Orders under the Export Control Act (1982) which were in force at the time of Decision VII/5..

Treatment of an empty ship prior to loading to meet exporting country s regulatory requirements.

- ***Example:*** MB fumigation of empty ships holds at a port in Canada carried out under the direction of the inspection authorities because cosmopolitan grain pests were intercepted.
- ***Reasoning:*** This would be categorised under QPS as a pre-shipment treatment as it was carried out to comply with the export requirements of the exporting country s legislation in force at the time of Decision VII/5.

In-transit fumigation of freight containers loaded on a train and subsequently exported by ship.

- ***Example:*** To meet official phytosanitary requirements, MB fumigation of milled rice in bags in freight containers at the rice mill. Subsequent transfer to port and export by ship within 14 days of treatment.
- ***Reasoning:*** This would be categorised under QPS as a pre-shipment treatment as it was carried out directly prior to export to meet official phytosanitary requirements.

8.7.2 Uses considered by MBTOC to not be QPS treatments

8.7.2.1 Exporter carries out MB treatment prior to export as a quality control measure

Treatment of a cargo at export against infestation of non-quarantine insects pests as a precaution against mandatory treatment if infestation is detected on import.

- ***Example:*** MB fumigation of cut flowers destined for Japan at the point of export. No phytosanitary certificate is required by the importing country s quarantine authorities.
- ***Reasoning:*** This does not fall within the QPS exemption either as a quarantine or a pre-shipment treatment as the treatment was not specifically targeted against nominated quarantine pests, nor was it carried out as an officially required measure by either the importing or exporting country, despite being conducted at the point of export and shortly prior to shipment.

MB may be applied under direction of Japan s quarantine authorities if any live insects are intercepted on arrival. Fumigation carried out on detection of infestation at import similarly do not fall within the QPS exemption, as they are neither carried out against nominated quarantine pests nor conducted directly prior to export.

8.7.2.2 Importing contractor requests treatment prior to export as a quality control measure

Contractual requirement for MB fumigation of a commodity prior to export to meet the importer s quality specification.

- ***Example:*** Importers of cassava chips from Thailand require MB treatment to manage infestation in the commodity for quality reasons and to avoid having to carry out disinfestation treatments on receipt.
- ***Reasoning:*** This is not covered under the QPS exemption as the MB treatment was not directed at a nominated quarantine pest and was not carried out under official direction or to meet an importing country s official phytosanitary requirements.

8.7.2.3 Contractor requests treatment as a quality control measure

MB treatment of a commodity in-store as a routine pest control measure against cosmopolitan pests weeks or months prior to transport.

- ***Example:*** MB treatment of grain in long-term storage some distance away from an export terminal against cosmopolitan stored product pests. The grain is destined for local processing.
- ***Reasoning:*** This is not covered by the QPS exemption as the treatment was not directed against nominated quarantine pests and was not done immediately prior to export to meet official requirements.

8.7.2.4 Treatment of commodities by the importing country found to be infested on receipt

MB treatment of a commodity immediately after import when cosmopolitan (non-quarantine) pests are detected.

- ***Example:*** Fumigation of containerised cocoa beans immediately after importation when found to be infested with cosmopolitan grain pests e.g. flour moths.
- ***Reasoning:*** This was not covered by the Q exemption as the treatment was not directed against declared objects of quarantine and the pests were already well-established in the importing country. It is not considered a PS treatment as MB is not an officially required treatment. There is no allowance in the definition of QPS for use of MB in the importing country as a result of inadequate pest control measures.

8.7.2.5 Treatment of land prior to export of crop

MB treatment of land prior to planting a crop destined for export.

- ***Example:*** Fumigation of land prior to planting strawberries for fruit production for export.
- ***Reasoning:*** This is not covered by the QPS exemption as the treatment was not targeted at quarantine pests nor carried out directly prior to export for official phytosanitary reasons.

8.7.3 Categorising quarantine and pre-shipment treatments

Annex 8.1 contains a logic diagram to further assist Parties in correctly categorising MB treatments as quarantine or pre-shipment.

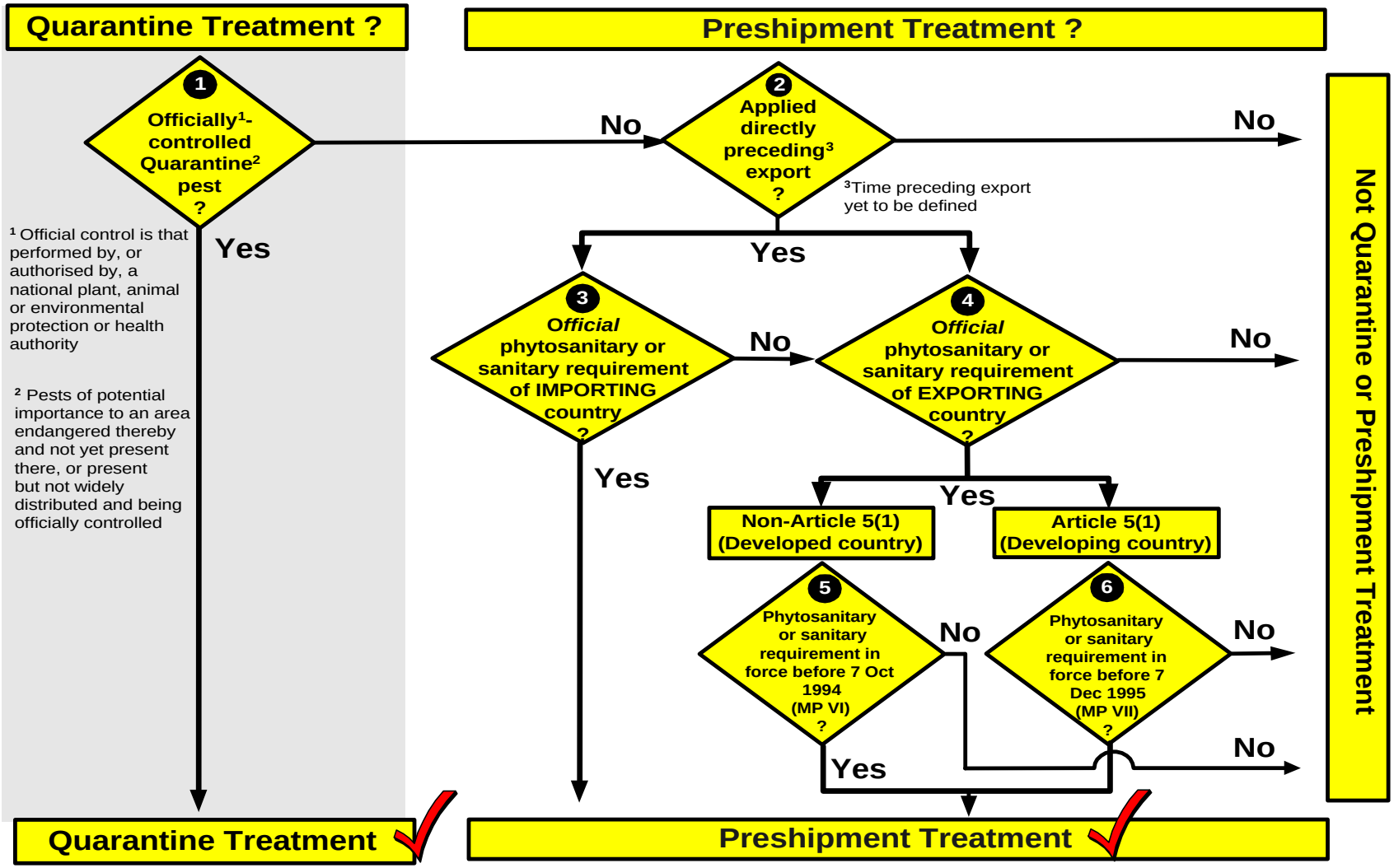
This logic diagram could also assist with designing a form to accurately monitor, record and quantify QPS usage. QPS usage is reportable annually to the Ozone Secretariat.

8.8 References

Anon. 1997. New revised text approved by the FAO Conference at its 29th Session - November 1997. *International Plant Protection Convention.* 17 pp.

TEAP. 1998. Montreal Protocol on Substances that Deplete the Ozone Layer UNEP Technnology and Economics Assessment Panel. April 1998 Report. Section 3.5: Methyl Bromide. UNEP, Nairobi. 192pp.

Annex 8.1 Logic diagram to assist in categorising quarantine and pre-shipment treatments



Chapter 9

Reducing methyl bromide emissions

9.1 Summary

Emissions from fumigation operations occur through leakage and permeation during treatment (inadvertent emissions) and from venting at the end of a treatment (intentional emissions). Estimates of the proportion of methyl bromide (MB) used that is released into the atmosphere vary widely because of: differences in usage pattern; the condition and nature of the fumigated materials; the degree of gas-tightness; and local environmental conditions. Some MB may also be converted to non-volatile materials making it incorrect to equate production with emissions.

Under current usage patterns, the proportions of applied MB eventually emitted to the atmosphere are estimated by MBTOC to be 31 - 88%, 85 - 95%, 69 79% and 90 - 95% of applied dosage for soil, perishable commodities, durable commodities and structural treatments respectively. These figures, weighted for proportion of use and particular treatments, correspond to a range of 43 - 87% overall emission from agricultural and related uses, with a best estimate of overall emissions of 73%, or 50,126 t based on 1996 production of 68,666 t.

Emission volume release and release rate to the atmosphere during soil fumigation depend on a large number of key factors. Of these, the type of surface covering; time that surface covering is present; soil conditions during fumigation; MB injection depth and rate; and whether the soil is strip or broadacre fumigated are considered to have the greatest affect on emissions. Under ideal conditions, when all these factors are controlled and impermeable films are used, emission volumes as low as 3% have been observed. It is unlikely, however, that these results will ever be repeated in the field due to the handling difficulties of laying plastic sheets during fumigation and leakage from the edges, tears, cracks and other events. The use of Virtually Impermeable Film sheeting and reduced application rates of MB, offer the greatest potential for immediate reduction of emissions, although cost and several non-air quality related environmental and health issues (recycling, disposal and possibility of increased bromide ion concentration in soil) are seen as barriers to their adoption.

Available containment techniques for decreasing MB leakage are in limited use world-wide. Lack of adoption is constrained particularly by lack of incentives, lack of promotion of relevant technologies and by perceived or real increases in costs and logistical problems. A high degree of containment is a prerequisite for efficient recovery of the used MB. Many facilities used for fumigating perishables, particularly for quarantine, already have a high standard of gas-tightness leading to very low leakage rates (often less than 5% of applied dosage).

There has been limited research into the development of recovery and recycling systems for MB. Most development work is directed at recovery from enclosures used for structure or commodity fumigation (which only represents about 24% of global production). Some of the newer research is aimed at developing simple recycling technologies whereas most of the potential recovery and recycling systems previously considered were complex and may have been expensive to install compared with the cost of the fumigation facility itself. Some systems would also have had high running costs associated with energy requirements and many would have required a level of technical competence to operate, not normally found at fumigation facilities. Only a few special examples of recovery equipment are in current commercial use.

Unlike some other ozone depleting substances where the interim needs of Article 5(1) countries can be met in part by banks of recycled material, it is unlikely that this method will be practical for MB. This is because some of the MB used in any application reacts and breaks down and because some of the recovery and recycling technologies under development are only suitable for in-plant recycling.

