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CHEMICAL METHODS FOR THE CONTROL OF VECTORS AND PESTS OF PUBLIC HEALTH IMPORTANCE

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World Health Organization
Division of Control of Tropical Diseases
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GENERAL CONSIDERATIONS

1.1 Introduction

Every year there are hundreds of millions of cases of insect- and rodent-borne diseases, indicating the major threat to global public health that vector-borne diseases are. Operational, financial and managerial problems, together with environmental change, pesticide resistance and population movement have caused an increase in the prevalence of many of these diseases in recent years. Such diseases which include malaria, filariasis, schistosomiasis, dengue, trypanosomiasis and leishmaniasis, represent a significant impediment to social and economic development.

Selective vector control is an integral part of many vector-borne disease control activities. Its implementation envisages targeted site-specific use of available vector control methods, taking into consideration technical and operational feasibility, resources and infrastructure.

The available vector control methods are mainly based on environmental management, biological control and the use of chemicals. With rare exceptions, environmental management and biological control have limited applicability on their own, and chemical control is still considered as the most important element in the integrated control of vector borne diseases.

This is the fifth edition[1] of a guide to the use of chemical methods for control of vectors and pests of public health importance[2]. It provides staff involved in operational vector control programmes with practical information on the safe and effective use of pesticides as well as information on individual and household level chemical protection from insect and rodent pests. Since the publication of the previous edition of this manual in 1984 there has been a shift in emphasis in the use of pesticides for vector control. In many endemic countries, vector control strategy has begun to move away from large, centrally organised vertical programmes to regional or district based programmes integrated into general health services. A reduction in donor funding for the maintenance of spray programmes, pesticide resistance and increasing concern over environmental and safety implications of the widespread use of chemicals has resulted

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[1] This revision was edited by Dr D C Chavasse (London School of Hygiene and Tropical Medicine) and Dr H H Yap (Vector Control Research Unit, Universiti Sains Malaysia). The original version and the first, second, and third revisions appeared, respectively, in the eighth, tenth and thirteenth reports of the WHO Expert Committee on Insecticides. The fourth revision was prepared by Dr C Y Chow, Dr R Le Berre and Dr M Vandekar, Dr D E Weidhaas and Dr A Smith.

[2] Copies of this and any other WHO documents mentioned in this book can be obtained on request from the Division of Control of Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland.

in greater emphasis on the selective use of safe pesticides with minimal impact on non-target organisms.

Mounting concern over chemical pollution has led to renewed interest in expanding the role of environmental management and biological control as vector control methods. As a result integrating chemical methods with other methods of control, wherever feasible, is considered desirable and decreases the reliance on pesticide use. Each vector control programme should be examined closely to determine the extent to which non-chemical control measures can be incorporated. The selection and integration of different chemical and/or non-chemical methods of pest control should be based upon, as far as possible, their efficacy, sustainability and cost-effectiveness. It is beyond the scope of this manual to judge the cost effectiveness of the vector control strategies covered in the wide range of settings where they may be employed, although this subject is addressed elsewhere[3]. Despite the growing contribution of alternative measures, chemical control will continue to play a vital role in vector borne disease control, particularly where rapid and effective control is essential, such as during disease epidemics.

For several vector species, environmental sanitation through source reduction and health education is the fundamental means of control: ideally, it is the primary method of control, with others serving as a supplement, not substitute, to it. Emphasis on community-based vector borne disease control has intensified in recent years. Notably the demonstration of the potential for insecticide treated mosquito nets to reduce mortality and morbidity due to malaria (see chapter 15) has led to the promotion of net usage in many malarious areas. There has also been an increase in emphasis on personal and household level protection from insect and rodent vectors (see chapters 13, 14 and 16), as well as community participation for eliminating vector breeding sites. It is an important part of vector control programmes that information on simple, effective and acceptable methods for vector source reduction and personal protection are available to communities at a reasonable cost.

The well-known insecticide classes (the organochlorines, the organophosphates, the carbamates and the pyrethroids) are still the mainstay of vector control programmes. However, since the publication of the last edition of this manual, use of pyrethroid insecticides has increased as that of the organochlorine and some of the more toxic organophosphate compounds has decreased. The role of the organochlorines has diminished due to concerns over environmental impact, residues in export crops and safety to humans. DDT is still used for malaria and leishmaniasis vector control in countries where it is available and where the local vector species are susceptible. Following a review of literature on safety aspects of DDT use for malaria vector control, a WHO study group recently concluded that there was no justification on toxicological grounds for changing current policy on DDT use, although in view of

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[3] *Guidelines for cost-effectiveness analysis of vector control.* Joint WHO/FAO/UNEP/UNCHS Panel of Experts on Environmental Management for Vector Control. Geneva, World Health Organization, 1993

the availability of alternative insecticides, DDT no longer merits promotion as 'the insecticide of choice'.

Use of the bacterial insecticides, *Bacillus thuringiensis israelensis* (serotype H-14) and *Bacillus sphaericus* has increased in response to a need for safe, pest-specific compounds to which the target pest is generally susceptible. Although these materials are considered as biological control agents, they have been included in this manual for consideration alongside chemical insecticides in selecting larvicides for control of mosquitos and blackflies.

The Insect Growth Regulators (IGRs) have also become more widely used over the past 12 years. IGRs can be divided into juvenile hormone analogues (juvenoids) such as pyriproxyfen, methoprene, fenoxycarb and hydroprene, and chitin synthesis inhibitors such as triflumuron, cyromazine, diflubenzuron. Juvenoids affect the normal growth process of insects, while chitin synthesis inhibitors disrupt the transformation processes. IGRs have been most widely used against mosquito vectors, although they are active against a wide range of public health pests. IGRs are formulated in a variety of controlled-release formulations that release minute quantities of the active ingredients over a period of time so that longer-lasting, more effective control can be achieved with one treatment. In polluted water, the juvenoid dosage required for effective control is higher than for the same species in a clean water breeding site. In general, the IGRs have a high margin of safety to fish, birds, mammals and most aquatic non-target organisms, although some are safer than others. They also possess extremely low toxicity to humans. However, some IGRs do adversely affect aquatic crustaceans and species closely related to mosquitos which share the same habitat.

1.2 Scope and layout of the manual

Following the approach adopted in the last edition, each pest group is covered in its own chapter. In this edition, extra chapters have been included on snails, rodents, house dust mites, insecticide treated mosquito nets and household insecticide products. The layout for the chapters on specific pest groups includes a brief introduction to the pest species, their medical importance and the role of chemicals in the context of overall control strategy. This is followed by sections on the different chemical approaches to control under the headings listed below. Where there is little to say under specific headings, all the information is put together into one or two paragraphs to reduce fragmentation of the text.

(a) Target area. This term refers to the main target site for pesticide treatment and covers the breeding areas of the immature stages and the resting and feeding sites of the adult vector or pest.

***(b) Insecticides*.** While reference is made to many insecticides in general use, it is not the purpose of this document to provide a comprehensive list of all insecticides currently used in vector control. Most compounds or formulations are excluded if they require highly experienced and equipped professional pesticide control operators for their application. As far as possible, names approved by the International Organisation for Standardisation are used, and listed alphabetically. Therefore, their order does not imply any preference for one compound or formulation over the other. Similarly, *the presence or absence of any given pesticide in a list in no way constitutes a recommendation for or against its use by the World Health Organisation*[4]. The decision to apply a compound rests with national health authorities or individual vector control personnel. However, no reference is made to proprietary names, since there are too many to mention individually and the active ingredients of these products may be changed from time to time. It is therefore important to consult the label on the container of every pesticide to check the identity of the active ingredients, recommended dose and safety measures before used.

***(c) Application procedure*.** As it is not possible to describe in detail all possible methods of application, only those most commonly used are given.

***(d) Treatment cycle*.** Application of pesticide and the frequency of retreatment depends on the species of vector and its bionomics, the pesticide selected and its formulation, the effectiveness of the dosage used, the types of site to be treated under local climatic conditions, the disease transmission period and the target level to which diseases are intended to be controlled. Treatment cycles may vary greatly from one geographical area to another and, therefore, those indicated in this manual constitute only a basic guideline.

***(e) Precautions*.** Close attention should be paid to chapter 17, "Safe use of pesticides". The hazard of a compound is directly related to the way it is used. Pesticides that are hazardous to spraymen, house occupants, and the environment should not be used. Only those that are approved for the particular use by the relevant national authority should be considered. Before application, the user should read the label carefully to determine any handling precautions, restrictions on people handling the pesticide, and any hazard to non-target organisms. It is the responsibility of the vector control programme director to make certain that the pesticides are used in such a way as to avoid injury or damage[5].

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[4] Pesticide compounds which have passed WHO Pesticide Evaluation Scheme (WHOPES) and for which specifications are available are listed in Annex I. The specifications can be obtained on request from the Division of Control of Tropical Diseases, WHO, 1211 Geneva 27, Switzerland.

[5] See: *The WHO recommended classification of pesticides by hazard and guidelines to classification 1996-1997.* Geneva, World Health Organization, 1996 (unpublished document, WHO/PCS/96.3). See also: *Safe use of pesticides.* WHO Technical Report Series No. 813, 1991.

1.3 Selecting an appropriate chemical control strategy.

Effective application of any control measure must be based on a fundamental understanding of the ecology, bionomics and behaviour of the target species. Effective vector control also requires careful training and supervision of pest control operations and periodical evaluation of the impact of the control measures on vector density and on disease statistics. Where applicable, environmental sanitation methods should be applied in conjunction with chemical pesticides.

In selecting a pesticide and the appropriate formulation, consideration should be given to the biological effectiveness against the pest concerned, the susceptibility status of the target organism, the methods of application, its safety to humans, toxicity to non-target organisms, the registration status of the pesticide for the required use and its cost. If possible, small trials on the efficacy of a formulation and application method should be carried out under local conditions before committing to the purchase of large quantities. Consideration should also be given to transportation requirements and the availability of application equipment. Due regard should also be given to the impact of the compounds on the environment, including fish, birds and beneficial invertebrates. The determination of cost should be based on the expense of the material as applied and not strictly upon the purchase price of the chemical. These aspects should be discussed with the representatives of potential suppliers so that informed choices can be made on the most appropriate pesticide for the local context. It is emphasised that some methods outlined in this guide are based on experience acquired in one country only or in a single field-trial, and caution therefore is necessary if they are being considered for use as the basis for large-scale operations elsewhere.

1.4 Pesticide formulations

Pesticides are rarely used in their pure or technical form. Usually, the technical grade material (active ingredient) is mixed with various non-insecticidal ingredients to create a pesticide formulation. These inert ingredients serve a variety of functions. They may be combined with the active ingredient to enhance stability, reduce toxicity, improve efficacy or facilitate handling of the product. The type of pesticide formulation may markedly affect the results obtained in control. When absorbent surfaces are to be sprayed, suspensions of water-dispersible powders are frequently more effective biologically than emulsions or solutions, but they can leave an unpleasant deposit on treated surfaces. Microencapsulated products tend to provide long-term control and are more effective in exposed environments, such as outdoors. Safety, efficacy, residual life and ease of handling must all be considered when selecting a particular formulation. A range of commonly used formulations is described briefly below.

Dustable powder (DP) and granule (GR)-Dustable powders are prepared by mixing the insecticide with an inert carrier. This type of formulation is used mainly to control lice and fleas. Granules are made by impregnating, extruding, or coating coarse inert carrier particles with 10-100 g of the active ingredient per kg (1-10%). When used to control mosquito larvae, better penetration of vegetation is obtained with granules than with dustable powder.

Emulsifiable concentrate (EC)-active ingredient plus solvent and emulsifier. This is an economical form in which to ship high concentrations of insecticides (25-500 g/l (2.5-50%)) for later dilution with water. They are easy to mix and apply and leave few visible deposits on the surface treated. In addition little agitation is usually required to keep ECs in suspension. However, ECs may have a strong smell and are absorbed by porous surfaces. They may burn plant foliage and are easily absorbed through the skin, thereby increasing the potential risk to operators.

Emulsion oil-in-water (EW)-This formulation consists of an active ingredient, possibly dissolved in a solvent and combined surfactants, which are dispersed as fine oil phase droplets in water. This oil-in-water emulsion is usually stable for long periods and contains relatively low levels of solvent and surfactants compared with emulsifiable concentrates. With liquid active ingredients the concentration can be as high as 500 g/l. The formulation can only be diluted with water for application. With this type of formulation it has been possible to incorporate agents that retard the evaporation of water, making water diluted sprays more effective for ULV space spray treatments.

Capsule suspension (CS)-The active ingredient of these products is encased in tiny plastic polymer capsules which are suspended in water for spraying. The capsules release the insecticide slowly, extending the compound's residual life. They are not readily absorbed by porous surfaces and they adhere easily to insects, increasing insect/insecticide contact. They have few odour problems and a good residual effect, as the active ingredient is protected from sunlight and volatility. However, they tend to be more expensive than other formulations, may leave visible deposits and require agitation during application.

Slow-release formulations-These formulations are usually prepared as briquettes or strands, to provide controlled release of larvicides.

Solution-Made up of the active ingredient and solvent. Since many insecticides are insoluble in water, most solutions are prepared in solvents such as fuel oil or kerosene. Other solvents, such as acetone and xylene, may be used for chemicals that are particularly soluble in petroleum products. Solutions are prepared on a weight per volume (w/v) or weight per weight (w/w) basis.

Suspension-Wettable powder and water, or suspension concentrate and water.

Suspension concentrate (SC)-These are stable suspensions of a solid active ingredient in a fluid intended for dilution with water before use. They may be considered as somewhere between an EC and a WP in that the active ingredient is in the form of crystalline particles. These are not absorbed into porous surfaces or through the skin as readily as ECs, nor do they leave a visible residue, as do WPs, since the particles are tiny.

Technical grade-The active ingredient in its purest commercial form. It is rarely used in this form to control insects, except in Ultra Low Volume (ULV) applications of some insecticides for mosquito and fly control.

Wettable powder (WP) and water-dispersable powder (WDP)-Active ingredient plus wetting agent plus inert carrier. These formulations are used to prepare water-based suspensions. For public health use, WPs and WDPs normally contain the active ingredient at a concentration of 100-500 g/l (10-50%). Wettable powders and WDPs tend to be odourless and are not absorbed into porous surfaces or through the skin. They do, however, provide a hazard when being mixed as the dry particles may become airborne and be inhaled. Masks should therefore be worn during mixing.

1.5 Pesticide application equipment

Selection of properly designed application equipment for the recommended method of control is an important part of vector control planning. Most programmes continue to rely on hand-operated equipment, with the compression sprayer most commonly used for various control operations such as residual treatment and the application of larvicides and molluscicides. The operation and maintenance of motorised equipment requires additional skills and problems will arise unless specially trained personnel are there to supervise. Throughout this manual a range of application equipment is referred to for delivering pesticides to the target site. A brief description of commonly used equipment is given below[6].

Hand-operated compression sprayer-These sprayers are designed to apply pesticide onto surfaces with which the pest will come in contact or to breeding sites. A pesticide and water mix is either added to the tank or mixed within it. The tank is then pressurised by forcing air into it using a hand-operated plunger. A lever on the sprayer arm controls the release of spray through the nozzle. Filtering the water while filling the sprayer, regular maintenance and prompt replacement of damaged nozzle tips are essential to the sprayers' effectiveness, as otherwise, abrasion from particles in the water can cause deterioration, resulting in an excessive increase in discharge rate. A main disadvantage of this sprayer is that as the tank is emptied, pressure decreases with an accompanying reduction in the rate of delivery, unless there is a pressure control valve fitted to the outlet. Bearing in mind the cost of insecticides and the dose required to control the target pest, it is important to ensure the correct rate of application through monitoring the pressure inside the tank (using the gauge) and maintaining nozzle tips in good condition. The majority of problems encountered with these sprayers in the field are related to lack of proper cleaning at the end of each day. Regular inspection and checking of parts by trained personnel is essential.

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[6] See: *Equipment for Vector Control.* Geneva, World Health Organization. 3rd edition, 1990.

