

WHO/CDS/WHOPES/2002.5 Rev.1

***MALARIA VECTOR CONTROL***

**DECISION MAKING CRITERIA  
AND PROCEDURES FOR  
JUDICIOUS USE OF INSECTICIDES**

**By:**

**Dr J.A. Najera and Dr M. Zaim**

**WORLD HEALTH ORGANIZATION  
Communicable Disease  
Control, Prevention and Eradication  
WHO Pesticide Evaluation Scheme (WHOPES)**

**© World Health Organization 2003**

All rights reserved.

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted lines on maps represent approximate border lines for which there may not yet be full agreement.

The mention of specific companies or of certain manufacturers' products does not imply that they are endorsed or recommended by the World Health Organization in preference to others of a similar nature that are not mentioned. Errors and omissions excepted, the names of proprietary products are distinguished by initial capital letters.

The World Health Organization does not warrant that the information contained in this publication is complete and correct and shall not be liable for any damages incurred as a result of its use.

The named authors alone are responsible for the views expressed in this publication.

## Contents

	<b>Page</b>
<b>Acknowledgements</b>	<b>vii</b>
<b>1. Introduction</b>	<b>1</b>
<b>1.1 The Global Malaria Control Strategy</b>	<b>1</b>
<b>1.2 The role of vector control in the strategy of malaria control</b>	<b>3</b>
<b>1.3 Indications for vector control</b>	<b>5</b>
<b>1.4 Vector bionomics, human ecology and vector control</b>	<b>7</b>
<b>1.5 Available vector control methods and their classification</b>	<b>11</b>
1.5.1 Methods of reducing human-vector contact	12
1.5.2 Methods aimed mainly at reducing vector density	13
1.5.3 Methods aimed mainly at increasing adult vector mortality	16
<b>1.6 Operational characteristics of different vector control methods</b>	<b>17</b>
1.6.1 Minimum coverage required for activity	17
1.6.2 Rapidity of impact	18
1.6.3 Integration of vector control activities	19

<b>2. Chemical control</b>	<b>22</b>
<b>2.1 Types of application</b>	<b>22</b>
<b>2.2 What to apply</b>	<b>23</b>
2.2.1 Methods, insecticides and formulations suitable for different situations	23
2.2.2 Dosage and effect	24
2.2.3 Safety of users, operators and the environment	25
2.2.4 Acceptability and affordability	26
2.2.5 Resistance and avoidance of contact	28
2.2.6 Possibilities of integrating different approaches and methods	30
2.2.7 Monitoring and evaluation	32
<b>2.3 Where to apply</b>	<b>36</b>
2.3.1 Epidemiological and operational criteria - stratification	36
2.3.2 Coverage requirements for effectiveness	37
<b>2.4 When to apply</b>	<b>37</b>
<b>2.5 How to apply</b>	<b>38</b>
2.5.1 Health information and education	39
2.5.2 Equipment and maintenance	40
2.5.3 Protective measures	40
2.5.4 Monitoring of exposure	41

2.5.5	Disposal of containers and surplus insecticides	42
<b>3.</b>	<b>Indoor residual spraying</b>	<b>45</b>
<b>3.1</b>	<b>What to apply</b>	<b>47</b>
3.1.1	Insecticides and formulations - vector susceptibility, effectiveness and safety	47
3.1.2	Resistance, avoidance and resistance management	50
3.1.3	Acceptability	52
3.1.4	Dosage	53
<b>3.2</b>	<b>Where to apply</b>	<b>54</b>
3.2.1	Definition of targets of application	55
3.2.2	Preparation of houses before spraying	56
<b>3.3</b>	<b>When to apply</b>	<b>57</b>
3.3.1	Type of spraying cycle	57
3.3.2	Timing in relation to transmission season	58
3.3.3	Duration of working day and safety	58
<b>3.4</b>	<b>How to apply</b>	<b>59</b>
3.4.1	Equipment and maintenance	59
3.4.2	Protective measures	60
3.4.3	Disposal of containers and surplus insecticides	62

3.4.4	Operational problems, responsibility of operations	62
3.4.5	Health information and education	64
<b>4.</b>	<b>Insecticide-treated mosquito nets</b>	<b>66</b>
<b>4.1</b>	<b>What to apply</b>	<b>68</b>
4.1.1	Insecticides and formulations for treatment	68
4.1.2	Safety	69
4.1.3	Basic requirements, time, costs and acceptability	72
4.1.4	Specifications	73
<b>4.2</b>	<b>Where to apply</b>	<b>74</b>
4.2.1	Delimitation of areas and population to be protected	74
4.2.2	Requirements for indoor and outdoor protection (population habits)	74
<b>4.3</b>	<b>When to apply</b>	<b>75</b>
<b>4.4</b>	<b>How to apply</b>	<b>76</b>
<b>5.</b>	<b>Larviciding</b>	<b>80</b>
<b>5.1</b>	<b>What to apply</b>	<b>80</b>
5.1.1	Available larvicides and formulations	80
5.1.2	Environmental impact	85
5.1.3	Resistance	85

<b>5.2</b>	<b>Where to apply</b>	<b>85</b>
5.2.1	Delimitation of areas and population to be protected	86
5.2.2	Choice of actual or potential breeding places	86
<b>5.3</b>	<b>When to apply</b>	<b>87</b>
5.3.1	Periodicity of treatment cycles	87
5.3.2	Timing in relation to transmission season, seasonality of operations	87
<b>5.4</b>	<b>How to apply</b>	<b>88</b>
5.4.1	Equipment for aerial and ground application	88
5.4.2	Responsibility for treatment operations	88
<b>6.</b>	<b>Space spraying</b>	<b>91</b>
<b>6.1</b>	<b>What to apply</b>	<b>92</b>
6.1.1	Indications for space spraying	93
6.1.2	Insecticides and formulations	94
6.1.3	Knock-down and potential residual effect	95
6.1.4	Environmental impact	96
6.1.5	Resistance	96
<b>6.2</b>	<b>Where to apply</b>	<b>96</b>
6.2.1	Delimitation of areas and population to be protected	97

<b>6.3</b>	<b>When to apply</b>	<b>97</b>
6.3.1	Periodicity of treatment cycles	98
<b>6.4</b>	<b>How to apply</b>	<b>99</b>
6.4.1	Choice of equipment	99
6.4.2	Responsibility for operations	102
<b>7.</b>	<b>References cited</b>	<b>103</b>
<b>Annex 1.</b>	<b>WHO Regional Offices</b>	<b>106</b>



## Acknowledgements

The Department of Communicable Disease Control, Prevention and Eradication (CPE) wishes to thank the following for their critical review of this publication and for their valuable comments and suggestions:

- Dr A. Arata, Alexandria, Virginia, USA.
- Dr C. Boase, Haverhill, Suffolk, England.
- Mr R. Bos, Water, Sanitation and Health, Sustainable Development and Healthy Environments, World Health Organization, Geneva, Switzerland.
- Dr P. Carnevale, Institut de Recherche pour le Developpement, Montpellier, France.
- Dr M. Coetzee, University of Witwatersrand, Johannesburg, South Africa.
- Dr C.F. Curtis, London School of Hygiene and Tropical Medicine, London, England.
- Dr P.K. Das, Vector Control Research Centre, Pondicherry, India.
- Dr C. Frederickson, Pan American Health Organization, Brasilia, Brazil.
- Dr D. Kelli, Public Health Project Team, CropLife International, Brussels, Belgium.
- Dr G. Matthews, International Pesticides Application Research Centre, Imperial College, Ascot, England.
- Dr M. Macdonald, US Agency for International Development, Washington, DC, USA.
- Dr A. Mnzava, WHO Regional Office for the Eastern Mediterranean, Cairo, Egypt.
- Dr M. Nathan, Communicable Disease Control, Prevention and Eradication, World Health Organization, Geneva, Switzerland.
- Dr C. Prasittisuk, WHO Regional Office for South-East Asia, Delhi, India.

- Dr E. Renganathan, Communicable Disease Control, Prevention and Eradication, World Health Organization, Geneva, Switzerland.
- Dr V.P. Sharma, WHO Regional Office for South-East Asia, New Delhi, India

This publication has been funded in part by the Roll Back Malaria (RBM).

## **1. Introduction**

The purpose of this publication is to help to ensure the safe and effective use of insecticides in malaria vector control. The choice of the methods to use should be preceded by decisions on the composition of a selective approach to vector control that is specific in time and space and may or may not require the application of insecticides. This introduction positions chemical vector control within the context of an overall malaria control strategy.

### **1.1 The Global Malaria Control Strategy**

The Global Malaria Control Strategy, as adopted by the Ministerial Conference in 1992, consists of the following four basic technical elements (WHO, 1993):

- early diagnosis and prompt treatment;
- planning and implementing selective and sustainable preventive measures, including vector control;
- detecting epidemics at an early stage and containing or preventing them; and
- strengthening local capacities in basic and applied research to permit and promote the regular assessment of a country's malaria situation, and in particular, the ecological, social and economic determinants of the disease.

Making "disease diagnosis and treatment" the first general priority is based primarily on the fundamental obligation of health services to provide care for the sick, thus preventing mortality and reducing incapacity, when it is clear that eradication is not feasible in the short term. It is

also based on the extension of health services to the periphery so as to provide the required infrastructure for channelling the health information and education needed to improve the use of personal protection measures and eventually to deploy any new technology which may be suitable for general application, whether a vaccine or a sustainable method of vector control.

The selection of the actual interventions to be made in any particular area should be based firstly on its ecological and epidemiological characteristics, which may determine the effectiveness of potential interventions, and secondly on the socio-political and economic situation, which may determine whether they can be applied correctly and whether the results achieved can be maintained.

The term stratification has been coined to define the process of eco-epidemiological characterization of endemic areas so as to guide the selection of effective interventions. This is a process intended to reduce, simplify and understand better a complex problem and to facilitate the formulation of solutions. This characterization should start with an analysis of all the available information, including the history of malaria vector control interventions, followed by the recognition of the main eco-epidemiological types identified in the global strategy. This will enable feasible interventions to be identified. The feasibility of control will depend on:

- the coverage, organization and quality of the health services, including specific health programmes;
- the participation of other partners and the local communities in health initiatives; and

- the existence of, or the possibility of developing the necessary human and material resources to implement the required interventions.

While in some areas anti-malarial interventions may be limited for a number of years to improving the quality of timely diagnosis and treatment, many other areas require, and have the resources necessary for implementing vector control, either to prevent or control epidemics or to reduce the disease burden. The identification and characterization of such areas constitutes a further development of stratification, which should be viewed as a process which will intensify the study of the local epidemiology in response to the evolution of the problem and the analysis of the response to interventions.

## **1.2 The role of vector control in the strategy of malaria control**

As the second basic element of the Global Malaria Control Strategy, selective application of transmission control measures must be considered wherever malaria is endemic. Since no method of active immunization is available and mass chemotherapy has very limited application, the only way of controlling transmission is usually that provided by the various methods of vector control.

The WHO Study Group on Vector Control for Malaria and other Mosquito-borne Diseases (WHO, 1995) defined selective vector control as the application of targeted, site-specific control activities that are cost-effective. The principal objective of vector control is the reduction of malaria morbidity and mortality by reducing the levels of transmission.

The Study Group further defined selective vector control as the selective use of one or more of the available control methods, the decision-makers having taken into account:

- the disease status and risks in order to decide on the needs and priorities of vector control;
- the vector, human behaviour and the environment in order to determine which vector control methods are suitable and where they are needed; and
- the resources available to implement action.

Vector control methods vary considerably in their applicability and cost, and the sustainability of their results. While the control of transmission will be of some benefit whatever the situation, the choice of vector control will depend on the magnitude of the malaria burden, the feasibility of timely and correct application of the required interventions and, most important of all, the possibility of sustaining the resulting modified epidemiological situation.

Vector control is undoubtedly necessary to prevent an epidemic when the conditions leading to a sudden increase in transmission or human exposure have been detected in an epidemic-prone area. Nevertheless, in any attempt to reduce the vectorial capacity in an endemic area, it is necessary to take into account the sustainability of the resulting change in endemicity. Most vector control operations will have a significant and obvious impact on the malaria burden of the population concerned. However, if the unfavourable ecological or social conditions persist, the discontinuation of vector control may, because of the decreased immunity of the population, result in an epidemic return of transmission, and the longer the controlled situation has been artificially maintained, the more severe will the impact be.

### 1.3 Indications for vector control

The main indications for vector control are described below.

- *Control and/or prevention of malaria epidemics.* This will require, if they can be carried out before the expected peak of transmission, residual spraying or the treatment of mosquito nets if nets are widely used in the affected area. If the epidemic has already started the use of emergency vector control measures, such as space spraying may be considered, if such methods have been effective for the target species in the same ecological setting and if resources are available for their immediate implementation. In the prevention of malaria epidemics when alarm signals have been detected and an epidemic preparedness system is in operation, indoor residual spraying and/or treatment of mosquito nets (if they are widely used) may be indicated, depending on the time available for action.
- *Elimination of new foci of infection in malaria-free areas.* Depending on the extension and number of such foci, space spraying or indoor residual spraying should be considered as emergency measures.
- *Prevention of seasonal peaks of malaria transmission.* These may sometimes have the characteristics of seasonal epidemics. It may then be possible to institute routine seasonal application of indoor residual spraying and/or treatment of mosquito nets. It may also be worth considering environmental management methods, source reduction or larviciding in areas of high population density, such as urban areas or in development projects, in order to reduce the risk of transmission in the future.

- *Control of transmission in high-risk situations.* Such situations exist in labour or refugee camps, where non-immunes and infected people may come together in conditions of high transmission potential. Similar situations exist in outposts (army, police, prospectors, etc.) in endemic areas. If malaria control is taken into account when the high-risk situation is being created (e.g. when refugee or labour camps are being established), it may be possible to consider environmental measures such as site selection or basic sanitation. However, malaria control is usually required when there is little possibility of changing the location of such camps, although minor improvements in sanitation should be always considered. Emergency malaria control is often required and mass treatment of fever (or mass drug administration) may be the only possibility. Vector control is particularly indicated when mass chemotherapy is used, as a reduction of transmission will reduce the spread of resistant parasites selected by the massive use of drugs.
- *Reduction of transmission in areas of high drug resistance.* Most of these areas will fall into one or more of the categories described above. Drug resistance may be particularly high in areas which have been subjected to high selection pressure following the massive use of anti-malarials where vector control was considered difficult to organize. Perhaps the most suitable method in these situations will be the use of insecticide-treated materials, although this may pose serious logistic problems in some areas.
- *Control of endemic malaria.* The method most likely to produce sustainable control is the use of insecticide treated materials, although indoor spraying has been and still is the most widely used. Again, in areas of



high population density, environmental management and larval control should be considered, since it may be feasible to integrate malaria control with other mosquito-control activities aimed at controlling other vector-borne diseases or even the control of mosquito nuisance.

#### **Indications for vector control**

- **Prevention and control of malaria epidemics;**
- **Elimination of new foci of infection in malaria-free areas;**
- **Prevention of seasonal peaks of malaria transmission;**
- **Control of transmission in high-risk situations;**
- **Reduction of transmission in areas of high drug resistance; and**
- **Control of endemic malaria**

#### **1.4 Vector bionomics, human ecology and vector control**

The bionomics of the different species of malaria vectors, about 60 of which are vectors and 30 are of major importance, varies considerably. Some of the characteristics of their bionomics make certain species more or less vulnerable to the various methods of vector control. Ideally, a vector control intervention should be targeted to the particular vector species concerned and be free from undesirable effects on humans or the environment. This was the aim of the so-called "species sanitation" developed during the 1920s, which unfortunately has rather limited applicability. Even for those species potentially suitable for local species sanitation, the cost of the required study of the bionomics

and of the necessary environmental modifications is often prohibitive.

Even if the acquisition of the detailed knowledge of all the bionomic characteristics needed for species sanitation is not feasible, knowledge of the larval habitats and adult behaviour will be necessary in order to select the appropriate line of attack, not only for source reduction, but also the more general chemical methods, including both larviciding and adulticiding.