If recovery is to be recognised as an acceptable method of reducing MB emissions to the atmosphere, it will be necessary to set specifications on aspects of fumigation such as equipment efficiency and acceptable levels of emission.

9.2 Introduction

During any fumigation operation there are three distinct sources or opportunities for MB to be emitted to the atmosphere:

- By leakage during the actual fumigation treatment.
- During venting of the fumigation space immediately after fumigation or removal of the cover sheets when a deliberate discharge to the atmosphere takes place.
- Following treatment when the treated soil, commodity or structure slowly emits any adsorbed MB.

The first and to some extent the third type can be controlled or reduced by better containment of the fumigation site (Section 9.4). Leakage in these instances is undesirable from the fumigation perspective as it reduces the effectiveness of the treatment as well as having worker safety implications. The second can only be controlled by recovery followed by recycling, reclamation or by destruction (Sections 9.5 and 9.6). These terms are defined in the Glossary at the beginning of this Assessment. For most fumigation operations, venting following fumigation results in the largest discharge. Emission of adsorbed MB is the next largest followed by leakage, although this is very commodity and site dependent.

Section 9.3 estimates the global amount of MB emitted from current uses; Section 9.4 discusses the potential for MB emission reduction through better fumigant application technologies for soil, commodity and structural treatments; Sections 9.5 and 9.6 discuss technology available or under development for emission reduction following fumigation; and finally Section 9.7 discusses constraints to their implementation.

9.3 MB Emissions from Current Uses

A proportion of any applied dosage of MB reacts with the treated material such as soil, grain, fruit or the associated structures and packing material. The end product of this reaction is typically the non-volatile bromide ion, various methylated products and carbon dioxide. These have not been identified as ozone depleters. The proportion of non-volatile bromide residue formed as a result of a treatment is a direct measure of the proportion of the applied MB *not* emitted to atmosphere. The proportion emitted is found by difference. This mass balance approach is typically used to estimate quantities of MB released to atmosphere from a treatment. It gives a conservative estimate and is simple to use as bromide ion tends to be easily detected and quantified. An allowance must be made for natural bromide ion already present prior to treatment.

An alternative approach is to observe the quantities emitted directly. This is experimentally difficult as it relies on quantification of a number of fluxes of gas and may miss some important ones. The approach tends to underestimate the emissions, but is often used in soil fumigation studies.

The proportion of applied MB converted to fixed residues and thus not released to the atmosphere, varies widely with the particular treatment situation. It is influenced, *inter alia*, by the degree of gas-tightness (sealing, permeability of the enclosure) and temperature, moisture content and reactivity of the treated material. With soil fumigation, the mode of application is also a major factor since it influences the contact time between the MB and substrate and thus the opportunity for varying degrees of reaction and dispersion within the soil before loss from the system.

There is remarkably little firm quantitative field data available on the production of bromide ion or other measures of loss of MB from particular systems. For the purposes of this report, MBTOC has relied on some particular data for specific situations and estimates provided by MBTOC members. Ranges of estimates have been given. These are used to encompass both the true variability to be expected with different sites, techniques and situations and the range of opinions expressed by experts within MBTOC. An approximation of the quantity of MB lost to the atmosphere has been made by integrating this information over the total usage of MB (Table 9.1 and supporting calculations in Annex 9.1).

Table 9.1 includes estimates for emissions from four types of application to soils. The variation given in two of these is wide and reflects the range of data available to MBTOC experts. It is not possible to provide a weighting of figures within these ranges to give a precise average emission as the distribution of emissions over the global range of practice cannot be estimated because of lack of data. However, it may well be that the true value differs substantially from the average value of range quoted.

Table 9.1 Estimated usage of MB and emissions to atmosphere for different categories of fumigation by major use category (derived from 1996 production data)

Type of Fumigation and commodity	Amount used (excl. feedstock usage) (tonnes)	(%)	Estimated emissions (tonnes)	(%)	Notes
Enclosed Space (durables)					
Grains, nuts, dried fruit etc.	4580		2336 3206	51 70	*a,b*
Timber	4317		3799	88	*a*
Subtotal	8897	12.96%	6135 7005	69 79	
Enclosed Space (structural)	2044	2.98%	1839 1942	90 95	*c*
Enclosed Space (perishables)	5091	8.59%	5016 5606	85 95	*d*
Soil Fumigation					
Soil injection - shallow with tarp	27985		6716 24907	24 89	*e*
Soil injection - deep with tarp	2073		435 - 622	21 30	*e*
Vapourised gas - with tarp	20730		8292 19071	40 92	*e*
Soil injection - deep without tarp	1036		829	80	d
Subtotal	51824	75.47%	16273 45429	31 88	
Total agricultural usage	68666		29263 59982	43 87	
Mean emission Over all categories			50,126	73	*f*

a Calculations supporting these figures given in Annex 9.1.
b Higher emission rate estimated from residue data for bag stacks by MBTOC (Annex 9.1).
d Values estimated by MBTOC. Calculations consistent with higher figure given in Annex 9.1.
c Range of values estimated by individual MBTOC members on basis of experience and published studies.
e See Table 9.2 for summary of sources.
f MBTOC recognises that the true value of emissions may differ substantially from this mean.

The overall usage figures given in Table 9.1 are derived from estimates of 1996 production (See Table 3.1). The usage figures for the individual sectors are based on tonnages used in various applications derived from previous estimates from the various MBTOC sub-committees. The proportions of applied MB eventually emitted to the atmosphere globally are estimated to be 31 - 88%, 85 - 95%, 69 79% and 90 - 95% of applied dosage for soil, perishable commodities, durable commodities and structural treatments respectively. These figures, weighted for proportion of use and particular treatments, correspond to a range of 43 - 87% overall emission from agricultural and related uses, with a best estimate of overall emissions of 73%, or 50,126 t based on 1996 production data.

9.4 Emission Reduction Through Better Containment

9.4.1 Soil fumigation

It is generally understood, that MB emissions to the atmosphere from soil fumigation can come from any of three major sources:

i) MB emitted through plastic sheets during fumigation;
ii) MB lost from edges during fumigation; and
iii) MB emerging from soil after lifting the sheets after fumigation.

The total emitted is unlikely to be 100% because of breakdown of applied MB in the soil. Degradation is due to reaction with soil organic matter and some mineral constituents as well as other reaction pathways such as hydrolysis (De Heer *et al.* 1983). It is estimated that emission from the standard polyethylene (PE) sheeting predominantly used world-wide for soil fumigation from hot gas treatments is 40-92% (Table 9.2). Emissions from soil injection at 25 cm (shallow injection) are generally around 15% less.

Table 9.2 Estimated emission loss to the atmosphere from soil fumigation (Yates *et al.* 1997)

Type of fumigation	% MB emitted	Mass balance	Source
Soil injection, shallow (25 cm) with tarp	34 - 87	104	Yagi *et al.* (1993,1995)
	32 89	-	Majewski *et al.* (1995)
	61 (average)	101 (average)	Yates *et al.* (1996 a,b,c)
	45	-	Williams *et al.* (1997)
Soil injection, deep (60 cm) with tarp	21 - 30	-	Yates *et al.* (1997) MBTOC estimates
Soil injection, deep (60 cm) without tarp	80	-	MBTOC estimates
Hot gas with tarp	40 - 92	-	MBTOC estimates

9.4.1.1 Use of plastic covers

In most countries, existing regulations require plastic sheets for 3 to 5 days to retain as much MB as possible in the soil. Although many types of film can be used for fumigation (Bakker 1993; de Heer *et al.* 1983; Hamaker *et al.* 1983) thin (approx. 30 μm to 40 μm) high or low density polyethylene tarps (HDPE or LDPE) are generally applied.

The barrier properties of films can vary considerably based on plastic composition, windspeed, temperature and film thickness (Basile *et al.* 1986; de Heer *et al.* 1983). For example, high density polyethylene films tend to provide a greater barrier to MB than low density polyethylene films. Also for monolayer films, there is a direct correlation between film thickness and permeability to MB, as film thickness increases, permeability decreases. The development of virtually impermeable films (VIFs) which are significantly less permeable to MB than LDPE (van Wambeke *et al.* 1983; Thomas 1998) offers an

opportunity for significant reduction in emissions. Although recent regulatory requirements of several countries (e.g. Spain, Italy) have included these films as an option for covers during soil fumigation, their commercial use is still limited due to availability, cost and difficulties with handling in the field (Bakker 1993; Thomas 1998).

9.4.1.2 Virtually impermeable films

VIF films have been available commercially for more than 15 years, but interest in their use has intensified recently in response to restrictions on MB (van Haasteren 1995; Anon. 1996). VIF is a gas-tight film which is virtually impermeable to MB. They consist of multi-layer laminates with outer layers of low density polyethylene and a barrier layer of polyamide or ethylene vinyl alcohol. The major advantage of VIFs during soil fumigation is that they trap more MB, thus not only reducing emissions but also allowing a reduction in the initial MB dose. For this reason, they offer potential to improve the efficacy of several other fumigant alternatives to MB such as metam sodium and chloropicrin which have been shown to pass through polyethylene up to 10 times faster than MB.

Since 1994, several large reviews which critically appraise the suitability and feasibility of VIF films have been released (Anon. 1996; Anon 1997; Thomas 1998). Despite the first films being developed and used in the early 1980s, it is estimated that less than 5% of the plastic used for soil fumigation uses VIF films. Studies have demonstrated the relative efficacy of VIFs and standard PEs for control of a variety of different pathogen/crop combinations and quoted research on mass balance studies that provide evidence for emission reduction.

Achievable emission reductions from the use of VIF tarps will depend on application characteristics (e.g. sealing of tarp edges, depth of injection, tarp handling); environmental conditions (e.g. temperature, pH, soil moisture levels and organic matter content); the amount of MB used (as little as possible without reducing efficacy); and most importantly, degradation of the MB in the soil, which corresponds to the duration of the tarp cover period. However, the longer the tarp is on the soil, the more likely both the tarp and seal points could deteriorate due to wind or other weather conditions.

Under ideal conditions in the laboratory, the diffusion rate of MB through VIF was more than 1000 times less compared with PE. However, in practice an improvement factor of only 2 - 3 was observed due to deterioration of the film, leakage at the edges, cracks, holes and other factors (Anon 1996). Emissions can be reduced by taking more care in sealing edges, sealing overlaps and by repairing mechanical damage to the cover. Following these measures, it is anticipated that emission reductions of 30% or higher can be attained with VIFs. In cases where the application is not purely mechanical, the success of using new plastics greatly depends on the skill of the operator and the degree of quality control exercised.

VIF films can also reduce rates of MB applied to soil by 30 to 50% and still maintain *ct*-product values needed for effective pest control, crop growth, yield and quality that are at least as good as standard treatments. Variable reduction in rates have been found because of the large number of factors that can affect the performance of VIFs. In Holland, the initial introduction of VIF films in the early 1980s led to a substantial reduction in dose (from 100 g m^{-2} to 40 g m^{-2}) but in practice it proved hard to maintain these levels. At the end of the

phase-out period in 1991, dosages were practically back to the full rates (van Haasteren 1994).