Mist-blowers (power-operated)-This equipment can either be portable or vehicle-mounted. Portable knapsack mistblowers are powered by a two stroke engine producing a high velocity air stream which blows out a low volume of insecticide as a fine mist. The volume emitted can be regulated through restrictors, but at high flow rates large droplets are produced. Large droplets deposit insecticide onto surfaces whereas the smaller droplets act like an aerosol, settling on insects either in flight or at rest. Although water is added to the insecticide formulation, overall application volumes for mist-blowers are relatively small. Ultra Low Volume (ULV) sprays can also be applied with the smallest restrictors. Knapsack mist-blowers can cover a large area in a relatively short time and provide ease of access to areas, such as narrow streets, through which vehicle-mounted equipment cannot pass. The main difficulties occur when starting these machines, because fuel mixture (oil and petrol) left in the engine after use evaporates, leaving an oily residue over the spark plug. This can be avoided if the fuel is switched off as the method of stopping the machine at the end of spraying, resulting in combustion of all fuel in the carburettor so that no mix is in contact with the spark plug overnight. Air, fuel filters and nozzles should be cleaned regularly and water used in the insecticide mix should be clean or filtered, as blades of grass or dirt can easily block the nozzle aperture. The disadvantages of the knapsack mist-blower are the risk of burns from the engine and the discomfort caused by heat, vibration and noise.

Aerosol generators (power-operated)-These are cold aerosol ULV sprayers for application of insecticides in their technical form or, more usually, diluted in oil or water. The machines can be hand-held but larger versions are truck mounted. Since the volume sprayed per unit area is much smaller than with thermal foggers, they can cover larger areas more quickly. Portable ULV aerosol generators may be more efficient in cases where access by road is difficult or where indoor spraying is required. The large truck mounted machines can cover larger urban areas where road access is reasonable. The most important consideration with ULV aerosol generators is the calibration and accuracy of the droplet size. For flies and mosquitos, this should be in the range of 15-25 microns. Factors that need to be considered when choosing a method for ground application of aerosols include behaviour and activity times of target pests, availability of trained staff for supervision and maintenance, cost effectiveness and safety of operation. Only insecticide formulations recommended for ULV use by the manufacturer should be applied by ULV application equipment.

Thermal foggers (power-operated)-These machines, which are either portable or vehicle mounted, are preferred in many vector control programmes, despite the extra cost. The highly visible fog is psychologically more acceptable to the user and to those who wish to see the control operations carried out. However, the droplet size is far less controlled than with ULV machines and a wide range of droplet sizes-from sub-micron to 200 microns- are produced. Therefore, some insecticide will go to waste due to convection currents or early fall out. When using thermal foggers, consideration should be given to increasing the concentration of insecticide and decreasing proportionally the flow rate to reduce formulation costs. There is a potential fire hazard when thermal foggers are used, especially when the pulse-jet foggers are carried indoors. It is important that only well-trained personnel, using appropriate insecticide formulations and having access to a fire extinguisher, are entrusted with their operation. The advantage of the pulse-jet fogger is its simplicity of design and construction, as there are no rotating parts and no lubrication required. However, its loud noise can be objectionable and operators should wear ear protection.

Aerial spraying equipment-Large-scale and emergency vector control programmes often benefit from the use of aircraft to apply chemicals. Aircraft are especially well suited for the rapid treatment of large areas or areas where wet soil, water, rough terrain, dense woody vegetation or densely populated urban areas during emergencies prohibit the use of ground or hand held equipment. Aerial spraying can be used both for adulticiding and applying course larviciding sprays. Accurate placement of sprayed chemicals is usually more difficult from aircraft than with ground application equipment, since many interacting factors affect the trajectory of the particles after they are released. Good quality sprayers can produce controlled droplet sizes, but these often need to be larger than for ground application to compensate for evaporation on their decent. Ideally, by the time the droplet reaches the ground level it should be 15-25 microns. Therefore, the decision to use aerial spraying should be carefully considered, particularly with regard to safety when spraying populated areas. Aerial spraying should not be considered if buildings preclude low level flying as experience has shown that spraying from heights above 75 m is ineffective. Political pressure for immediate action has sometimes resulted in inappropriate and consequently ineffective use of aircraft for vector control. Although rapid action may be required, several factors should first be considered including safety, timeliness, cost, meteorological conditions, vector habitat, biological effectiveness, availability of equipment, operational sites and trained crews.

Dusters-Dusters are most commonly used to apply dust for the control of human lice or rodent fleas for preventing epidemics of typhus or plague. The hand-activated, plunger-type duster is designed for control of arthropod pests on the individual and is appropriate for treating small numbers of people as the dust can easily be blown into sleeves and other garment openings. These dusters can also be used to apply dusts to rodent burrows for flea control. Powered equipment for mass dusting of human populations tends not to be very reliable as the quantity and direction of dust flow is difficult to regulate and blockages are apt to occur. The 'Millbank duster' has been found to be very effective for louse control in refugee situations and can be constructed at short notice (see chapter 7). Although dusts contain only a small proportion of active ingredient, the main concern in the field is the risk of inhalation of pesticide particles smaller than 10 microns in diameter. This problem is accentuated if the operator walks into a cloud of dust without an appropriate face mask or respirator.

1.6 Pesticide resistance

Pesticides have been the cornerstone of vector borne disease control for the past 50 years. Use of chemicals on a vast and increasing scale has led to the widespread development of resistance as a result of selection by insecticides for mutant genes which cause resistance. The number of insecticide resistant arthropods of public health importance has risen from 2 in 1946 to 150 in 1980 and 198 in 1990. Multiple resistance has appeared in some species, making their control by available chemical methods extremely difficult and expensive. It appears that among vectors of public health importance, tsetse flies, triatomine bugs, trombiculid mites and snail hosts of human schistosomiasis are the only groups in which resistance does not present a problem for control. The current status of pesticide resistance to specific vectors in different geographic areas is listed in the WHO Technical Report 'Vector Resistance to Pesticides'[7].

The operational criterion of resistance has usually been taken as the survival of 20% or more of the individuals tested at the currently known diagnostic concentrations of commonly available pesticides using WHO test kits in the field. The diagnostic concentrations are not intended to mimic the doses applied in the field, but are concentrations found to reliably kill strains which have never encountered pesticide and are therefore assumed to be susceptible. The diagnostic concentrations for commonly used insecticides against a wide range of pest species are listed in the WHO report referred to above. Reported resistance of a particular vector species in a particular area does not in itself necessitate a change in policy for control programmes in that area. The programmes should however begin planning ahead for the possible need of alternative strategies and pesticides. Only if current measures cease to control disease to the required level should an adjustment in strategy or pesticide be adopted. It is possible that even in the presence of resistance that overall mortality achieved by the pesticide is sufficient to suppress transmission either because vector resistance levels are not sufficiently high or because the pesticide has some other effect, such as reducing human/vector contact.

Resistance monitoring should be an integral part of vector control programmes. The susceptibility of vectors should be ascertained before the start of control operations to provide baseline data for programme planning and pesticide selection. Ongoing surveillance throughout the programme will allow early detection so that resistance management strategies can be implemented or, in the case of late detection, evidence of control failure can justify the replacement of the pesticide. Resistance monitoring can be easily carried out using the standard WHO test kits which are available from the Division of Control of Tropical Diseases, World Health Organisation, 1211 Geneva 27, Switzerland.

Resistance management is designed to prevent, or delay as much as possible, the development of resistance to a pesticide while at the same time maintaining an effective level of disease control. It requires a reliable system of disease surveillance, resistance monitoring and early detection. It is important to recognise that only a limited number of pesticides are available for use in public health programmes. Susceptibility of vectors and pests to these pesticides should be considered a valuable

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[7] *Vector resistance to pesticides.* WHO technical report series No.818, 1992.

resource that must be conserved as far as possible. Resistance management may be achieved by one or more of the following approaches:

- Limitation of pesticide use to areas with high levels of disease transmission.
- Limitation of pesticide use to the seasons in which peak disease transmission or pest nuisance occurs.
- Use of non-chemical control methods either alone or as a supplementary measure in the seasons or areas in which they are applicable and cost-effective.
- Replacement of residual pesticides by non-residual pesticides, the latter to be applied only when they are essential for adequate vector or nuisance control.
- Use of methods that kill only adult females rather than both sexes or all stages of the life cycle.
- Switching or rotating between unrelated insecticides as dictated by the results of susceptibility tests to each compound, any seasonal factors which limit the usability of particular compounds or by a pre-arranged plan based on knowledge of the likelihood of resistance developing to each compound.

From the resistance management stand point, it is advisable to select a pesticide that produces resistance within a single pesticide class. For example, most organophosphates used in mosquito larviciding programmes have produced resistance only to other compounds in that class. However, after initial production of resistance, an increase in the frequency of spraying or the dosage has resulted in the cross-resistance spectrum being extended to carbamates. It is also clear that pesticides which degrade slowly are more likely to produce resistance than those which degrade rapidly. Therefore, where infestation to a harmful level is transitory, the use of persistent pesticides is undesirable. If two or more unrelated, effective and safe pesticides are available, they can be considered for use in response to the development of resistance. Alternatively, they may be used in rotation to delay resistance or in a mixture designed to kill all but the rare, double-resistant individuals.

2

MOSQUITOS

Mosquitos are responsible for transmitting the most important vector-borne diseases, i.e., malaria, filariasis and dengue, as well as yellow fever and encephalitis. In selecting a mosquito control strategy, a detailed knowledge of the biology of the target species is essential as measures which are effective for one species may be inappropriate for another. Where possible, environmental management for the permanent destruction of breeding sites should be practiced. Another potential alternative to chemical control is biological control, an example of which would involve stocking breeding sites with larval predators such as fish. In general, however, environmental and biological approaches are either limited in their applicability or require a higher degree of ecological knowledge. Protection from mosquito bites can be achieved using repellents (chapter 14) or insecticide treated mosquito nets (chapter 15).

2.1 *Anopheles* spp.

Some species of *Anopheles* are important malaria vectors. In areas where the vectors are strongly endophilic, i.e., they tend to rest indoors, interior residual house spraying can give very effective control. Vectors that are mainly exophilic, but tend to feed or rest indoors briefly, can be effectively controlled by indoor residual spraying with insecticides that have a good airborne effect (see Table 1). In refugee camps, spraying the inside of tents with residual insecticides can reduce malaria transmission. In areas where vectors are strongly exophilic and/or exophagic, i.e., they rest and bite outdoors, other control methods, such as use of insecticide treated mosquito nets or exterior space spraying (for emergency control), should be considered.

Many vector species have developed resistance to the organochlorine compounds and some are also resistant to organophosphate and carbamate insecticides. Before adopting a new insecticide into a control programme, local vector susceptibility should be assessed and, if use is to be long-term, resistance monitoring surveys should be carried out (see section 1.6).

2.1.1 Interior residual treatment

Interior residual treatment can have a much greater impact on malaria transmission than attacking breeding sites, because it can reduce the longevity of vectors as well as their density. In practice, the effectiveness of house spraying for malaria control depends on adherence to the specified criteria of the insecticide and application procedure, public acceptance of spraying, the availability of well-maintained equipment, adequately trained spraying personnel, efficient supervision and strong financial support. The size of the operational area depends on local circumstances and is influenced by the distribution of malaria and malaria vectors, distance from important breeding sites, the flight range of the vectors and demographic features.

(a) Target area. Generally, all the interior walls and ceilings in a house are treated. In addition to permanent human dwellings, field huts where people sleep during the planting or harvesting season and animal shelters may have to be sprayed, depending on local vector behaviour. In some cases, which is indicated by the resting behaviour of the target species, treatment may be confined to the ceiling or the lower or upper half of the walls. In others, the undersides of furniture, outside eaves and porch may need to be treated. It should be noted that the residual effect of insecticides may be short on some surfaces (e.g., porous mud-walls, oil-painted wood and alkaline white wash).

(b) Insecticides. Several factors need to be considered in the selection of an insecticide for indoor spraying, including availability, cost, residual effectiveness, safety, vector susceptibility and excito-repellency (see section 1.3). Insecticides suitable for interior residual treatment are listed in Table 1. DDT is still used in areas where a regular supply exists and local vectors are susceptible. However, it is no longer promoted as the insecticide of choice for indoor spraying in view of the characteristics and availability of alternative insecticides (see section 1.1). Because of the hazard to man and domestic animals, neither dieldrin nor fenthion are recommended for indoor spraying.

(c) Application procedures. Hand-operated compression sprayers are widely used to apply the insecticide and water mixture as a coarse spray. Suspensions of water-dispersible powders are generally applied because they are cheaper and their residual effect lasts longer, particularly on porous surfaces. However, the more expensive solutions or emulsifiable formulations may have to be employed in certain situations, particularly where householders object to powder deposits. Directions for preparing spray dilutions are given in chapter 18.

(d) Treatment cycle. The frequency of retreatment depends on the duration of residual effectiveness of the insecticide at the dosage used, the type of surface sprayed, vector bionomics, the malaria transmission season and climatic conditions. House spraying rounds should be carried out just before periods of high malaria transmission. The average duration of effectiveness for the different insecticides is given in Table 1. However, early retreatment is required if insecticide deposits are removed from surfaces by re-plastering, whitewashing, re-roofing, or smoke deposits.

(e) Precautions. Care must be taken to protect spraymen, the public and domestic animals from unnecessary or prolonged exposure or accidental ingestion of insecticide. Safety guidelines for protecting, monitoring and treating spraymen are discussed in chapter 17. Proper and regular maintenance of spraying equipment also contributes to protecting spraymen from unnecessary contamination (see section 1.5).

2.1.2 Space treatment

Space treatment for malaria control should only be employed in exceptional circumstances because operational costs are high, the residual effect is low and other, more cost-effective approaches are usually available. Space spraying may be justified for control of certain exophilic and exophagic vectors and during malaria epidemics in urban areas, where rapid immobilisation of infective mosquitos is required.

(a) Target area. If the target species is exophilic, treatment is applied outdoors wherever the vector mosquitos rest. If the vector is endophilic, treatment should be applied indoors and outdoors.

(b) Insecticide. Suitable insecticides applied as cold aerosol sprays or as thermal fogs are indicated in Table 2.

(c) Application procedures. Where possible, applications should coincide with the flying times of the local vector. Exterior space-treatments with cold aerosols are carried out using vehicle-mounted ULV equipment. The doors and windows of houses should be left open for maximum penetration of the insecticide. Where aerial application is indicated, rotary atomizers can be mounted onto suitable aircraft. Interior treatments or exterior treatments in confined urban areas can be made with portable ULV equipment. Thermal fogging is applied using hand-carried or vehicle mounted equipment. Dosages applied using thermal fogs and cold aerosols are indicated in Table 2.

(d) *Treatment cycle.* For control of malaria epidemics, daily retreatment will have the maximum impact on vector density, as there is no residual effect associated with this application technology. For more routine control of exophilic and exophagic vectors, weekly retreatments during peak malaria transmission is sufficient.

(e) *Precautions.* Spraymen should be well protected to avoid exposing their skin to insecticide concentrates and should avoid inhaling insecticide droplets. Care should be taken to ensure that people and animals are not directly exposed to the spray.

2.1.3 Larviciding

Larviciding can be a useful method for malaria control programmes, particularly in areas where breeding sites are accessible and relatively limited in number and size. Such criteria are often met in urban areas, where larviciding in a central area may be combined with indoor residual spraying in a barrier zone of houses around the periphery of the town or city. As many of the vector breeding sites as possible should be eliminated through environmental management to reduce the number to which larvicides need to be applied.

(a) Target area. Before implementing a larviciding programme, surveys should be carried out to estimate the relative importance of different types of vector breeding sites. This will vary considerably depending on species and local environment. Targeting only the most important sites may improve operational cost-effectiveness.

(b) Insecticides. The insecticides listed in Table 3 are suitable for larviciding. The period of effectiveness of chemical larvicides depends greatly on the quality of the water treated, and may vary from months in clean water to only a few days in more polluted water. The higher dosages are therefore indicated for polluted water. The organochlorines, such as DDT, are not recommended for larviciding because of their persistence in the environment. Likewise, insecticides with high mammalian toxicity are not recommended as larvicides. Although considered ecologically unacceptable in some situations, oils such as malariol, flit MLO or fuel oil can be effective for limited periods when applied to breeding sites.

Insect growth regulators (IGR) (see section 1.1) and the microbial insecticides *Bacillus thuringiensis israelensis* (serotype H-14) and *Bacillus sphaericus* may offer alternatives to common chemicals for larviciding. The IGRs are very safe insecticides, are active at low concentrations and remain effective for 2-20 weeks depending in the compound, the mosquito species and the nature of the breeding site. IGRs may effect non-target organisms and should not be used in breeding sites with an abundance of arthropod species unless an impact assessment has been carried out. *B. thuringiensis* H-14, which is more active than *B. sphaericus* against malaria vectors (with the possible exception of *Anopheles gambiae*), is specific to mosquito larvae but frequent retreatment is necessary with current formulations. A corn-based granular formulation of *B. thuringiensis* H-14 is considered most appropriate for *Anopheles* control, as the floating corn kernels deliver the insecticide to the water's surface, where the larvae are situated. An aqueous formulation may also be applied.