Larval habitats vary enormously, reflecting the evolutionary adaptability of mosquitoes. Potential water habitats include both permanent and temporary bodies of water, fresh and brackish water, standing water and canals and open streams, in bright sun light or deep shade. Larvae can thrive even in indoor containers, in shallow pools and deep wells, in clean drinking water and in water highly polluted with organic matter, in large open marshes and in the tiny pools of water that collect in plant axils, in tree holes, in rock or crab holes, in cattle footprints or in discarded tins or other artificial containers. Although some species have the ability to adapt to a fairly wide range of breeding places, most are much less adaptable, providing a number of useful targets for larval control. Nevertheless, the feasibility of this targeted attack depends on the accessibility of the breeding places.

Equally variable are the biting and resting habits of adult female mosquitoes. Vectors' preferences for human or animal blood as well as their frequency of feeding, together with their expectation of life, are the main determinants of the probability of their transmitting malaria. Vectors biting mainly humans and with a high expectation of life can maintain very high transmission rates at very low density, so that methods aimed at reducing vector density will require degrees of

effectiveness difficult to achieve. In contrast, some species may be important vectors, even if they prefer feeding on animals, because of the very high vector density that they maintain. These species are therefore more sensitive to density reduction. The time of feeding is also very important, both for vector efficiency and for the effectiveness of control. The most efficient vectors tend to bite mainly in the middle hours of the night, when people are in deep sleep, while vectors biting at dusk or dawn are more likely to be an obvious nuisance, thereby causing people to defend themselves more effectively against them. Bednets and indoor spraying will be more effective against vectors of the first type if people sleep indoors.

It is important to understand the resting habits of the vectors, whether for digesting their blood meal or for maturing their eggs, in order to ascertain their vulnerability to methods aimed at reducing their expectation of life, whether these methods are aimed at the whole vector population or only that portion of it frequenting human dwellings for biting or resting.

The following terms are used to define the more important characteristics of vectors' feeding and resting habits in relation to human habitations:

- anthropophily and zoophily indicate the vector's preference for human or animal blood, and are estimated by analysing the blood of a sample of freshly fed mosquitoes. The "human blood index" is defined as the proportion of females having fed on humans;

## DECISION-MAKING PROCESS

Stratify area according to the disease burden and epidemiology of transmission (see 1.1)



Determine if there is a role for vector control in each epidemiological stratum and in current local circumstances (see 1.3)



If there is a role for vector control, determine vector(s) in each stratum



For each vector implicated, determine:

- Breeding sites
- Adult resting sites
- Blood feeding behaviour
- Ecology
- History of insecticide resistance



Determine which method(s) of vector control is suitable (see 1.4 and 1.5)



Where the use of insecticides is essential, select the method of application (see 1.4 and 1.5)

- endophagy and exophagy indicate the tendency to bite indoors or outdoors; and
- endophily and exophily indicate the tendency of vectors to rest indoors or outdoors during the whole or part of the period of blood digestion and egg development

It is also important to understand the mechanisms of survival during adverse weather conditions (cold winters or long dry periods), although this will require a detailed knowledge of the biology of the vector species concerned. In practice, it has been easier to study, and use for planning control, the conditions of hibernation (survival in winter) than those of aestivation (survival in hot dry periods).

Even the way of recognising the role of an anopheline species as a malaria vector varies in relation to the whole of the vector bionomics. The most direct way of incriminating an anopheline as a malaria vector is to find sporozoites in its salivary gland, but in those vectors where the vectorial capacity depends on high density it is often practically impossible to find sporozoites because of the extremely large samples which would have to be analysed in order to find them. Pooled samples analysed by means of immunological assays may be required to determine infection rates.

## **1.5 Available vector control methods and their classification**

Vector control methods can be classified in different ways for different purposes. From an epidemiological point of view, it may be advisable to classify vector control methods according to the principal effect to be obtained

and therefore the link in the chain of transmission most directly affected by their application. Such a classification may be useful in the selection of a control method:

### 1.5.1 Methods of reducing human-vector contact

This category covers all methods in which a barrier is established between vectors and humans, and includes the following:

- *Mosquito nets and insecticide treated mosquito nets.* Although untreated mosquito nets have a long history of use in controlling malaria transmission, the introduction of net treatment with pyrethroid insecticides of residual action has considerably increased their effectiveness by adding to the barrier effect of the net the repellent and killing action of the insecticide. In particular, the repellent effect of pyrethroids prevents feeding through the net and often also the penetration of mosquitoes through holes in the net. As compared with indoor house spraying, this method also has the advantage of being effective for individual protection. The mass effect, as with any other method of control, depends on high coverage but, when coverage is low, individuals using the nets are protected. For this reason, their use can be progressively introduced in a population by promotional activities supported by information, education and communication. The main limitation is the potential for transmission by early biting vectors before people retire to sleep. This is presumably the reason why it has often been found in field trials that this method is more effective in protecting children than adults. Its effectiveness could be improved by some complementary measures, such as the use of repellents, mosquito coils or other household

pesticides, for the protection of individuals remaining outdoors for long periods after dark.

- *House protection with screening of windows, eaves and doors.* This is an effective method if properly implemented and maintained. It remains almost exclusively a method of individual and family protection, since it requires a high investment and has high care and maintenance costs.
- *Use of repellents.* These may be applied either directly on the skin (as a cream, lotion or aerosol) or on clothes. The use of repellents is also only a measure of individual protection that can be recommended as a complement to the use of bednets and house protection methods, to be used after dark before retiring under the mosquito net or by people who have to stay outdoors during some part of the night. In epidemics, repellents have been distributed in some malaria control programmes, although their cost-effectiveness remains doubtful.
- *Fumigant insecticide dispensers.* These are widely used throughout the tropics for individual protection, particularly in the form of mosquito coils and, in urban areas, electrically heated dispensers.

#### 1.5.2 Methods aimed mainly at reducing vector density

It is well recognised that the impact of vector control on the transmission potential (reproduction rate, vectorial capacity) is directly proportional to the reduction of the vector density. Nevertheless, in most endemic areas reproduction rates are greatly in excess of those required to maintain transmission, huge reductions in density may therefore be required to achieve effective control. Most practical methods aiming at the reduction of vector

densities require the treatment of vector breeding places, leading to their elimination or to a considerable reduction of breeding in the treated sites. Their effect on malaria transmission will therefore depend on the relative importance of the treated breeding places in maintaining vector density. However, it is not unusual to find that, even if some breeding places have very high larval densities, transmission is maintained mainly by rain-dependent temporary breeding sites. The main limitation of these methods is therefore the difficulty of locating and treating all breeding places essential for the maintenance of malaria transmission. These methods include all forms of larval control, as described below:

- *Source reduction by environmental management.* This includes drainage, flushing, filling, and rendering river and lake margins unsuitable for anopheline breeding. These are the classical methods of malaria sanitation, which may be used for all mosquito breeding in general or targeted to the specific breeding places of malaria vectors of local importance (the so-called species sanitation), which requires, as previously mentioned, a thorough knowledge of the bionomics of the local vectors. In general, these methods have relatively high investment costs and may be cost-effective only in urban areas or some types of development projects. They are suitable for the elimination of permanent breeding places, the importance of which should be assessed before embarking on the expensive process of eliminating them. Nevertheless, when properly executed and maintained, their sustainability is relatively easy.

Environmental management methods should be seriously considered in agricultural production systems and in urban settings in certain areas. Moreover, in a fully man-made environment, environmental



management should be the first line of defence in reducing malaria transmission risks.

There is a clear link between the environmental conditions created by certain agricultural practices and the risks of vector-borne disease transmission. Irrigation in its different forms, crop selection and possibly crop rotation, together with chemical inputs into the agricultural production process, can all have an impact on these risks. Farmers, by the nature of their work, are involved in environmental management on a daily basis, and can play a crucial role in reducing them. A clear understanding of agricultural production systems where malaria transmission takes place is therefore essential in considering possible changes in such systems and in selecting right personnel (often agricultural extension workers) to ensure that the necessary health-oriented environmental management measures are taken by farming communities.

- *Larviciding*. This includes the use both of chemical insecticides and those of biological origin, such as the toxin of *Bacillus thuringiensis israelensis* and insect growth regulators. It requires the treatment of all breeding places, and may present the same problems as source reduction when temporary breeding places are of great epidemiological importance. In contrast to sanitation methods, larvicides normally have little residual effect, and require regular and frequent applications.
- *Biological control*. For anophelines, this is practically limited to the use of predators (mainly larvivorous fish), which are most effective in man-made breeding sites (e.g. ponds, cisterns or irrigation systems). Although such predators suffer from the same problems of coverage as all the other anti-larval measures, they

may become established in a more permanent form although, as with most natural interacting populations, they will tend to establish an equilibrium with their prey, which will have to be disturbed by frequent seeding of the predator or pathogen concerned.

- *Space spraying of insecticides.* Although its main effect is a rapid reduction of vector density, when applied at relatively short intervals (less than the duration of the sporogonic cycle), the resulting increase in adult mosquito mortality will, if the required coverage can be achieved, rapidly reduce transmission. Space spraying has been extensively used for controlling epidemics of mosquito-borne diseases such as dengue and some types of encephalitis. It has only occasionally been used in malaria epidemic control and as a complementary measure against exophilic vectors. Its main limitation is the difficulty of applying them at night, when vectors are flying, and the poor penetration of insecticide fogs into the day time resting places of the vectors. In addition it may be difficult to mobilize all the necessary resources for space spraying before the epidemic declines naturally.

### 1.5.3 Methods aimed mainly at increasing adult vector mortality

Increasing adult vector mortality reduces their expectation of life and therefore the probability that the parasite will complete its development. Although density will usually also be reduced, the reduction in the daily survival of the vector has a disproportionately greater impact on transmission. The two methods available for increasing adult vector mortality are described below.

- *Indoor residual spraying.* This includes all methods of indoor spraying with residual insecticides, thus

targeting the killing effect to house resting vectors and constituting a most efficient way of using the insecticide to kill vectors likely to transmit malaria. Although pyrethrum was the insecticide first used, indoor spraying of insecticides became the most popular method of malaria vector control with the introduction of DDT and other residual insecticides. Its main limitation is that exophilic vectors may exist and may not come into contact with sprayed surfaces. In addition, this behavioural trait may be selected as a result of the insecticide treatment.

- *Community wide use of insecticide treated nets.* When a large proportion of the population in a community is protected by insecticide-treated nets there may be a significant reduction of vector survival, density and sporozoite rate (“mass impact”) and hence of malaria transmission, and a corresponding increase in community protection.

## **1.6 Operational characteristics of different vector control methods**

There is considerable variability in the main methods of vector control in relation to a number of operational characteristics.

### **1.6.1 Minimum coverage required for activity**

Some methods are effective only at the individual or family level, e.g. non-treated mosquito nets or house screening, community protection is then only achieved with total coverage . Other methods, such as the use of insecticide-treated materials, are not only more effective as individual protection, but their effect on the community is greater than the sum of the individual protection since, as coverage increases, there is an impact on the vector

population. In contrast, indoor residual spraying requires a high coverage if any protection, either of individuals or the community, is to be achieved, since there is a threshold effect which will vary in accordance with the concentration or dispersal of human habitations in relation to breeding places, the anthropophily of the vector, its flight range and its resting habits. Similarly larval control methods require an even higher degree of coverage, and a few or temporary breeding places may often be sufficient to maintain a high malaria transmission, even when a large number of permanent breeding places are treated or eliminated.

#### 1.6.2 Rapidity of impact

It is important to assess the need for rapid impact in selecting a vector control method, distinguishing between individual and collective impact. If it is possible to conduct a field trial, this may be done by monitoring the number of new cases and their suspected place of origin. In general, the introduction of mosquito nets or of house screening would be expected to protect their users immediately, but would only achieve collective protection slowly, as problems of logistics and of health education would tend to hamper their wide implementation. In contrast, indoor residual spraying is not as immediately protective, since existing infected vectors may continue to bite even if they will die later when resting on sprayed walls after biting. As a collective measure, however, it may be rapidly implemented. Finally, space spraying is the most rapidly effective and, in areas of relatively high population density, can be quickly implemented. For this reason, it has been considered for emergency vector control, although its applicability is rather limited (see 1.5.2).

### 1.6.3 Integration of vector control activities

The integration of interventions targeting the same communities and using the same human and material resources is a requirement for efficient health care, even if the vertical type of organization may be more effective in short-term campaigns.

Ideally, malaria vector control activities should be part of a broader vector control management programme. This may be defined as a set of evidence-based decision-making procedures aimed at planning, delivering, monitoring and evaluating targeted, cost-effective and sustainable combinations of regulatory and operational vector control measures having a measurable impact on disease transmission.

Nevertheless, the technical and managerial aspects of the problem are not independent of one another and, in most cases, and particularly in malaria control, a service is not created *de novo* for the implementation of a technically planned programme. Instead, a programme must be executed by a pre-existing service with relatively few modifications

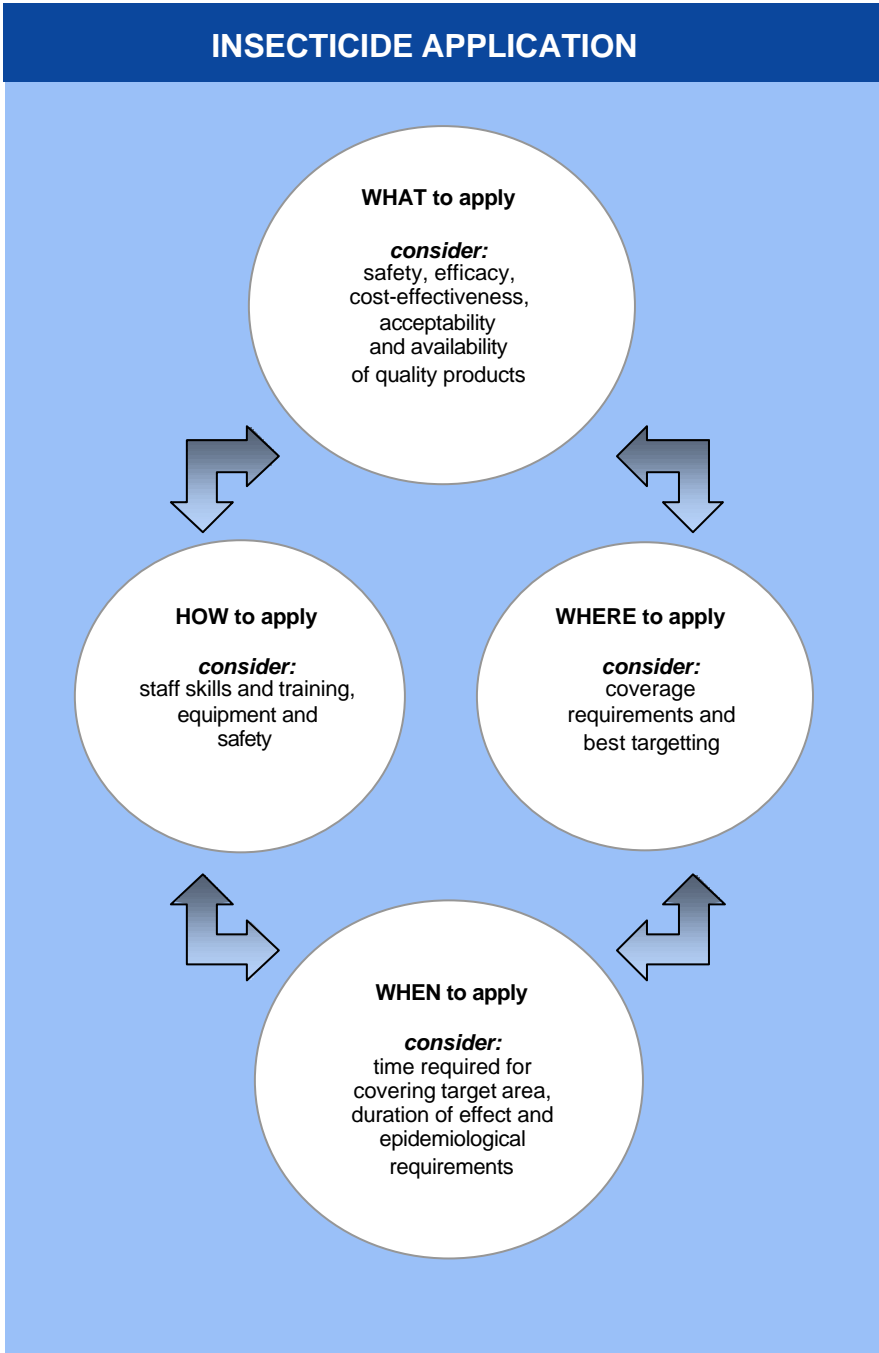
The historical development of modern malaria control after many countries had established vertical services for malaria eradication, has influenced the way in which countries have attempted to develop their malaria control programmes. These therefore vary considerably from country to country and even sometimes between different areas in the same country.