Concerns expressed about the introduction of VIFs for soil fumigation (Thomas 1998) include:

i) Switching from PE films to VIF films would not necessarily result in a consistent reduction in MB emissions. Unless use of VIFs was accompanied by significantly longer tarp cover periods (from between 10 to 20 days) use of VIFs would likely result in significantly higher levels of MB emissions when the VIF sheeting was removed, thus increasing potential farm worker and residential exposure.

ii) If the use of VIFs was linked to a required increase in cover period, emission reductions would likely occur, but the extent of those reductions would depend on soil conditions, which may be optimised by addition of certain fertilisers and soil amendments (Yates 1997) and possibly other changes to application procedures, such as deeper injections. Plastic sheet integrity would also need to be ensured.

iii) Use of VIFs could present several non-air quality related environmental and health issues. PE plastics are currently disposed of in land-fills or burned in the field. Plastic sheet recycling and biodegradable plastics are being examined. VIFs may be more expensive to land-fill since they are typically heavier than PE plastics and may be more difficult to recycle because of the combination of plastics used to make them.

iv) Bromine levels may increase in fumigated soil and the higher levels could either leach into ground and surface water or lead to higher residues in food (Anon 1997). This problem, if it does occur, will be very specific to each location and will be minimised where lower MB doses can be used.

The present cost of VIF is about 2.5 to 4 times higher than standard PE which makes the VIF treatment more expensive. The ultimate cost of using VIF has not yet been determined because the system is not fully developed and large scale production of the films has not yet occurred. A reduction in VIF cost is expected when commercial use expands.

9.4.1.3 Other factors affecting emissions from soils

Irrespective of what surface barrier is used to trap MB, there are a number of key factors which affect emissions of MB during soil fumigation.

9.4.1.3.1 Soil characteristics

Studies of MB degradation in various soil types have shown that soil type greatly affects degradation, depending upon the time the MB is held in the soil. High organic matter and soil water content and increasing bulk densities are major factors which assist reduction in emissions (Gan *et al.* 1997; Thomas 1998).

9.4.1.3.2 Increasing the period of plastic sheeting

Tarps left on soil for longer periods increase the resident time MB is in the soil, thereby decreasing emissions. Wang *et al.* (1997) demonstrated that emissions were reduced from 64% (PE 5 d) to 37.5% (VIF 5 d) and from 56.4% (PE 10 d) to <3% (VIF 10 d) in a sandy loam soil.

9.4.1.3.3 Irrigation

MB emissions can be reduced if the air filled porosity of the soil is reduced by increasing the water content. The presence of water increases the hydrolysis of MB to bromine ions. Irrigation reduces the variability in the distribution of MB in the soil, thus achieving a more reliable fumigation result (Wang *et al.* 1997).

9.4.1.3.4 Organic amendments and fertilisers

It has been shown that the addition of nitrogen fertilisers and organic amendments enhance degradation of MB. Lime, ammonia fertiliser and ammonia oxidation bacteria increased the degradation rate of MB in soil (Ou *et al.* 1997; Gan 1997). These products have been shown to enhance degradation of MB. However, further research is required to identify their use for emission reduction.

9.4.1.3.5 Rolling the soil surface

A light rolling (pressing) of soil immediately after shank application closes furrows and seals the soil surface. This decreases direct emission from the injection points (channelling) within the first 24 hours after application and may assist reduction of total emissions (Anon 1997).

9.4.1.3.6 Formulations

A major reduction in emissions can be achieved by using formulations with lower concentrations of MB. Formulations with less MB but with chloropicrin (67:33) decrease MB doses to soil and therefore reduce MB emissions.

9.4.1.3.7 Reduction in rate

Using VIF films and 50% of the MB rate (between 140 and 250 kg ha^{-1}) similar control (i.e. 100%) of nematodes, weeds and fungi have been achieved compared with full rates (280 to 500 kg ha^{-1}) using PE barrier films (Anon 1997; Gamliel *et al.* 1997; Yates *et al.* 1997).

In some countries (e.g. the USA) the potential for reducing MB dosages for soil fumigation compared to many other countries will be less because dosages are already low. In 1994 estimates of rates of MB used for soil fumigation in many European countries was between 50 100 g m^{-2}; in the UK 75 100 g m^{-2}; compared to rates as low as 20 g m^{-2} in regular use in the USA (Thomas 1998). Recent regulatory restrictions have reduced these high rates in

several countries such as in Spain in 1998 when rates were reduced from 50 80 g m^{-2} to 40 g m^{-2}.

9.4.1.3.8 Depth of injection

Emissions of MB can be reduced by injecting the material deep into the soil, depending upon soil degradation conditions. For example, in field and laboratory studies, increasing the depth of injection from roughly 25 to 60 cm resulted in a 40% decrease in emissions under tarped conditions (Yates *et al.* 1996). In laboratory studies, it was shown that increasing injection depth delays the occurrence of maximum volatilisation flux and also decreases cumulative emissions (Gan *et al.* 1997). The deeper the MB is injected the lower the emissions. At 25 cm, a depth which approximates industry standards for most crops, emissions ranged between 27 to 89% and at 60 cm emissions ranged between 3 to 21% (Table 9.3). Deeper shank injections increased the path distance, thus increasing the residence time for degradation (Wang *et al.* 1997a,b) and minimising emissions.

9.4.1.3.9 Broadacre vs. bed

Strip fumigation can reduce the amount of MB by 20-40% as only the crop rows are treated rather than the entire field. This technique is common in tomato and strawberry crops. However, the edge effect predominates and losses of MB from the edge of the bed tends to off-set some of the advantages of strip fumigation.

Table 9.3 Percentage emissions of MB from a sandy loam soil following application using buried drip tubes

Barrier film status and authors	Days after MB application			
	5 days		10 days	
	Depth of application			
	25 cm	60 cm	25 cm	60 cm
Wang, Yates, Ernst, Gan, Gao and Becker, 1997				
Bare soil	87	60	-	-
PE film	59	15	-	-
VIF film	42	< 15	-	-
Wang, Yates, Ernst, Gan and Jury, 1997				
PE film	64	-	56	-
VIF film	37	-	< 3	-

Note: Estimates of MB emission % using ion chromatography are made from determining the concentration of bromide ion remaining in soil after 42 d (Wang, Yates, Ernst, Gan and Jury 1997) or 133 d (Wang, Yates, Ernst, Gan, Gao and Becker 1997) following MB application.

9.4.1.4 Practices to reduce emissions from soil

There are a number of practices that could reduce MB emissions from soil treatments including:

- Limiting the frequency of MB fumigation by requiring intervals of 12 60 months between treatments. Alternative treatment methods could be implemented in the intervening period such as IPM, steam, solarisation, alternative fumigants and predatory fungi treatments. Reductions of 17 50% are feasible by implementing a reduction in fumigation frequency (refer to Table 8.1 in Anon 1997). Reductions of >75% are feasible when other methods of pest control are used in combination.
- Increased monitoring and recording of pests, for example: in the UK, diagnostic tests are available for *Verticillium dahliae, Pythium* spp. and *Plasmodiophora brassicae* and diagnostic tests are being developed for the *Rhizoctonia solani* fungi; in New Zealand, indirect tests have been adopted for monitoring replant diseases using old season root stock and soil and comparing against a healthy standard; nematodes and pathogens are monitored in the USA; in South Africa proof of diseases is needed in order to use MB in orchards.
- Imposing permit systems which could ensure that only technically necessary fumigation would be carried out (e.g. The Netherlands in 1981). The criteria for permits could be proof of: (a) disease present and (b) that other pest control options have been examined. An organisational structure is needed to support this.
- Reducing doses by combining MB with other treatments in addition to VIFs, e.g. solarisation or biological controls (see Chapter 4 - Alternatives to Methyl Bromide for Soil Treatments).
- Adjusting pesticide controls, e.g. Italy in 1994 reduced the maximum dose to 60 g m^{-2} and in 1998 Spain introduced a maximum rate of 40 g m^{-2} and 20 g m^{-2} when used in combination with VIFs. Anon (1997) indicted substantial emission reductions if pesticide authorities reduced permitted MB doses (usually 50 60%).
- Regulate the users of MB to contractors only and licence and train operators responsible for fumigation.
- Where possible, shift practices from hot gas methods using high concentrations of MB to soil injection using mixtures of MB/chloropicrin at lower MB concentrations, or substitute other chemical and non chemical treatments.

9.4.2 Structural and commodity fumigation

Post-harvest disinfestation of perishable commodities using MB is performed in fixed-wall structures such as fumigation chambers, or under gas-tight tarpaulins.

Controlled conditions allow manipulation of the key fumigation parameters: dosage, temperature and time. Greater control is potentially more achievable in an enclosed structure than in relatively uncontrolled field situations. The dosage can be reduced by increasing either the temperature or the time, or both, providing the commodity is able to tolerate the conditions. Forced air circulation could also allow reduction of the dosage. MB could be conserved by developing high temperature schedules with or without longer fumigation durations, providing the marketability of the produce is acceptable.

Improving the gas-tightness of fumigation facilities will prevent unwarranted leakage of MB into the atmosphere. Simple test criteria have been available to the industry for determining

the gas-tightness of chambers (Bond 1984) and these are part of the mandatory fumigation requirements for export of many perishable commodities to Japan.

More accurate measuring equipment to weigh MB will minimise excessive use of MB. This equipment could also be attached to equipment used for fumigation from small cylinders (e.g. 5 kg) which would avoid the use of small cans (about 1 kg).

A combination of gases e.g. MB with carbon dioxide and phosphine, allows a reduction in MB, is less phytotoxic to cut flowers and ornamentals than MB or phosphine alone and has the same insecticidal activity. Reduced emissions can also be achieved by using reduced MB dosages in combination with carbon dioxide and/or heat. The MAKR system is an alternative treatment which combines MB and carbon dioxide to reduce MB dosage from 24 36 g m^{-3} to 8 g m^{-3}. By adding 10% carbon dioxide, the amount of MB required is reduced by 50 66%. The carbon dioxide is heated, expanded and introduced into a structure with MB. The effects of carbon dioxide are twofold: it provides more efficient dispersion of MB into all parts of the structure; and increases the respiration rate of insects, reducing the amount of MB needed to eradicate the infestation. Currently this structural treatment is only registered in the United States.

9.4.2.1 Fumigant recovery

Currently, most fumigation chambers release MB into the atmosphere at the end of the fumigation period. Equipment currently under development to recover MB could be attached to the fumigation chamber which would allow up to about 80% of the gas to be captured for subsequent fumigation operations and which would otherwise be deliberately vented (see Section 9.5). The exact proportion able to be reused is dependent on commodity adsorption and losses to the facility. In the absence of legislation mandating their use or local clean air requirements, the impetus to install recovery systems will depend mainly on the cost-benefit of savings from reduced MB use.

The aim of containment in the use of MB for the fumigation of structures is to enable reduced dosages to be effective and to reduce emissions to the atmosphere. Containment alone would not normally be considered as a viable possibility to reduce emissions to the atmosphere without effective recovery technology. However, improved containment and monitoring may in fact be considered as a strategy for reducing emissions from structures while maintaining efficacy.

Containment and emission reduction strategies for structures involve: leakage control; extending the fumigation period, while ensuring adequate *ct*-products are achieved; and pressure testing. This aspect of fumigation can be enhanced by improved monitoring of fumigant concentrations and adjusting dosages where they are excessive. Recovery and recycling are under development to further reduce emissions (see Section 9.5).