(c) Application procedures. Application of liquid insecticide is usually carried out with the same equipment as indoor residual spraying, i.e., hand-operated compression sprayers. In some breeding sites, application of granular formulations may be more appropriate.

(d) Treatment cycle. In most instances, the interval of retreatment for chemical larvicides is 10-14 days, but it may be longer in standing clear water or for higher dosages. The approximate interval for IGRs is one month and for the microbial insecticides one week.

(e) Precautions. Care must always be taken not to exceed the recommended dosage when insecticides are applied to water that might be used by humans or domestic animals, or that contains wildlife of importance to man and his environment.

2.2 *Aedes* spp.

The main urban vector of dengue and yellow fever is *Aedes aegypti*, with *Aedes albopictus* as a secondary dengue vector in South-East Asia and the Western Pacific. In recent years, *A. albopictus* has also established itself in the United States, Brazil, Honduras, Mexico, Guatemala, the Dominican Republic, El Salvador, Nigeria, Italy and Albania. *Aedes polynesiensis* and *A. pseudoscutellaris* are arboviral and filarial vectors in the South Pacific. At least eight other *Aedes* species of the *Stegomyia* subgenus, including *A. africanus* and *A. simpsoni* s.l. as well as species of other subgenera such as *A. (Diceromyia) furcifer-taylori* are important vectors of yellow fever in non-urban areas.

Except for some African strains, *A. aegypti* lives in close association with man, mainly breeding in artificial containers in the domestic environment. *Aedes albopictus* uses both artificial and natural breeding sites. All the other important *Aedes* species prefer natural breeding sites, such as tree holes, plant axils and coconut husks. The domestic forms of *A. aegypti* feed indoors and outdoors, mainly in the early morning and the last 3-4 hours of daylight and prefer to rest indoors in secluded places, e.g., under sinks, in curtain folds or in wardrobes. *Aedes albopictus* is less domestic than *A. aegypti* and tends to rest and feed outdoors, as do most of the other important vector species. It is generally accepted that *Aedes* species have a flight range of less than 400 metres, although recent studies indicate that *A. aegypti* may disperse over much larger distances during oviposition.

An essential component of routine *Aedes* control is the removal or destruction of domestic breeding sites such as tyres, tin cans, flower pots and animal feeding containers. Domestic water storage containers may be important breeding sites and should be covered appropriately to prevent mosquito access, emptied and scrubbed once a week, or treated with insecticides considered safe for use in drinking water (see section 2.2.1). Alternatively, biological control agents such as fish (*Gambusia* spp. and *Poecilia* spp.), or copepods can be added to water tanks or drums. Community involvement is important for effective *Aedes* control, so health education is an integral part of effective control programmes[1].

Chemical control of *Aedes* mosquitos may include application of larvicides as part of the routine control strategy or space treatment, either in anticipation of or during epidemics of dengue or yellow fever. Indoor residual treatment may also be effective for control of *A. aegypti*. Because resistance can be a problem in the chemical control of *Aedes*, insecticides should only be used in conjunction with adequate and competent susceptibility testing.

2.2.1 Larviciding

Larviciding should only be considered as a complementary measure to basic sanitation. It is only feasible against strictly domestic species, such as *A. aegypti*. It is not usually practical against species breeding in hard to find natural sites such as leaf axils and tree holes. Because *A. aegypti* often breeds in water storage containers, larvicides must have extremely low mammalian toxicity and not change the taste, odour or colour of the water. At present, four compounds meet these criteria; temephos, *B. thuringiensis* H-14, the insect growth regulator (IGR) methoprene and permethrin. Clearance by the International Programme for Chemical safety (IPCS) should be requested for any insecticide which may be applied to drinking water. In areas where *A. aegypti* breeds in septic tanks or soak-away pits, expanded polystyrene beads may be applied as long as flooding of these sites does not regularly take place.

(a) Target area. Surveys should be carried out to determine the principal breeding places and how and when they should be treated. Breeding sites in jars, tyres, discarded containers, cisterns, ant-traps, plant containers, etc., should only be treated if removal and destruction is not feasible.

(b) Insecticides. Insecticides suitable for larviciding are listed in Table 3. Solutions, emulsions, granules or slow-release formulations can be applied to containers of non-potable water and are usually applied at dosages calculated for surface application. This is expressed as weight of active ingredient per unit area, e.g., g a.i./ha (see Table 3). For treatment of drinking water, temephos (the most widely used) and methoprene are applied at dosages not exceeding 1 mg of a.i./l (1 ppm) and permethrin is approved for use at 15μg/l. Common salt added to ant traps at 0.02-0.04 mg/l is also effective.

Microencapsulated formulations have been developed to regulate the release of larvicide. The release of the active ingredient is controlled for a period of 5-7 days in warm water and over a longer period in cooler water, thereby adjusting to the slower rate of larval development at lower temperatures. Briquettes have also been formulated which, through erosion and mechanical breakdown, provide controlled release of the

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[1] See: WHO/WPRO 1995, *Guidelines for Dengue Surveillance and Mosquito Control.*

active ingredient for about 25 days. Coconut shell chips and corn cobs impregnated with the larvicide have also proven effective.

(c) Application procedures. Hand-operated compression sprayers can be used to apply the insecticides as a peripheral spray in and around containers of non-potable water and adjacent surfaces. This produces a residue that can destroy existing and subsequent larval infestations, as well as adult mosquitos that frequent the sites. Aerial applications are sometimes necessary where large areas are involved. A syringe or pipette can be used for treating indoor flower vases and ant-traps. In treating containers of drinking water, enough insecticide should be added for the volume of the container (e.g., 1 g of 1% temephos granules for 10 litres of container volume) even if the container is not full of water.

(d) Treatment cycle. The mosquito species, rainfall pattern and types of breeding site involved all affect the treatment cycle. In a few cases, 2-3 treatments per year, carefully spaced between periods of rainfall, may be sufficient. More frequent treatment may be required depending on water quality and exposure to sunshine.

(e) Precautions. Extreme care must be taken when treating potable water to avoid dosages toxic to humans.

2.2.2 Residual treatment

Residual treatment of houses has not been routinely used for *Aedes* control although there is good evidence that such treatments can be effective. For example, the elimination of *A. aegypti* from the Mediterranean region is attributed to residual house spraying with DDT for malaria eradication. Also, the present high rates of DDT resistance in *A. aegypti* in the Caribbean is attributed to malaria control campaigns. Residual insecticides can be used for treatment of potential breeding containers, whether they hold water or not, and for spraying adjacent surfaces up to 60 cm from each container. This approach is known as perifocal spraying, a term which is sometimes used to describe insecticide application in an area around a reported dengue case. Suitable insecticides (e.g., those in Table 1, excluding the OCs) can be applied using hand-operated compression sprayers. Care must be taken not to treat containers used to store water for human or animal use.

2.2.3 Space treatment

There has been considerable controversy concerning the efficacy of aerosol insecticide applications during dengue and yellow fever emergencies. Any control method that reduces the number of infective adult mosquitos, even for a short period of time, should reduce virus transmission during that time, but it remains to be proven whether such a short-term impact can be epidemiologically significant in the long run. Certainly, there is no well-documented example of this interrupting an epidemic. However, if space spraying is employed early on in an epidemic situation, transmission may be delayed. This in turn would give time for larviciding and community-based source reduction to have a long-term result. Thus, if disease surveillance is competent enough to detect cases in the early stages of transmission and if funds are available, emergency space spraying can be initiated at the same time as source reduction measures are intensified.

In addition to insecticide susceptibility, application rate, droplet size and indoor penetration of the insecticide are all crucial to the efficacy of this method. Indoor penetration of insecticide will depend on house construction, whether doors and windows are left open during spraying and, in the case of vehicle-mounted application equipment, residential block configuration and the route of the spray vehicle.

(a) ***Target area.*** Total coverage can rarely be achieved, so attention should be focused on areas where people congregate, e.g., high-density housing, schools, hospitals and areas where disease cases and/or high vector densities have been recorded. Selective space treatment up to 400 m from the home of diagnosed cases has been practised in the past but in general, by the time a case is detected and a response mounted, the infection will have spread to a wider area. Where space treatment is applied from outside, residents should be encouraged to leave windows and doors open during application to aid penetration of the insecticide. Application from the outside may be less effective where houses have solid walls, glazed windows and high garden walls. In such cases, indoor space or residual treatments are likely to be more effective. For control of forest dwelling yellow fever vectors in Africa, space treatment up to 40 m into the forest can be achieved using ULV equipment from the forest fringe or footpaths running through the forest.

(b) Insecticides. Suitable insecticides for ground and aerial application as cold aerosols or thermal fogs are indicated in Table 2. The choice of insecticide formulation for space spray in and around living premises should take into consideration its immediate environmental impact, and the response of the community. Some insecticides listed (Table 2) may cause irritation when used in ULV or thermal fogging operations. Water-based formulations of pyrethroids mixed with piperonyl butoxide have been shown to be effective for *Aedes* control and have a less harmful environmental impact and are more acceptable to the community.

(c) Application procedures. Space sprays can be applied as either thermal fogs at about 10-50 l/ha or as ULV applications of undiluted or partially diluted technical insecticide in the form of a cold aerosol of droplets of controlled size (15-25 microns) at a rate of 0.5-2.0 l/ha. Portable or vehicle mounted thermal fog generators or ULV cold aerosol generators can be used for ground application. If the affected area covers more than 1000 ha, or if it cannot be covered by ground equipment within 10 days, aerial ULV is sometimes used. However, problems due to improper penetration of the resting sites of the target species, similar to those for aerosols dispensed from road vehicles do arise.

Application rates vary with the susceptibility of the target species and environmental considerations. Fog and ULV applications should be carried out when air velocities are below 10 km/h and, if possible, when there are temperature inversions. Applications should also correspond to the activity of the target species, so that while for *Anopheles* spp. or *Culex* spp. they are usually carried out early in the morning or at dusk, for some *Aedes* spp. daytime applications may be more appropriate, although thermal convection may cause rapid dispersal of spray droplets. Timing of application may also be governed by presence of people in their houses so that doors and windows can be opened if spray is applied from the outside.

Indoor treatments using portable ULV machines or thermal fog generators are particularly effective against *A. aegypti,* because of its resting behaviour and is the only choice where access to vehicles is restricted. Vehicle-mounted equipment should be driven at speeds between 5 and 15 km/h in a cross-wind direction, so that the fog or mist moves at right angles to the line of travel. The aerosol is directed to cover a swath of 60-90 m width. Discharge rate varies greatly from a few litres to several hundred litres per hour depending on the speed of the spray vehicle, the dosage of active ingredient required (see Table 2), and the strength of the formulation applied. For ULV applications from large aircraft, the speed would be 240 km/h at 60 m above the ground with a swath spacing of 180m. Small fixed wing aircraft are flown at 160 km/h at a height of 30 m above the ground with a swath width of 50-100m. For emergencies, agricultural spraying aircraft, including helicopters, can be used. They should be fitted with rotary atomisers or other suitable nozzles calibrated for the insecticide, its formulation and the desired application rate.

(d) Treatment cycle. Where a rapid reduction in vector density is essential, space treatment should be carried out every two to three days for 10 days. Further applications should be then carried out once or twice a week to sustain suppression of the adult vector population. However, continuous entomological and epidemiological surveillance is needed to determine the appropriate application schedule and the effectiveness of the control strategy adopted.

(e) Precautions. Where house-to-house space treatment is carried out with portable equipment, special safety measures are necessary for the operators. In addition to normal protective clothing, they should wear face masks and only operate the equipment for short periods of time. ULV aerial applications should only be carried out by highly skilled pilots trained to undertake ULV spraying at the proper speeds and heights (see section 1.5). Ground reconnaissance should be made before treatment to safeguard non-target animals and beehives. Fogging in urban areas can be a traffic hazard and spotting of vehicles may result, particularly when large droplet sizes are used.

2.3 *Culex* spp.

Some species of *Culex* are important vectors of disease. *C. quinquefasciatus* is a vector of Bancroftian filariasis in urban areas of East Africa and parts of Asia and it is a pest in all tropical towns and cities. *C. pipiens* has been linked with the transmission of epidemic Rift Valley fever. Other vectors are restricted to specific geographic areas, such as *C. tritaeniorhynchus* which is mainly responsible for transmitting Japanese encephalitis, *C. tarsalis* for St Louis encephalitis and *C. annulirostris* for Murray Valley encephalitis and Ross River disease. The many other vector or pest species of Culex are too numerous to mention.

Most *Culex* species rest outdoors, except for *C. quinquefasciatus,* which is a domestic mosquito, with over 50% resting on non-sprayable surfaces in the house, such as mosquito nets, clothes, hangings and furniture. For this reason, indoor residual house spraying is of limited use, particularly when the insecticide involved does not have volatile or fumigant properties. Furthermore, *C. quinquefasciatus* adults have developed high levels of resistance to organochlorine and organophosphate insecticides in many areas. Therefore, larviciding has become the principal method of chemical control for most species of *Culex*, especially in urban and semi-urban areas.

Environmental sanitation should be an integral part of effective *C. quinquefasciatus* control. Before implementing chemical control, breeding sites should be mosquito-proofed or destroyed wherever possible. This may involve unblocking drains to maintain water flow, draining areas of flooded land, filling in small collections of polluted water and repairing chipped or cracked concrete lids of septic tanks. In the special situation posed by pit latrines which have a free water surface (i.e., not covered in scum), cess pits and septic tanks, all of which may produce vast numbers of *C.quinquefasciatus*, a layer of expanded polystyrene beads, 1 cm deep, can be applied to prevent breeding. However, care should be taken to investigate the likelihood of beads being scattered about the environment as a result of treated sites flooding or being emptied.

2.3.1 Residual fumigation

A residual fumigant, eg. dichlorvos, is used for the treatment of catch basins or storm drains along streets. Each basin has an air space of 50-250 l above the water level. A single dispenser weighing 100 g and containing dichlorvos 200 g/kg (20%) in resin is used for each basin and suspended approximately 15 cm above water level. The period of efficacy is 3-4 months.

2.3.2 Space treatment

This is mainly for the purpose of controlling outbreaks of arbovirus disease and the insecticides and application procedures used are the same as for the control of *Aedes* mosquitos (see section 2.2.3). For exophilic species, the outdoor resting sites should be targeted for treatment.

2.3.3 Larviciding

(a) Target area. The breeding sites of *C. quinquefasciatus* are collections of polluted water such as cesspools, drains, latrines and ditches, while *C. tritaeniorhynchus* breeds in clearer water such as that found in rice fields, swamps and marshes. *Culex annulirostris* breeds in almost any type of ground water, whereas *C. tarsalis* prefers sewage lagoons, pastures, and irrigated croplands.

(b) Insecticides. Chemicals used as larvicides are listed in Table 3. Current practice relies chiefly on the use of organophosphates, despite increasing levels of resistance in some areas. For residual control, the dosage should be markedly increased to provide a longer period of activity. Fuel oil or oils fortified with chemical insecticide may be used for short term control. Applications of the IGR pyriproxyfen have been shown to be effective in preventing adult emergence from collections of polluted water for 1-3 months. Slow release formulations of methoprene can also be effective. *Bacillus sphaericus* has been used to effectively control *C. quinquefasciatus* in polluted breeding sites.

(c) Application procedures. Hand-operated compression sprayers are adequate for application of liquid insecticide to localized breeding sites. For confined breeding places such as latrines, where polystyrene bead treatment is not feasible, it has been found practicable to express dosages of insecticides as mg/l (ppm) rather than g/ha. The purpose is to introduce into the breeding-place a specific amount of insecticide adapted to each situation through application of a precise volume of formulated compound to each site (eg. 240 ml chlorpyrifos 5 g/l (0.5%) per catch basin or 5 g of 100 g/kg (10%) granules per latrine). For extremely polluted sources, such as sewage treatment plants, the insecticides may be introduced into the effluent by a drip technique. In contaminated ponds, floating booms have been used to confine heavy oil larvicides to the breeding areas on the perimeter. Where areas of flooded grassland are important breeding sites, granular formulations are suitable as they can fall through the grass to the water below. Aerial application is useful for treating extensive breeding areas. Liquid formulations are applied at 5-10 l/ha to control *C. tritaeniorhynchus* in rice fields.