Integration of malaria control may refer to the integration of the malaria control programme into services that are broader in scope. This has been done in some countries by creating services for the control of major endemic

diseases (or tropical diseases) or, as in other countries, malaria (and malaria vector control) has been fully integrated into the general health services.

Integration of vector control services may also refer to the amalgamation of all the services aimed at controlling the vectors of diseases, thus establishing a resource to meet the needs of many disease control programmes.

## INSECTICIDE APPLICATION



## **2. Chemical control**

In spite of the wide variety of vector control methods potentially useful for malaria control, the fact that malaria tends to be concentrated in the poorest, most isolated and least educated populations of the world reduces considerably the feasibility of the large-scale implementation of methods requiring high investment, careful maintenance or a high level of technical competence for their precise targeting. These are the main reasons why large-scale malaria vector control became possible only after the introduction of residual insecticides and has remained basically dependent on different forms of chemical control.

### **2.1 Types of application**

Each vector control method requires a different type of application and often a particular insecticide, or at least a particular formulation, suitable for that type of application. The different types of application pose different risks to the population, the applicators and the general environment, while at the same time, they may have to meet different requirements if they are to be effective when used for the different methods of vector control previously mentioned. The main types of chemical application suitable for malaria control are:

- indoor residual spraying,
- treating materials with insecticide,
- larviciding, and
- space spraying.

Nevertheless, certain general considerations apply to all insecticides used in the control of vector-borne diseases. This is due mainly to the fact that vector control often



requires the application of insecticides to surfaces or materials which may come into close contact with people or contaminate food or water which might be consumed before the insecticide is inactivated. The safety requirements for public health insecticides are therefore particularly strict.

## **2.2 What to apply**

### **2.2.1 Methods, insecticides and formulations suitable for different situations**

The first step in selecting insecticides suitable for malaria control is to determine whether a candidate insecticide is effective and whether it is available in one or more formulations which can safely be used for vector control. WHO, in collaboration with industry and a network of analytical laboratories, research institutions and vector control programmes throughout the world has established the WHO Pesticide Evaluation Scheme (WHOPES) to determine the effectiveness, safety for humans and the environment, and the conditions for the use of public health pesticides. WHOPES also develops specifications for pesticides<sup>1</sup> and application equipment (WHO, 1990) for international trade and quality control, and has also published practical guidelines for the purchase of pesticides for use in public health (WHO, 2000b).

WHOPES maintains close links with the Programme on Chemical Safety (PCS), which reviews toxicological and ecotoxicological information on pesticides. It guides the safety evaluation through the WHOPES testing process and draws up the WHO Recommended Classification of

---

<sup>1</sup> WHO specifications for pesticides (interim and full) are available on the WHO homepage on the Internet at [www.who.int/ctd/whopes](http://www.who.int/ctd/whopes).

Pesticides by Hazard (WHO, 1998a). This classifies compounds by hazard as:

- a) extremely hazardous (class Ia);
- b) highly hazardous (class Ib);
- c) moderately hazardous (class II);
- d) slightly hazardous (class III);
- e) unlikely to be hazardous (UH)

After an insecticide is recommended by WHOPES for use in vector control, WHO continues to consolidate, validate and disseminate the experience acquired by the different control programmes using insecticides in different situations. These experiences are reviewed by the WHOPES Working Groups and periodically by WHO Expert Committees on Malaria (e.g. WHO, 2000a) and on Vector Biology and Control (e.g. WHO, 1991, 1992) as well as by WHO Study Groups on different aspects of vector control (e.g. WHO, 1995).

### 2.2.2 Dosage and effect

Dosage is the amount of active ingredient measured in grams or milligrams applied per unit area measured in square metres for indoor residual spraying and insecticide-treated mosquito nets, or in hectares for outdoor space spraying and for larviciding. For dispensers of fumigant insecticides, the actual dose will be the concentration of insecticide in the treated air volume, while the dosage will be the number of dispensers to be used for the size of the room to be treated.

The optimal dosage is the minimum needed to produce the desired effect. Although there is a dose-effect relationship within the range of effectiveness, the relation between dose and toxicity is more important, particularly for chemicals used for malaria control, since they are

applied in or close to human habitations. The dose of these chemicals can therefore be varied only within narrow limits, the least toxic pyrethroids being the only exception to this rule.

### 2.2.3 Safety of users, operators and the environment

Safety is a top priority whenever any preventive measures are taken. The different types of insecticide applications used for vector control pose different risks and these, as well as ways to prevent them, should be clearly assessed at four different levels, namely (1) the safety of the population concerned; (2) the safety of the applicators and handlers of the insecticide used; (3) safety in storage and transport and (4) the safety of the environment.

The risk to the population will depend on the potential for contact with treated or contaminated materials. This may vary from the application of a larvicide to water which could be used for drinking to the potential contact with a sprayed wall or contaminated floor (in indoor residual spraying). There is also the possibility of an accidental overdose. All necessary information, education and communication measures should be taken to ensure that the population is capable of taking the necessary precautions to avoid dangerous contamination.

The applicators and handlers of the insecticide may be exposed to a continuous and higher risk than the inhabitants of the treated area. For each type of application and for each insecticide formulation used, the protective clothing and other devices required should be specified. In the selection of a particular application, it is necessary to consider whether it is suitable for the climate of the area concerned. The applicators must be trained in use of the necessary protective devices and supervised to ensure that they are actually used in the field.

Safety in storage and transport includes not only the safety of those handling the insecticide containers but also the prevention of accidents which may result in the contamination of people, food or the environment. This requires not only safe packing and the training of handlers, but also regulations to prevent the transport of insecticide containers in vehicles which may also be used to transport livestock or foodstuffs.

The risks to the environment, including the impact on non-target organisms and the persistence, vary considerably with the type of application and the insecticide used. Risks are also associated with the disposal of unused insecticide residues and the cleaning of equipment in the field. Insecticides may also do serious damage to painted surfaces.

#### 2.2.4 Acceptability and affordability

The acceptability of vector control interventions varies in relation to the perceived benefits by the population, the degree of inconvenience caused and the investment of time, effort, and in some cases, money. In addition, perceived dangers may lead to refusal.

Whereas continuous acceptability and user participation are prerequisites for effective use of insecticide-treated mosquito nets, other vector control methods may demand only occasional participation, cooperation or simply passive acceptance by the majority of beneficiaries. For example, indoor residual spraying requires acceptance of spraying, which is normally carried out by an external team at relatively long intervals. Nevertheless, complete spraying needs the active cooperation of householders in order to prepare the houses for spraying and subsequently to maintain the insecticide residue without major disturbance (e.g. re-plastering of walls).

Space spraying of houses, although performed by specialised teams, requires the cooperation of householders to open windows and doors if the application is made outdoors, and to close them if it is applied indoors.

Larviciding, except in the case of domestic vectors such as *An. stephensi*, typically requires access only to the compounds or fields where breeding places are located.

The perceived or real benefits of chemical control may change over time, e.g., indoor residual spraying and insecticide-treated mosquito nets sometimes initially motivate users because of their spectacular effect on nuisance insects, such as bedbugs, lice, flies and mosquitoes, but over time these effects may diminish or become less evident.

Inconveniences which can limit acceptability include:

- the obvious residue left by WP formulations of insecticides used for indoor residual spraying on wooden or painted walls and furniture.
- unpleasant odour of some insecticide products.
- the interference of mosquito nets with air circulation in hot humid climates.
- the contamination of crops kept in the houses, which may affect their acceptance in the market.
- the contamination of silk worm colonies or beehives in or near sprayed houses.

Affordability is also an essential factor in determining the suitability of a potential insecticide product and choice of application method. The determination of cost should be based on the cost of the product as applied and not strictly on its purchase price. This includes consideration of the

amount of active ingredient in the formulation, cost of shipment and handling (including local transport and storage), as well as dosage, frequency and cost of application.

Affordability and the potential for its improvement will vary in relation to the distribution of the financial costs between the public sector, the community and the end users. The current tendency to establish cost sharing mechanisms and to privatise services brings the question of affordability directly to each of these levels.

The improvement of affordability by individual users may require the regulation (or subsidising) of the trade of certain basic commodities such as mosquito nets and insecticides, the public support of certain activities, such as the re-treatment of mosquito nets, and the setting up of mechanisms for care of the poor.

#### 2.2.5 Resistance and avoidance of contact

The selection of an insecticide will obviously depend on the susceptibility to it of the malaria vectors in the area in which it is to be applied and on the vector bionomics and behaviour, which must be such as to permit its contact with the insecticide. These may vary with time as the vector may develop resistance or avoiding behaviour as a result of its continuous exposure to the insecticide. The selection pressure exerted on the vector population vary greatly with the type of application and the fraction of the vector population actually exposed.

True insecticide resistance or physiological resistance has been defined as the ability, in a population of insects, to tolerate doses of an insecticide that would be lethal to the majority of the individuals in a normal population of the same species, and developed as a result of the selection

pressure exerted by the insecticide. A vector population becomes resistant because the insecticide progressively eliminates the majority of the susceptible individuals while allowing the survival and reproduction of those possessing some mechanism whereby its toxic effect is avoided. The most important of such mechanisms are the possession of detoxification enzymes or the modification of the target of the insecticide so as to prevent it from binding at the site of action. Selection for insecticide resistance is greatly enhanced when the same insecticide is widely used in agriculture or in two or more types of application, such as indoor spraying and larviciding, in the same area.

*Cross-resistance* is the resistance to an insecticide developed in an insect population as a result of selection pressure by another insecticide, often but not necessarily belonging to the same chemical category, for which the resistance mechanism is the same.

*Multiple resistance* is the simultaneous resistance to several insecticides of different categories, normally acquired by separate exposure to the insecticides concerned.

Insecticide avoidance, also called “behavioural resistance”, is the ability of some vectors to avoid contact with an insecticide. This is particularly important for indoor residual spraying and for the use of insecticide-treated mosquito nets. In the former, it is generally detrimental to control, but in the latter may be beneficial, since it will help to reduce contact between human and the vector.

WHO has developed a practical test to detect resistance in mosquitoes. Standard kits, impregnated papers for determining the susceptibility of adults, and standard solutions for determining larval susceptibility, are available from WHO, on application to the Department of

Communicable Disease Control, Prevention and Eradication, World Health Organization, 1211 Geneva 27, Switzerland, or the WHO Regional Offices (see Annex 1). The susceptibility test kits include detailed instructions on how to carry out the tests.

The assessment of vector susceptibility is an essential step in the planning and epidemiological evaluation of any malaria control programme in which the use of insecticides is being considered. Testing should be carried out :

- to establish the baseline susceptibility of the different vectors in the area;
- to monitor the possible changes throughout the period of insecticide application;
- to identify the mechanisms (WHO, 1998b) of resistance and cross-resistance; and
- to assess the vector's susceptibility to potential alternative insecticides if there is a need for change.

It must be emphasized that the detection of resistance in a test does not necessarily mean that the insecticide concerned will cease to be effective in the field. Epidemiological impact assessments are therefore necessary to decide whether a change of insecticide is required.

#### 2.2.6 Possibilities of integrating different approaches and methods

No vector control method will be cost-effective (or even effective) in all situations. It is logical to assume that combinations of a number of methods will compensate for the deficiencies of each individual method. However, this assumption must be tested in each individual situation since it is quite likely that the obstacles preventing adequate coverage with one control measure will also



prevent such coverage when it is used in combination with another. For example, it has often been suggested that vector control might be the appropriate control measure in those areas where parasite resistance to common anti-malarial drugs poses serious problems in disease treatment. However, in many areas, parasite resistance has been selected as the result of continued efforts to control malaria transmission by the mass administration of anti-malarial drugs where vector control was not possible.

After the conditions for the success of the various control methods have been identified, the integration of different approaches and methods should be pragmatically considered. Many endemic countries are concentrating their efforts on promoting and supporting the use of insecticide-treated materials, but the services engaged in these activities should also identify epidemic-prone areas and those requiring more active seasonal vector control. Integration or co-ordination with other agencies or programmes is also important since they may be able to implement control interventions which may help to prevent malaria transmission. Examples of such programmes include dengue control programmes and programmes for control of nuisance mosquitoes in large urban areas in endemic countries, even if the only benefits to be expected are the sharing of professional entomological skills and some administrative back up. Similarly, in programming malaria vector control operations, it is advisable to take into account the considerable decline in vector densities which may follow the large-scale and frequently repeated aerial applications of insecticides to cotton or rice crops.

## 2.2.7 Monitoring and evaluation

Any vector control intervention for malaria control should set precise objectives in relation to its expected contribution to the overall goal of malaria control. These objectives should be based on the particular epidemiological problem as well as the specific impact that the measure or measures selected may have on the chain of transmission (see Table 1).

**Table 1. Aspect of vector population expected to be affected by different types of vector control methods**

Method	Adult density	Adult survival	Human biting
<b>Larval control</b>			
- Source reduction	+	-	-
- Larvivorous fish	+	-	-
- Larviciding	+	-	-
<b>Control of man-vector contact</b>			
- Insecticide treated mosquito nets	+/-	+/-	+
- Improved housing	-	-	+
- Mosquito repellents	-	-	+
<b>Adult mosquito control</b>			
- Indoor residual spraying	+	+	+
- Space spraying	+	+/-	-

+ reduction expected

- no effect

+/- effect in some situations

Monitoring and evaluation are essential components of any vector control programme for their effective management, starting with the identification of clearly stated, realistic, measurable objectives, and the

identification or development of an appropriate information system, based on the existing infrastructure (RBM, 2000).

Monitoring should be an on-going activity aimed at measuring the quality of the activities carried out and their progress in relation to the programmed timetable. It should identify obstacles and provide a basis for identifying aspects of the programme which may require modification. Monitoring will require the identification of appropriate process indicators.

Evaluation is the periodic assessment of progress towards the achievement of the objectives (by measuring impact indicators) and goals of the programme (by measuring outcome indicators). Examples of process, impact and outcome indicators are shown in tables 2 and 3, adapted from WHO, 1995.

**Table 2. Process (operational) and impact (entomological) indicators for vector control (adapted from WHO, 1995)**

<b>Control method</b>	<b>Process indicators</b>	<b>Impact indicators</b>
<b>Indoor residual spraying</b>	- Dosage (R)	- Daytime indoor resting (R)
	- Coverage (R)	- Human biting rate (T)
	- Timing (R)	- Human blood index (T)
	- Persistence (R,T)	- Parous rate (T)
	- Status of equipment (R)	- Sporozoite rate (S)
	- Resources utilised (R)	- Insecticide susceptibility status (R)
	- Cost (R)	- Adult mosquito density (T)

<b>Insecticide-treated mosquito nets</b>	<ul style="list-style-type: none"> <li>- Dosage (R)</li> <li>- Coverage (R)</li> <li>- Use (R)</li> <li>- Persistence (R)</li> <li>- Resources utilised (R)</li> <li>- Cost (R)</li> </ul>	<ul style="list-style-type: none"> <li>- Biting cycle in relation to sleeping habits (S)</li> <li>- Human blood index (T)</li> <li>- Insecticide susceptibility status (R)</li> <li>- Human biting rate (T)</li> <li>- Sporozoite rate (S)</li> <li>- Adult mosquito density (T)</li> </ul>
<b>Larviciding</b>	<ul style="list-style-type: none"> <li>- Coverage (R)</li> <li>- Persistence (R, T)</li> <li>- Resources utilised (R)</li> <li>- Cost (R)</li> </ul>	<ul style="list-style-type: none"> <li>- Presence and density of larvae (R)</li> <li>- Adult mosquito density (R)</li> <li>- Insecticide susceptibility status (R)</li> </ul>
<b>Space spraying</b>	<ul style="list-style-type: none"> <li>- Coverage (R)</li> <li>- Area of influence (R)</li> <li>- Resources utilised (R)</li> <li>- Cost (R)</li> </ul>	<ul style="list-style-type: none"> <li>- Human biting rate (2)</li> <li>- Adult mosquito density (R)</li> <li>- Parous rate (2)</li> <li>- Insecticide susceptibility status (R)</li> </ul>

(1) Indicators may be monitored regularly (R), selectively for specific purposes(S) or for detecting trends (T).