9.4.2.2 Volume displacement techniques

Gas impermeable balloons have been developed for the displacement of empty space within structures. These may be used to reduce the quantity of fumigant required to fill a space. One of the present disadvantages of this strategy is that there may be inadequate circulation of the gas.

9.4.2.3 Transfer of knowledge and training

Programmes for transferring knowledge and training must be developed to bring about a successful transition aimed at reducing MB use and emissions and/or to replace MB with alternatives and substitutes for structural pest control.

The mechanisms for transferring knowledge for many substitutes and alternatives are already well established in developed nations, where extensive information is readily available in existing texts and other resource materials. New ideas and technologies are disseminated through industry journals and conferences.

Particularly crucial to lessening or eliminating MB for structural pest control is training for pest identification, monitoring and utilisation of new technologies. Programmes for training pest control managers and personnel in Article 5(1) countries should be tailored to social and cultural conditions, pest species and structural situations and to provide human health and environmental protection in each region.

9.5 Emission Reduction Through Recovery and Recycling

A number of techniques have been proposed or investigated for their potential to recover or capture MB from fumigation operations and some are now in limited use. Depending on the technique used, recovery can lead to the MB either being emitted to the atmosphere at some later stage (not relevant to this report) being recycled within the fumigation facility (discussed in this section) or being destroyed (discussed in the following section).

For technical or economic reasons only three recovery and recycling techniques are currently in commercial use at the time of writing this report. These are: (1) adsorption onto active solid substrates such as activated carbon and zeolite; (2) refrigeration and condensation; and (3 between-chamber transfer. Several others are being actively researched.

If containment and recovery are to be specified as the means of reducing MB entering the atmosphere, it will be necessary to define the maximum permissible quantity or concentration that may be emitted. This will allow specification of efficiencies required for recapture equipment.

9.5.1 Activated carbon

Activated carbon can adsorb relatively large amounts (up to 10 - 30% by weight depending on activated carbon type and conditions) of MB. It is widely used throughout the world to remove trace amounts of organic contaminants from gas streams.

For fumigation operations, a vessel containing activated carbon is installed in the gas vent line. At the end of the fumigation treatment, the gas mixture containing MB and air is passed through the activated carbon onto which the MB is adsorbed. The proportion retained on the activated carbon depends mainly on the amount of free activated carbon available and the rate at which it adsorbs depends on the concentration in the gas stream, gas flow rate, activated carbon characteristics and temperature. At a low MB loading, a MB recovery rate close to 100% is achievable. However, for most systems, some MB will be emitted to the atmosphere.

Eventually the adsorption capacity of the activated carbon is reached and it needs to be regenerated or disposed. Regeneration can be achieved by passing hot gas over the activated carbon and could be the basis of a reclamation process. Alternatively, the activated carbon and MB can be incinerated in a specialised facility. However, concerns about emissions of toxic chemicals may prevent this from being a viable option in some areas.

Although there has been much research into the potential use of activated carbon with MB, there are only a few known commercial fumigation installations world-wide which have, or have had in the past, activated carbon beds installed to recover MB. There was a 30 m^3 chamber in Belgium which is no longer in use. There are five 30 m^3 chambers in the Netherlands (one transportable) each with a 70 kg filter of activated carbon. With these chambers fumigation at 30 g m^{-3} is carried out and a 40 - 50% recovery is achieved. The activated carbon lasts for 40 fumigation operations and the spent carbon containing the adsorbed MB is incinerated in a special incineration facility. There is also a 30 m^3 chamber in Thailand fitted with a 72 kg bed of activated carbon. The chamber is used for fumigating asparagus and green okra exported to Japan. The system is capable of reducing MB concentrations in the vented gas to 5 ppm within 30 minutes. The fully absorbed activated carbon is disposed of in a sanitary land-fill.

An activated carbon system has also been developed by Rentokil UK for use with their fumigation bubble, a well-sealed plastic tent enclosure used for fumigation of small structures. A 10 kg activated carbon bed which can hold up to 1.5 kg MB (equivalent to 5 fumigation cycles) is used. Regeneration of the activated carbon is achieved by blowing hot air through the beds. This results in direct emissions to the atmosphere. However, its use was intended only to prevent emissions that might endanger people in the immediate vicinity of the fumigation operation not as a means of preventing emissions to the atmosphere. Further research is being carried out on methods of disposal or recovery of the captured MB.

Although activated carbon systems provide the most immediate opportunity for reducing MB emissions, they have usually only been considered for very small facilities where commodities or structures are fumigated and where, for reasons of protecting the immediate surroundings, very low concentrations of MB are permitted. Very large activated carbon beds containing tonnage quantities of carbon would be required for the fumigation of large structures or enclosures such as mills, grain silos or tarpaulin fumigation. Unless the MB is directly recovered for direct reuse, once the activated carbon has been fully loaded it will be necessary to remove the carbon for disposal or regeneration in an appropriate manner. While this is by no means impossible, there are regulatory implications associated with the transportation and storage of toxic materials.

It is technically possible to recycle MB adsorbed on activated carbon by heating the carbon, traditionally by passing hot air over it, or by altering the pressure (temperature and pressure swing adsorption). Circulating air strips that desorb MB from the activated carbon and the mixture can potentially be reintroduced into the fumigation chamber. The MB is reclaimed as a high concentration mixture in air suitable for direct reuse as a fumigant, but some topping up will be necessary to compensate for system losses so as to achieve a satisfactory fumigation concentration.

Pilot scale studies have demonstrated the technical feasibility of such a process (Smith 1992) with up to 95% of the recoverable MB being available for direct reuse. The technique has not yet been demonstrated on commodity fumigation where the build-up of other gas phase impurities, if any, may be of concern both from product quality and regulatory view points.

In Germany, a mill has been equipped with a recycle system based on temperature swing adsorption on activated carbon (Stankiewicz and Schreiner 1993). This transportable recycle system has some extra features such as an enrichment step to obtain high concentration and also condensation. This reduces the size and transportation effort and enables high concentrations during the recycle desorption even when the concentration in the extracted air at the end of the recovery is low. This technique could also be used for soil fumigation operations (open field or glasshouse with sheeting).

The prototype plant for recovery of MB from the fumigation operations was commissioned in September 1994 at a mill with a volume of 35,000 m^3. Of 1,260 kg of MB applied to the mill, 565 kg was available for recovery at the end of the fumigation treatment. Of this, only 325 kg was able to be adsorbed and of that only 180 kg was available for reuse. The recycling process was very slow which resulted in the mill being out of action for longer than normal. For some configurations, nitrogen will be used as the desorption gas to avoid potentially explosive MB and air mixtures.

In this case desorption with recycling is achieved by a combination temperature/pressure swing adsorption could be carried out using heating by direct electrical resistance. This avoids the use of excessive diluting air. Both these process steps have already been successfully used to recover CFC-11 and for cleaning exhaust air from soil clean-up to remove volatile organic compounds (VOCs) from soil (Schreiner, H., pers. comm. 1998).

9.5.2 Zeolite

Zeolites are a special type of silica-containing material which have a porous structure that make them valuable as adsorbents and catalysts. They are found naturally and can also be manufactured to precise specifications. Processes based on the use of zeolite adsorbents to remove CFCs from vented air streams are in commercial use.

Zeolite adsorbents have been developed for the recovery and direct recycling of MB (Nagji and Veljovic 1994a) and for recovery with indirect recycling (Willis, pers. comm. 1998). Although zeolites are more expensive than activated carbon, they have high adsorptive capacity, particularly at low concentrations. They can be manufactured to very narrow pore size distribution tolerances for specific applications and it may be possible to avoid any

potential problems of contamination of the recovered MB with other volatile compounds, by utilising the selective sorption that is conferred by a particular pore size range.

Pilot scale demonstration trials of the recovery and direct recycling process were conducted in July 1994 in Washington State, to demonstrate the technical feasibility of the technique for recovering MB from cherry fumigation operations. Recovery in excess of 90% was achieved (Nagji and Veljovic 1994b). Analysis of the recycled MB showed no other volatile compounds from the fruit were released. However, these tests need to be confirmed over a large number of adsorption/desorption cycles.

A full size prototype plant was installed by The Port of San Diego Authority in 1995 to reduce emissions from a 2,100 m^3 quarantine chamber. Large scale trials in 1995/96 at the more humid San Diego location were unsuccessful because of the suspected formation of hydrobromic acid (HBr) possibly by the interaction of MB and water vapour in the recirculating air during the recycling stage of the process. Apart from the introduction of an undesirable compound, there was evidence of corrosion to some internal components of the plant. The trials at San Diego have been abandoned.

A similar smaller recovery plant has been installed and successfully commissioned at a fumigation facility in Chile. Recoveries of more than 94% of the MB from the fumigation chamber and recycling rates of 87% were achieved. At the time of preparation of this report, approval had not been granted by USA authorities for the quarantine treatment of grapes using recycled MB.

The zeolite recovery and recycling process has been altered and improved so that direct recycling is no longer necessary. Instead, the MB is recovered from the zeolite bed, refined in an off-line step and is available as fresh MB for any subsequent fumigation operation. This change significantly reduces the complexity of operation of the recovery plant because it is no longer necessary to have complex or expensive analytical equipment to measure MB concentrations, as there is no direct recovery and reinjection into the fumigation operation. Indications from early tests are that recoveries of at least 75% of the available MB are achievable. At the time of preparation of this report, data from the purity tests of the recovered MB were not available. This process has the potential to provide a simple means of reducing emissions from a range of fumigation operations. No data are available on costs or regulatory issues.

9.5.3 Condensation and activated carbon

A plant in California which recovers MB from cotton fumigation has been in regular use since December 1993. At this particular site, fumigation is performed in chambers under vacuum and the potential discharge of MB occurs when the vacuum is released at the end of fumigation and after each of the subsequent air washes. The fumigation plant with its condensation and activated carbon recovery system apparently meets the local air quality requirements. Access to the plant is restricted and no data have been supplied to determine the level of recovery or recycling.

9.5.4 Refrigeration and condensation

A pressure/cooling condensation process is in use in California USA to recover MB, where it is in a highly concentrated form in the vent gas lines from cylinder filling at a bulk handling facility.

9.5.5 Between-chamber transfer

At sites where there are multiple vacuum chambers treating large quantities of commodities there is the opportunity to reduce the amount of MB being emitted to the atmosphere by transferring the MB that would otherwise be vented at the end of a fumigation treatment to an adjacent chamber where a treatment is about to commence. This process needs equipment for accurate and rapid measurement of MB concentrations to be available so that the topping up dose required to compensate for MB lost through adsorption into the commodity and through reactive breakdown can be calculated. This technique is used at a fumigation facility in the Ivory Coast (Dosso 1998).

9.5.6 Technologies under development

Research in Japan has led to the development of a new adsorbent called MBAC which is a mixture of activated carbon and special substances (amines) which have a greater adsorptive capacity for MB than activated carbon alone. This material can be produced as sheets and introduced into packaging to recover the slowly desorbing MB from fumigated commodities and also has potential to recover some MB from soil fumigations. A granular and a sheet product have been developed for use in adsorbing the MB which is slowly emitted after a fumigation treatment (Kawakami & Soma 1995). The Japan Methyl Bromide Industries Association has conducted evaluation tests (Muraoka T., pers. comm. 1998). Efforts are now being made to develop domestic markets for the product. There are no details available on techniques for disposing of the contaminated adsorbent.