*(d) **Treatment cycle.*** Applications at intervals of 1-2 weeks are usually required for temporary treatments with oil alone, or oil fortified with chemical larvicides. For control of susceptible *C. quinquefasciatus* breeding in polluted concrete drains and in pit latrines, organophosphates can remain effective for 2-8 weeks. Treatment with microbial insecticides prevent breeding for 1-2 weeks and, depending on environmental conditions, IGRs prevent emergence of viable adults for 2-20 weeks.

*(e) **Precautions.*** Residual applications must not be made to any area where fish or other important wildlife are found, or where the run-off from the treated area will endanger non-target organisms in other areas.

2.4 *Mansonia* spp.

Several species of Mansonia are important vectors of lymphatic filariasis (*Wuchereria bancrofti* and particularly *Brugia malayi*). *M. uniformis* is the most widely distributed species. The larvae of Mansonia attach themselves to the roots of aquatic plants such as *Pistia, Eichhornia, Salvinia* and *Scirpus* and to irrigated grasses. The simplest method of control is to destroy these plants. In situations where removal of host plants is not practical but control of *Mansonia* immatures is required, chemical or microbial insecticides may be used (Table 3). The adults are mainly exophilic, although a considerable number of certain species may remain in the house after feeding on man. These can best be controlled through indoor residual house spraying, as done for *Anopheles* control (see section 2.1).

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Table 1: Insecticides suitable for interior treatment against mosquito vectors

Insecticide	Chemical type[a]	Dosage of a.i.[b] (g/m^2)	Duration of effective action (months)	Insecticide action	Toxicity: [c] oral LD_{50} of a.i. for rats (mg/kg of body weight)
Alpha-cypermethrin	PY	0.02-0.03	4-6	contact	79
Bendiocarb	C	0.1-0.4	2-6	contact & airborne	55
Carbosulfan	C	1-2	2-3	contact & airborne	250
Chlorpyrifos-methyl	OP	0.33-1	2-3	contact	>3000
Cyfluthrin	PY	0.02-0.05	3-6	contact	250
Cypermethrin	PY	0.5	4 or more	contact	250
DDT	OC	1-2	6 or more	contact	113
Deltamethrin	PY	0.01-0.025	2-3	contact	135
Etofenprox	PY	0.1-0.3	3-6 or more	contact	>10,000
Fenitrothion	OP	2	3-6	contact & airborne	503
Lambda-cyhalothrin	PY	0.02-0.03	3-6	contact	56
Malathion	OP	2	2-3	contact	2100
Permethrin	PY	0.5	2-3	contact	500
Pirimiphos-methyl	OP	1-2	2-3 or more	contact & airborne	2018
Propoxur	C	1-2	3-6	contact & airborne	95

[a] C = carbamate; OC = organochlorine; OP = organophosphate; PY = synthetic pyrethroid
[b] a.i.= active ingredient
[c] Toxicity and hazard are not necessarily equivalent; the factors influencing the latter are discussed in section 17.1.1.

Table 2: Insecticides suitable for application as cold aerosol sprays or thermal fogs for mosquito control

Insecticide	Chemical	Dosage of a.i.[b] (g/ha)		Toxicity:[c] oral LD_{50} of a.i.[b] for rats (mg/kg of body weight)
		Cold aerosols	Thermal fogs[d]	
Bendiocarb	C	4-16	-	55
Bioresmethrin	PY	5	10	>7000
Chlorpyrifos	OP	10-40	150-200	135
Cyfluthrin	PY	1-2	2	250
Cypermethrin	PY	1-3	-	250
Cyphenothrin	PY	2-5	-	318
Deltamethrin	PY	0.5-1.0	-	135
Dichlorvos	OP	150	200-300	56
D-phenothrin	PY	5-10	-	>5000
Etofenprox	PY	10-20	10-20	>10,000
Fenitrothion	OP	250-300	270-300	503
Lambda-cyhalothrin	PY	1.0	1.0	56
Malathion	OP	112-693	500-600	2100
Naled	OP	56-280	-	430
Permethrin	PY	5	10	500
Pirimiphos-methyl	OP	230-330	180-200	2018
Propoxur	C	100	-	95
Resmethrin	PY	2-4	-	2000
Zeta-cypermethrin	PY	1-3	-	106

[a] C = Carbamate; OP = Organophosphate and PY = Synthetic pyrethroid
[b] a.i. = active ingredient
[c] Toxicity and hazard are not necessarily equivalent; the factors influencing the latter are discussed in section 17.1.1.
[d] The strength of the finished formulation when applied depends on the performance of the spraying equipment used.

Table 3: Insecticides suitable as larvicides for mosquito control[a]

Insecticide	Chemical type[b]	Dosage of a.i.[c] (g/ha)	Formulation[d]	Duration of effective action (weeks)	Toxicity:[e] oral LD_{50} of a.i.[c] for rats (mg/kg of body weight)
B. thurigiensis H-14	MI	[f]	AQ,GR	1-2	>30,000
B. sphaericus	MI	[f]	GR	1-2	>5,000
Chlorpyrifos	OP	11-25	EC, GR, WP	3-17	135
Chlorpyrifos-methyl	OP	30-100	EC,WP	2-12	>3000
Deltamethrin	PY	2.5-10[g]	EC	1-3	135
Diflubenzuron	IGR	25-100	GR	2-6	>4640
Etofenprox	PY	20-50	EC, oil	5-10	>10,000
Fenitrothion	OP	100-1000	EC, GR	1-3	503
Fenthion	OP	22-112	EC,GR	2-4	586
Fuel oil	-	[h]	soln	1-2	negligible
Malathion	OP	224-1000	EC, GR	1-2	2100
Methoprene	IGR	100-1000	Slow release suspension	2-6	34,600
Permethrin	PY	5-10	EC	5-10	500
Phoxim	OP	100	EC	1-6	1975
Pirimphos -methyl	OP	50-500	EC	1-11	2018
Pyriproxyfen	IGR	5-10	EC, GR	4-12	>5000
Temephos	OP	56-112	EC, GR	2-4	8 600
Triflumuron	IGR	40-120	EC,WP	2-12	>5000

[a] **Pyrethroids are not normally recommended for use as larvicides because they have a broad spectrum impact on non-target arthropods and their high potency may readily potentiate larval selection for pyrethroid resistance.**

[b] IGR = insect growth regulator; MI = microbial insecticide; OP = organophosphate; PY = synthetic pyrethroid

[c] a.i. = active ingredient

[d] AQ = aqueous; EC = emulsifiable concentrate; GR = granules; soln = solution; WP = Wettable powder

[e] Toxicity and hazard are not necessarily equivalent; the factors influencing the latter are discussed in section 17.1.1.

[f] Dosage according to the formulation used.

[g] The lowest levels are recommended for fish-bearing waters.

[h] Apply at 142-190 l/ha, or 19-47 l/ha if a spreading agent is added.

3

FLIES

In this chapter, chemical methods for the control of synanthropic flies, tsetse flies (*Glossina* spp.), blackflies (*Simulium* spp.), sandflies (*Phlebotomus* and *Lutzomyia* spp.) and several less important genera will be discussed.

3.1 *Musca domestica* and other synanthropic species.

These flies live in close association with man, and include the housefly family with the genera *Musca, Fannia, Muscina*, and the biting *Stomoxys* (family Muscidae), the blowflies, *Chrysomya, Calliphora, Lucilia*, and the fleshflies, *Sarcophaga*, as the most important. *Musca domestica*, the housefly, is the most common species found throughout the world and will be the focus of this section.

The breeding sites of these flies are animal and human excreta and a wide variety of other organic matter, particularly domestic garbage. Experimental and epidemiological studies have shown that, because of their filth-breeding and filth-feeding habits, some synanthropic species can be important vectors of diseases such as shigellosis and other diarrhoeal diseases (*Musca domestica*) and trachoma (*Musca sorbens*). Epidemics of such diseases may be common where high human and fly population densities are associated with unsanitary conditions, as may be found in refugee camps. Flies are, however, rarely the sole transmitting agents in any disease epidemic.

Environmental sanitation is the fundamental measure for fly control. Proper disposal of refuse, manure, compost and other organic waste is of prime importance in the elimination of fly breeding sites. As far as possible, flies should be kept away from young children and food by fly-proofing houses, particularly kitchens, and covering stored food. In some countries, baited fly traps are used to reduce fly nuisance and biological control is also an option for reducing fly density. Insecticides should be used only as a supplement to other control methods, not as a substitute.

There are several methods of chemical fly control. Before adopting one, a thorough understanding of the local fly population's breeding, feeding and resting habits is needed, as well as knowledge of the insecticides to which the flies are resistant.

3.1.1 Residual treatment

(a) Target area. The treatment is directed against surfaces in and around animal shelters, fly breeding sites and areas where flies congregate for feeding or resting. The night time resting sites are particularly important, houseflies preferring edges of objects, strings, wires and thatch material under roofs of houses or animal shelters. When average temperatures are high, many houseflies remain outside at night and rest on the exterior of surfaces of buildings, fences, trees and shrubs. Blowflies and fleshflies normally rest outdoors.

(b) Insecticides. Preliminary assessment of insecticide susceptibility should be undertaken before selecting an insecticide for control of any medically important insect. This is particularly important in the case of houseflies as resistance is so widespread. Housefly populations have developed resistance to DDT and related compounds in all parts of the world. Organophosphate resistance is also common and seems to be increasing world-wide, in terms of the level, distribution and compound involved. Resistance to some carbamates is common in areas where organophosphate use has been intense and resistance to pyrethoids is an increasing problem in many areas. Resistance to insect growth regulators (IGRs) is not a problem if they are used for direct treatment of manure, although moderate resistance has been observed if they are mixed into animal feed. Compounds acceptable for use in dairies and poultry houses are listed in Table 4. The final formulations are either emulsions or suspensions, with the former preferred in situations where the deposit must be inconspicuous. Suspension concentrates (SC) offer superior residual efficacy over emulsifiable concentrates (EC). The addition of sugar to the finished formulations at 2-3 times the strength of the toxicant increases the effectiveness of treatment with some insecticides. However, this may favour the development of mould in areas of extreme humidity.

As a rule, the risk of developing insecticide resistance is greater when residual sprays are used than with other treatments against adult flies. For this reason, the intensive use of persistent pyrethroids as a residual treatment is not recommended unless no alternative exists.

(c) Application procedures. Either hand-compression or power-operated sprayers are used to apply the formulations. The spray volumes required vary greatly with the nature of the surface to be treated. Forty to eighty ml/m^2 may suffice for smooth non-sorptive surfaces, but volumes up to 250 ml/m^2 may be required for treatment of highly sorptive surfaces, such as refuse tips or refuse collection areas.

(d) Treatment cycles. Effectiveness may last from a few weeks to a few months depending on the insecticide, dosage, surface treated, climate, and resistance of the local flies. When compounds are applied to shelters housing non-dairy animals, the dosage may be increased to the maximum, as given in Table 4, with corresponding extension of the residual effect.

(e) Precautions. Contamination of food and drinking-water with any toxicant should be avoided. Avoid spraying animals and surfaces that they might lick. Use of organophosphate compounds is not permitted inside restaurants in certain countries.

3.1.2 Space treatment

Space treatment is the most effective method of rapidly reducing fly density inside or outside houses. Insecticides applied as aerosols at relatively low doses will kill adult flies that come in contact with the spray droplets. However, there is no residual effect of the insecticide and larvae and pupae in the breeding sites are unaffected.

(a) Target area. Indoor treatment is directed towards dwellings, kitchens, restaurants, shops, poultry farms and animal stables. Outdoors, the areas to be treated are night time fly resting sites, refuse dumps, recreation sites, markets, food industry sites, garbage containers and garbage trucks.

(b) Insecticides. Suitable insecticides for space treatment against flies are listed in Table 5. For indoor treatment, water based or deodorized kerosene formulations of the less hazardous insecticides are recommended. In some countries, indoor space spraying with organophosphates is not permitted. Due to the risk of resistance developing, stable pyrethroids are also banned in some countries. Mixtures of pyrethroids synergized with piperonyl butoxide (Table 6) and used in ULV or thermal fog formulations have been found to be very effective for fly control outdoors.

(c) Application procedures. For indoor treatment, hand sprayers, portable ULV equipment or thermal fog generators are used. For outdoor treatment, vehicle-mounted units are most appropriate although portable equipment can be used in areas where vehicle access is limited. The rate of dispersion of a ULV or fog formulation is determined by the target dose, the speed of the vehicle or person, and the swath width, which can vary between 20-30 m in urban areas to 100 m in open spaces. For fly control, the rates of dispersion have been found to be in the order of 0.5-2.0 l/ha for ULV applications and 10-50 l/ha for thermal fogs. In community control activities, the equipment has been mounted on vehicles that move through streets at 8-16 km/h and disperse the formulation at 24-48 l/km. The early morning is the best time for application as the temperature is cool and flies are aggregated in their night time resting sites. Later in the day the flies are more evenly distributed and the insecticide spray may be dispersed by rising warm air currents.

(d) Treatment cycle. Indoor space treatment of dairies, food processing plants and other places where hygienic conditions are important may need to be carried out daily to ensure effective fly control. In the case of outdoor space spraying in towns, villages or refugee camps, treatment should be applied every day for 1-2 weeks to kill adults as they emerge from breeding sites in the area. Once the breeding cycle has been broken the spraying interval can be extended to once or twice a week, depending on the rate of immigration of flies from outside the control area. To guide the precise timing of space treatments, adult fly density can be easily monitored by hanging sticky fly papers in kitchens or near night time resting sites. It is important not to spray too frequently or to use insecticide concentrations higher than strictly necessary because over spraying will lead to the build up of sub-lethal residues of insecticide in the environment, as a result of fall out, which may facilitate the development of resistance.

(e) Precautions. Food and water should be protected during indoor space treatment and people and animals should be kept out of the way of outdoor space sprayers.

3.1.3 Larviciding

Larviciding as a fly control measure has several drawbacks. Fly breeding media tend to accumulate and change continuously and therefore frequent treatments with larvicides are required. The penetration and distribution of the larvicide in the medium is often problematic, the natural predators of fly larvae may be killed and exposure to insufficient concentrations of insecticide in the breeding media may favour the development of resistance. In countries which can afford to maintain larviciding programmes, application several times during the fly season is recommended. In countries without the resources to maintain such programmes, larviciding is not recommended for routine fly control, although it may be necessary at the height of the fly season and during epidemics of fly borne diseases such as dysentery.

(a) Target area. The main breeding sites of the housefly and related species are as follows:

- *Musca domestica* (housefly): refuse, animal or human excrement
- *M. sorbens (face fly)*: human excrement
- *M. vestutissima* (bush fly): cattle droppings
- *Calliphora* spp., *Lucilia* spp.: meat, fish, garbage
- *Muscina* spp. (false stable fly): garbage
- *Chrysomya* spp. (blowfly): latrines, meat, fish
- *Sarcophaga* spp. (flesh fly): meat, animal excrement
- *Fannia* spp. (lesser housefly): animal excrement
- *Stomoxys calcitrans* (stable fly): straw stacks, piles of weeds, grass and animal excrement

When fly densities are high, it is important to identify the predominant species and identify the principal breeding sources. Time and money can be saved and contamination of the environment reduced by targeting only the most important breeding sites.

(b) Insecticides. IGRs are recommended for use as larvicides as they are chemically unrelated to adulticides. IGRs such as diflubenzuron (oral LD_{50} for rats >4640 mg/kg) (0.5-1.0 g a.i./m^2), cyromazine (oral LD_{50} for rats 3300 mg/kg) (0.5-1 g a.i./m^2) and pyriproxyfen (0.05-0.1 g a.i./m^2) can be used. Compounds belonging to the traditional insecticide classes should in general be reserved for control of adult flies. However, various organophosphate, carbamate, and pyrethroid insecticides are effective larvicides. Where fly populations are susceptible, diazinon is effective at 0.3-1.0 g a.i./m^2 and other organophosphate and carbamate compounds can be used at slightly higher dosages of 1-2 g a.i./m^2. The use of pyrethroids should be reserved for space treatment.