(2) When space spraying is continued for at least a few weeks

**Table 3. Selected indicators for evaluating impact of vector control on malaria (outcome indicators)**

Vector control method	Target population	Outcome indicator
Indoor residual spraying	<ul style="list-style-type: none"> <li>- Number of people in the area of spray operations</li> <li>- Number of people in the houses sprayed</li> </ul>	<ul style="list-style-type: none"> <li>- Percentage reduction in malaria incidence (fever, severe malaria, parasitaemia) in target areas or groups</li> <li>- Infant parasite and spleen rates in endemic areas</li> <li>- Percentage reduction in malaria mortality</li> </ul>
Insecticide-treated mosquito net	<ul style="list-style-type: none"> <li>- Number of people in the area of bednet operations</li> <li>- Number of people living in houses in which nets are used</li> <li>- Number of people using nets</li> </ul>	<ul style="list-style-type: none"> <li>- Percentage reduction in malaria incidence (fever, severe malaria, parasitaemia)</li> <li>- Percentage reduction in malaria incidence in target groups (e.g. children)</li> <li>- Percentage reduction in malaria mortality and all-cause mortality</li> </ul>
Larviciding	<ul style="list-style-type: none"> <li>- Number of people in the operational area</li> </ul>	<ul style="list-style-type: none"> <li>- Percentage reduction in malaria incidence (fever, severe malaria, parasitaemia)</li> </ul>

## **2.3 Where to apply**

Vector control measures should be selectively applied so as to avoid the continuous indiscriminate application of routine measures over wide areas which, with time, becomes ineffective and wasteful. It is therefore necessary to decide, based on precise criteria, where vector control should be implemented so as to reduce the burden of malaria incidence on the affected population.

### **2.3.1 Epidemiological and operational criteria – stratification**

Once the overall country stratification has led to the selection of the areas where vector control is indicated, it will be necessary to continue with a more detailed stratification of those areas to select the measures which will be appropriate, operationally feasible and financially sound.

This detailed stratification will be required when the seriousness of the malaria problem demands more effective measures. For example, when a malaria control programme relies on the promotion of the use of insecticide-treated materials, it may be recognised that increasing coverage is a rather slow process and that it will be necessary to plan to use other methods in some areas where there is regular intense seasonal transmission and to draw up a plan for epidemic preparedness in fringe areas where epidemics have occurred. This plan should include epidemic forecasting and the possibility to mobilise teams for carrying out indoor residual spraying in rural areas and perhaps larviciding in towns, and should be ready to go into action as soon as the alarm is given. At the same time, it will be

necessary to reach agreements with other agencies as to the vector control methods to be used in urban areas and development projects

### 2.3.2 Coverage requirements for effectiveness

All vector control measures require a high degree of coverage of the areas to be treated if the population is to be protected. The requirements will vary depending on the type of intervention concerned and the bionomics of the vector. It is also necessary to consider whether the expected overall effect of the intervention will be the result of the addition of individual protection (e.g. barriers designed to prevent human-vector contact) or whether the intervention requires a high level of coverage in order to be effective at all (e.g. indoor residual spraying or larviciding). Depending on the resting habits of the vector and its flight range, as well as the distance between breeding places and human habitations, it may be concluded that, in general, larviciding will require a higher level of coverage than indoor residual spraying. For the latter, it may be assumed that, during the time required for sporogony, endophagic vectors will have a probability of entering sprayed rooms several times while, with larviciding, vectors from untreated breeding places will obviously survive.

## 2.4 When to apply

The timing of the application of any vector control method should be based on: (i) the time required to cover the target area; (ii) the duration of the effect; and (iii) the epidemiological requirements.

The design of the control programme may call for the elimination of transmission during the whole of the transmission season or merely its reduction in those areas

or periods in which it may impose an unbearable burden on the population by virtue of its intensity or its interference with essential economic activities, such as planting or harvesting.

It will again be necessary to take into consideration the need to maintain effective vector control during the periods when malaria transmission must be controlled, the operational requirements to complete the effective coverage of the whole area to be protected and the expected duration of the effect of the measure applied. This last will depend on the characteristics of the insecticide used and its formulation (e.g. its residual activity, either as a larvicide or an indoor spray) and on the nature of the substrate to which the insecticide is applied (e.g. movement of the water of a breeding place to which larvicides have been applied, or absorption or adsorption by the wall surface of insecticides sprayed indoors).

## **2.5 How to apply**

How insecticides should be applied, as well as who should be responsible for their application, will vary considerably in accordance with the programme design. The body responsible for the execution of the programme may vary from a more or less autonomous government department, to a private enterprise subject to more or less compulsory, government guidance and supervision. The training and supervision of sprayers and the use of high-quality equipment for insecticide application are essential if the application of insecticides is to be both safe and effective, and should be given the greatest attention.



### 2.5.1 Health information and education

Information, education and communication are of the greatest importance in the guidance and support of both communities and individuals, and in ensuring their participation in the planning and execution of local operations.

Messages should be clear, informative and concise, supported by training, and always followed by appropriate logistical support in the form of equipment and materials, as well as supervision aimed at solving operational problems.

In addition, the operational modalities adopted by the Roll Back Malaria (RBM) partners<sup>2</sup> require the coordinated involvement of government services and community organizations with the support of non-governmental organizations and the private sector. The mobilization of all these forces requires information and education at many levels in order to involve all the possible participants in a working programme.

Even for those activities which may not be carried out by members of the community, such as emergency spraying for the control of an epidemic, it will be necessary, as a minimum, to provide, through whatever media may be available (e.g. television, radio, newspapers), general information on the purpose and nature of the intervention, as well as on the action that may be taken by the population.

---

<sup>2</sup> WHO was joined in October 1998 by UNICEF, UNDP and the World Bank, in founding the global partnership of Roll Back Malaria. They were later joined by a broader group of partners including governments of countries affected by the disease, multi and bilateral agencies, non-governmental organizations, private sector representatives and research groups.

## 2.5.2 Equipment and maintenance

The choice of equipment will depend on the method of vector control selected, the scale of the operation, and the insecticide and formulation to be used. A wide variety of equipment for the application of insecticides, and suitable for public health use, is available, ranging from hand-compression sprayers and granule dispensers to aircraft spraying equipment. In general, preference should be given to simpler equipment, which should be easy to operate and maintain under operational conditions in the field.

A variety of specialized equipment is available for each type of application. As for insecticides, WHOPES tests and evaluates such equipment and develops specifications for quality control which are published periodically (WHO, 1990). It is essential when choosing a particular application and the equipment required, to make appropriate budgetary provision for spare parts and maintenance.

## 2.5.3 Protective measures

All use of pesticides involves a risk of contamination, which should be avoided or reduced as much as possible. This subject is discussed later for each control method.

For the general population the greatest risk of contamination is associated with indoor applications (e.g. indoor residual spraying, although other applications also have possible risks, e.g. direct exposure to aerial sprays, contamination of drinking-water or irrigated vegetables by larvicides, etc. All these can be avoided by the proper health information and education of the people exposed,

including guidance on the protective measures to be taken before and during the intervention.

Operators should have protective equipment and clothing appropriate to the insecticide used and the climate under which it is being used, e.g. hats, face wraps, goggles, gloves and boots, and have two sets of working clothes.

It will always be necessary to take the basic precautions to prevent unnecessary contamination. In particular:

- Hands and face should be washed after insecticide has been handled.
- Eating, drinking and smoking should be forbidden while working, except after washing and before restarting work.
- The number of hours worked should be fixed according to the risk of exposure and should not be exceeded.
- Overalls and hats should be washed daily and whenever they have been heavily contaminated.
- Operators should have a shower at the end of each day's work; this is particularly important when they have been working with organophosphate insecticides.
- If respirators are used, they must fit well around the nose and mouth, they must be washed and dried, and the cartridge must be changed daily or whenever it becomes obstructed.

#### 2.5.4 Monitoring of exposure

Exposure may be measured by using new disposable overalls and gauntlets for a minimum period of one hour

during any one day's work. Exposure of any part of the body may be measured by using standard (10x10 cm) exposure pads. These consist of pieces of a-cellulose or white absorbent paper, backed with glassine paper, aluminium foil or polyethylene. They should be sent after use to a laboratory for analysis.

For some insecticides, it is possible to measure the amount of the insecticide or its metabolites present in accessible body fluids. Facilities for the collection, preservation and dispatch of samples should then be provided in the field, and protocols developed in accordance with the compound used and the experience of the operators, in consultation with the analytical laboratory.

The routine monitoring of exposure may not be necessary in operational programmes with established safety practices. For most organophosphates, however, it will be necessary to monitor the level of acetyl cholinesterase in any worker who may have been exposed to contamination. Spray operators will need to be monitored at regular intervals.

### 2.5.5 Disposal of containers and surplus insecticides

Current guidelines for the disposal of containers and of any surplus insecticide require that paper or plastic containers holding pump charges should be thoroughly emptied into the spray pump. The empty containers should be collected by the team supervisors and brought to the central storage area for proper disposal by qualified staff (FAO, 1999).

Metal insecticide containers should be rinsed three times as soon as they are emptied; the rinsate should be used to dilute the next spray suspension. Any insecticide

remaining in containers, or the last rinsate of the day, should be emptied into pit latrines, if available, or into pits dug specially for this purpose away from sources of drinking-water; insecticide residues must be diluted with more water before being poured into pits.

Metal containers should be punctured or otherwise rendered unusable for any other purpose. They should not be burned or buried since such practices are potentially very hazardous, but should be returned to the distributor or taken to an approved collection scheme for safe disposal.

The cleaning and disposal, or recycling, of insecticide containers may pose serious problems in many malaria control programmes, as many countries have found it difficult to implement existing guidelines on the disposal of insecticide containers. Many metal containers are therefore reused in a variety of ways without adequate cleaning.

In view of these problems, the WHO Expert Committee on Vector Biology and Control (WHO, 1991) considered that containers of insecticides designated as “Class III: slightly hazardous” or “unlikely to present acute hazard in normal use” could, after thorough cleaning, be used for purposes other than the storage of food, drink or animal feed. Advice on washing procedures may be found in the report of the WHO Expert Committee (WHO, 1991) or in the WHOPES guidelines (Najera & Zaim, 2001).

Even when cleaning is allowed, it should be remembered that the reuse of insecticide containers is always dangerous, and health services should make sure that the containers accepted for reuse have been selected and cleaned by properly trained personnel.

Good inventory control by means of codes or serial numbers on the containers is essential so that it will be possible to check that they have been collected or to identify the culprit if they are used for unauthorized purpose.

### **3. Indoor residual spraying**

In view of the general applicability of this method and the relatively well established standardization of application techniques and equipment, indoor residual spraying continues to be the most widely used (and abused) method of malaria vector control. WHOPES has issued a document on insecticides for indoor residual spraying (Najera & Zaim, 2001) dealing with the criteria for the selection of insecticides, safety and environmental protection, efficacy and residual effect, vector ecology and behaviour, and operational issues, including cost and the disposal of obsolete insecticides. The document also reviews the main characteristics of the insecticides recommended by WHOPES for indoor residual spraying.

The first decision to be made is whether indoor residual spraying is a suitable intervention for the malaria problem of the particular area concerned. The choice should be based on an evaluation of the results of previous vector control activities. In order to improve the interpretation of whatever records exist, it will be necessary to collect all the available information on vector bionomics and behaviour, as well as on the sleeping habits of the people. Where indoor residual spraying is the choice for vector control, it will be necessary to select the areas and structures to be sprayed and to define the criteria for their inclusion.

For indoor residual spraying to be effective, apart from the identification of an effective insecticide, a number of other conditions must be met, as described below.

- The vector should preferably be endophilic. However, spraying may be effective to some extent against vectors which are partially exophilic, i.e. they rest

indoors only for a few hours after biting and then spend most of the time required for blood digestion and egg development outdoors.

- The human habitations should have walls on which to apply the insecticide. In many areas, although the village houses have walls, a considerable proportion of the population spend long periods of time in huts in the fields to protect their crops and farming equipment, and these consist only of a roof and a partial wall on the windy side. They are also often quite widely dispersed, which makes their localization and spraying rather costly and only partially effective. Similar precarious shelters are used for long periods of time by people engaged in mining for gold or gems or in other activities in the jungle.
- People should stay indoors during the main biting period of the vector although, if they sleep outdoors, as in many hot and arid areas, spraying may be effective if the vector uses the houses as their main daytime resting place for egg development (exophagy with endophily).
- Finally, the required coverage must be achieved before, and maintained during the transmission season. This is particularly important in the control of epidemics. When an epidemic is recognised following an alarming increase of malaria cases, it is likely that the resource mobilization needed to implement spraying will take a long time. Spraying is then not advisable, since the epidemic will probably be subsiding as transmission is coming to its end.



### **3.1 What to apply**

The choice of the insecticide and formulation should be based on the susceptibility of the local vectors, the characteristics of the various compounds and the formulations of the available products (residual effect, excito-repellency, need for the use of protective devices, environmental safety, etc.), and their cost . Other specific local problems, such as the potential contamination of, and deleterious effects on essential cultures for the local economy, such as bees or silk worms, or the possible contamination of crops kept in the houses for long periods, as in the drying of tobacco leaves, may also have to be taken into account. Other factors that must be considered are discussed below.

#### **3.1.1 Insecticides and formulations - vector susceptibility, effectiveness and safety**

Information on the insecticides approved by WHOPES for indoor residual spraying, classified according to their chemical categories, are given in Table 1. It is noteworthy that some chlorinated hydrocarbons previously used in malaria control, namely HCH, lindane and dieldrin, are no longer recommended, HCH and lindane because of the widespread resistance to them and dieldrin because of its toxicity to humans.

The first considerations for the choice of a potential insecticide and formulation to be used for a particular situation should be the proven effectiveness against the local vector species and its safety.

Testing for susceptibility (WHO, 1981) should be the first simple procedure to be conducted, followed by series of

## **INDOOR RESIDUAL SPRAYING (IRS)**

**The main purpose of IRS is to reduce the survival of malaria vector(s) entering houses.**

**IRS is of little use for control of malaria vectors which rest outdoors, particularly if they also bite outdoors and do not enter the sprayed house.**

**To ensure its expected impact (community protection), all potential resting surfaces of vector(s) should be sprayed with appropriate insecticide, at a dosage that is sufficient to remain effective throughout the transmission season**

**Understanding of malaria epidemiology and resting behaviour of the vector is crucial to proper targeting of insecticide application in time and space**

**The residual action of the insecticide depends on the insecticide compound and formulation, as well as the type of surface and climatic conditions**

bio-assay tests to check the residual effect on common sprayable surfaces in the area (WHO, 1998b).

However, susceptibility is not the only determinant of effectiveness. It is therefore considered essential, even if the insecticide has proved effective elsewhere, to undertake small field trials to validate their effectiveness under local conditions, when considering any new introduction of an insecticide or formulation in a new area.

**Table 4. WHOPES-recommended insecticides for indoor residual spraying against malaria vectors**

Insecticide compounds and formulations <sup>a</sup>	Class <sup>b</sup>	Dosage (g/m <sup>2</sup> )	Duration of effective action (months)
Alpha-cypermethrin WP and SC	P	0.02-0.03	4-6
Bendiocarb WP	C	0.1-0.4	2-6
Bifenthrin WP	P	0.025-0.050	3-6
Cyfluthrin WP	P	0.02-0.05	3-6
DDT WP <sup>c</sup>	OC	1-2	>6
Deltamethrin WP, WG	P	0.020-0.025	3-6
Etofenprox WP	P	0.1-0.3	3-6
Fenitrothion WP	OP	2	3-6
Lambda-cyhalothrin WP	P	0.02-0.03	3-6
Malathion WP	OP	2	2-3
Pirimiphos-methyl WP and EC	OP	1-2	2-3
Propoxur WP	C	1-2	3-6

<sup>a</sup> EC = emulsifiable concentrate; WG = water dispersible granules; WP = wettable powder; SC = suspension concentrate.

<sup>b</sup> OC = organochlorine; OP = organophosphate; C = carbamate; P = pyrethroid.

<sup>c</sup> For the conditions for using DDT, see the Stockholm Convention on Persistent Organic Pollutants (POPs) (UNEP, 2001).