9.6 Emission Reduction Through Recovery and Destruction

9.6.1 Ozone destruction

A plant was installed in late 1996 at another cotton fumigation site in California USA. It uses ozone to destroy the MB in the discharge and air washes from a vacuum chamber. Activated carbon is used to scrub any residual traces of MB from the discharge air stream. At the date of writing, results from two monitored trials indicated that in excess of 90% of MB used was destroyed. The destruction plant is large and has a significant electrical power requirement for the ozone lamps and the blowers.

9.6.2 Adsorption into reactive liquids

Amines typically react with MB to give methylated non-volatile products. A system based on organic amines and alkali for removing residual MB from fumigated 28 m^3 freight containers in Russia has been described (Rozvaga and Bakhishev 1982). No information was available to MBTOC on whether this system is in current use. Mordkovich *et al.* (1985)

have also described a technique using aqueous sodium sulphite as a neutraliser and a mixture of ethylene diamine and sodium carbonate as an adsorbent. Again, it is not known whether these techniques have achieved general use.

Research was carried out in the 1970s with a technique for liquid scrubbing to remove MB from fumigation operations (Anon 1976). The process was developed and tested on timber fumigation under stacks and consisted of equipment to circulate MB and air from the fumigation enclosure through a tank of aqueous monoethanolamine (50%) and back to the fumigation tent. The process achieved 70% reduction in MB concentrations, but was slow taking 40 - 60 minutes to achieve this level of reduction. The size of the necessary equipment for full scale operation and the difficulties of handling the contaminated liquid material have prevented commercial development.

9.6.3 Thermal and catalytic destruction

A process to control emissions has been developed on a laboratory scale by the USDA in California (Leesch 1997). The process has been successfully tested on a prototype system using a slip stream from a fumigation system. The process is based on using activated carbon to capture the MB and then transferring the exhausted activated carbon to a remote site where it is reactivated and the MB destroyed thermally (Leesch *et al.* 1998). A MB producer is also involved and initial thoughts are to sell MB at a price which includes the cost of capture and destruction. Further trials are delayed until a co-operator for commercial scale trials can be found.

There is present research in Japan on the catalytic decomposition of MB. Promising recent results from using new Mn/Cu-zeolites indicate that satisfactory levels of destruction can be obtained at lower temperatures than previously achieved and the production of CO will be minimised. This research is still at an early stage of development.

9.7 Constraints

Most of the recovery technologies mentioned above and all the recycling technologies are complex in nature. They are likely to be relatively expensive to install compared with the cost of the fumigation facility itself and in some instances may be more expensive. Some systems would have high operating costs associated with the energy needed. Many would require a level of technical competence to operate that would not normally be found at many fumigation facilities.

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Annex 9.1 Calculation of percent emission of MB from treatments using the mass balance approach

1. **Derivation of formula:**

Consider an enclosure containing product at density, ρ, in t m^{-3} with an applied dosage of C_0 gm^{-3} MB. If all the MB is converted into bromide, the resulting residue (X) will be:

$$X = (C_0 / \rho) \times 0.85\ gt^{-1}\ \text{(ppm, w/w); (0.85 factor converts MB to } Br^- \text{ by mass)}$$

If the actual residue is x g t^{-1}, then the percentage not converted and assumed to be emitted to atmosphere is given by:

$$X - x * \frac{100}{X}\ \% \qquad (1)$$

2. **Calculation of emission of MB from bulk and bag stack treatments of grain:**

The average emissions from bulk grain treatments under re-circulatory treatment with MB on import into Japan were calculated according to Equation (1) and used to give an estimate of emissions from bulk grain fumigation generally (Table 9.4).

Table 9.4 Fumigation of cereal grains on import into Japan (1992 data) with calculated emissions of MB based on bromide ion residue levels in commodity after treatment

Commodity	Quantity fumigated (t)	MB applied (kg)	Estimated quantity MB residue level (mg kg^{-1})	Equivalent MB residue (kg)	% emitted[a]
Wheat	910,597	55,996	20	18,212	67.5
Buckwheat	21,403	1,316	50	1,070	18.7
Maize	11,056,507	679,903	30	331,695	51.2
Other grains	2,616,647	160,907	33	86,349	46.3
Totals	**14,605,154**	**898,122**	**-**	**437,326**	**51.3**

[a] Calculated as 100 * (1-(MB residue/MB applied))

Data source: A. Tateya, MAFF, Japan

Typical residues of bromide in bag stack treatments of cereal grain are in the 5 - 10 g t^{-1} region per application. Actual residues will vary substantially with proficiency of the treatment and the nature and state of the commodity. For the purposes of this report, the following were assumed: product density of 0.7 t m^{-3}, dosage of 24 g m^{-3} MB and residue of 8.5 g t^{-1} bromide (MBTOC estimates).

On the basis of equation (1) calculated emission: 70%.

3. **Calculation of MB emissions from treatment of dried fruits and nuts:**

3.1 ***Dried fruits***

In a typical fumigation, product density is 0.37 t m^{-3}. For a dosage of 24 g m^{-3} over 24h plus 24h a typical residue is 5 g t^{-1} bromide ion with 4 g t^{-1} organic bromide, i.e. under-sorbed MB. Assuming 60% of the organic bromide reacts to give bromide ion while 40% is desorbed as MB, expected residue from the treatment is 7.4 g t^{-1} (MBTOC estimates).

On the basis of equation (1) this is equivalent to a total release of 87% and a release of 68% after the initial 24 h of airing.

3.2 ***Nuts***

In a typical fumigation, product density is 0.34 t m^{-3}. For a dosage of 56 g m^{-3}, over 24h plus 24h aeration, a typical residue is 40 g t^{-1} bromide ion plus 48 g t^{-1} organic bromide. Assuming 60% of the organic bromide reacts and 40% desorbs on further airing, total expected residue from the treatment is 69 g t^{-1} (MBTOC estimates).

On the basis of equation (1) this is equivalent to a total release of 51% and a release of 36% after the initial 24h of airing.

4. **Calculation of MB emissions from treatment of perishables:**

4.1 ***Nectarines***

A fumigation of nectarines (Hinsch *et al.*, 1992) at a product density of 0.18 t m^{-3} and at a dosage rate of 48 g m^{-3} MB over 2 h resulted in a bromide residue of about 6 g t^{-1} with a natural level of <2 g t^{-1}.

On the basis of 4 g t^{-1} residue, equation (1) gives an emission of 98%.

Figures of 85 - 95% emissions from perishable commodities were adopted by MBTOC since typical fumigation treatments are likely to be performed at higher product density and with more reactive product, both tending to lower emission percentage. The March 1994 TEAP report gives lower estimates of emissions for perishables, but these figures do not take into account slow desorption of sorbed material and only give recoverable MB (i.e. free space concentration) at the end of the fumigation period.

5. **Sample calculations for emissions of MB resulting from fumigation of timber (logs) in the hold of a ship prior to import into Japan (data source: A. Tateya, MAFF, Japan):**

(1)	Volume of hold	7,508.0 m^3
(2)	Volume of logs	4,085.0 m^3
(3)	Space volume [(1) - (2)]	3,423.0 m^3
(4)	Dosage	25.0 g m^{-3}
(5)	Total dose [(1) * (4)]	187.7 kg
(6)	Observed final gas concentration	31.7 g m^{-3}
(7)	Gas in free space at end of treatment [(6) * (3)]	108.5 kg

(8) Therefore, gas vented at the end of fumigation as % of total dose, assuming no desorption:

$$\frac{(7)}{(5)} * 100 = 57.8\%$$

(9) MB residue in the timber.

(9.1) Timber weight at apparent specific gravity of 0.9 t m^{-3} [(2) * 0.9] = 3,676.0 t

(9.2) On the basis of inorganic bromide residue of 5 g t^{-1} produced in the timber, weight of residual inorganic bromide is: 3,676 ∗ 5 = 8,380.0 g

(9.3) Converting this to equivalent MB on basis of molecular weights = 21.8 kg

(10) Thus, the total emission of MB is given by: (5) - (9.3) [187.7 - 21.8] = 165.9 kg

(11) Total % emission of MB fumigation from timber in this case:

$$\frac{(10)}{(5)} * 100 = \frac{165.9 * 100}{187.7} = 88.4\%$$

Data from nine holds (2 ships) gave about 88% emission of applied MB on the basis of the same method of calculation. Treatment at approx. 23°C and 25 g m^{-3} application rate.

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Appendix 2

Montreal Protocol Decisions, Declarations and Resolutions relating to methyl bromide

Introduction to the Montreal Protocol, its adjustments and amendments

The Montreal Protocol on Substances that Deplete the Ozone Layer was agreed on 16 September 1987 and entered into force on 1 January 1989.

The Second, Fourth, Seventh and Ninth Meetings of the Parties to the Montreal Protocol adopted, in accordance with the procedure laid down in paragraph 9 of Article 2 of the Montreal Protocol, certain adjustments and reductions of production and consumption of the controlled substances listed in the Annexes of the Protocol. These adjustments entered into force, *for all the Parties,* on 7 March 1991, 23 September 1993, 5 August 1996 and 4 June 1998, respectively.

The Second, Fourth and Ninth Meetings of the Parties to the Montreal Protocol adopted, in accordance with the procedure laid down in paragraph 4 of Article 9 of the Vienna Convention, three Amendments to the Protocol the London Amendment (1990), the Copenhagen Amendment (1992) and the Montreal Amendment (1997).

The London and Copenhagen Amendments entered into force, *only for those Parties which ratified the particular amendments*, on 10 August 1992 and 14 June 1994 respectively.

The Montreal Amendment will enter into force, *only for those Parties which ratify it,* on 1 January 1999, provided that at least twenty instruments of ratification, acceptance or approval of the Amendment have been deposited by States or regional economic integration organizations that are Parties to the Montreal Protocol. (No State or regional economic integration organization may deposit such an instrument unless it has previously, or simultaneously, deposited such an instrument to the Copenhagen Amendment.)

Annex E: Controlled substance

Group	Substance	Ozone-Depleting Potential
Group I		
CH_3Br	**Methyl bromide**	**0.6**

Article 6: Assessment and review of control measures

Beginning in 1990, and at least every four years thereafter, the Parties shall assess the control measures provided for in Article 2 and Articles 2A to 2H on the basis of available scientific, environmental, technical and economic information. At least one year before each assessment, the Parties shall convene appropriate panels of experts qualified in the fields mentioned and determine the composition and terms of reference of any such panels. Within one year of being convened, the panels will report their conclusions, through the Secretariat, to the Parties.