(c) Application procedures. Either hand-operated compression or power-operated sprayers are used to apply larvicides (solutions and emulsions) at a rate sufficient to wet the upper 10-15 cm of the breeding medium thoroughly, i.e., 0.5-5 l/m^2 depending on the medium. The maggots may be deep in the medium and will not be effected by cursory application. Dust and granule formulations may also be used, particularly for chicken manure. Where insecticides are applied to refuse dumps for fly control, controlled tipping should be practiced. This involves covering the top and sides of the refuse dump, each day after tipping has ceased, with a 30 cm deep layer of soil or sand and then compacting it. The heat generated by fermentation will kill many maggots and those not killed will be unable to emerge. In this situation the insecticide should be applied to the earth covering to kill the few females which emerge. The working face should not be treated as a precaution against the development of resistance.

(d) Treatment cycle. Generally, breeding sites need to be treated every 1-2 weeks although the IGRs may remain effective up to one month.

(e) Precautions. Avoid spraying domestic fowl and their feed and drinking-water.

3.1.4 Baits

(a) Target area. Baits are placed or applied in sites where adult flies congregate to feed, such as in and around poultry farms, dairies and food-handling establishments.

(b) Insecticides. Table 7 lists insecticides used in toxic fly baits. Dry baits contain 10-20 g a.i./kg (1-2%) in a carrier, such as sugar or sugar plus sand, ground corncobs or crushed oyster shells. Liquid baits contain 1-2 g a.i./l (0.1-0.2%) insecticide and sugar

100 g/l (10%) in water. The baits may contain special attractants such as fish meal, fermenting yeast or the house fly pheromone muscalure.

(c) Application procedures. Dry baits are scattered in a thin layer by hand from a bag, shaker-top can or similar container at a rate of 60-250 g/100m^2. Liquid applications can be made using a hand-compression sprayer or a sprinkling can, at the rate 4 litres per 100 m^2. Viscous paint-on baits, composed of an insecticide 20-60 g a.i./l (2-6%) with a binder and sugar to form a "paint", can be applied with a paintbrush as spot applications at a rate of 150 g/100 m^2. This method is the most versatile and convenient application as it can be placed wherever flies congregate, including vertical surfaces such as posts, supports and walls and it has a long residual effect.

To avoid the need for frequent renewal of baits, special reservoir containers can be designed. Gelatine or agar baits can be applied to a wire mesh square attached to a wooden paddle. The paddles are distributed over the area by inserting them into the ground or by attaching them to existing supports.

(d) Treatment cycle. Scatter baits may need to be applied 1-6 times per week depending on the rate of consumption by flies. Liquid bait dispensers or dry bait stations (trays) may work for 1-2 weeks. The paint-on baits may remain effective for 1-2 months or longer.

(e) Precautions. As baits contain a sweetening agent and food material, care should be taken that they are not placed where children or domestic animals are likely to come into contact with them.

3.1.5 Cords and strips

During the night, house flies prefer to rest on the edges of objects or on strings and wires. This behaviour suggests the use of insecticide impregnated tapes, strips or cords for fly control. This method is a useful way to control flies. It is inexpensive, has a long-term residual effect and there is a lesser chance of resistance developing than with residual sprays. However, the reduction in fly density may be rather slow. Insecticide treated cords or strips may be hung from the rafters or ceilings of dwellings, restaurants, poultry farms or animal stables.

The insecticide, such as azamethiphos, diazinon, dimethoate, dimetilan (oral LD_{50} for rats 47 mg/kg), fenchlorphos, malathion, propoxur or suitable pyrethroids, is incorporated into a cotton cord, spongy plastic band or gauze band. Solutions or emulsions of organophophate and carbamate compounds at concentrations of 100-250 g/l (10-25%) or pyrethroids at 0.5-10 g/l (0.05-1%) are used. The strips or cords are suspended under the ceiling, attached to the support by stapling or tying. One metre of cord is used for each square metre of floor space and dark or red materials are often better than light colours. The insecticide can be added to sugar or an attractant plus glue or oil to make a durable film. The effectiveness is for 2-6 months depending on insecticide, dosage and hanging site. Gloves should be worn when positioning cords or strips, which should not be suspended over food containers or watering troughs.

3.2 *Glossina* spp. - tsetse flies

Several species of tsetse flies are vectors of human and animal trypanosomiasis (*Trypanosoma brucei gambiense, T.b.rhodesiense, T.vivax, T.congolense,* and *T.b.brucei*). In West and Central Africa, *T.b.gambiense* (causing trypanosomiasis in humans) is transmitted by *Glossina palpalis, G. fuscipes,* and *G. tachinoides,* in East and Southern Africa, *T.b.rhodesiense* (causing trypanosomiasis in humans) is transmitted principally by *G. morsitans, G. swynnertoni* and *G. pallidipes.* Control measures include spraying habitats with insecticide, the application of non-residual space sprays, use of traps or insecticide treated screens and treatment of domestic livestock. So far insecticide resistance has not been encountered in the chemical control of tsetse flies.

3.2.1 Treatment of habitats

In the past, spraying habitats with insecticide was the most common form of tsetse fly control. It is now seldom carried out as the principal component of control programmes, although there still may be situations where insecticidal treatment of habitats is required.

(a) Insecticides and formulations. Only organochlorine and pyrethroid insecticides have been widely used for tsetse control. Due to adverse environmental effects, the use of DDT and dieldrin for residual spraying of vegetation is not recommended. However due to its relative instability in the environment the organochlorine, endosulphan, is still recommended and offers the only realistic alternative to the pyrethroids. In terms of formulation, wettable powders, which are cheap to produce and comparatively stable, are suitable for residual treatment in the dry season but not during the rainy season. Emulsifiable concentrates and suspension concentrates are better options for residual treatments in humid areas or during the rainy season. ULV solutions for non-residual application do not necessarily require dilution with water, which may be an advantage where water is scarce, but appropriate application equipment must be used.

(b) Methods of application.

Ground application of persistent insecticides. The aim is to produce a chemical barrier by placing a persistent insecticide on the resting places of tsetse flies in a well defined area. Deltamethrin is commonly used at 12-60 g a.i./ha applied as a 0.05% solution. Other pyrethroids which have been less widely used include alphacypermethrin, cyfluthrin and lambda-cyhalothrin. Spraying is generally carried out in the dry season and the insecticide deposit must last at least two months. Hand-operated compression or power-operated sprayers are used for insecticide application. Ground applications are carried out only on specific types of vegetation, e.g., riverine vegetation, thicket edges, forest islands, transitional vegetation between different types of woodland, vegetation around water-holes or along cattle routes, game trails, roads and tracks. Such application is known as discriminative. Within these target areas spraying is conducted selectively, i.e., only to those parts of the tree or shrub where the flies rest during the day or night. The target areas and the application site on the vegetation varies from place to place, but is related to the dry season habitat of the fly.

Aerial spraying. Fixed-wing aircraft are used mainly against savanna tsetse flies (*G. morsitans, G. swynnertoni* and *G. pallidipes*). These aircraft, which should fly just above tree-top level, are used for spraying non-residual ULV insecticides. Concentrated insecticides (formulated in oil solvents) are applied in the form of aerosol droplets. The droplets have to penetrate the woodland canopy and remain in the air long enough to make direct contact with the adult tsetse flies at rest or flying. Several applications of the insecticide have to be made at 2 to 3 week intervals until all pupae have had time to develop into adult flies. The insecticide most used to date is endosulfan (oral LD_{50} for rats, 80 mg/kg of body weight) as a 350 g a.i./l (35%) concentrate in oil solution. Droplet diameter should be 20-40 microns. The insecticide is generally sprayed in the range of 6-20 g a.i./ha each cycle. The lower range of dosage is applied in open flat terrain, but in hilly country, thickly wooded habitats and riverine woodland, dosages at the higher end of the range tend to be used. Deltamethrin has been used in aerosol sprays at a dosage of 0.25 g a.i./ha each cycle, with the spray applied at the rate of 1 l/km^2, and alphacypermethrin has been applied at 0.21 g a.i./ha as a ULV formulation.

Helicopters have also been used to apply ULV and persistent insecticides. With the latter, the aim is similar to that of ground applications, in that spraying is applied essentially to the dry season habitats of the flies. However, when helicopters are used, some advantage may occur from deposits of insecticides in the upper canopy of the vegetation, which is often the night resting-site of some tsetse species. Insecticides which have been widely used include endosulphan, sprayed at 1000 g a.i./ha and deltamethrin at 12.5-30 g a.i./ha. Other pyrethroids may also be effective but have not been widely used.

The helicopter must be fitted with nozzles or disc atomizers. The droplet size in general use for residual applications is approximately 150 µm volume median diameter. For non-residual (ULV) applications, atomisers which produce droplets of 20-40 microns should be fitted. Helicopter spraying covers the ground much more quickly than ground spraying and can cover areas that ground teams may find difficult to reach. It is, however, much more expensive than ground spraying. Recent experiments have shown that this method is not applicable in certain bio-climatic conditions (forest and savanna-forest mosaic).

3.2.2 Traps and targets

Traps and targets can be considered as a highly selective method of tsetse control that can be applied without danger of pollution. Traps, of a variety of designs, are usually used without insecticide. The flies normally die within the trap, but can be exposed to a chemosterilant, such as pyriproxyfen or triflumuron, prior to being allowed to escape. To draw flies in from a distance, the traps need to be sufficiently attractive. This can be enhanced through modifying the shape and colour of the traps and, for some species, the addition of olfactory attractants such as acetone, octenol, phenols and cow urine.

Targets are pieces of cloth impregnated with insecticide on which the tsetse flies settle. Insecticide retreatment is necessary at varying intervals, depending on the product, dosage, material used and time of year. For some species, target efficiency can be increased with the addition of olfactory attractants.

Insecticides for impregnation of traps and targets should have the following properties: high toxicity at low doses and short contact time, good persistence, absence of repulsion, and low toxicity to the user. The synthetic pyrethroids, usually formulated as suspension concentrates or emulsifiable concentrates, best satisfy these requirements. The material, weave and colour of the cloth to which the insecticide is to be applied is important. Synthetic fibres are generally better than cotton, while blue cloth is attractive to tsetse and black cloth the most frequently landed upon. Deltamethrin and alphacypermethrin at 0.3 g a.i./m^2 remain effective for 2 to 3 months on cotton/polyester and for longer on voile or polyamide mosquito netting. Recently, cyfluthrin, betacyfluthrin and lambda-cyhalothrin have been found to be effective for treatment of traps and targets. Retreatment in the field can either be carried out by dipping in insecticide solution or spraying with a hand-operated compression sprayer.

3.2.3 Livestock bait

This technique for tsetse control can be regarded as a modification of the target method whereby insecticide treated domestic animals, primarily cattle, are used as living targets. For this method to succeed, it is necessary that large numbers of domestic livestock are present in the area, that a high proportion are available for insecticide treatment and that they are the main source of blood for the local tsetse population. The pyrethroid insecticides formulated as suspension concentrates are most suitable for animal treatment and can be applied through dipping, spray races, hand spraying or as 'pour-ons'. Deltamethrin is most widely used at a final concentration of active ingredient of 0.00375% for dipping, 0.005% for spraying or 1% as a pour-on (volume applied depends on animal size). Treatment should be repeated every two weeks for dipping and spraying and every 3 to 4 weeks for pour-on. Flumethrin (oral LD_{50} for rats, 41-3849 mg of a.i./kg of body weight, depending on the vehicle used for oral administration) is another compound, widely used for tsetse control (pour-on 1%, bi-weekly application). Alphacypermethrin, cyfluthrin and lambdacyhalothrin are being developed as alternative insecticides for the treatment of livestock bait.

3.2.4 Precautions

Residual spraying by aircraft is potentially the most harmful to the environment, especially when the target is a riverine species. Ground application is more selective and, therefore, less hazardous. Aerosol applications of endosulfan and pyrethroids involve minimal danger to warm-blooded vertebrates, but fish and invertebrates may be at risk. Protective clothing and gloves should be worn when handling insecticides for tsetse control, particularly during treatment of animal bait.

3.3 *Simulium* spp.- blackflies

Bloodsucking female blackflies are vectors of onchocerciasis in Africa (the *Simulium damnosum* complex and the *S. neavei* group), Mexico and Central and South America (*S. ochraceum, S. metallicum* and *S. callidum*). The most important onchocerciasis focus is in West Africa, where the Onchocerciasis Control Programme (OCP) has been carrying out vector control since 1975. Larviciding is the only feasible method of vector control. It is relatively straight forward to carry out in West Africa where *S. damnosum s.l.* tends to breed in the rapids of large rivers but more difficult in Latin America, where the *Simulium* vectors breed in small streams which are difficult to access.

3.3.1 Larviciding

(a) Target area. The insecticide is introduced into rivers and streams in several places. The number of application points should be determined by a preliminary survey and will vary from area to area and river to river according to the breeding habits of the local vector and the characteristics of the watercourse, such as flow rate.

(b) Insecticides. Insecticides suitable for *Simulium* control are listed in Table 8. In the OCP area, temephos is the preferred larvicide because of its effectiveness, its range (the distance over which it remains effective) and its safety for non-target fauna. However, the appearance in 1980 of resistance in West Africa required users to adopt a strategy of alternating insecticides with different modes of action so as to forestall the appearance of new cases of resistance. This strategy of rotation of insecticides has proved effective and today few *Simulium* populations in the OCP area are still truly resistant to organophosphates.

Pyraclorfos is never used at river discharge rates below 15 m^3/s because of its toxicity. Phoxim does not endanger the environment but is less effective. Permethrin is used at very low doses, which is suitable for high flow rates, although it is somewhat toxic to non-target fauna. *Bacillus thuringiensis* H-14 is used at high doses and has a low range. It is never used above discharges of 15 m^3/s, otherwise its use is justified because of its safety in the environment and the unlikelihood of resistance developing to it.

Pirimiphos-methyl and chlorpyrifos-methyl can also be used as blackfly larvicides in areas where cross-resistance with temephos does not occur.

(c) Application procedures. Application from aircraft (fixed-wing aircraft for large rivers, helicopters for small and medium-sized rivers) is employed for rapid coverage of extensive areas. For smaller areas, simple methods of application have been successful, e.g., in the eradication of *S. neavei* from Kenya. Here, applications were largely made by suspending a 20 litre container with a hole in the bottom over a stream. Other simple methods of application include insecticide-treated briquettes, as used in Guatemala for control of *S. ochraceum*, a small stream breeder.

(d) Treatment cycle. Because of seasonal reinvasion by migrating females, streams in tropical climates should be retreated at 7-day intervals where necessary in order to suppress transmission or reduce it to a tolerable level. In areas where water temperatures are lower, intervals of 10-14 days or even longer may suffice.

(e) Precautions. Because of the potential risk to the aquatic environment, careful consideration must be given to the selection of larvicides and monitoring protocols. Monitoring involves the continuous survey of fish populations and the populations of benthic invertebrates on which most fish feed. Any insecticide used must be degradable and have minimal toxicity.

3.4 *Phlebotomus* spp., *Culicoides* spp., and related genera

3.4.1 *Phlebotomus* and *Lutzomyia* spp.

Female sandflies (*Phlebotomus* and *Lutzomyia* spp.) suck the blood of man and of many kinds of animal, typically at night. The adults rest in soil cracks, rock crevices, limestone caves, tree holes and animal burrows. Larvae breed in soil, but are difficult to locate. Sandflies are vectors of visceral leishmaniasis (kala-azar), dermal or cutaneous leishmaniasis, sandfly fever (pappataci fever) and Peruvian verruga (Oroya fever). The choice of control method can be made only after intensive epidemiological studies have identified the vectors and their behaviour, as well as the reservoir hosts, their biology and the circumstances in which man is at risk. Environmental management around residential areas, e.g., removal of rubble and garbage, filling in crevices in walls and destruction of animal burrows, should be carried out as far as practicable to reduce the number of sandfly resting places. The most widely used and effective control measure is residual insecticide spraying, supplemented by ground application of thermal fogs or cold aerosols. For epidemic control, ULV aerial spraying of residential areas may be justified. Because sandflies feed at night, insecticide treated mosquito nets and curtains can provide protection from blood seeking sandflies (see chapter 15)

3.4.1.1 Residual treatment

The interior wall surfaces of the dwelling are treated as if for control of malaria vectors (see section 2.1.1). The same insecticides can be used at the same application rates and frequencies. If the spraying is against sandflies only, it may be sufficient to spray entrance hallways, sleeping areas, and areas around doors and windows. Nearby animal shelters, stone walls and other resting-sites around the house should also be treated. The insecticides listed in Table 1 for residual treatment for mosquitoes are suitable for sandfly control at the same dosage rates. Diazinon 40 g a.i./l (4%) can be used for treatment of garbage. The insecticides can be applied using knapsack sprayers, with special attention to spraying cracks and crevices. Depending on the characteristics of the surfaces sprayed and the insecticide used, retreatment is required after 3-6 months.