In general, all WHOPES-approved formulations are safe if used with the recommended protective devices and safety procedures. In certain severe climatic conditions, however, it may be difficult to ensure that the required protective measures are taken in the field, and an insecticide requiring simpler protective measures should then be chosen.

Once an insecticide and its appropriate formulation have been selected, it is essential to choose a good-quality product. Products that appear to be similar may not all contain the correct concentration of active ingredient. Even if the concentration is correct, the product may be poorly formulated and may suspend badly, blocking sprayers and giving uneven coverage. It may also deteriorate rapidly during storage and produce toxic derivatives.

WHOPES can assist national vector control programmes in the quality control of pesticides. The procedures can be carried out on the programme's behalf at WHO-designated collaborating centres. WHO's supply services are available to national programmes and projects, to agencies under the jurisdiction of the Ministries of Health or comparable authority of Member States and to non-governmental organizations in official relations with WHO. WHO country representatives throughout the world and the WHO Regional Offices (see Annex 1) can provide information on how to order using the WHO supply service.

### 3.1.2 Resistance, avoidance and resistance management

The potential development of insecticide resistance is a common threat to any programme, relying on the

continuous or repeated use of indoor residual spraying, even if the local vectors were initially fully susceptible. It is therefore very important to monitor vector susceptibility periodically during programme operations.

Selection for resistance is often the result of the use of the same, or related insecticides, in outdoor applications, mainly in agriculture. The selection of the insecticide to be used in indoor residual spraying should therefore be based not only on the determination of the susceptibility of the vector population at the planning stage, but also on the general use of insecticides in the area, particularly if there is extensive cultivation of cotton, rice or other crops requiring the treatment of large areas with insecticides. It would also be desirable to study the history of any development of resistance in neighbouring areas and in the same vector species in other areas.

The same applies with respect to the avoidance of contact with the sprayed surfaces. It will be necessary to monitor possible changes in vector behaviour by means of exit traps and the observation of man-biting behaviour. Although vector avoidance often prevents the vector from absorbing a lethal dose of the insecticide and therefore enables it to survive, when the house is the only suitable daytime resting place, as in many arid areas, excito-repellency may decrease the probability that the vector will survive and will therefore contribute to the reduction of transmission.

Although much research has been done, there is no reliable way of preventing the development of resistance. Some procedures have, however, been suggested, which may be useful under certain circumstances (see below):

- The selective use of the insecticide by restricting coverage to areas and periods of recognised risk will

allow, as far as possible, the dilution of resistance genes from non-sprayed areas. Such selective use should take into account all insecticide use in the area concerned, including use in controlling nuisance insects and in agriculture.

- Mixtures of unrelated insecticides may also be used, provided that there is no resistance in the area concerned to the products used in the mixture. Such mixtures should be produced industrially to avoid problems of mixing incompatible products or formulations in the field. The safety of the mixtures should also be assessed in such applications.
- Finally insecticides may be rotated. Although this may present logistical and acceptance problems and has not been used systematically in indoor spraying, it may be simpler than the simultaneous use of two insecticides. Switching of insecticides has normally been done only after resistance has developed, but it is not clear whether programmed rotation will enable two insecticides to be used for longer periods than switching to another insecticide when resistance is detected and switching back if resistance levels decline.

### 3.1.3 Acceptability

House spraying requires the coordinated coverage of all sprayable surfaces at regular intervals (spraying cycle). The aim is to maintain a high coverage of all potential vector resting places with the effective dose of insecticide during the entire period when transmission must be controlled.

When residual spraying is to be used, a plan must be drawn up that will ensure that the required coverage will

be achieved for the specified period and that sufficient human and material resources will be available for this purpose.

Whether spraying is done by a specialized organization or by the community itself, indoor spraying requires the continued collaboration of the population, which may easily be eroded if people are not made continuously aware of the need for vector control. This is particularly important if some of the early benefits of spraying, such as the control of nuisance insects, are lost with time. It is therefore essential to maintain active contact with the community through an effective information, education and communication mechanism.

#### 3.1.4 Dosage

As previously mentioned, dosage is the amount of insecticide applied per unit area. It is normally expressed as grams or milligrams of active ingredient per square metre ( $\text{g/m}^2$  or  $\text{mg/m}^2$ ) of sprayable surface. Doses vary considerably for the different insecticides. Most of the pyrethroids are effective at doses of 10 - 50  $\text{mg/m}^2$ , while DDT, organophosphate and carbamate insecticides generally require doses of 1 - 2  $\text{g/m}^2$  (see Table 4).

There is some relation between dosage and residual effect, but the latter is far from being directly proportional to the former. The duration of the residual effect depends on product inactivation due to UV radiation, absorption or adsorption onto the sprayed surface or inactivation by it, and changes in the sprayed surface itself (e.g. replastering of mud walls). As a result, a considerable increase in dose would be necessary to prolong the residual effect significantly, while with most insecticides any increase above the optimal dose will also increase the risk of unacceptable side-effects. As a result, for most

insecticides, there is very little possibility of changing the dosage - effect relationship, either to compensate for reduced susceptibility or to increase the duration of the residual effect. Any increase in dose beyond what is needed to maintain the required effect is not only wasteful but may be both dangerous and likely to promote the selection of resistance.

### **3.2 Where to apply**

As with any control intervention, the selection of indoor residual spraying as an element of the strategy of malaria control requires the definition of the population to be protected and the areas where the measure should be applied. The epidemiological situation will determine which areas should receive total coverage for a relatively long period of time and which should be covered only on the detection of certain alarm signals, if this is feasible (see WHO, 2001b).

In the areas to be sprayed, indoor residual spraying requires, in principle, the coverage of all potential places where the vector might rest, at least for the first few hours after feeding and while searching for a host within what may be considered as an epidemiological unit. This is the area where the vector circulates freely between a number of breeding places and blood sources needed to maintain its population. This epidemiological unit may be as small as an isolated group of houses together with a number of breeding places. The extension and the intensity of the malaria problem, as well as the mobility of the population affected, will determine whether the unit of intervention should consist of these basic epidemiological units or whether much larger intervention units, such as entire valleys, areas between certain altitudes, etc., should be used.



### 3.2.1 Definition of targets of application

Based on the objectives of the control programme and a knowledge of the bionomics and the biting and resting behaviour of the vector concerned, the actual targets to be sprayed should be clearly defined and a geographical reconnaissance of the area conducted so that maps and guidelines for the sprayers can be prepared as follows:

*Areas to be sprayed.* The intervention units, previously defined, should be mapped or clearly marked so that they can be easily recognised by the spraying squads. Maps and/or identifying criteria should be made available for guiding those responsible for the spraying operations.

*Structures.* The types of structures to be sprayed should be selected. As a minimum, they should include all human habitations where vector - man contact is likely to occur. For example, in many rural areas people may spend long periods of time in "farm huts" within their fields and these may be very important in maintaining transmission. They are often only lean-tos, consisting of no more than a roof and one or two partial walls. A decision will have to be taken whether they should be sprayed or not. Similarly, other structures, such as animal shelters, latrines, stores or outhouses, may be important resting places for partially exophilic blood-fed mosquitoes. In all these cases, it will be necessary to conduct entomological studies to decide what potential contribution to malaria control would be made by the spraying of these structures.

*Rooms.* In principle, all the rooms of a human habitation should be sprayed, particularly bedrooms and other rooms where people may congregate after dark, such as sitting rooms or kitchens. It is often found that people object to

the spraying of rooms where small children or sick people sleep. It is important to persuade people that these rooms should be sprayed and that children and sick people should be temporarily moved so that spraying can be carried out.

*Sprayable surfaces.* Whatever the objective of malaria control (e.g. prevention of epidemics or control of transmission in endemic areas), indoor residual spraying requires a high degree of coverage of potential resting places, including all walls, ceilings and furniture. The spraying of window frames and both sides of doors is often necessary, since they may be temporary resting places for vectors entering or leaving a room.

Some vectors are known to rest on walls only up to a height of 1.5 to 2 m and spraying may sometimes be restricted to these parts of the walls, leaving the ceilings unsprayed. However, vector habits frequently change once spraying is applied. It is therefore important to monitor vector resting habits and to check that restricting spraying to the lower parts of walls is still justified.

Such restrictions may result in considerable savings in insecticides and in spraying times, but their validity should be checked before they are adopted.

### 3.2.2 Preparation of houses before spraying

Correct spraying requires the careful preparation of the rooms to be sprayed. In particular:

- all food, cooking utensils, bedding and clothes must be protected from the insecticide by taking them outside the house before spraying starts; and

- all portable furniture and any pieces of furniture leaning against the walls should be removed so that the walls and all sides of all the pieces of furniture can be sprayed.

It is therefore necessary to inform the population in advance of the day and time that the spray team will conduct the spraying so that the house can be prepared before the spraying is due to start.

### **3.3 When to apply**

All sprayable surfaces must be covered by an effective dose of insecticide during the entire period when transmission needs to be controlled.

The repetition of spraying operations at regular intervals is called the “spraying cycle”, described in terms of the interval between repetitions, e.g. a six-month cycle. Each spraying of all sprayable houses in an area over a period of time is called a “spraying round”.

#### **3.3.1 Type of spraying cycle**

The epidemiological requirements and the residual effect of the insecticide formulation on the main sprayable surfaces will determine the frequency of the spraying cycle.

In areas with seasonal transmission, the insecticide selected for use should be effective during the period of time that transmission is likely to occur. Areas requiring continuous protection should be sprayed regularly. In these areas, it may be possible to make the spraying round last as long as the spraying cycle so as to provide continuous protection and to keep spraymen employed throughout the year.

### 3.3.2 Timing in relation to transmission season

The requirement that effective coverage should be maintained during the entire transmission season, implies that spraying of the whole area to be protected should be completed before the beginning of that season (often the rainy season) and that, if the residual effect of the insecticide is insufficient, the area should receive a second spraying.

This requirement has operational implications which must be taken into account particularly when the operations are conducted by decentralized services, in order to ensure the timely reception of supplies and the training or retraining of spraymen.

### 3.3.3 Duration of working day and safety

The duration of the working day should be such as to ensure that the exposure of spraymen to the insecticide remains within the limits allowed by the safety requirements. Whenever more toxic insecticides, such as fenitrothion, are used, it will be necessary to monitor worker exposure and contamination.

Spraymen cannot avoid a certain degree of contamination when spraying. It is therefore imperative to monitor their exposure carefully. The necessary protective measures are described in 2.5.3.

In addition, with most organophosphate insecticides, blood samples for the determination of cholinesterase activity should be taken at least every week and whenever there has been any accidental exposure.

### **3.4 How to apply**

The application of indoor residual spraying has been standardized over the past 50 years throughout the world. The use of DDT over a long period for this purpose has led to the development of spraying habits in many areas that are not necessarily in conformity with the desirable standards, even for DDT. Such habits were acquired at a time when concerns about the potential adverse effects of persistent accumulation of pesticides in human fat and about their environmental impact were not widespread. In any case, it is always necessary to check the working practices of sprayers in order to ensure that neither humans nor the environment are endangered. This is particularly important when insecticides with greater acute toxicity than DDT are to be used.

#### **3.4.1 Equipment and maintenance**

Indoor residual spraying requires the application of a uniform dose of insecticide to all the sprayable surfaces. This can best be achieved by means of compression sprayers that meet WHO specifications. Although reasonably effective spraying has been achieved with simple stirrup pumps, an adequate dosage can never be achieved with agricultural sprayers, which have to be continuously pumped, and do not have proper fan nozzles.

WHO-approved compression sprayers are sturdy enough to maintain the pressure needed to produce a flat fan swath and to resist rough handling in the field. WHO specification WHO/VBC/89.970 covers the quality requirements (WHO, 1990). These sprayers should be fitted with nozzle tips producing the required swath and discharge rate, and with pressure gauges or control flow valves (CFV) graduated to deliver the required rate of application. Nozzle tips are fairly quickly eroded by

insecticide suspensions at high pressure and should therefore be made of highly resistant materials (hardened steel, ceramics, etc.) and be checked frequently to avoid waste of insecticide or irregular dosage.

The WHOPES manual on indoor residual spraying (WHO 2000c) describes procedures for the safe and effective use of insecticides for indoor residual spraying, and also covers the maintenance of equipment.

### 3.4.2 Protective measures

The safe use of insecticides for indoor residual spraying requires a number of precautions (see below).

*Inhabitants of sprayed houses.* As mentioned previously, the removal or physical protection of all foodstuffs and cooking or eating utensils is imperative. In addition, inhabitants should be advised not to enter a sprayed room until the spray is dry, and to sweep all floors before allowing free entry into the house. This is particularly important for families with small children or indoor domestic animals that may have greater contact with the floor.

*spraymen and other handlers of insecticides.* The use of protective devices and safe working practices are essential to avoid or reduce the contamination of spraymen, packers and mixers with the insecticide. In most spraying programmes in which insecticides of low acute toxicity (such as DDT and malathion) have been used, it has been considered sufficient to wear overalls, broad-brimmed hats to cover the neck of the overalls, gloves and shoes or boots, the openings of which should be covered by the long trousers of the overalls. More toxic or more irritating insecticides require more elaborate

protective devices, such as light masks, goggles, visors and respirators.

Packers and mixers have a higher risk of contamination and should therefore use rubber gloves, masks or respirators and protect their eyes with a visor made of transparent plastic attached to the hat. The current trend is for insecticides to be delivered from the manufacturer in prepacked pump charges, preferably in water-soluble sachets, which can be dropped directly into the pump tank, so that packers and mixers are not needed. Suspension concentrate (SC) and emulsifiable concentrate (EC) formulations in dosage-regulating containers and water-dispersible granular formulations are also available that limit exposure during spray tank preparation.

Squad leaders should enforce safe behaviour and the appropriate use of protective devices. They should be familiar with early signs of intoxication and monitor members of their squad for any sign of poisoning.

It is necessary at all times to take basic precautions to prevent unnecessary contamination. In particular:

- Hands and face should be washed after filling each pump charge.
- Eating, drinking and smoking should be forbidden, except after washing and before starting to spray.
- Spraymen should not be exposed to insecticide for more than 6 hours each day.
- Overalls and hats should be washed daily, especially if they have been heavily contaminated.

- Spraymen must take a shower at the end of each day's work, particularly when they have been working with organophosphate insecticides.
- If respirators are used, they must fit well around the nose and mouth, they must be washed and dried, and the cartridge must be changed daily or whenever it becomes obstructed.

### 3.4.3 Disposal of containers and surplus insecticides

It may be necessary for spraying teams to carry and use insecticide containers in the field. They may use many pump charges and the containers may have to be washed in the field on completing the work. It is imperative to adhere strictly to the recommendations on the disposal of containers and surplus insecticides (see 2.5.5). In particular, they will be using for each pump a prepacked paper or plastic container holding the pump charge. It is essential that the contents of each container is completely emptied into the pump. The empty containers, after the triple rinse mentioned in 2.5.5, should be collected by the team supervisors and brought to the central storage area for proper disposal by qualified staff, in accordance with the FAO/WHO/UNEP guidelines (FAO, 1999).

It is also essential to follow the recommendations for the disposal of larger metal containers. Even if the cleaning of containers of the safer insecticides may be allowed, the reuse of containers is always dangerous. If containers are to be reused they must be selected and cleaned by properly trained personnel.

### 3.4.4 Operational problems, responsibility for operations

As repeatedly stressed, indoor residual spraying requires very high coverage in order to be effective, since it does



not provide personal protection to individuals unless they constitute an isolated epidemiological unit. Spraying should be: (a) total (i.e. all the dwellings are sprayed); (b) complete (i.e. cover all sprayable surfaces); (c) sufficient (i.e. ensure the uniform application of the required dose to all sprayable surfaces); and (d) regular (spraying should be repeated at regular intervals so as to ensure that an effective residue is in place during the whole transmission season).

The need to cover all the houses means that a complete knowledge of the geography of the area is necessary and that the spraymen cover all outlying houses and scattered populations. A geographical reconnaissance is generally required, to update local maps and census data.

The meeting of these standards requires a disciplined and competent organization with properly equipped and trained spraymen, and efficient logistical support. Traditionally, indoor residual spraying has been conducted based on the operational model of the malaria eradication campaigns of the 1950s and 1960s, which called for a strong autonomous and centralized organization. This no longer exists in most areas, while the need for such centralization has been questioned, particularly as many countries are embarking on a general policy of decentralization. In any case, special attention should be paid to:

- the logistics of operational support, supplies and supervision;
- planning the required regular application of indoor residual spraying and the technical guidance required for decentralized operations; and

- the responsibility of individuals and of the community. It is expected that decentralized operations will benefit from social control by the population, provided that people are conscious of the benefits of malaria control and the need for indoor residual spraying.