Meetings of the Parties

First Meeting of the Parties	Helsinki	2 5 May 1989
Second Meeting of the Parties	London	27 29 June 1990
Third Meeting of the Parties	Nairobi	19 21 June 1991
Fourth Meeting of the Parties	Copenhagen	23 25 November 1992
Fifth Meeting of the Parties	Bangkok	17 19 November 1993
Sixth Meeting of the Parties	Nairobi	6 7 October 1994
Seventh Meeting of the Parties	Vienna	5-7 December 1995
Eighth Meeting of the Parties	San José	25 27 November 1996
Ninth Meeting of the Parties	Montreal	15 17 September 1997

Funding for a limited number of methyl bromide projects (1993)

The Fifth Meeting of the Parties authorised the Executive Committee to provide funding for a limited number of methyl bromide projects for data collection, information exchange within the scope of country programmes, in line with paragraphs 1 (b) and (c) of decision IV/23 of the Fourth Meeting of the Parties, as well as for a limited number of methyl bromide alternative demonstration projects, which should be selected with the assistance of the Technology and Economic Assessment Panel; and requested the Implementing Agencies to cooperate according to their specific areas of expertise to assist in implementing the present decision.

[Source: UNEP/Ozl.Pro/5/12 Decision V/23 sections 1, 2]

Assessment Panels

The *Seventh Meeting of the Parties* decided in *Decision VII/34:*

1. To note with appreciation the work done by the Scientific, Environmental Effects, and Technology and Economic Assessment Panels and the Technical Options Committees and Working Groups in preparing their reports of November 1994, March 1995 and November 1995;

2. To request the three Assessment Panels to update their reports of November 1994 and submit them to the Secretariat by 31 October 1998 for consideration by the Open-ended Working Group and by the Eleventh Meeting of the Parties to the Montreal Protocol in 1999;

[3&4 Not relevant to MB]

5. That the Technology and Economic Assessment Panel should keep the Parties to the Montreal Protocol informed of any important new technical and economic developments on a year-to-year basis. It should furthermore:

   (a) Complete by 31 March of each year the evaluation of essential-use nominations submitted for 1997 and beyond;

   (b) Metered dose inhalers, not relevant for MB

   (c) Report progress and developments in the control of substances by 31 March of each year;

   (d) Not relevant to MB

   (e) With regard to its organization and functioning:

      (i) Proceed with efforts to increase participation of Article 5 country experts, subject to budgetary constraints, and to improve geographical and expertise balance;

      (ii) Present procedures and criteria for the nomination and selection of members of the Technology and Economic Assessment Panel;

      (iii) Request the Secretariat to appoint a small informal advisory group from both Article 5 and non-Article 5 Parties to meet with the Technology and Economic Assessment Panel and to report back to the Parties on the progress made; and

      (iv) Report to the Parties at the thirteenth meeting of the Open-ended Working Group, in 1996, including:

         a. A description of member expertise highlighting relevance, affiliation, country of residence and period of service to the Technology and Economic Assessment Panel;

b. Its methods of operation, including appointment of new members to subsidiary bodies, promotion to chair and other matters; and

c. Options proposed for restructuring the Technology and Economic Assessment Panel and its Technical Options Committees and Working Groups, including the financial and chairing issues in compliance with the terms of reference as set out in various decisions, including decision I/3, and propose adjustments, if deemed necessary, to those terms of reference.

(f) Prepare a document listing the uses and possible applications of ozone-depleting substances listed in Annex C to the Protocol, enabling Parties to collect information on their consumption levels for the purpose of compliance with reporting requirements;

(g) Collaborate with the Industry and Environment Programme Activity Centre of the United Nations Environment Programme to prepare, in accordance with the provisions of decision VII/22, the report on inventory and assessment of technologies and know-how to phase out ozone-depleting substances, including an elaboration of the terms under which transfers of such technology and know-how take place;

6. That the enhanced participation of the Parties operating under Article 5 and countries with economies in transition should be funded by the Secretariat with an adequate budget allocation or could be also provided by additional voluntary contributions which all Parties are encouraged to offer;

7. To offer the assistance of the Scientific, Environmental Effects, and Technology and Economic Assessment Panels to the subsidiary body on science and technology under the United Nations Framework Convention on Climate Change, as necessary;

8. To request the Technology and Economic Assessment Panel to present the annual schedules of its meetings and workshops to the Secretariat.

Definition of "quarantine" and "pre-shipment applications" (1995)

The *Seventh Meeting of the Parties* decided in *Decision VII/5* that:

(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 authorized 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;

(c) In applying these definitions, all countries are urged to refrain from use of methyl bromide and to use non-ozone-depleting technologies wherever possible. Where methyl bromide is used, Parties are urged to minimize emissions and use of methyl bromide through containment and recovery and recycling methodologies to the extent possible.

Reduction of methyl bromide emissions (1995)

The Seventh Meeting of the Parties decided in Decision VII/6

That Parties should endeavour to reduce methyl bromide emissions by encouraging producers and users to take appropriate measures to implement, inter alia, good agricultural practices and improved application techniques.

Review of methyl bromide controls (1995)

The *Seventh Meeting of the Parties* decided in *Decision VII/8:*

1. To request the Technology and Economic Assessment Panel to prepare a report to the Ninth Meeting of the Parties to enable the Parties to consider further adjustments to control measures, on methyl bromide. In undertaking this task, the Panel should address, *inter alia,* the availability of viable alternatives of methyl bromide for specific applications;

2. That, in considering the viability of possible substitutes and alternatives to methyl bromide, the Technology and Economic Assessment Panel shall examine and be guided by the extent to which technologies and chemicals identified as alternatives and/or substitutes have been tested under full laboratory and field conditions, including field tests in Article 5 countries and have been fully assessed, *inter alia*, as to their efficacy, ease of application, relevance to climatic conditions, soils and cropping patterns, commercial availability, economic viability and efficacy with respect to specific target pests.

Assessment of the possible need for and modalities and criteria for a critical agricultural use exemption for methyl bromide (1995)

The *Seventh Meeting of the Parties* decided in *Decision VII/29:*

1. To note that the latest Montreal Protocol Scientific Assessment underscores the need for a phase-out of methyl bromide because of its significant role in depleting the ozone layer;

2. To recognize, however, the concerns regarding the applicability of the existing essential-use criteria and process for evaluating the use of methyl bromide in the agricultural sector, and the availability of alternatives for important agricultural uses of this compound;

3. To request the Technology and Economic Assessment Panel to examine need for and the modalities (including the essential-use process) and criteria that could be used to facilitate review, approval and implementation of requests for critical agricultural use exemptions. In recommending suitable modalities and criteria, the Technology and Economic Assessment Panel may take into consideration:

   (a) Whether alternative practices or substitutes exist that are commercially available and efficacious;

   (b) The relative costs and benefit of alternative practices and substitutes to allow the Parties to assess their economic viability, taking into account the scale of application and the individual circumstances of particular uses;

   (c) Whether a Party has demonstrated that all economically feasible actions are being taken to minimize use and any associated emissions from the approved exemption, and that continued efforts are being made to evaluate and develop alternatives to the use of methyl bromide for this application;

   (d) The feasibility of placing a cap on the total percentage of baseline production and consumption permitted under an essential use for any particular country; and

   (e) A range of alternative decision-making and implementation processes;

4. To request the Technology and Economic Assessment Panel to prepare a study of the possible uses of market-based measures to allow for greater flexibility in implementing the requirements for limitations on methyl bromide;

5. That the Technology and Economic Assessment Panel s analysis should be presented for consideration to the Open-ended Working Group at its thirteenth meeting to facilitate a decision by the Eighth Meeting of the Parties.

Trade and supply of methyl bromide in cylinders (1996)

The *Eighth Meeting of the Parties* decided in *Decision VIII/14:*

1. To note with appreciation the work done by the Technology and Economic Assessment Panel and its Methyl Bromide Technical Options Committee pursuant to decision VII/7 of the Seventh Meeting of the Parties;

2. To clarify decision I/12A of the First Meeting of the Parties as follows: trade and supply of methyl bromide in cylinders or any other container will be regarded as trade in bulk in methyl bromide.

Critical agricultural uses of methyl bromide (1996)

The *Eighth Meeting of the Parties* decided in *Decision VIII/16:*

1. To note with appreciation the work done by the Technology and Economic Assessment Panel and its Methyl Bromide Technical Options Committee pursuant to decision VII/29 of the Seventh Meeting of the Parties;

2. To request the Technology and Economic Assessment Panel to further examine and report to the Ninth Meeting of the Parties on the different options on the issue of critical use of methyl bromide, as presented to the thirteenth meeting of the Open-ended Working Group in the June 1996 TEAP Report.

Control of trade in methyl bromide with non-Parties (1996)

The *Eighth Meeting of the Parties* decided in *Decision VIII/15:*

To consider the issue of control of trade in methyl bromide with non-Parties at the Ninth Meeting of the Parties to the Montreal Protocol in 1997.

[MBTOC comment: There is no record of Parties addressing this issue at the ninth Meeting]

Methyl bromide Control Schedules (1997)

Adjustments agreed at the Ninth Meeting of the Parties relating to the controlled substance in Annex E i.e. methyl bromide

[Source: Article 2H in Annex III of the report of the Ninth Meeting of the Parties]

The Ninth Meeting of the Parties to the Montreal Protocol decides to adopt, in accordance with the procedure laid down in paragraph 9 of Article 2 of the Montreal Protocol and on the basis of the assessments made pursuant to Article 6 of the Protocol, the adjustments and reductions of production and consumption of the controlled substance listed in Annex E to the Protocol as follows:

1. Paragraphs 2 to 4 of Article 2H of the Protocol shall be replaced by the following paragraphs:

    2. Each Party shall ensure that for the twelve-month period commencing on 1 January 1999, and in the twelve-month period thereafter, its calculated level of consumption of the controlled substance in Annex E does not exceed, annually, seventy-five per cent of its calculated level of consumption in 1991. Each Party producing the substance shall, for the same periods, ensure that its calculated level of production of the substance does not exceed, annually, seventy-five per cent of its calculated level of production in 1991. However, in order to satisfy the basic domestic needs of the Parties operating under paragraph 1 of Article 5, its calculated level of production may exceed that limit by up to ten per cent of its calculated level of production in 1991.

    3. Each Party shall ensure that for the twelve-month period commencing on 1 January 2001, and in the twelve-month period thereafter, its calculated level of consumption of the controlled substance in Annex E does not exceed, annually, fifty per cent of its calculated level of consumption in 1991. Each Party producing the substance shall, for the same periods, ensure that its calculated level of production of the substance does not exceed, annually, fifty per cent of its calculated level of production in 1991. However, in order to satisfy the basic domestic needs of the Parties operating under paragraph 1 of Article 5, its calculated level of production may exceed that limit by up to ten per cent of its calculated level of production in 1991.

    4. Each Party shall ensure that for the twelve-month period commencing on 1 January 2003, and in the twelve-month period thereafter, its calculated level of consumption of the controlled substance in Annex E does not exceed, annually, thirty per cent of its calculated level of consumption in 1991. Each Party producing the substance shall, for the same periods, ensure that its calculated level of production of the substance does not exceed, annually, thirty per cent of its calculated level of production in 1991. However, in order to satisfy the basic domestic needs of the Parties operating under paragraph 1 of Article 5, its calculated level of production may exceed that limit by up to ten per cent of its calculated level of production in 1991.

5. Each Party shall ensure that for the twelve-month period commencing on 1 January 2005, and in each twelve-month period thereafter, its calculated level of consumption of the controlled substance in Annex E does not exceed zero. Each Party producing the substance shall, for the same periods, ensure that its calculated level of production of the substance does not exceed zero. However, in order to satisfy the basic domestic needs of the Parties operating under paragraph 1 of Article 5, its calculated level of production may exceed that limit by up to fifteen per cent of its calculated level of production in 1991. This paragraph will apply save to the extent that the Parties decide to permit the level of production or consumption that is necessary to satisfy uses agreed by them to be critical uses.