3.4.1.2 Space spraying

Ground application of the insecticides listed in Table 2 should be used for public meeting places, e.g., outdoor markets, in areas where sandflies are prevalent. Aerial application of entire towns may be justified during epidemics of leishmaniasis.

3.4.2. *Culicoides* spp., *Leptoconops* spp. and *Styloconops* spp.

These biting midges are vicious pests. Certain species of *Culicoides* also act as vectors of the filarial worms *Mansonella perstans* and *M. streptocerca* in Africa and *M. ozzardi* in the islands of the Caribbean. (On the mainland of South America the vectors of *M. ozzardi* are *Simulium* spp. of the amazonicum group). Biting midges breed mainly in mud and sand but have also been found breeding in tree holes and rotting banana stumps. Their flight range varies with species, size, productivity of the breeding area and climate, but may extend up to 3 km. For many species, though, the flight range is limited to 100-400 m. If possible, engineering methods such as management of water level, draining, and irrigation should be adopted for midge control. The effectiveness of such interventions will depend greatly on prior accurate identification of the larval habitats.

Chemical control is justified, once application of larvicides or space sprays can be carried out. Effective larviciding requires accurate location of the larval habitats and correct timing of applications in relation to seasonal abundance and where there is intertidal breeding, in relation to tidal flow. Important breeding sites are often found in mangrove swamps and in the intertidal zone. Malathion (1120-1400 g a.i./ha), diazinon (336 g a.i./ha) or temephos (56-112 g a.i./ha) may be applied, as well as other insecticides which will have minimum impact on the environment and non-target fauna, using hand-compression or power-operated sprayers. Retreatment may be required after 1-2 months. Space spraying with insecticides indicated in Tables 5 can provide temporary relief. Where there is intertidal breeding, space spraying operations should coincide with any pattern of adult emergence related to the tide-cycle.

3.5 *Chrysops* spp. and other tabanids

These insects are commonly called horse flies or deer flies, and can cause severe annoyance. Some species act as mechanical vectors of animal diseases such as anthrax, tularaemia and surra, and two species of *Chrysops* are vectors of Loa Loa in Africa. It is difficult to control *Chrysops*, both in its adult and larval stages. The insecticides listed in Table 4 may be used for residual treatments, and those listed in Table 5 for outdoor space treatment for the control of adult *Chrysops* in littoral and bushy areas.

Useful references

Food and Agriculture Organization of the United Nations (1993) Training manual for tsetse control personnel. Volume 5: Insecticides for tsetse and trypanosomiasis control using attractive bait techniques.

World Health Organization (1986) The housefly - biology and control. Unpublished document WHO/VBC/86.937.

World Health Organization (1988) Biology and control of Glossina species, vectors of African trypanosomiasis. Unpublished document WHO/VBC/88.958.

World Health Organization (1995) Onchocerciasis and its control. Technical report series No. 852.

Table 4: Suitable insecticides for residual treatment for fly control

Insecticide	Chemical type[a]	Concentration of formulation as applied (g/l)	Dosage of a.i.[b] (g/m^2)	Toxicity: [c] oral LD50 of a.i.[b] for rats (mg/kg of body weight)	Remarks
Alpha-cypermethrin	PY	0.3-0.6	0.015-0.03	79	1
Azamethiphos	OP	10-50	1.0-2.0	1010	1
Bifenthrin	PY	0.48-0.96	0.024-0.048	55	1
Bromophos	OP	10-50	1.0-2.0	1600	1
Chlorpyrifos-methyl	OP	6-9	0.4-0.6	>3000	1&5
Cypermethrin	PY	2.5-10.0	0.025-0.1	250	1
Cyphenothrin	PY	-	0.025-0.05	318	1
Cyfluthrin	PY	1.25	0.03	250	1
Deltamethrin	PY	0.15-0.30	0.0075-0.015	135	1
D-phenothrin	PY	-	2.5	>5000	1
Diazinon	OP	10-20	0.4-0.8	300	1
Esfenvalerate	PY	0.5-1.0	0.025-0.05	87	1
Etofenprox	PY	2.5-5	0.1-0.2	>10000	1
Fenchlorphos	OP	10-50	1.0-2.0	1740	1
Fenitrothion	OP	10-50	1.0-2.0	503	1
Lambda-cyhalothrin	PY	0.7	0.01-0.03	56	1
Permethrin	PY	1.25	0.0625	500	1
Pirimphos-methyl	OP	12.5-25.0	1.0-2.0	2018	1
Zeta-cypermethrin	PY	0.4-0.8	0.02-0.04	106	1
Dimethoate	OP	10-25	0.046-0.5	150	2
Fenvalerate	PY	10-50	1.0	450	2
Malathion	OP	50	1.0-2.0	2100	3
Naled	OP	10	0.4-0.8	430	4
Bendiocarb	C	2-8	0.1-0.4	55	4
Propetamphos[d]	OP	10-20	0.25-1.0	106	4

[a] OP = organophosphate, PY = synthetic pyrethroid, and C = carbamate
[b] a.i. = active ingredient
[c] Toxicity and hazard are not necessarily equivalent; the factors influencing the latter are discussed in section 17.1.1.
[d] If applied by non-commercial operators, this insecticide should be supplied, for safety resons, in a diluted form not exceeding 50 g/l (5%) of active ingredient.

1. May also be used in milk rooms, restaurants and food stores.
2. Animals must be removed during treatment; not to be used in milk rooms.
3. Only premium grade malathion should be used in milk rooms and food-processing plants.
4. Not to be used in milk rooms; at strength of 2.5 g/l (0.25%) may be applied to chicken roosts, nests, etc., without removing the birds; animals must be removed.
5. In chicken houses, birds must be removed at application time and brought back afetr 4 hours .

Table 5: Suitable insecticides for space treatment for fly control[a]

Insecticide	Chemical type[b]	Dosage of a.i.[c] (g/ha)
Bioresmethrin	PY	5-10
Chlorpyrifos-methyl	OP	100-150
Cypermethrin	PY	2-5
Cyphenothrin	PY	3.75
Deltamethrin	PY	0.5-1.0
D-phenothrin	PY	6.25
Diazinon	OP	336
Dichlorvos	OP	336
Dimethoate	OP	224
Esfenvalerate	PY	2-4
Etofenprox	PY	10-20
Fenchlorphos	OP	448
Lambda-cyhalothrin	PY	0.5-1.0
Malathion	OP	672
Naled	OP	224
Permethrin	PY	5-10
Pirimiphos-methyl	OP	250
Resmethrin	PY	2-4
Zeta-cypermethrin	PY	2-4

[a] For toxicity data see Tables 2 and 4
[b] PY = synthetic pyrethroid; OP = organophosphate
[c] a.i. = active ingredient

Table 6: Pyrethroid mixtures used in ULV and thermal-fog formulations for fly control

Pyrethroid mixtures	Concentration		Toxicity:[a] oral LD_{50} of a.i.[b] for rats (mg/kg of body weight)
	ULV (g/ha)	Fog (g/ha)	
Permethrin +	5.0-7.5	5.0-15.0	500
S-bioallethrin +	0.075-0.75	0.2-2.0	700
Piperonyl butoxide	5.25-5.75	9.0-17.0	>7500
Bioresmethrin +	-	5.5	>7000
S-bioallethrin +	-	11.0-17.0	700
Piperonyl butoxide	-	0-56	>7500
Phenothrin +	5.0-12.5	4.0-7.0	>5000
Tetramethrin +	2.0-2.5	1.5-16.0	>5000
Piperonyl butoxide	5.0-10.0	2.0-48.0	>7500
Etofenprox +	5-10	5-10	>10000
Piperonyl butoxide	10-20	10-20	>7500
Lambda-cyhalothrin +	0.5	0.5	56
Tetramethrin +	1.0	1.0	>5000
Piperonyl butoxide	1.5	1.5	>7500
Cypermethrin +	2.8	2.8	250
S-bioallethrin +	2	2	700
Piperonyl butoxide	10	10	>7500
Tetramethrin +	12-14	12-14	>5000
D-phenothrin	6-7	6-7	>5000
D-tetramethin +	1.2-2.5	1.2-2.5	>5000
Cyphenothrin	3.7-7.5	3.7-7.5	318
Deltamethrin +	0.3-0.7	0.3-0.7	135
S-bioallethrin +	0.5-1.3	0.16-1.3	700
Piperonyl butoxide	1.5	1.5	>7500

[a] Toxicity and hazard are not necessarily equivalent; the factors influencing the latter are discussed in section 17.1.1.
[b] a.i. = active ingredient

Table 7: Insecticides used in toxic baits for fly control.

Insecticide	Dry scatter	Liquid sprinkle	Liquid dispenser	Viscous paint-on
OP compounds				
Azamethiphos	++[b]			++
Bromophos				+
Diazinon	++	+	+	+
Dichlorvos[a]	+	++	++	+
Dimethoate[a]		+		++
Fenchlorphos	+	+		+
Malathion	+	+		+
Naled	+	+		+
Trichlorfon[a]	++	++	++	++
Phoxim				++
Carbamates				
Dimetilan[a]		+	++	+
Methomyl	++			++
Propoxur	+			
Formaldehyde[a]			+	

[a] These compounds are water soluble.
[b] += has been used, ++= is commonly used

Table 8: Insecticides used in rotation by the OCP for Simulium larval control

Insecticide	Chemical type[a]	Concentration g a.i./l	l/m³/sec river discharge	Toxicity:[b] oral LD_{50} of a.i.[c] for rats (mg/kg of body weight)
Bacillus thuringiensis (H-14)	MI	-	0.72	>30,000
Carbosulfan	C	250	0.12	250
Permethrin	PY	200	0.045	500
Phoxim	OP	500	0.16	1975
Pyraclofos	OP	500	0.12	237
Temephos	OP	200	0.72	8600

[a] C = carbamate; MI = microbial insecticide; OP = organophosphate; PY = synthetic pyrethroid

[b] a.i. = active ingredient

[c] Toxicity and hazard are not necessarily equivalent; the factors influencing the latter are discussed in section 17.1.1.

4

FLEAS

Fleas are widely distributed throughout the world. Both sexes suck blood and the females require it for maturation of their eggs. Some species, such as the Oriental rat flea, feed frequently (usually once a day or more) though most can withstand long periods without nourishment. Eggs are generally laid on the host and later drop to the ground or into the nest of the host where the larvae hatch, grow, pupate and develop into adult fleas. The immature stages are usually found in areas frequented by the host animal, such as rodent nests and burrows.

Many genera of fleas have been implicated in the transmission of a range of pathogens, but it is their role as vectors of bubonic plague and murine typhus that is most important. Species of *Xenopsylla,* particularly *Xenopsylla cheopis*, the Oriental rat flea, are the most important vectors and commonly infest rodents in many parts of the world.

During an outbreak of bubonic plague, control of the vector fleas should precede any measures taken against rodents. Otherwise, a further increase in plague cases may occur as a result of large numbers of fleas leaving their dead rodent host to seek new sources of blood. The most rapid and effective method of controlling fleas is the application of an appropriate insecticide formulated as a dusting powder. For flea control in the general environment, pyrethroids should be avoided as they are apt to irritate fleas which causes them to escape before receiving a lethal dose.

4.1 *Xenopsylla* spp.

In addition to *X. cheopis, X. astia* in India and *X. brasiliensis* in Africa may be involved in transmitting plague. Because rodents are the principal hosts of these fleas, the main sites of treatment are rodent burrows and runways. After coming into contact with the dust, the rodents will spread it on their fur while grooming. In houses or other buildings, the bottom of all walls and the floor for a distance of 15-30 cm from the wall should be treated with patches of dust. Where there is above-floor storage of food or where the wall/roof junction of the dwelling is open, dusts should be applied on top of the wall and along the rafters where runways are evident. Other areas in which rodents might live or visit, such as piles of wood, debris or rubbish in the vicinity of houses, should also be treated (see also chapter 13).

The insecticide dusts commonly used for flea control are listed in Table 9 and are effective against both adult and larval fleas. Hand-operated dusters are most commonly used to apply the dusts. Rodent frequented sites should be thoroughly covered with dust applied in patches about 0.5 cm thick and 20-25 cm wide on runways and around and in burrow entrances. For the control of fleas on wild rodents, about 30 g of dust should be blown into each burrow. The residual pyrethroid and carbamate insecticides remain effective for 2-4 months but organophosphates of the same formulation may be less persistent. Some insecticides are now formulated as a microencapsulated product and this considerably extends their period of effectiveness. Retreatments are generally carried out when the *X. cheopis* index (i.e., the number of fleas per rat) rises above one. However, during an outbreak of disease, the occurrence of a new human case in a treated area requires immediate retreatment of the patient's dwelling and of other dwellings within 200 m as soon as possible. In any area where plague is endemic, or in which it may threaten, periodic insecticide susceptibility tests should be carried out on the probable vector flea species to ensure that insecticides used in an emergency control programme are effective.

In situations where port areas are infested with fleas and plague is present, the fumigation of ships, using cyanide or methyl bromide gas, may be necessary in accordance with the International Health Regulations. This treatment must be carried out by fully qualified persons only in view of the extreme hazard to humans associated with these compounds. To prevent the spread of plague from endemic areas via rodents or fleas in containerized cargoes, dichlorvos resin strips can be enclosed in the container at the rate of one per 9 m^3. Exposure for 24 hours should be sufficient to kill adult *X. cheopis* on rats.

In areas of sylvatic plague, the permanent reservoirs are non-commensal rodents, such as ground squirrels, voles, and gerbils, and individual cases or outbreaks of plague are frequently traced to reservoirs in these animals. The control of wild rodents and their fleas is more exacting than that of commensal rodents. Bait boxes containing insecticide powder can be used. The rodent is coated in the insecticide as it feeds which it then carries back to its nest. The use of large bamboo tubes as bait boxes, with an insecticide dust at each open end, has proved successful in certain areas.

4.2 *Pulex* spp.

The most common *Pulex* species is *P. irritans* which, although it is called the human flea, may feed on commensal rats, pigs, dogs and cats. In houses, the flea rests by day in cracks and crevices as well as rugs and bedding. If dwellings are regularly and thoroughly swept or vacuumed, the flea infestations cannot become established. Therefore, adequate household hygiene, particularly in bedrooms, is the first requirement for *Pulex* control.

Pulex fleas do not usually remain on the person after feeding, so emulsions, solutions or suspensions of the insecticides listed in Table 10 should be applied directly to the sleeping area and beds. The mattress, cracks and crevices in the floor and bed should be treated. If inhabitants object to the odour of insecticide on bedding, then sheets and blankets should be washed or dry-cleaned on the day the house is treated to ensure complete control. One treatment combined with adequate household hygiene should be sufficient. As a safety precaution, infants' bedding should be washed or dry-cleaned instead of being treated with insecticide.

4.3 *Ctenocephalides* spp.

4.3.1 Treatment of animals

The common species are *C. felis* (the cat flea) and *C. canis* (the dog flea). Control of these fleas depends on treatment of domestic pets and their living quarters. Dogs and cats may be treated with dusts, sprays, dips, foams or shampoos, or may be provided with special, insecticide impregnated collars. Suitable insecticides for treating dogs and cats are indicated in Tables 9 and 11. These products are to be applied to the hair on the back and/or neck and used strictly according to the manufacturers' recommendation. Dusts are commonly used because of their safety and convenience, but they are less effective than other methods. They can be applied from a shaker-type duster, puff duster or garden-type hand duster, and should be rubbed thoroughly into the fur. Spraying can be undertaken using a hand sprayer, and should thoroughly wet the animal's coat. Aerosols from hand-operated pressure cans may also be used. Care should be exercised to prevent the insecticide from getting into the animal's eyes and mouth and certain treatments should not be used on young animals, as indicated in Table 11.