#### 3.4.5 Health information and education

These constitute the main instruments in building up the necessary support for the intervention, and are essential when implementation becomes the responsibility of the local authorities or even of informed individuals.

Although, in vertical malaria eradication campaigns, in principle, the importance of health information and education in carrying out indoor residual spraying was recognised, few serious efforts were made to inform and educate the population. Instead, greater reliance was placed on legislation compelling people to accept the interventions. Nevertheless, some good educational materials, such as posters, pamphlets and even films, were produced, although they seldom had a wide enough distribution. As health information and education became increasingly neglected, both the acceptability of the intervention and quality and effectiveness declined.

Current activities will require close contact with the different partners in order to achieve at a clear distribution of responsibilities and a coherent plan of work.

## **INSECTICIDE-TREATED MOSQUITO NETS (ITN)**

**ITN is an effective personal protection measure where malaria transmission occurs in the middle of the night**

**Pyrethroid treatment of nets gives added personal protection over an untreated net by irritating, repelling or killing blood- sucking mosquitoes**

**As the total coverage of the community by ITN is approached impact on the vector density and survival may become sufficient to interrupt malaria transmission, hence provide community protection**

**the insecticide requirement for ITNs is normally considerably less than for IRS, since the treated surfaces are considerably smaller**

**The periodicity of re-treatment of the nets is based mainly on the type of insecticide, its dosage and the washing and conditions of use.**

**Use of alkaline soaps and vigorous washing can remove and neutralise the pyrethroid insecticide on nets**

#### **4. Insecticide-treated mosquito nets**

Nets have long been used to protect against mosquitoes, including malaria vectors. However, they are often torn or hung in such a way that mosquitoes can enter or bite through them. It is mainly to prevent this that the treatment of nets with an insecticide and/or repellent was developed. With the discovery of synthetic pyrethroids of relatively low mammalian toxicity but a rapid insecticidal and excito-repellent impact on mosquitoes, the treatment of nets became a practical possibility. Pyrethroid treatment of nets gives greater personal protection than untreated nets by irritating, repelling or killing mosquitoes before they can find a place to bite through the net or, if the net is damaged, before they can find a hole through which to enter and bite once inside.

Insecticide-treated nets are, in principle, suitable for any epidemiological situation, provided that they are accessible, acceptable and used by the population in such a way (in place and time) as to interrupt man - vector contact effectively. Obvious exceptions are people exposed when carrying out various forms of night work (e.g. rubber-tappers in the jungles of South America or South-East Asia) or those exposed to day biting forest anophelines, the main example being the subgenus *Kerteszia* in South America. As mentioned above, they are an effective means of individual protection. As coverage increases, therefore, the effect on the community becomes the addition of the protected individuals, and as total coverage is approached, the "mass killing effect" on the vector population may become sufficient to interrupt transmission before total coverage reached.

Apart from the improvement in personal protection resulting from the addition of a chemical barrier to the net, a mosquito net is a rational place to put a residual insecticide. Mosquitoes are attracted to the net by the odour and carbon dioxide emitted by the sleeper inside it, essentially turning the treated net into a baited trap. Thus many more mosquitoes are killed for a small investment in a residual insecticide. The area of the nets required to cover a family is generally much less than that of the walls and ceiling of their house which will require treatment if conventional house spraying is used. Furthermore, netting, especially if made from synthetic fibre, is a better substrate for the retention of a residual insecticide compared, for example, to a mud wall. In villages in which impregnated nets are widely used, a reduction in density, mean age and sporozoite rate of the *Anopheles* population has often been observed. However, such a "mass effect" depends on high coverage of the population, which has so far been obtained in field trials. Some of the most remarkable impacts on malaria recorded, e.g., on child mortality in The Gambia, can be attributed only to the improved personal protection of children if their nets are treated. So far, only the pyrethroids have proved to be both safe and effective in treating mosquito nets. The present lack of an alternative class of insecticide for this application is a cause for concern because the emergence of resistance remains a possibility, although it is not currently a major problem.

Some of the same arguments about the treatment of mosquito nets also apply to the treatment of curtains over windows, doors, eave gaps and other apertures in houses. In fact, the area of curtains required to cover all the apertures in a house may be less than that of the mosquito nets that the family would require. They would also provide indoor protection when people are not in bed. On the other hand, it is more difficult to cover all the

apertures of a tropical rural house in order to give as good protection as a mosquito net would to a sleeper.

Insecticide-treated mosquito nets have been successfully used by people sleeping out of doors in the hot season, and can easily be carried and used by nomadic people and migrant workers. Treated nets may be particularly useful where national control programmes have been interrupted. People with treated nets can help to protect themselves from malaria in the absence of a functioning national health system. A useful alternative for people sleeping outside may be the use of treated tents, blankets and chaddars, which are being evaluated in different situations.

## **4.1 What to apply**

### **4.1.1 Insecticides and formulations for treatment**

Pyrethroids are today the only insecticides recommended for the treatment of mosquito nets. The frequent contact of people with an insecticide-treated net makes the requirements for product safety much stricter for such treatment than even for indoor residual spraying. A treated net should be non-toxic to children, who may suck the net, and must not be irritating when in contact with exposed skin. These requirements can be met by using only WHOPES-approved insecticides for net treatment.

Table 5 lists the WHOPES recommended insecticide products for the treatment of mosquito nets. It is noteworthy that the pyrethroids listed have an important, but compound-specific, excito-repellent effect on most vector species. It has been observed that the presence of one mosquito net in a room may also protect, at least partially, individuals sleeping outside the net. Moreover, at least in the case of *A. gambiae* in West Africa, it has been

shown that effective protection can be obtained even in the presence of a high frequency of the *kdr*-resistance gene in the vector population (N'Guessan, 2001).

**Table 5. WHOPES-recommended insecticide products for treatment of mosquito nets**

Insecticide product <sup>a</sup>	Dosage (Active ingredient in mg/m <sup>2</sup> of netting)
Alpha-cypermethrin 10%SC	20-40
Cyfluthrin 5%EW	50
Deltamethrin 1%SC and WT25%	15-25
Etofenprox 10%EW	200
Lambda-cyhalothrin 2.5%CS	10-15
Permethrin 10%EC	200-500

<sup>a</sup> SC = aqueous suspension concentrate; EW = emulsion, oil in water; WT = water dispersible tablet; CS = capsule suspension (microencapsulated); EC = emulsifiable concentrate.

#### 4.1.2 Safety

The toxicity of pyrethroids is due to their affinity for, and intrinsic effect on, receptors or targets within the sodium channels essential for nerve conduction. Being highly lipophilic, pyrethroids pass through cell membranes and are absorbed through the skin as well as by inhalation and ingestion. However, their rapid metabolism greatly reduces the magnitude of the resultant toxicity (WHO, 1991; Zaim et al., 2000).

People are at risk of exposure to insecticides through accidental swallowing or drinking of the insecticide products, inhaling solvent vapours of emulsifiable

concentrate formulations, splashing the product into the eyes or onto the skin during net treatment, and insecticide residues during net use.

In long-term toxicity studies of pyrethroid insecticides commonly used for the treatment of mosquito nets, no teratogenic, carcinogenic or mutagenic effects have been detected in experimental animals. The volatility of pyrethroids is very low; given the low dosages of insecticide used for the treatment of nets, there is practically no risk of inhalation toxicity for the users of treated nets. There is no indication, in addition, that oral contact with the net at recommended dosages would pose a health hazard even to a child.

Acute toxicity or irritation, may, however, occur as a result of the handling of insecticides in applying them to mosquito nets. People directly involved in dipping large numbers of nets are at greater risk. However, people who occasionally treat their own nets are less exposed to toxicity or irritation.

Among available liquid formulations, the water-based products, namely the emulsion, oil in water (EW) and aqueous suspension concentrate (SC) formulations, are preferred. Their odour is less marked, they are less flammable, and there is a lower risk of toxicity if they are accidentally swallowed or splashed on to the skin or into the eyes. Permethrin is the only pyrethroid insecticide still used as an emulsifiable concentrate. However, only the use of public health grade permethrin is recommended.

Solid formulations, such as water-dispersible tablets (WT) or granules, have many advantages since they are easy to handle, transport and store, and there is less risk of accidental spillage and contamination than with liquids. A bittering agent should be incorporated into the product to



prevent deliberate or accidental ingestion, especially by children.

The adverse effects reported by net dippers include, tingling and burning sensations (paraesthesia), eye pain and irritation, swelling of the face, headache and dizziness. The paraesthesia can be unpleasant, especially if pyrethroid concentrate comes into contact with the skin of the face, but has no long-term consequences. Those affected should stop work, remove any contaminated clothing and wash the area of skin concerned with soap and a large quantity of clean water.

In view of the marked potential for exposure to insecticides in the process of treating mosquito nets, the use of rubber gloves is essential. Mouth and nose masks should be worn when dipping large numbers of nets, especially with emulsifiable concentrate formulations.

Transitory side-effects associated with the use of treated nets have also been reported by householders. They include skin itching, eye burning, nasal irritation and sneezing, these occur mainly during the first few days after net treatment, but most last for less than 24 hours.

While field use of pyrethroids for the treatment of mosquito nets at the recommended dose poses little or no hazard to those treating the nets, the supply of insecticide “over the counter” (OTC) for the treatment of nets by householders has particular safety concerns. It is strongly recommended, therefore, that insecticides for the home treatment of mosquito nets should be marketed only in single-unit doses. Moreover, if presented as a liquid formulation in bottles, the use of child-proof caps should be mandatory. The OTC supply of high-concentration permethrin (e.g. 50% EC) should be avoided. Such high

concentrations of permethrin should be used only by trained staff.

#### 4.1.3 Basic requirements, time, costs and acceptability

As mentioned above, insecticide-treated mosquito nets may be progressively introduced into a community in the expectation that their effectiveness in individual protection will help to promote the continuous spread of their use.

Similarly, from the point of view of cost, because it provides individual protection, it is the vector control method most suitable for cost recovery. In fact in most current programmes, the aim is commercial distribution, public funds being devoted to only promotion, information and social marketing. There is not yet enough information to be able to assess how far these programmes will cover the most peripheral and impoverished sectors of the population, which are likely to be those that will suffer most severely from the burden of malaria. Ways should be found of compensating for “market failures” and methods of increasing the accessibility of insecticide-treated mosquito nets to marginalized populations.

Although malaria control programmes will promote and support the procurement, distribution and use of insecticide-treated mosquito nets with the objective of controlling malaria, it is often found that people accept and use them because they protect against nuisance mosquitoes (*Culex*, *Aedes* and *Mansonia*) and other nuisances, such as bedbugs and lice. In The Gambia, in a national bednet programme for malaria control, it was found that the extent of the use and retreatment of bednets was directly related to the density of nuisance mosquitoes, and only indirectly to the malaria incidence. It should be realised, however, that the effect on these pests is generally much shorter lived than it is for *Anopheles*. It

is possible that bedbugs and lice will develop pyrethroid resistance fairly soon after the introduction of bednets. It is therefore necessary, when the effect on these pests is a main motivation for their use, to demonstrate the important benefits of malaria control and to find alternative means of pest control.

Since the acceptability of insecticide-treated mosquito nets is related, as indicated above, to their obvious effect on nuisance pests, this factor will usually also have been responsible for the demand for them and for the establishment of a market for untreated bednets. Sometimes, however, although the conditions for acceptability are present, no trade has developed because there has been no commercially available product that matches the habits and purchasing capacity of the population. In addition, the use of bednets may not be acceptable because of unfavourable climatic conditions, such as high humidity and temperature with little wind, where any slight reduction in ventilation may become unbearable. It is therefore very important, when the use of insecticide-treated mosquito nets is being considered as a malaria control method, to find out whether they will be acceptable and, if not, whether the objections to them can be overcome with information, education and communication.

#### 4.1.4 Specifications

In addition to the WHO specifications for pesticides developed and published by WHOPES (see 2.2.1), the generalization of the use of insecticide-treated mosquito nets will require the development of specifications for netting materials. The first steps towards this end were taken at an informal consultation in Geneva, at which the current situation was studied, interim specifications drawn

up, and the mechanism for further development was established (WHO, 2001a).

## **4.2 Where to apply**

### **4.2.1 Delimitation of areas and population to be protected**

Whatever the method of distribution adopted, the area in which mosquito nets are actually distributed is much less easily controlled than that in which spraying is carried out, since nets may often be found outside the area in which they were distributed, if there is a demand for them. Moreover, this fact and the accumulative way in which coverage can be achieved, should not be discouraging in a programme aiming at national coverage, even if some nets are sold outside the area or even where subsidized nets are smuggled across international borders as has been reported.

### **4.2.2 Requirements for indoor and outdoor protection (population habits)**

The protection provided by insecticide-treated mosquito nets is limited mainly to the people under the nets and the time that they are under them, although people staying or sleeping in a room where a treated net is being used will also be protected to some extent. This means that people staying outdoors during part of the night or in other rooms will not be protected. Some complementary measure, will therefore be necessary, depending on the biting habits of the local vectors during the time when such people may be exposed.

Such complementary measures may presumably be repellents applied to the skin (lotions or sprays), and repellent dispensers or mosquito coils, provided that they are properly located to protect exposed people. The

choice of these complementary measures should therefore be based on the study of the pattern of night biting of local vectors.

### **4.3 When to apply**

When insecticide treated mosquito nets are used special attention must be paid to both the system of distributing the nets and to periodic retreatment with insecticide. As mentioned above, the activities required on the part of the malaria control programme will have to be adapted to the method of distribution when this method of vector control is adopted.

In most malaria control programmes, the aim is to ensure that, whatever method of distribution is used, all nets sold are treated at the time of purchase. A more serious problem is that of establishing functional periodic retreatment cycles based on the epidemiological needs, the residual effect of the formulations on different materials, and the habits of the population in washing their nets, especially when people have to pay for the retreatment.

From the epidemiological point of view, the maximum protection is required during the transmission season or its peak, where transmission is perennial. When programmes play an active role in the distribution, whether free or subsidized, retreatment is normally carried out at special events, such as National Anti-malaria Week (or day) or Health Day. These should be timed, if possible, to ensure the maximum coverage with freshly treated nets during the transmission season. Even when distribution is left entirely to commercial undertakings, official events to promote and demonstrate the use of insecticide-treated mosquito nets should be organized just before the start of the transmission season.

The periodicity of retreatment should be chosen based on regional investigations that determine the actual residual effect of the insecticide under the conditions of use in the area concerned (climate, exposure to direct sun when used outdoors, washing habits, etc). These studies should determine the best method of washing the nets, taking into account the effects of local soaps, the use of hot water, the drying conditions, the frequency of washing, etc., which should be promoted by information, education and communication and during treatment or promotional events.

If nets are sold commercially and individuals are responsible for treatment, the end user should be informed that, if they wash their nets more often than recommended, they should also retreat them more frequently.

When the risk of an epidemic is detected or even when an actual epidemic is detected at an early stage, it will be desirable to organize a retreatment event in areas where coverage with treated nets is high, provided that this will not interfere with the implementation of emergency control measures that may be more effective.

#### **4.4 How to apply**

Nets are treated by dipping them in basins or plastic bags containing insecticide mixed with water. To simplify the treatment of nets, one dose of insecticide (Table 6) is added to 0.5 or 2 L of clean water for polyester and cotton nets, respectively, regardless of their size. These doses have been based on the highest recommended concentrations (see Table 5) and for a family size net of 15 m<sup>2</sup>. They are expected to give longer persistence, i.e., to tolerate more washes, and will have a more visible

impact on nuisance mosquitoes. This impact may be important in achieving greater compliance, since it is often the main motivating factor for most people to use insecticide treated nets.

**Table 6. Amount of insecticides recommended for net treatment**

Insecticide product <sup>a</sup>	Dosage per mosquito net
Alpha-cypermethrin 10%SC	6 ml
Cyfluthrin 5%EW	15 ml
Deltamethrin 1%SC	40 ml
Deltamethrin WT	One tablet
Etofenprox 10%EW	30 ml
Lambda-cyhalothrin 2.5%CS	10 ml
Permethrin 10%EC	75 ml

<sup>a</sup> SC = aqueous suspension concentrate; EW = emulsion, oil in water; WT = water dispersible tablet; CS = capsule suspension (microencapsulated); EC = emulsifiable concentrate.