2. Paragraph 5 of Article 2H of the Protocol shall become paragraph 6.

B. Article 5, paragraph 8 *ter* (d)

1. The following shall be inserted after paragraph 8 *ter* (d) (i) of Article 5 of the Protocol:

(ii) Each Party operating under paragraph 1 of this Article shall ensure that for the twelve-month period commencing on 1 January 2005, and in each twelve-month period thereafter, its calculated levels of consumption and production of the controlled substance in Annex E do not exceed, annually, eighty per cent of the average of its annual calculated levels of consumption and production, respectively, for the period of 1995 to 1998 inclusive;

(iii) Each Party operating under paragraph 1 of this Article shall ensure that for the twelve-month period commencing on 1 January 2015 and in each twelve-month period thereafter, its calculated levels of consumption and production of the controlled substance in Annex E do not exceed zero. This paragraph will apply save to the extent that the Parties decide to permit the level of production or consumption that is necessary to satisfy uses agreed by them to be critical uses;

2. Paragraph 8 *ter* (d) (ii) of Article 5 of the Protocol shall become paragraph 8 *ter* (d) (iv).

Production of an Assessment (1997)

The *Ninth Meeting of the Parties* decided in *Decision IX/25:*

1. To note the statement of the Co-Chairs of the Scientific Assessment Panel that, while the Scientific Assessment of Ozone Depletion will be ready by October 1998, as requested by the Seventh Meeting of the Parties in its decision VII/34

Critical-use exemptions for methyl bromide (1997)

The *Ninth Meeting of the Parties* decided in *Decision IX/6:*

1. To apply the following criteria and procedure in assessing a critical methyl bromide use for the purposes of control measures in Article 2 of the Protocol:

   (a) That a use of methyl bromide should qualify as critical only if the nominating Party determines that:

      (i) The specific use is critical because the lack of availability of methyl bromide for that use would result in a significant market disruption; and

      (ii) There are no technically and economically feasible alternatives or substitutes available to the user that are acceptable from the standpoint of environment and health and are suitable to the crops and circumstances of the nomination;

   (b) That production and consumption, if any, of methyl bromide for critical uses should be permitted only if:

      (i) All technically and economically feasible steps have been taken to minimize the critical use and any associated emission of methyl bromide;

      (ii) Methyl bromide is not available in sufficient quantity and quality from existing stocks of banked or recycled methyl bromide, also bearing in mind the developing countries need for methyl bromide;

      (iii) It is demonstrated that an appropriate effort is being made to evaluate, commercialize and secure national regulatory approval of alternatives and substitutes, taking into consideration the circumstances of the particular nomination and the special needs of Article 5 Parties, including lack of financial and expert resources, institutional capacity, and information. Non-Article 5 Parties must demonstrate that research programmes are in place to develop and deploy alternatives and substitutes. Article 5 Parties must demonstrate that feasible alternatives shall be adopted as soon as they are confirmed as suitable to the Party s specific conditions and/or that they have applied to the Multilateral Fund or other sources for assistance in identifying, evaluating, adapting and demonstrating such options;

2. To request the Technology and Economic Assessment Panel to review nominations and make recommendations based on the criteria established in paragraphs 1 (a) (ii) and 1 (b) of the present decision;

3. That the present decision will apply to Parties operating under Article 5 and Parties not so operating only after the phase-out date applicable to those Parties.

Emergency methyl-bromide use (1997)

The *Ninth Meeting of the Parties* decided in *Decision IX/7:*

To allow a Party, upon notification to the Secretariat, to use, in response to an emergency event, consumption of quantities not exceeding 20 tonnes of methyl bromide. The Secretariat and the Technology and Economic Assessment Panel will evaluate the use according to the critical methyl bromide use criteria and present this information to the next meeting of the Parties for review and appropriate guidance on future such emergencies, including whether or not the figure of 20 tonnes is appropriate.

Multilateral Fund (1997)

The *Ninth Meeting of the Parties* decided in *Decision IX/5:*

1. That, in the fulfillment of the control schedule set out in paragraph 8 ter (d) of Article 5 of the Protocol, the following conditions shall be met:

   (a) The Multilateral Fund shall meet, on a grant basis, all agreed incremental costs of Parties operating under paragraph 1 of Article 5 to enable their compliance with the control measures on methyl bromide. All methyl-bromide projects will be eligible for funding irrespective of their relative cost-effectiveness. The Executive Committee of the Multilateral Fund should develop and apply specific criteria for methyl-bromide projects in order to decide which projects to fund first and to ensure that all Parties operating under paragraph 1 of Article 5 are able to meet their obligations regarding methyl bromide;

   (b) While noting that the overall level of resources available to the Multilateral Fund during the 1997 1999 triennium is limited to the amounts agreed at the Eighth Meeting of the Parties, immediate priority shall be given to the use of resources of the Multilateral Fund for the purpose of identifying, evaluating, adapting and demonstrating methyl bromide alternative and substitutes in Parties operating under paragraph 1 of Article 5. In addition to the US$10 million agreed upon at the Eighth Meeting of the Parties, a sum of US$25 million per year should be made available for these activities in both 1998 and 1999 to facilitate the earliest possible action towards enabling compliance with the agreed control measures on methyl bromide;

   (c) Future replenishment of the Multilateral Fund should take into account the requirement to provide new and additional adequate financial and technical assistance to enable Parties operating under paragraph 1 of Article 5 to comply with the agreed control measures on methyl bromide;

(d) The alternatives, substitutes and related technologies necessary to enable compliance with the agreed control measures on methyl bromide must be expeditiously transferred to Parties operating under paragraph 1 of Article 5 under fair and most favourable conditions in line with Article 10A of the Protocol. The Executive Committee should consider ways to enable and promote information exchange on methyl bromide alternatives among Parties operating under paragraph 1 of Article 5 and from Parties not operating under paragraph 1 of Article 5 to Parties operating under that paragraph;

(e) In light of the assessment by the Technology and Economic Assessment Panel in 2002 and bearing in mind the conditions set out in paragraph 2 of decision VII/8 of the Seventh Meeting of the Parties, paragraph 8 of Article 5 of the Protocol, sub-paragraphs (a) to (d) above and the functioning of the Financial Mechanism as it relates to methyl bromide issues, the Meeting of the Parties shall decide in 2003 on further specific interim reductions on methyl bromide for the period beyond 2005 applicable to Parties operating under paragraph 1 of Article 5;

2. That the Executive Committee should, during 1998 and 1999, consider and, within the limits of available funding, approve sufficient financial resources for methyl-bromide projects submitted by Parties operating under paragraph 1 of Article 5 in order to assist them to fulfil their obligations in advance of the agreed phase-out schedule.

Revised formats for reporting data under Article 7 of the Protocol (1997)

The *Ninth Meeting of the Parties* decided in *Decision IX/28:*

1. To note with appreciation the work done by the Implementation Committee and the Secretariat on the review and redesign of the formats for reporting data under Article 7 of the Montreal Protocol;

2. To note that the issue of reporting data is an important one and that it is an area to which the Parties may consider giving greater consideration;

3-5 [Not specifically related to methyl bromide]

6. To stipulate that, for the purpose of the data-collection only, when reporting data on the consumption of methyl bromide for quarantine and pre-shipment applications, the Parties shall report the amount consumed (i.e., import plus production minus export) and not actual use ;

7. To note that the revised data forms in annex VII to the report of the Ninth Meeting of the Parties *[see Section U2.12 of this Update]*, when completed, largely fulfill the reporting requirements under the Montreal Protocol, excluding those for essential-use exemptions.

Czech Republic (1997)

The *Ninth Meeting of the Parties* decided in *Decision IX/32:*

1. To note the Czech Republic s non-compliance in 1995 with the freeze in the consumption of methyl bromide. According to the information provided by the Czech Republic, in 1995 a total of 11.16 ODP tonnes of methyl bromide was imported, of which 7.9 ODP tonnes was consumed in 1996, and no methyl bromide was imported in 1996;

2. To note that, consequently, although the 1995 imports of methyl bromide exceeded the freeze level of 6.0 ODP tonnes for the Czech Republic, the average annual consumption for the two years 1995 and 1996 was below that level;

3. That no action is required on this incident of non-compliance but the Czech Republic should ensure that a similar case does not occur again.

Regional data collection on methyl bromide

The Seventeenth Meeting of the Executive Committee, accepting in principle the need to consider funding requests related to methyl bromide but emphasising, however, the desirability of such projects being submitted on a regional rather than an individual-country basis, approved three regional methyl bromide data-collection and demonstration workshops. In doing so, the Committee agreed that approval of those projects did not prejudice any other country-specific proposals for methyl bromide projects that may be submitted.

[Source: UNEP/Ozl.Pro/ExCom/17/60, Decision 17/8 para. 16]

Interim guidelines on methyl bromide demonstration projects

The Twentieth Meeting of the Executive Committee decided to adopt interim guidelines on methyl bromide projects and allocated a sum of US $100,000 to implementing agencies for preparation of demonstration projects on alternatives to methyl bromide. It further requested the Implementing Agencies to prepare a coordinated first tranche of projects with a total cost not exceeding US $3 million. The Committee will re-examine the applicability of the interim guidelines at its Twenty-second Meeting.

[Source: UNEP/Ozl.Pro/ExCom/20/72, Decision 20/49, para 75]

Strategy and guidelines for methyl bromide investment projects

The Twenty-third Meeting of the Executive Committee decided to request the Secretariat to convene a meeting of implementing agencies and interested bilateral donors, with the participation of the Methyl Bromide Technical Options Committee and some interested non-governmental organizations, for the purpose of developing a strategy and guidelines for investment projects in the methyl bromide sector; and urged the implementing agencies to make every effort to present well-considered investment projects in the methyl bromide sector during 1998.

[Source: UNEP/Ozl.Pro/ExCom/23/68, Decision 23/44 para. 72]

Resolutions and declarations on methyl bromide

Resolution on methyl bromide, fourth Meeting of the Parties (1992)

[Source: Annex XV of the report of the Fourth Meeting of the Parties]

The Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer

Resolve in the light of serious environmental concerns raised in the scientific assessment, to make every effort to reduce emissions of and to recover, recycle and reclaim, methyl bromide. They look forward to receiving the full evaluations to be carried out by the UNEP Scientific Assessment Panel and the Technology and Economic Assessment Panel, with a view to deciding on the basis of these evaluations no later than at their Seventh Meeting, in 1995, a general control scheme for methyl bromide, as appropriate, including concrete targets beginning, for Parties not operating under paragraph 1 of Article 5, with, for example a 25 per cent reduction as a first step, at the latest by the year 2000, and a possible phase-out date.