Special plastic collars that release micronized dust containing insecticides, such as carbamates, organophosphates and pyrethroids may be used on dogs and cats. These collars have a longer lasting effect than dust and spray treatments. The frequency of treatment of dogs and cats depends on the chances of reinfestation by fleas emerging from the premises and/or through contact with infested pets. Flea collars are effective for 3-5 months. Other treatments usually give only short-term control, although fipronyl is absorbed and stored in the epidermis where it continues to kill fleas for approximately two months in cats and three months in dogs. Recently, a pet collar, containing the insect growth regulator, methoprene, has become available and offers alternative to collars containing common insecticides. This product may afford protection for up to one year.

Concomitant use of modern adulticides and IGRs, is now recommended to ensure consistent long-term prevention and control of flea infestations and to avoid the rapid development of flea resistance to various chemicals.

4.3.2 Treatment of premises

The interiors and exteriors of premises are commonly treated with sprays. Spot and foundation treatments may be applied instead of comprehensive treatment of the entire property. Interior treatment should be applied to the sleeping quarters and bedding of animals, under rugs, in cracks and crevices in floors and to the edges of carpets at the wall/floor join. Exterior treatment should include all areas frequented by animals if the climate permits flea development in these places. Oil-based or water-based sprays containing the insecticides listed in Table 10 are most suitable for interior and exterior treatment. Methoprene (0.1%) and pyriproxyfen (0.01%) can prevent the development of flea larvae to adults with a long residual effect, but should normally be combined with an adulticide. Before spraying rooms, animal bedding and upholstered furniture should be cleaned. A hand sprayer or compressed-air sprayer can be used for spraying indoors or outdoors at a rate of 4-8 litres/100 m^2. A fine mist spray should be used for interior treatment in order to avoid staining fabrics and during exterior treatment, sprays should not be allowed to drift onto ornamental plants. Generally, a single treatment is adequate to control an infestation.

Useful reference

World Health Organization (1985) Fleas. Unpublished document WHO/VBC/TS/85.1.

Table 9: Insecticide dusts commonly employed for the control of rodent fleas

Insecticide	Chemical type[a]	Concentration (g/kg)	Toxicity:[b] oral LD_{50} of a.i.[c] for rats (mg/kg of body weight)
Bendiocarb	C	10	55
Carbaryl	C	50	300
Chlorpyrifos	OP	20	135
Deltamethrin	PY	0.5	135
Diazinon	OP	20	300
Etofenprox	PY	5	>10000
Fenitrothion	OP	20	503
Malathion	OP	50	2100
Permethrin	PY	5	500
D-phenothrin	PY	4	>5000
Pirimiphos-methyl	OP	20	2018
Propetamphos[e]	OP	20	106
Propoxur	C	10	95

[a] C = carbamate; OP = organophosphate; PY = synthetic pyrethroid

[b] Toxicity and hazard are not necessarily equivalent; the factors influencing the latter are discussed in section 17.1.1.

[c] a.i. = active ingredient

Table 10: Insecticides used for control of *Pulex* fleas

Insecticide	Chemical type[a]	Concentration (g/l)	Toxicity:[b] oral LD_{50} of a.i.[c] for rats (mg/kg of body weight)
Alpha-cypermethrin	PY	0.3-0.6	79
Bendiocarb	C	2.4	55
Bifenthrin	PY	0.48-0.96	55
Chlorpyriphos	OP	2-5	135
Chlorpyrifos-methyl	OP	5	>3000
Cypermethrin	PY	0.5-2.0	250
Deltamethrin	PY	0.3	135
D-phenothrin	PY	2-4	>5000
Fenoxycarb	IGR	0.6	>10000
Lambda-cyhalothrin	PY	0.3	56
Malathion	OP	20	2100
Methoprene	IGR	1-5	34600
Pyrethrum	PY	2	500-1000
Permethrin	PY	2.5	500
Pirimiphos-methyl	OP	10	2018
Zeta-cypermethrin	PY	0.4-0.8	106

[a] C=carbamate; IGR=insect growth regulator; OP = organophosphate compounds and PY=synthetic pyrethroid

[b] Toxicity and hazard are not necessarily equivalent; the factors influencing the latter are discussed in section 17.1.1.

[c] a.i. = active ingredient

Table 11: Insecticides used for flea control on pets

Insecticide	Chemical type[a]	Formulation	Concentration g/kg or g/l	Toxicity:[b] oral LD_{50} of a.i.[c] for rats (mg/ kg of body weight)
Carbaryl	C	dip or wash	5	
		dust[d]	20-50	300
Chlorpyriphos	OP	dust or shampoo	8	135
Deltamethrin	PY	spray or shampoo	0.025	135
D-phenothrin	PY	dust or shampoo	2-4	>5000
Etofenprox	PY	dust	5	>10000
		spray or shampoo	5-10	
Fipronil	PZ	spray	2.5	92
Malathion	OP	dip	2.5	2100
		dust	50	
		spray	5	
Methoprene	IGR	shampoo	0.2	34600
		spray	1-5	
Natural pyrethrins+ synergist		dust, spray or shampoo	2+20	500-1000
Permethrin	PY	dust	10	500
		spray or shampoo		
		wash	1	
Propetamphos	OP	collar	100	106
Propoxur	C	spray	10	95
		dust	10	
Pyriproxyfen	IGR	spray[e]	0.75-1.0	>5000
Rotenone	extract[f]	dust	10	132-1500

[a] C=carbamate; IGR=insect growth regulator; OP=organophosphate; PY=synthetic pyrethroid and PZ=pyrazole

[b] Toxicity and hazard are not necessarily equivalent; the factors influencing the latter are discussed in section 17.1.1.

[c] a.i. = active ingredient

[d] Should not be used on cats under four weeks of age.

[e] Pyriproxyfen is usually mixed with d-phenothrin.

[f] extract = extract of derris root

5

BEDBUGS

Two species of bedbugs - *Cimex lectularius* (the common bedbug) and *C.hemipterus* (the tropical bedbug) - are closely associated with man. They differ very little in their biology, except that the latter species does not thrive outside of the tropics. All nymphal stages and both adult sexes feed on blood at intervals of 3-7 days, depending on temperature. Adults can withstand long periods (up to a year) without nourishment if temperature and humidity conditions are favourable. During the day, bedbugs hide in cracks, crevices, and dark places, but at night they are active. While bedbugs are very annoying pests, they have never been shown to be important in the transmission of disease, though there is some speculation that they are involved in the transmission of certain viruses.

5.1 *Cimex lectularius* and *C. hemipterus*

Control consists of applying interior residual sprays or dusts to surfaces that the bed bugs crawl over to reach the host. Bed springs, slats, mattresses, cracks and crevices in the walls and floors, and furniture should be treated. Care should be taken to ensure penetration of the insecticide into the hiding places of the bedbugs. Infested bed clothes should be washed or dry-cleaned. Suitable insecticides for bed bug control are listed in Table 12. Microencapsulated insecticide formulations will have a longer residual effect than other formulations. Pyrethroids not only show high lethal activity, but also a flushing effect. The addition of natural pyrethrins at 1-2 g/l (0.1-0.2%) to organophosphate and carbamate insecticide formulations will increase effectiveness by irritating the bedbugs and causing them to leave their hiding places, thereby increasing their contact with fresh insecticide deposits.

Hand sprayers, compressed air sprayers and dusters are used to apply the insecticides. For walls, baseboards and floors, sprays may be applied to the point of run off at approximately 1 litre per 25-50 m^2. In many instances, a single, thorough treatment with residual insecticide will be sufficient to eliminate the infestation. If the infestation persists, retreatment should be carried out at not less than two week intervals. Infant bedding, including the crib, should not be treated with residual insecticide. Treated mattresses should dry completely before use. Residual spraying should be undertaken early in the day so that the room will dry by night time.

Mosquito nets treated with pyrethroid insecticides for malaria control (see chapter 15) are also effective in controlling bed bug nuisance. This may be important in persuading people to use their nets regularly.

Useful reference:

World Health Organization (1985). Bedbugs. Unpublished document WHO/VBC/TS/85.2.

Table 12: Insecticides suitable for bed bug control

Insecticide	Chemical type[a]	Concentration[d] g/l or (g/kg)	Toxicity:[b] oral LD_{50} of a.i.[c] for rats (mg/kg of body weight)
Alpha-cypermethrin	PY	0.3-0.6	79
Bendiocarb	C	2.4-9.6 (10)	55
Bifenthrin	PY	0.48-0.96	55
Carbaryl	C	10	300
Chlorpyifos	OP	2-5	135
Cypermethrin	PY	0.5-2.0	250
Deltamethrin	PY	0.3 (0.5)	135
Diazinon	OP	6	300
Lambda-cyhalothrin	PY	0.03	56
Malathion	OP	20	2100
Permethrin	PY	1.0-2.0 (5)	500
Pirimiphos-methyl	OP	10	2018
Propetamphos	OP	5-10	106
Zeta-cypermethrin	PY	0.4-0.8	106

[a] C=carbamate; OP=organophosphate; PY=synthetic pyrethroid

[b] Toxicity and hazard are not necessarily equivalent; the factors influencing the latter are discussed in section 17.1.1.

[c] a.i. = active ingredient

[d] The numbers in brackets refer to dust formulations.

6

TRIATOMINE BUGS

Species of *Triatoma, Panstrongylus* and *Rhodnius*, commonly known as cone-nose bugs or kissing bugs, are the vectors of *Trypanosoma cruzi* which causes Chagas disease. Over 18 million people in Mexico and Central and South America are infected with *T.cruzi* with a further 100 million at risk of infection. The trypanosomes are mainly transmitted to man in the faeces of triatomine bugs. Once on the human skin, the parasites penetrate mucus membranes, or any wound or abrasion, as a means of entry into the circulation. Chagas disease is a zoonosis and over 100 species of small mammal have been found to be naturally infected with *T.cruzi*. The disease is a problem in rural areas where lower quality housing makes a more suitable habitat for the triatomine bugs.

Over 120 species of Triatominae are currently recognised, and over half of these have been found naturally infected with *T. cruzi*. Because of their similar behaviour and physiology, all species should be considered as potential vectors, but the most important are those that colonise domestic and peridomestic habitats. The most highly domestic species is *Triatoma infestans*, which is the principal vector in Argentina, Bolivia, Brazil, Chile, Paraguay, Southern Peru and Uruguay. *Rhodnius prolixus* is an important vector in Central America and the northern countries of South America, e.g., Colombia, Guyana and Venezuela. Other less important vectors include *T. braziliensis* and *Panstrongylus megistus*, found in parts of central and north-eastern Brazil, and *T. dimidiata*, which is found principally in Central America. There are also domestic species of triatominae which often occupy peridomestic habitats such as chicken coops, guinea-pig runs and goat corrals.

Triatomine bugs spend most of their time in cracks, fissures and other hiding sites in the walls and ceilings of human dwellings and animal habitations. They feed on a variety of host animals and their bite may cause severe dermal reactions in humans, including intense itching, nausea, flushed face and rapid pulse.

Treatment of Chagas disease is difficult and, on a public health scale, impractical. Thus control programmes rely primarily on the control of the triatomine vectors. Of the wide range of control methods that have been tested, only house improvement and the use of insecticide have been effective in the control of triatomine bugs. These interventions can be used together although their operational impact differs. House improvements reduce the number of houses infested, irrespective of their infestation rates, whereas insecticides reduce the overall infestation density. House improvements which eliminate resting places, including laying compacted earth or concrete floors, plastering walls and replacing thatch roofs with tiles or corrugated metal, should be carried out as quickly as possible and then maintained to prevent reinfestation. Residual spraying of insecticides on the inside walls of houses and outbuildings is the principal method used by national vector control programmes, and spraying operations are similar to those used in many malaria control programmes.

Triatomine bugs are particularly susceptible to chemical control because they have a low reproductive rate compared to other insect pests as well as low genetic variability, which makes the development of insecticide resistance less likely. Generally, fifth instar nymphs are better able to tolerate insecticides than earlier instars or adults.

6.1 *Triatoma, Panstrongylus* and *Rhodnius* spp.

(a) Target area. The interior surfaces of sleeping quarters, dwelling rooms and outhouses should be treated, with special attention given to cracks in the surface. The thatched roofs of dwellings should also be treated. Treatment of peridomestic animal shelters should be undertaken at the same time to reduce the chances of reinfestation of the dwelling.

(b) Insecticides. Suitable insecticides for residual treatment for triatomine bug control are listed in Table 13. In the past, the application of WP formulations of HCH (lindane) at 0.5-2.0 g a.i./m^2 was the most common control method although organophosphates and carbamates were also used. In the 1980s, synthetic pyrethroids gradually replaced other insecticides for residual spraying. Pyrethroids are very effective against triatomine bugs at low doses and have greater residual activity on mud walls compared to other classes of insecticide. These attributes make control using pyrethroids highly cost-effective. Recently an insecticidal paint containing a slow release formulation of fenitrothion and malathion has been developed and can be used to control triatomine bugs.

(c) Application procedures. Residual treatments are usually applied with hand-operated compression sprayers.

(d) Treatment cycle. The period of residual effectiveness varies with the insecticide, substrate and vector species. In previous campaigns where lindane was used, it was generally necessary to respray houses at 3-6 month intervals to ensure elimination of surviving vector populations. Operational procedure has been modified with the advent of the pyrethroids which allow a single mass treatment of all houses, followed by a check on infestation rates after one year. If more than 5% of the total number of houses in a particular community show evidence of reinfestation after a year, every house is sprayed again. In communities with less than 5% reinfestation, selective respraying is carried out in the reinfested houses and in neighbouring houses and animal shelters within 200 m of the target house. The 5% cut-off point is derived from studies in Brazil which showed that with less than 5% of houses infested, new cases of Chagas disease are rare.

(e) Precautions. Care should be taken during spraying to avoid contaminating water sources, food, cooking utensils and infant bedding with insecticide.

Useful references

Schofield, C.J. (1994) Triatominae, biology and control. Eurocommunica publications, West Sussex, UK.

World Health Organization (1987) The triatomine bugs - biology and control. Unpublished document WHO/VBC/87.941.

Table 13: Suitable insecticides for interior residual treatment for triatomine bug control

Insecticide	Chemical type[a]	Dosage of a.i.[b] (g/m^2)	Toxicity:[c] oral LD_{50} of a.i. for rats (mg/kg of body weight)
Alpha-cypermethrin	PY	0.1	79
Bendiocarb	C	0.4-1	55
Beta-cyfluthrin	PY	0.025	450
Bifenthrin	PY	0.05	55
Cyfluthrin	PY	0.05	250
Cypermethrin	PY	0.125	250
Deltamethrin	PY	0.025	135
Fenitrothion	OP	1	503
Lambda-cyhalothrin	PY	0.03	56
Malathion	OP	2	2100
Permethrin	PY	0.25-0.5	500
Propoxur	C	1	95

[a] C=carbamate; OP=organophosphate; PY=synthetic pyrethroid

[b] a.i. = active ingredient

[c] Toxicity and hazard are not necessarily equivalent; the factors influencing the latter are discussed in section 17.1.1.

7

LICE

There are three species of human louse: the body louse (*P. humanus*), the head louse (*P. capitis*) and the crab louse or pubic louse (*Phthirus pubis*). All nymphal stages and both sexes of adult human lice are blood-sucking.

The body louse is generally found attached to clothing in contact with the body and to the courser body hair. The head louse is generally confined to the hair of the head, but may be found, although rarely, on hairs on other parts of the body. The crab louse generally lives in the pubic area but may also be found on the eye lashes, particularly in children. All species and forms spend their whole life-cycle on the host, away from which they cannot thrive for more than a short time.

Only the body louse has been implicated as a vector of disease, i.e. epidemic typhus, endemic relapsing fever and trench (quintana) fever. The transmission of epidemic typhus is not caused by the bite of lice but occurs when the infected lice or their faeces are scratched into the site of the bite or into the excoriated skin. Transmission can also take place through inhalation of infected louse faecal dust. Relapsing fever is transmitted only when the infected lice are crushed directly onto skin, as neither the faeces nor the bites are infectious. Epidemics of these diseases are often associated with wars or the effects of natural disasters when standards of hygiene are low and people are living in close proximity. Louse-borne disease in temperate regions is transmitted predominantly in winter.

7.1 *Pediculus humanus*

Cleanliness is important in preventing body louse infestations. The easiest control method of occasional infestations is to expose infested clothing to a minimum temperature of 70^{0}C for at least one hour. In emergency situations, it may be impractical or impossible for people to wash properly and fuel for heating water may be in short supply. In general, chemical control is required, especially where louse-borne disease threatens. Two application procedures have been tried. The oldest method, used extensively in Europe during and after the Second World War, involves application of insecticidal dusts to the infested population. The second approach involves the impregnation of clothing with a suitable pyrethroid insecticide. Treatment campaigns should target people most exposed to the threat of disease or areas of high population density where the spread of lice can easily take place.