Mosquito nets may be treated at the household (home treatment) or community (mass treatment) level. Dip-it-yourself kits for home treatment may be available through shops, health centres and special community programmes. Mass treatment by trained personnel may be provided by dipping centres and mobile teams. Simplified guidelines for the treatment and use of mosquito nets, with special reference to Africa, are being published by WHO.

***Long lasting insecticidal mosquito nets (LLINs)*** are ready-to-use pretreated mosquito nets, which require no retreatment during their expected life span (4 - 5 years). They have several important advantages over conventional mosquito nets. These include eliminating the need to retreat the nets (one of the main obstacles to the use of insecticide-treated mosquito nets in many parts of the world), avoiding problems associated with the storage and handling of insecticides by non-professionals and in the community, reducing insecticide use, and minimizing the environmental hazards caused by the release of insecticide into natural water bodies, and therefore represent a judicious use of insecticides. Quality control is essential in ensuring their safety and expected insecticidal activity.



## LARVICIDING

**Larviciding is most useful where breeding sites are accessible and relatively limited in number and size**

**Targeting the most important vector breeding sites may improve operational efficiency and cost-effectiveness**

**Larviciding, using insecticides, should be considered as a complementary measure to environmental management**

**Larviciding exerts more selection pressure on the vector population than IRS and ITNs, since it affects both sexes**

**Residual effect of larvicides varies considerably with the water quality. The higher dosages are indicated for polluted water**

**Some larvicide formulations have rather long residual effect on standing water. But, most natural breeding sites are likely to be disturbed and other breeding places formed, so larviciding programmes may use cycles which may vary between two and ten weeks.**

**Larviciding should avoid the treatment of water that could be used for drinking of human and domestic animals or that could contaminate food stuff.**

## **5. Larviciding**

Although larviciding was one of the first methods of vector control to be an outstanding success, today its indications are rather limited. In fact, the early successes were achieved when malaria control was limited to important economic development projects, and larviciding lost its predominance when malaria control was extended to cover entire endemic areas.

As mentioned above (see 1.5.2), larviciding is indicated only for vectors which tend to breed in permanent or semipermanent water bodies that can be identified and treated and where the density of the human population to be protected is sufficiently high to justify the treatment with relatively short cycles of all the breeding places. These prerequisites practically reduce the indications for larviciding to some urban areas, labour or refugee camps, and development projects. In these situations, it is possible that larviciding programmes may be complementary to environmental measures aimed at controlling malaria and other mosquito-borne diseases or nuisance mosquitoes in integrated control programmes.

### **5.1 What to apply**

#### **5.1.1 Available larvicides and formulations**

A variety of larvicides are or have been used for malaria control (see Table 7), including chemicals and insecticides of biological origin varying in their modes of action, efficacy, safety, formulations, cost and availability. Larvicides of potential use are discussed below.

*Petroleum oils.* These were among the first larvicides to be used and are still used for stagnant waters which are

unsuitable both for animal drinking and for irrigation. Oils act mainly by forming a film on the water surface which prevents larvae from breathing. The heavier the oil the less dispersible it will be and the more easily blocked by vegetation. Different grades of oil may be chosen, depending on the water temperature. Heavy oils, such as crude or used motor oil, may disperse adequately only at higher temperatures. Lighter oils, such as kerosene or diesel, are not only more easily dispersible but also less persistent, which may be desirable in cleaner waters.

The dose of oil needed varies with its dispersibility. This may be increased by the addition of detergents or vegetable oils, which would also reduce the cost of the application and improve its effectiveness by increasing its penetration of emerging vegetation. For example, 140-190 litres of diesel oil may be required per hectare, while only 18-50 litres of vegetable oil may be needed.

*Monomolecular surface films.* These act in the same way as petroleum oils by denying access by the larvae to the surface to breathe. They have the advantage of being biodegradable, but the film that they form is so thin that a slight breeze may break it. As a result, they are used mainly for smaller bodies of water such as pools, ponds and containers, but also for larger aquatic habitats if these are sheltered from the effects of wind.

*Common chemical insecticides.* Current practice relies chiefly on the use of organophosphate insecticides, despite increasing levels of resistance in some areas. Temephos, which has a very low mammalian toxicity has been the most widely used mosquito larvicide worldwide. It may be applied to water for the irrigation of food crops, and has also been used for treating drinking-water. It is, however, toxic to fish. Fenthion is also commonly used

when contamination of drinking-water and food can be avoided

DDT cannot be used as a larvicide for environmental reasons. Actually any use of DDT outdoors is proscribed.

Pyrethroids are not recommended for use as larvicides because of their wide spectrum impact on non-target arthropods and fish. In addition, their high potency, may result in the rapid selection of resistance.

The use as a larvicide of a product belonging to the same insecticide family, or having the same resistance mechanism, as the insecticide used for adulticiding, is not recommended. Larviciding exerts a stronger selection pressure on vector populations than indoor residual spraying and the use of insecticide-treated mosquito nets, as it acts on both sexes.

*Larvicides of biological origin.* The bacterium *Bacillus thuringiensis israelensis* (Bti) produces toxins which are very effective in killing mosquito and blackfly larvae after ingestion. It is harmless to fish, higher animals and humans at normal dosages and, depending on the formulation used, may be suitable for use in water used for drinking (with due attention to potential microbial contaminants in the formulated product) or for the irrigation of food crops. It has the disadvantage that it is active only by ingestion and is rather heavy, sinking into the water, while anophelines are surface feeders.

Another bacterium, *B. sphaericus*, also produces a toxin. It has characteristics similar to those of *Bti* but is more effective in polluted water against *Culex* mosquitoes, while *Bti* is more effective in clean water.

*Insect growth regulators (IGRs).* These are chemical compounds that are highly toxic to mosquito larvae by preventing their development into adults. They have very low toxicity to mammals, birds, fish and adult insects, but are toxic to crustaceans and immature stages of aquatic insects. Their use has generally been limited by their high cost and operational acceptability, but may be of particular interest where target species have developed resistance to organophosphate larvicides or where these compounds cannot be used because of their effect on the environment. IGRs can be divided into: (a) Juvenile hormone analogues, which prevent the development of larvae into viable pupae or of pupae into adults (they do not kill larvae); and (b) chitin synthesis inhibitors, which interfere with the moulting process, killing the larvae when they moult.

*Polystyrene beads.* These have been used in controlling culicinae by the treatment of abandoned wells and latrines. Although anophelines may breed in the former, this method is not normally suitable for treating anopheline breeding places. It has been used in India against *An. stephensi* in water tanks.

The most commonly used formulations are emulsifiable concentrates (EC). However solid formulations, including granules (GR) and slow-release formulations are also available.

**Table 7. WHOPES-recommended compounds and formulations for control of mosquito larvae**

Insecticide	Formulation <sup>a</sup>	Dosage of active ingredient
<b>Oils</b>		
Fuel oil	Solution	142-190 L/ha
Fuel oil + spreading agent	Solution	19-47 L/ha
<b>Organophosphates</b>		
Chlorpyrifos	EC	11-25 g/ha
Fenthion	EC	22-112 g/ha
Pirimiphos-methyl	EC	50-500 g/ha
Temephos	EC, GR	56-112 g/ha
<b>Insect growth regulators</b>		
Diflubenzuron	GR	25-100 g/ha
Methoprene	EC	20-40 g/ha
Pyriproxyfen	GR	5-10 g/ha
<b>Microbial insecticides:</b>		
<i>B. thurigiensis israelensis</i>	Slow-release formulations	(b)
<i>B. sphaericus</i>	Slow-release formulations	(b)

<sup>a</sup> EC = emulsifiable concentrate; GR = granule

<sup>b</sup> The dosage will depend on the formulation used.

In principle, larviciding should not be used in the treatment of water that could be used as drinking-water for humans or domestic animals or that could contaminate foodstuffs. However, temephos and methoprene at dosages not exceeding 1 mg of active ingredient (a.i.) per litre (1ppm), pyriproxyfen at dosages not exceeding 0.01 mg a.i. per litre, and *Bti* may be added to drinking-water for larviciding, if due attention has been given to the safety of the formulants used in the preparation of the final product, which varies from product to product.

### 5.1.2 Environmental impact

Most chemical larvicides are toxic to fish, so that residual applications should not be used in areas where fish, or wildlife in general, are found, or where the run-off from the treated area will endanger non-target organisms in other areas. In contrast IGRs and bacterial insecticides are strictly arthropod-specific and environmentally safe, although, as previously mentioned, their use in malaria control has been rather limited.

Some countries have designated certain environmentally sensitive areas, generally “wetlands”, as nature reserves, and pesticide use, especially of larvicides, may be severely restricted in such areas.

### 5.1.3 Resistance

Large-scale use of an insecticide for larviciding is likely to exert a high selection pressure on the vector because it affects both sexes. It is, therefore, important to monitor the susceptibility status of the vector at fairly short intervals wherever larviciding is used. Test kits and test procedures for the determination of susceptibility are available on request from the WHO Department of Communicable Disease Control, Prevention and Eradication, 1211 Geneva 27, Switzerland, or from WHO Regional Offices (see Annex 1).

## **5.2 Where to apply**

Because of the limited indications for larviciding for malaria control and the high degree of coverage needed if it is to be effective, it is very important to define precisely the area and the points where treatment should be applied.

### 5.2.1 Delimitation of areas and population to be protected

It is essential to conduct a geographical reconnaissance of the area, based on the best knowledge available of the bionomics of local vectors, so as to define the boundaries of the area containing human habitations which should be surveyed in search of breeding places. The distribution and number of breeding sites will often change dramatically with changes in the seasons. Mapping the location of every breeding place to be treated is essential in guiding both the operations and their supervision.

### 5.2.2 Choice of actual or potential breeding places

Although it may be suggested that only confirmed breeding places found by checking for larvae before treating should be covered, it is advisable to identify the type of water body used by the local vector for breeding and treat all potential breeding places.

Larval surveys should be conducted as a method of supervising the operations. When oils are used, it will be possible to see the oil film on the surface of the water, but larvae should be sought for particularly at places with emergent vegetation, as the oil film may have not penetrated there. With other larvicides, dipping for larvae is the only way of checking the effectiveness of treatment. When IGRs are used, and only larvae in the late stages of development or pupae are affected, positive larval collection will not be a sign of treatment failure, and successful impact can be demonstrated by the absence of adult emergence in floating cages in treated breeding sites.

Adult surveys are a very important means not only for assessing the quality of the larviciding operations, but also



as a guide to the finding of breeding places which may have been missed during the geographical reconnaissance and were therefore not included in the treatment programme.

### **5.3 When to apply**

#### **5.3.1 Periodicity of treatment cycles**

The residual effect of larvicides varies considerably depending on the water quality of the breeding place, but is relatively short for most larvicides. The repetition of treatments at fairly short cycles will be necessary, the interval between treatments being determined by the insecticide and the formulation used, as well larval developmental period. Although some larvicide formulations have a fairly long residual effect on standing water, most natural breeding places are likely to be disturbed and new breeding places formed, so that the cycles used in larviciding programmes may vary between 2 to 10 weeks.

#### **5.3.2 Timing in relation to transmission season, seasonality of operations**

It has often been suggested, in areas with a long dry season, that permanent breeding places should be treated during this season for controlling vectors such as *An. gambiae*, for which the peak of transmission occurs during the rainy season. Unfortunately, it is very difficult to identify all permanent breeding places and, where this approach has been tried, vector populations have increased at the beginning of the rains as if no dry season treatment had been done.

Larviciding should be considered as a method of reducing vector density and used where such density reduction will

affect malaria transmission. The treatment should therefore be applied when such reduction is needed.

## **5.4 How to apply**

### **5.4.1 Equipment for aerial and ground application**

Granules may be distributed by hand or with hand- or motor-operated applicators. Oils for the treatment of small irrigation canals or the margins of relatively small water bodies can be applied by means of a compression sprayer, poured from a can, or spread with a mop. More precise dosages and the application of liquid chemical larvicides (e.g. EC formulations) require the use of a compression sprayer.

Integrated mosquito control programmes may require the coverage of large areas of water by means of long-distance projecting sprayers or aerial spraying. Aerial spraying may also be used to treat the river banks covered with abundant vegetation. These treatments will normally prevent anopheline breeding in the treated areas.

Whenever insecticide is mixed and applied, the appropriate personal protective equipment and other safety measures, should always be determined before work is started. Such measures will vary widely depending on the insecticide and formulation used. Supervision will be necessary to ensure that appropriate measures are taken.

### **5.4.2 Responsibility for treatment operations**

The need to treat all potential breeding places calls for regularity and discipline in the application of larvicides which is difficult to achieve unless well organized. It also

requires access to all breeding places, which cannot be achieved without the active collaboration of the population.

As repeatedly mentioned, larviciding is operationally suitable only for densely populated areas, such as urban or project areas, in which the necessary resources can be mobilized for the operations. Responsibilities should therefore be shared between the centre and the periphery in a mutually supportive manner. For example:

- the planning of malaria control could be undertaken by the existing organization at district level, which also could provide the training, technical backup and logistical support;
- short-cycle operations should be conducted under the authority and direct supervision of the interested municipalities or communities, which would provide social control of the thoroughness and quality of the operation, complaining if visible failures occur;
- complementary measures of minor sanitation in and around the home should be the responsibility of individuals and the community;
- joint planning and guidance of decentralized operations will be essential in coordinating the various activities of the health services (e.g. other types of vector control) and the municipalities (e.g. nuisance control), and the resources available at different levels.

## SPACE SPRAYING

**Its main effect is a rapid reduction of vector density, and when applied at relatively short intervals (less than duration of sporogonic cycle), its action on increasing vector mortality will, if required coverage could be achieved, rapidly reduce transmission.**

**Space spraying intends to kill flying mosquitoes by contact with the insecticide in the air. Unless applied during the night, when most malaria vectors are active, the above objective may not be reached.**

**Space spraying requires the use of sophisticated equipment which needs precise calibration and adjustment of the flow rate, as well as handling insecticide concentrates, requiring properly trained**

**Space spraying has very limited indications for malaria control because operational costs are high, the residual effect is low, requires special and expensive equipment, and its efficacy is often very dependent on the meteorological conditions at the time of application.**

## 6. Space spraying

Space spraying has rather limited indications for malaria control, as previously mentioned (see 1.5.3), and has been used mainly as a complementary measure. Even in the emergency control of malaria epidemics, it is used mainly in conjunction with the extension of diagnostic and treatment facilities or the implementation of the mass treatment of fevers. It has sometimes been said that space spraying, mainly in the form of visible low-volume fogs, has been applied more as a public relations measure than as a reliable malaria control intervention. Space spraying is much less effective in malaria control than for diseases transmitted by *Aedes* or *Culex*. *Aedes* may be active during the day and both *Aedes* and *Culex* are fully active at dusk, while the most efficient malaria vectors are active in the middle of the night. Space spraying has been defined as the destruction of flying mosquitoes by contact with insecticides in the air. When used in malaria control, unless applied at night, hardly any flying anophelines would be encountered. It is therefore carried out in the hope of reaching resting mosquitoes and killing them or inducing them to fly through the insecticidal fog.

Nevertheless the quick coverage and relatively wide dispersal achieved has obvious advantages when these are essential. It has been used with some reported success in the control of malaria epidemics or of highly exophilic vectors, such as *A. dirus* in refugee camps in Thailand and *A. nuneztovari* in Venezuela.

Space spraying has the disadvantages that: (i) it may be wasteful (if it misses its target, or is used against a very widely dispersed target); (ii) it requires special and expensive equipment; (iii) it has no residual activity; and

(iv) its efficacy very often depends on the meteorological conditions at the time of application.

## **6.1 What to apply**

From the point of view of their form of action on the vector, all forms of space spraying of insecticides may be considered as different applications of the same method. However, there are considerable differences in the operational requirements, the penetration, and the impact on the target as between the different forms of dispersion in the air and types of application.

These differences mean that each of them can be regarded as almost a different method of vector control. The different forms of space spraying are characterized by differences in the use of diluents and in the size of the droplets produced and dispersed. Particle size determines the length of time that they will remain in suspension in the air, the number of droplets produced, and the ability to penetrate spaces that are not fully exposed to the flow of the spray, which is highly dependent on air currents.