Copenhagen, 25 November 1992

Declaration on methyl bromide, fifth Meeting of the Parties (1993)

[Source: Annex VII of the report of the Fifth Meeting of the Parties]

by Austria, Belgium, Denmark, Finland, Germany, Iceland, Israel, Italy, Liechtenstein, Netherlands, Sweden, Switzerland, United Kingdom, United States and Zimbabwe

The above Parties present at the Fifth Meeting of the Parties to the Montreal Protocol,

Concerned about the continuing depletion of the ozone layer of both the northern and southern hemispheres, partly due to methyl bromide,

Being aware that reductions in the emissions of methyl bromide will have a beneficial effect on the ozone layer, especially in the coming 10 years where chlorine concentrations in the atmosphere will reach a critical maximum,

Being also aware that in many cases more environmentally sound alternative substances,

methods and technologies are already available and others are rapidly being developed,

Stress the need to strengthen the control measures decided at the Fourth Meeting of the Parties to the Protocol,

Declare their firm determination to reduce their consumption of methyl bromide by at least 25 per cent at the latest by the year 2000, and to phase out totally the consumption of methyl bromide as soon as technically possible.

Bangkok, 17 19 November 1993

Declaration on methyl bromide, seventh Meeting of the Parties (1995)

[Source: Annex X of the report of the Seventh Meeting of the Parties]

by Australia, Botswana, Canada, Iceland, Mauritius, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom, United States of America, and Venezuela

The above Parties present at the Seventh Meeting of the Parties to the Montreal Protocol,

Commend the international community for taking constructive steps in strengthening controls on methyl bromide,

Being aware that faster movement towards phasing out methyl bromide would reduce the human and environmental impacts of ozone depletion,

Being aware that some Parties are able to adopt alternatives at an earlier stage, and that several Parties have adopted domestic policies to largely phase out methyl bromide in the next few years,

Declare their firm determination, at the national level:

(a) To encourage the widespread adoption of alternatives.

(b) To take all appropriate measures to limit the consumption of methyl bromide to those applications that are strictly necessary, and to phase out the consumption of methyl bromide as soon as possible.

Vienna, 7 December 1995

Declaration on Methyl Bromide, ninth Meeting of the Parties (1997)

[Source: Annex XII of the report of the Ninth Meeting of the Parties]

by Bolivia, Burundi, Canada, Chile, Colombia, Denmark, Ghana, Iceland, Namibia, Netherlands, New Zealand, Romania, Switzerland, Uruguay and Venezuela

Whereas, the World Meteorological Organization has concluded that methyl bromide is highly destructive to the ozone layer, and that the 1994 Scientific Assessment Panel concluded that the elimination of methyl bromide is the single most significant step Governments can take to reduce future ozone loss,

Whereas, it is also clear that methyl bromide is highly toxic to workers, public health, and the global ecosystem,

Whereas, TEAP 1994 and 1997 reports have identified a wide range of economically viable alternatives to methyl bromide in both industrialized and developing countries,

Whereas, a recent report by Environment Canada has estimated the global economic benefits associated with reduced UV-B exposure to be $459 billion by 2060,

Whereas, the tenth anniversary Meeting of the Parties to the Montreal Protocol failed to adopt a phase-out schedule which will adequately protect public health and the environment from increased UV-B radiation,

Be it resolved that:

Urgent action is needed on the national and international level to phase-out methyl bromide as soon as possible.

Therefore, the undersigned countries pledge to promote sustainable alternatives to methyl bromide in their own nations and worldwide.

Montreal, 17 September 1997

Definitions

5.1 Consumption means production plus imports minus exports of controlled substances (Montreal Protocol, Article 1).

5.2 Controlled substance means a substance in Annex A, Annex B, Annex C or Annex E to the Protocol, whether existing alone or in a mixture. It includes the isomers of any such substance except as specified in the relevant Annex, but excludes any controlled substance or mixture (blend) which is in a manufactured product other than a container used for the transportation or storage of that substance (Montreal Protocol, Article 1).

5.5 The amounts recovered, reclaimed or recycled (or reused) is not to be considered as Production , even though they are to be reported.

Recovery, Recycling and Reclamation have been defined by the Parties (Decision IV/24) as follows:

(a) Recovery : The collection and storage of controlled substances from machinery, equipment, containment vessels, etc., during servicing or prior to disposal;

(b) Recycling : The reuse of a recovered controlled substance following a basic cleaning process such as filtering and drying. For refrigerants, recycling normally involves recharge back into equipment. It often occurs on-site ;

(c) Reclamation : The re-processing and upgrading of a recovered controlled substance through such mechanisms as filtering, drying, distillation and chemical treatment in order to restore the substance to a specified standard of performance. It often involves processing off-site at a central facility.

5.6 Quarantine and pre-shipment applications have been defined by the Parties (decision VII/5) as follows:

(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 authorized 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.

5.8 The Parties decided at their Eighth Meeting (Decision VIII/14):

To clarify decision I/12A of the First Meeting of the Parties as follows: trade and supply of methyl bromide in cylinders or any other container will be regarded as trade in bulk in methyl bromide.

6.5 When calculating a Party s consumption, substances used as feedstock for the production of other chemicals are exempted.

6.6 When calculating a Party s consumption of methyl bromide, the quantities used for quarantine and pre-shipment (QPS) applications are exempted. In data form 1, quantities of methyl bromide imported for quarantine and preshipment applications should be entered separately at the bottom of the form, and *not deducted* from the total quantity imported. The Secretariat will make the necessary deductions.

7.6. When calculating a Party s consumption, the Montreal Protocol does not include ODSs used as feedstock for the production of other chemicals

7.7 When calculating a Party s consumption of methyl bromide, quantities used for quarantine and preshipment (QPS) applications are exempted

8.6 When calculating a Party s consumption of methyl bromide, quantities produced for quarantine and preshipment (QPS) applications are exempted

10.3. Non-Party means:

With respect to Annex E substances, all countries that have not ratified the Copenhagen Amendment.

10.4 The status of ratification of the 1987 Montreal Protocol and of the London and Copenhagen Amendments to the Montreal Protocol, can be found in a document published by the Secretariat and updated four times a year. This information is also available on the website of the Ozone Secretariat, at: http://www.unep.org/unep/secretar/ozone/ratif.htm.

11.4 Methyl Bromide Mixtures:

No.	Trade Name of Mixture	Composition			
		Component 1		Component 2	
1	methyl bromide with chloropicrin	methyl bromide	67%	chloropicrin**	33%
2	methyl bromide with chloropicrin	methyl bromide	98%	chloropicrin**	2%

** Not an ozone-depleting substance

Appendix

3

Sources of information on methyl bromide and ozone depletion

TITLE AND BRIEF DESCRIPTION OF CONTENTS	WEB SITE ADDRESS
Web links related to protection of the ozone layer, and the environment	
UNEP web site in Nairobi	http://www.unep.org/
Ozone Secretariat Mirror Site in Geneva	http://www.unep.ch/ozone/home.htm
UNEP Ozone Action Programme	http://www.unepie.org/ozonaction.html
Technology and Economic Assessment Panel (TEAP)	http://www.teap.org
World Meteorological Organization (WMO) Ozone Mapping Centre. Provides a list of daily ozone maps of the northern hemisphere taken daily between 1 November - 31 March.	http://www.wmo.ch/web/arep/nhoz.html
Ozone Action Information Clearinghouse (OAIC). This is a Database produced by United Nations Environment Programme - Industry and Environment (UNEP/IE) and is designed to provide technical and policy information about the phase-out of ozone-depleting substances, substitutes and new technologies and much more.	http://www.epa.gov/docs/ozone/intpol/oaic.html
WMO/UNEP Scientific Assessment of Ozone Depletion 1994. This NOAA site contains the text of the Executive Summary of the Scientific Assessment of Ozone Depletion: 1994, Common Questions About Ozone (a special section of the 1994 Assessment, list of international authors, contributors and reviewers of the Assessment and detailed contents of the full report.	http://www.al.noaa.gov/WWWHD/pubdocs/WMO UNEP94.html
Our Planet, Volume 9, Number 2 1997, which focuses on ozone layer depletion	http://www.ourplanet.com
UNEP's GEF-Financed Activities on the Stratospheric Ozone Layer	http://www.unep.org/unep/gef/ozone
Government web sites	
United States Environmental Protection Agency (USEPA)	http://earth1.epa.gov/ozone
Ozone Depletion. Contains information on ozone depletion science	http://earth1.epa.gov/ozone/science/science.html
US Regulations	http://earth1.epa.gov/ozone/title6/usregs.html
Methyl Bromide International Policy	http://earth1.epa.gov/ozone/mbr/mbrqa.html
Information for Consumers	http://earth1.epa.gov/ozone/olaw/consumer.html
Events related to ozone depletion International CFC and Halon Alternatives Conference	http://www.epa.gov/docs/ozone/events.html
Ozone – What is it and why do we care about it?	http://spso.gsfc.nasa.gov/nasa-facts/ozone/ozone.html

TITLE AND BRIEF DESCRIPTION OF CONTENTS	WEB SITE ADDRESS
Stratospheric Ozone Layer Environment Canada. Contains information on: State of the Stratospheric Ozone Layer, Canadian Federal Statutes, FAQs about ozone and an ozone quiz.	http://www.pwc.bc.doe.ca/ep/ozone/ods.html
Non-government web sites	
Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) General information about ozone depletion, global warming and alternative fluorocarbons plus production, sales and emissions data.	http://www.afeas.org
This is a database and WWW gateway to information sources in development and the environment. Each entry contains a short description of the source, a URL link where appropriate and contact information.	http://www.ids.ac.uk/eldis/eldis.html
Ozone Depletion	http://www.lib.ox.ac.uk/internet/news/faq/by-category.ozone-depletion.html
Greenpeace International Environmental Law and Multilateral Environmental Treaties.	http://www.greenpeace.org/~intlaw/
Information Sheet on Ultraviolet Radiation The human eye responds to light with wavelengths from about 790 nm (red) to 430 nm (violet).	http://www.niwa.cri.nz/lauder/uvinfo.html
Ozone Action. Simple fact sheets on Ozone Depletion and Climate Change. Learn more about the black market in CFCs and alternatives to Ozone Depleting Substances.	http://www.ozone.org
Ozone-depletion. Introduction to the Ozone Layer. Stratospheric Chlorine and Bromine.	http://www.cs.ruu.nl/wais/html/na-dir/ozone-depletion/.html
Ozone Depletion. The Antarctic Ozone Hole. UV Radiation and its Effects	http://www.cis.ohio-state.edu/text/faq/usenet/ozone-depletion/top.html
Programme for Alternative Fluorocarbon Toxicity Testing (PAFT). Summary of research on the toxicology of substitute fluorocarbons.	http://www.paft.org
Protonique. Written by a member of the UNEP Solvents, Coatings and Adhesives Technical Options Committee, this gives much practical advice for electronics manufacturers phasing out ozone depleting solvents with minimum risk of causing other environmental problems.	http://www.ourworld.compuserve.com/homepages/protonique/
SEDAC. Provides data and resources in the areas of ultraviolet (UV) radiation, ozone, and human health impacts of UV exposure for use by researchers, educators, government officials, health providers, students, and the general public.	http://sedac.ciesin.org/ozone
Stratospheric Ozone Law, Information and Science (SOLIS). Information and pointers to information relevant in some way to the ozone layer, including the topic of anthropogenic ozone depletion.	http://acd.ucar.edu/gpdf/ozone/index.html
Global Change home page	http://www.globalchange.org/
This is one of the few sites of German language text and figures which explains ozone depletion for German speakers.	http://www.hagen.de/OZON/ozon_i.htm