The size of the spray droplets is usually expressed in terms of their volume median diameter (VMD), i.e. the diameter at which half the spray volume will consist of droplets smaller than the VMD. It has been shown that a droplet size of 10 - 20  $\mu\text{m}$  is most effective against flying mosquitoes and in target penetration.

The use of thermal fogging and cold aerosol generators requires specialist training, especially as thermal fogging equipment needs attention throughout a treatment. Each form of application requires a particular type of equipment, a different formulation of the insecticide, and markedly different organization and training of applicators.

### 6.1.1 Indications for space spraying

The effectiveness of space spraying depends both on the accessibility of the target vector and the period when operations are conducted. Integration with other methods of vector control and the use of different techniques of space spraying may be required depending on the area to be treated.

The choice of methods of space spraying and the possible combinations are best considered separately for the two main applications of space spraying (see below).

In the emergency control of an epidemic detected in its developing phase and where there is sufficient evidence that the main determinant factor is an abnormal vector density or increased vector survival, the main objective will be to reduce vector density and increase vector mortality as soon as possible by all possible means. Space spraying offers a possibility of doing so, if all the resting places of the vector can be reached, and will then be the main vector control method used. All the affected communities should be covered, several types of application being combined in order to increase the penetration of the insecticide, including both outdoor application (use of motor-vehicle-mounted foggers to reach all resting places accessible from the road and even some peridomestic breeding places) and indoor application (for indoor-resting vectors);

In contrast, when the objective is to extend the effect of vector control to an exophilic vector, the main vector control measure may be indoor residual spraying (in the case of partial exophily) or the use of insecticide-treated mosquito nets, space spraying being limited to the treatment outdoors of all the known resting places of the

exophilic vector, one or two forms of application (e.g. backpack and motor vehicle) being used.

### 6.1.2 Insecticides and formulations

Table 8 shows the insecticides suitable for use as thermal fogs or cold aerosols for mosquito control.

Pyrethroids are becoming the predominant insecticides for use in space spraying, while organophosphates are becoming less acceptable because of their objectionable odour.

**Table 8. Selected insecticides suitable for use as cold aerosols and thermal fogs for mosquito control**

Compounds	Dosage of active ingredient (g/ha)
<b>Organophosphates</b>	
Fenitrothion	250 – 300
Malathion	112 – 600
Pirimiphos-methyl	250
<b>Pyrethroids</b>	
Cyfluthrin	1 – 6
Deltamethrin	0.5 – 1.0
Lambda-cyhalothrin	1.0
Permethrin	5 - 10
Resmethrin	2 - 4

Most space-spraying formulations are oil-based or contain additives which greatly inhibit evaporation. Oily carrier substances increase this effect still further, thus preventing the evaporation of even the smallest aerosol droplets over a longer period of time. Diesel is used as a base for thermal fogging, but creates a thick smoke and oily deposits which may cause public rejection. For



environmental reasons, water-based formulations have also been made available over the last 10 years, and may also contain substances which prevent rapid evaporation. In applying water-based ultra-low volume (UL) formulations with thermal foggers, however, it is important to note that the droplet spectrum is far broader - droplets of over 100 µm are produced which fall to the ground directly in front of the device and are therefore ineffective.

Common formulations for space spraying are:

*Emulsifiable concentrate (EC)*. A liquid, homogenous formulation to be applied as an emulsion after dilution in water.

*Emulsion, oil in water (EW)*. A fluid, heterogenous formulation consisting of a solution of insecticide in an organic liquid dispersed as fine globules in a continuous water phase.

*Ultra low volume (ULV) liquid (UL)*. A homogenous liquid ready for use through ULV equipment.

*Hot fogging concentrate (HN)*. A formulation suitable for application by hot fogging equipment, either directly or after dilution.

### 6.1.3 Knock-down and potential residual effect

Because of the small droplet size produced, ultra-low volume cold and thermal fogging applications have no residual effect and only remain effective for the few minutes that the fog remains airborne and the density of droplets is sufficient for it to come into contact with flying mosquitoes. Insecticides having this droplet spectrum are rapidly inactivated and have no residual effect after the droplets settle or are dispersed.

Pyrethroid insecticides have a rapid knock-down effect that eliminates mosquitoes rapidly in the area treated. Organophosphates, while equally effective in killing mosquitoes, do not have a rapid knock-down effect, and mosquitoes may be more active for a short period of time (minutes) before they die.

#### 6.1.4 Environmental impact

Ultra-low volume cold and thermal fog applications of insecticides for mosquito control generally have very little effect on the environment because of the short period of time for which the insecticide is active. Care must be taken, however, to avoid applications near fish-bearing water bodies. It is also recommended that such applications should not be carried out directly over such water bodies and that a no-treat barrier of 100 m should be maintained to prevent fish mortality. Home owners should be advised to cover domestic fish tanks and bird cages during the applications.

#### 6.1.5 Resistance

As for any application of insecticides, it is necessary to determine the susceptibility of the vector to the insecticide that is proposed to use. Although the impact of an insecticide fog on the vector population will be different from that of a sprayed surface on resting mosquitoes, space spraying applications are guided in the monitoring of susceptibility by the adult tests used for indoor residual spraying (WHO, 1981).

### **6.2 Where to apply**

The need to reduce the vector density as much as possible in order to control an epidemic, calls for a

concentration of effort on the areas where the epidemic is most severe and where the population density is highest. Vehicle mounted sprayers should be used in order to cover the whole area rapidly. It is essential that all doors and windows are left open so as to achieve the maximum possible penetration of the insecticide. In addition, house-to-house spraying indoors with hand-carried sprayers should be used to cover those dwellings or areas not accessible to vehicle-mounted sprayers.

The use of space spraying to reach daytime resting places of exophilic vectors is possible only when such resting places are not very widely dispersed or where the treatment of those closest to human dwellings has proved to be effective in reducing transmission. Mist blowers may be more suitable for this type of treatment than space fogs.

#### 6.2.1 Delimitation of areas and population to be protected

Environmental considerations and costs demand the most precise definition of the target areas so as to avoid waste, increase efficiency and attain the required coverage in the minimum time.

### 6.3 When to apply

Ultra-low volume cold and thermal fog applications are most effective if applied when the mosquitoes are most active. *Anopheles* are active only in the evening after dusk and during the night. Applications should therefore be made at dusk or at night during their periods of peak activity. These are also the periods in which favourable meteorological conditions prevail that permit the insecticidal fog to remain undisturbed and with consequent maximum exposure of flying mosquitoes.

In the middle of the day, the air close to the heated soil tends to rise and therefore to disperse the insecticide. It is in early morning or close to dusk, when the atmosphere may be quieter and there is often a temperature inversion, that the insecticide fog is likely to remain stable for many minutes near the ground in target areas.

Wind may be a serious obstacle to the distribution of the fog in the manner desired, so that spraying should preferably be done only when the wind velocity is less than 10 km/h.

When applying treatments, the spraying machine should be carried or driven at right angles to the direction of the wind, each successive pass being made upwind of the preceding one. This ensures that the spray cloud is evenly distributed throughout the sprayed area, and that the operator stays out of the spray cloud.

### 6.3.1 Periodicity of treatment cycles

The control of epidemics may require frequent treatment with vehicle-mounted thermal or cold foggers since no residual activity is expected. If this treatment is effective, the vector population should decline rapidly, but a repetition may be needed as the larvae or pupae survive and the adult population is replaced. As mentioned above, space treatments must be integrated with other vector control methods, and vehicle-mounted space spray treatments should be combined with treatment with portable equipment of alleyways and other areas inaccessible to vehicles.

When space spraying is complementary to other vector control methods, the objective of reducing transmission may be achieved with less frequent spraying. The timing

should be determined by means of local trials combined with knowledge of the transmission season.

The effectiveness of the main vector control method or methods used to achieve long-term control (source reduction, use of insecticide-treated materials, indoor residual spraying) should determine whether they need to be complemented with space spraying.

## **6.4 How to apply**

Space spraying requires the use of sophisticated equipment and the precise calibration and adjustment of the jet flow of the insecticide. Formulations for thermal fogging using solutions in organic solvents pose a special hazard to those handling the insecticide concentrate. Space spraying must, therefore, be carried out by properly trained personnel, using appropriate personal protection equipment.

### **6.4.1 Choice of equipment**

Aerial application by means of aircraft-mounted aerosol-spraying devices has sometimes been used for the control of dengue and other diseases caused by arboviruses, but is of practically no use in malaria control since the vectors are active at night. Aerial applications in the evening or at night are expensive and complicated, and are therefore rarely considered.

Various types of fogging equipment are available, both for mounting on vehicles and hand carried. Thermal foggers use a high temperature to vaporize the insecticide liquid, which then forms a dense cloud of small droplets. With cold foggers, the droplets are formed by the mechanical breaking up of the insecticide formulation either by passing it through high-pressure nozzles or by

passing a slow stream of insecticide through a high-velocity vortex of air. Manufacturers can provide information on the droplet spectra produced. The output of some vehicle mounted cold foggers can be controlled by the vehicle speed so that the correct dose is applied; spraying ceases if the vehicle has to stop.

Hand-carried or knapsack cold foggers have a small engine-driven compressor to provide sufficient air to create the fog. It is important to note that many portable units used for ULV application in agriculture apply insecticides at less than 1 L per hectare but do not produce the droplet spectrum required for mosquito control. The droplet size produced by this equipment should be such that a true ULV droplet spectrum is produced. The larger vehicle-mounted cold foggers use a heavy-duty blower powered by a four stroke engine.

Apart from the question of what types of equipment and insecticide formulations are available, the choice of the type of equipment will also depend on the characteristics of the two types of foggers (see below).

The visibility and odour of the fog are very marked with thermal fogs but almost unnoticeable with cold aerosols. Under certain circumstances, high visibility may be an advantage as it may help in directing the spray and allow people to escape direct contact with it. On the other hand, the smell is generally considered as a disadvantage and the dense fog may sometimes be the cause of traffic accidents. In addition, thermal fogs may produce a fire hazard when a diesel- or kerosene-based thermal fog is applied directly into a house with an open fire.

The lower concentration of active ingredient in thermal fogs may be also an advantage, although in some circumstances it may be an advantage that UL

formulations need very little carrier and have a much lower output volume.

The higher noise level of thermal foggers is a disadvantage, although the feeling that “something is being done about the problem” is more widespread with thermal fogging.

The advantages and disadvantages of thermal and cold fogging are summarized in Table 9.

**Table 9. Advantages and disadvantages of thermal and cold fogging**

	<b>Thermal fogging</b>	<b>Cold fogging</b>
<b>Advantages</b>	<ul style="list-style-type: none"> <li>- Dense fog is visible and allows observation of fog distribution</li> <li>- Low concentration of active ingredient in the spray</li> <li>- People can see the fog so feel that action is being taken</li> <li>- People can escape direct contact with the fog</li> </ul>	<ul style="list-style-type: none"> <li>- No traffic hazard as droplets are nearly invisible</li> <li>- Quantity of diluent is reduced because of reduced volume applied, but amount of active ingredient is unchanged</li> <li>- Lower noise level</li> </ul>

<b>Disadvantages</b>	- High cost of diluent	- Distribution of fog is difficult to observe
	- Strong odour of oil diluent	- People cannot easily avoid the fog
	- Potential traffic hazard due to dense fog	- High concentration of active ingredient in the sprayer
	- High noise level of the machine	

#### 6.4.2 Responsibility for operations

The technical and safety requirements of the handling of the insecticides and the equipment used in space spraying call for an organization that would be responsible for the planning and supervision of the operations, and for the training of the operators.

Health services will have to decide whether these activities should be the responsibility of any existing malaria or vector control programmes, whether a service responsible for emergency and epidemic preparedness and response should be established, or whether existing resources in municipal and/or development project organizations should be mobilized.



## 7 References cited<sup>3</sup>

Najera JA, Zaim M (2001) Malaria vector control. Insecticides for residual spraying. Geneva, WHO, *document WHO/CDS/WHOPES/2001.3*.

N'Guessan R., Darriet F, Doannio JMC, Chandre F, Carnevale P (2001) Olyset Net efficacy against pyrethroid-resistant *Anopheles gambiae* and *Culex quinquefasciatus* after 3 years' field use in Côte d'Ivoire. *Medical and Veterinary Entomology*, 15, 97-104.

FAO (1999) Guidelines for the management of small quantities of unwanted and obsolete pesticides. Rome, FAO, *Field document GCP/INT/650/NET*.

WHO (1981) Instructions for determining the susceptibility or resistance of adult mosquitoes to organochlorine, organophosphate and carbamate insecticides – Diagnostic tests. Geneva, WHO, *document WHO/VBC/81.806*.

WHO (1990) *Equipment for vector control*. Geneva.

WHO (1991) Safe use of pesticides. Fourteenth Report of the WHO Expert Committee on Vector Biology and Control. Geneva, WHO, *Technical Report Series*, No. 813.

WHO (1992) Vector resistance to pesticides. Fifteenth Report of the WHO Expert Committee on Vector Biology

---

<sup>3</sup> WHO documents are available from the Department of Communicable Disease Control, Prevention and Eradication, World Health Organization, 1211 Geneva 27, Switzerland.

and Control. Geneva, WHO, *Technical Report Series*, No. 818.

WHO (1993) *A global strategy for malaria control*. Geneva.

WHO (1995) *Vector control for malaria and other mosquito-borne diseases. Report of a WHO Study Group*. Geneva, WHO, *Technical Report Series*, No. 857.

WHO (1998a) *The WHO recommended classification of pesticides by hazard and guidelines to classification 1998-1999*. Geneva, WHO, *document WHO/PCS/98.21/Rev.1*.

WHO (1998b) *Techniques to detect insecticide resistance mechanisms (field and laboratory manual)*. Geneva, WHO, *document WHO/CDS/CPC/MAL/98.6*.

WHO (1998c) *Test procedures for insecticide resistance monitoring in malaria vectors, bio-efficacy and persistence of insecticides on treated surfaces*. Geneva, WHO, *document WHO/CDS/CPC/MAL/98.12*.

WHO (2000a) *WHO Expert Committee on Malaria. Twentieth Report*. Geneva, WHO, *Technical Report Series*, No. 892.

WHO (2000b) *Guidelines for the purchase of public health pesticides*. Geneva, WHO, *document WHO/CDS/WHOPES/2000.1*.

WHO (2000c) *Manual for indoor residual spraying. Application of residual sprays for vector control*. Geneva, WHO, *document WHO/CDS/WHOPES/GCDPP/2000.3. Rev 1*.

WHO (2001a) Specifications for Netting Materials (Report of an Informal Consultation, 8-9 June 2000). Geneva, World Health Organization, *document WHO/CDS/RBM/2001.28*.

WHO (2001b) Malaria early warning systems. Geneva, World Health Organization, *document WHO/CDS/RBM/2001.32*

UNEP (2001) Stockholm Convention on Persistent Organic Pollutants (POPs). Text and Annexes. Geneva, United Nations Environment Programme, *document UNEP/CHEMICALS/2001/3*.

Zaim M, Aitio A, Nakashima N. (2000) Safety of pyrethroid-treated mosquito nets. *Medical and Veterinary Entomology*, 14, 1-5

## **Annex 1. WHO Regional Offices**

- AFRO** World Health Organization  
Regional Office for Africa  
Parirenyatwa Hospital  
P.O. Box BE 773  
Harare, Zimbabwe
- AMRO** World Health Organization  
Regional Office for the Americas/  
Pan American Sanitary Bureau  
525, 23<sup>rd</sup> Street, N.W.  
Washington, D.C. 20037, USA
- EMRO** World Health Organization  
Regional Office for the Eastern Mediterranean  
WHO Post Office  
Abdul Razzak Al Sanhoury Street  
Naser City  
Cairo 11371, Egypt
- EURO** World Health Organization  
Regional Office for Europe  
8, Scherfigsvej  
DK-2100 Copenhagen, Denmark
- SEARO** World Health Organization  
Regional Office for South-East Asia  
World Health House  
Indraprastha Estate  
Mahatma Gandhi Road  
New Delhi 110002, India
- WPRO** World Health Organization  
Regional Office for the Western Pacific  
P.O. Box 2932  
1099 Manila, Philippines