7.1.1 The dusting technique

The dusting technique used in the 1940s involved creating two distinct enclosed areas (infested and treated). The target population then passed from the infested to the treated area through a series of choke points where they were dusted manually with DDT powder. This method was found to be effective because an existing infrastructure was present, labour was plentiful, logistics and finance were assured and compliance with the regime was not in question. In current emergency situations some of the prerequisites for effective control using the dusting technique may not be present and alternative approaches should be considered.

For mass treatment, dusts should be applied through the neck openings, up the sleeves and from all sides of the loosened waist of trousers. To delouse women, an extra quantity can be introduced down the neck of the dress and the application at the waistline omitted. The socks, head covering, the inner surfaces of extra garments and bedding should also be treated. Awareness of cultural and religious customs is essential in delousing programmes, particularly regarding the treatment of women.

In view of the spread of insecticide resistance in body louse populations, the choice of insecticide for a campaign should be preceded by a survey of insecticide susceptibility status. Suitable insecticidal dusts for body louse control are listed in Table 14. DDT is no longer the insecticide of choice due to resistance problems and the dangers associated with human exposure during dusting operations, although it can be used as a "last resort" measure where louse populations are still susceptible. Instructions for application accompanying the selected insecticide should be carefully followed.

Delousing dusts can be applied by any type of dusting apparatus from compressed air dusters to hand-operated dusters as well as application by hand. However, there have been some problems with compressed air dusters for mass treatment and hand application is somewhat wasteful. The recently developed Millbank Duster[1] is a CO_2 powered portable applicator which accurately and effectively delivers a dry stream of dust. One thorough treatment of infested clothing with insecticide should be sufficient, although retreatments may be required at 3 to 4 week intervals if infestations persist or reinfestation is expected. Dusting is not recommended for people with dermatological problems or exposed wounds. The precautions on the insecticide label should be carefully followed.

7.1.2 Treating clothing

The process of treating clothing with insecticide is simple, cheap and affords protection for at least six weeks, even with repeated washings. This avoids the problem of repeated treatments in areas difficult to access regularly. The pyrethroid insecticide, permethrin, is recommended for impregnation and should be diluted with water to give an optimal target dose of 0.65-1 g/m^2 on clothing. Due to the close proximity of the insecticide to the skin, only public health grade insecticide should be used. The clothing is dipped in the insecticide solution, removed and allowed to dry. This can be done in

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[1] The Millbank Duster is not commercially available, but can be quickly and easily constructed on-site. For more information, contact the Department of Military Entomology, Royal Defense Medical College, Millbank, London SW1P 4RJ, UK.

large tubs or baths and the amount of insecticide and water to be added should be proportional to the amount of clothes to be treated. Clothes should be sorted into synthetic, cotton and wool as each material absorbs different amounts of solution. In general, cotton absorbs twice as much as synthetic material, therefore cotton clothes should be dipped in a solution half as concentrated as that for synthetic clothes. Where relief organisations are introducing clothing or blankets to louse infested populations, pretreatment with insecticide is recommended (See section 15.4 for detailed procedure for treating fabrics with insecticide).

7.2 *Pediculus capitis*

Treatment is directed against the infested body part, usually the head, although heavy infestations may include other parts of the body covered in hair. Liquid formulations of the insecticides listed in Table 14 are more acceptable than the dust formulations. Liquids are applied by spraying or other means so that the hair is thoroughly wet. Treated persons should not wash affected parts for at least 24 hours. The amount applied is 10-20 ml of emulsion or 5-10 ml of solution per head. Louse eggs, as well as the adult stages, are killed, so one treatment is usually sufficient. Persistent infestations should be retreated at 1 to 2 week intervals. As head louse infestations are usually more common among school children, treatment may be undertaken in schools with the assistance and supervision of teachers. In order to reduce the possibility of reinfestation, it may be worthwhile to give small quantities of the insecticide, with instructions, to each household for use by other members of the family. In treating children, care should be taken to avoid getting insecticide into the eyes and mouth.

7.3 Phthirus pubis

Although crab lice are found most often in the pubic hair and in the perianal and axillary areas, they may occasionally infest hair of the trunk, thigh and beard, as well as the eyebrows and eyelashes. Insecticides used for control of body lice or head lice are also effective against crab lice. Powders or emulsions are usually applied by rubbing a small amount into the hair of the effected parts. Treated parts should not be washed for at least 24 hours after application. One application is usually sufficient but if necessary, retreatment may be done at 4-7 day intervals. Shaving pubic hair is unnecessary. For eliminating crab lice from the eyelashes, a vaseline ointment containing pyrethrins is recommended.

7.4 Precautions

For individual treatment, care should be taken to avoid getting insecticide in the eyes. Some powders used in the treatment of pubic lice may cause contact dermatitis. If this occurs, the insecticide should be washed from the affected area. For mass treatment of body lice with dusts, protective clothing including face masks or aspirators, should be worn by operators.

Useful references

Chetwyn, K.N. (1996) An overview of mass disinfestation procedures as a means to prevent epidemic typhus. Proceedings of the 2nd International Conference on Insect Pests in the Urban Environment (Ed. K.B. Wyldey). Printed by B.P.C. Wheatons, Exeter, UK.

Gratz, N.G. (1985) Treatment resistance in louse control. pp.219-230 in Cutaneous infestations and insect bites (eds. M.Orkin & H.I. Maibach. Published by Marcel Dekker, New York.

World Health Organization (1985) Lice. Unpublished document WHO/TS/85.3.

Table 14: Insecticide suitable for the control of human lice

Insecticide	Chemical type[a]	Formulation	Concentration g/l or g/kg	Toxicity:[b] oral LD_{50} of a.i.[c] for rats (mg/kg of body weight)
Bioallethrin	PY	lotion	3-4	700
		shampoo	3-4	
		aerosol	6	
Carbaryl	C	dust	50	300
Deltamethrin	PY	lotion	0.3	135
		shampoo	0.3	
Lindane	OC	dust	10	100
		lotion	10	
Malathion	OP	dust	10	2100
		lotion	5	
Permethrin	PY	dust	5	500
		lotion	10	
		shampoo	10	
D-phenothrin	PY	dust	2-4	>5000
		shampoo	2-4	
		lotion	2-4	
Propoxur	C	dust	10	95
Temephos	OP	dust	20	8600

[a] C = carbamate; OC = organochlorine; OP = organophosphate; PY = synthetic pyrethroid
[b] Toxicity and hazard are not necessarily equivalent; the factors influencing the latter are discussed in section 17.1.1.
[c] a.i. = active ingredient

8

COCKROACHES

Of the approximately 4000 species of cockroach, the majority are exophilic and relatively few are of concern to man. Some common domiciliary species are *Blattella germanica* (the German cockroach), *Blatta orientalis* (the Oriental cockroach), *Periplaneta americana* (the American cockroach), *P. australasie* (the Australian cockroach) and *Supella longipalpa* (the brown-banded cockroach).

The adults of most species normally possess two pairs of wings, but they rarely fly. Eggs are deposited in a capsule-like structure called ootheca, which is either laid in some appropriate location or, as in the case of the German cockroach, carried by the female till it is ready to hatch. Most domiciliary cockroaches are active at night and while feeding regurgitate fluid from their mouths. They are pests with an unpleasant smell, spreading filth and ruining food, fabrics and book bindings. They may also have some practical importance in the mechanical transmission of pathogenic bacteria, including those which cause diarrhoeal diseases.

Good food hygiene practices in kitchens are essential for restricting cockroach populations, but when infestations become a problem there are no realistic alternatives to the use of insecticides. Chemical control is based on residual application to surfaces over which cockroaches crawl and cracks and crevices where they hide. Insecticide resistance (see section 1.6) is an important problem in cockroach control and resistance to organochlorine, organophosphate, carbamate and pyrethroid insecticides has been reported for the German cockroach, which is the most important pest species. Pyrethroids combined with piperonyl butoxide (a monooxygenase inhibitor) can be effective against populations of monooxygenase-based resistant German cockroaches.

8.1 *Blattella* spp. and other genera

(a) Target area. Household areas that should be treated are primarily in the kitchen: behind and along baseboards or skirtings, in and around sinks, in and under cupboards, and around refrigerators. Special attention should be given to warm areas with high humidity. With regard to commercial establishments: restaurants, dairies and all food-storage areas should be treated. Other sites, such as food-preparation areas and ducts and pipes, also require treatment, but care should be taken not to contaminate surfaces on which food is prepared. The treated area should be minimised by structural modification where possible to reduce the number of hiding places. All sources of food should be removed or carefully sealed before application of insecticide.

(b) Insecticides. Before selecting an insecticide for treatment, the susceptibility of the local cockroach population should be assessed, as resistance to many insecticides is widespread. The insecticides commonly used are given in Table 15. Where feasible, alternating between insecticide classes is recommended to delay the build up of resistance. For the control of cockroaches resistant to organophosphates and carbamates, pyrethroids can be used for residual spraying. Insect Growth Regulators (IGR) can be used to control cockroaches, but because they are relatively slow-acting, they can be used in combination with a residual insecticide which results in a highly effective treatment.

(c) Application procedures. Residual spraying is usually carried out using a hand-operated compression sprayer with a fish-tail jet fitted for spraying surfaces and a pinstream nozzle to spray the insecticides into cracks and areas that are hard to reach. Generally, insecticide is applied at the rate of 4 l/100 m (linear measure) in a 0.3-0.5 m band of spray. In practice this means spraying until just before run off. In a catering environment, where most surfaces are non-porous by design, an emulsion or flowable concentrate is preferable, although wettable powders can be effective, particularly when applied to cockroach hiding places. The new water based microencapsulated formulations are effective at low doses, have lower mammalian toxicity and a longer residual life. In order to obtain a quick kill in heavy infestations or to drive the cockroaches from protective areas, a pyrethrin aerosol is sometimes used prior to the residual spraying.

Dust formulations are used to treat the interior of hollow walls as well as cracks and other inaccessible voids. However, they should not be applied to wet surfaces or in humid areas, as this will reduce their effectiveness. In appropriate sites a light, uniform film of dust may be applied with a puff duster. In addition to the dusts listed in Table 15, boric acid and silica gel are occasionally employed. These are both of very low mammalian toxicity, but act slowly and less effective.

Several types of bait are commercially available in the form of child-proof bait stations or gel pastes. Most organophosphate and carbamate insecticides can be added (1-2%) to baits and the addition of glycerol increases their attractiveness. The baits should be placed at sites frequented by the cockroaches. Various commercial lacquers and varnishes containing residual insecticide such as 1% cypermethrin, 0.5% alphacypermethrin or 2% diazinon can be painted onto walls and other surfaces and are effective for several months.

(d) Treatment cycle. Sticky traps, discreetly and strategically placed, will give continuous evidence of the success or otherwise of control measures. These should be inspected regularly and a follow-up treatment initiated if healthy cockroaches continue to appear after a week. At least one more treatment will be needed after about month (depending on the average temperature) in order to kill newly hatched nymphs from the original infestation.

(e) Precautions. Care must be taken to avoid contamination of food or food-preparation surfaces. For safety reasons dusts should not be applied in kitchens. Some

formulations may stain fabrics, wallpaper, floor tiles, or other household materials. Special situations, such as treatment of zoos or pet shops, may preclude the use of residual sprays or dusts, although limited pesticide application with a brush may be possible.

Useful reference:

Schal, C and Hamilton, R.L. (1990) Integrated suppression of synanthropic cockroaches. Ann. Rev. Entomol. 35: 521-551.

World Health Organization (1985) Cockroaches. Unpublished document WHO/VBC/TS/85.4.

Table 15: Insecticides suitable for cockroach control

Insecticide	Chemical type[a]	Formulation	Concentration (g/l or g/kg)	Toxicity:[b] oral LD50 of a.i.[c] for rats (mg/kg) of body weight)
Alpha-cypermethrin	PY	spray	0.3-0.6	70
Azamethiphos	OP	spray/bait	5-10	1010
Bendiocarb	C	spray	2.4-4.8	55
		dust	10	
		aerosol	2.5-10	
Beta-cyfluthrin	PY	spray	0.25	450
Bifenthrin	PY	spray	0.48-0.96	55
Chlorpyrifos	OP	spray	5	135
		aerosol	5-10	
		dust	10-20	
		bait	5	
		microcapsule	2-4	
Chlorpyrifos-methyl	OP	spray	7-10	>3000
Cyfluthrin	PY	spray	0.40	250
		dust	0.5	
		microcapsule	0.2-0.4	
Cyphenothrin	PY	spray	3	318
		aerosol	3	
Cypermethrin	PY	spray	0.5-2.0	250
Deltamethrin	PY	spray	0.5-0.30	135
		dust	0.5	
		aerosol	0.1-0.25	
Diazinon	OP	spray	5	300
		dust	20	
		microcapsule	3-6	
Dichlorvos	OP	spray	5	56
		dust	19	
Esfenvalerate	PY	spray	0.5-1	87
Etofenprox	PY	spray	5-10	>10000
		dust	5	
		aerosol	0.5	
Fenitrothion	OP	spray	10-20	503
		aerosol	5	
		bait	50	
		microcapsule	2.5-5	
Fenoxycarb	IGR	spray	1.2	>10000
Hydramethylnon	HY	bait	16.5	1200
Hydroprene	IGR	spray	0.1-0.6	34000
Lambda-cyhalothrin	PY	spray	0.15-0.3	56
Malathion	OP	spray	30	2100
		dust	50	
Permethrin	PY	spray	2.5	500
		dust	5.0	
		aerosol	2.5-5.0	
Pirimiphos-methyl	OP	spray	25	2018
		dust	20	

Propetamphos[d]	OP	spray	5-10	106
		dust	20	
		aerosol	20	
Propoxur	C	spray	10	95
		bait	20	
		dust	10	
Sulfuramid	SU	bait	10	543
Zeta-cypermethrin	PY	spray	0.4-0.8	106

[a] C = carbamate; HY=hydrazone; IGR = insect growth regulator; OP = organophosphate; PY = synthetic pyrethroid; SU=sulfonamide

[b] Toxicity and hazard are not necessarily equivalent; the factors influencing the latter are discussed in section 17.1.1.

[c] a.i. = active ingredient

[d] If applied by non-commercial operators it should be supplied, for safety reasons, in a diluted form not exceeding 50 g of active ingredient per litre.

9

TICKS AND MITES

Ticks are not only annoying pests but also vectors of many viral, rickettsial and bacterial diseases of man over a wide geographic and climatic range. Many ticks parasitise a variety of animal hosts, including birds and rodents, and complex ecological relationships often exist between vectors and hosts. The control of tick-borne diseases is further complicated by transovarial transmission of the disease agent from one generation of ticks to another. Each mobile stage of the tick's life-cycle, i.e. larva, nymph, and both sexes of adults, requires blood meals. Trombiculid mites, which include the vectors of scrub typhus (tsutsugamushi disease), feed on man and other animals only in the larval stage. The larvae do not take blood but suck lymph and semi-digested skin tissue. Ticks and mites can be controlled through insecticide application to animal hosts and places frequented by these hosts as well as through habitat destruction in the case of trombiculid mites. Repellents applied directly to the skin or to clothing can prevent attacks by ticks and mites. For longer term protection, clothing can be impregnated with permethrin at 0.65-1 g a.i. g/m^2 (see chapter 14).

9.1 *Ixodes, Dermacentor, Amblyomma* and other ixodid ticks

These are known as hard ticks and transmit viral diseases (e.g., Colorado tick fever, Crimean-Congo haemorrhagic fever, Kyasanur Forest disease and Far Eastern tick-borne encephalitis), rickettsial diseases (e.g., boutonneuse fever, Q fever, Siberian tick typhus and tick-bite fever) and the bacterial disease, tularaemia. Lyme disease, which is caused by the spirochaete *Borrelia burgdorferi* and transmitted by Ixodid ticks, is an important emerging tick-borne disease. Ixodid ticks are also responsible for tick paralysis in humans and domestic animals through their salivary secretions.

9.1.1 Interior residual treatment

Spraying is used mainly for control of the brown dog tick, *Rhipicephalus sanguineus* which is brought into dwellings by dogs and causes severe annoyance to man, and can transmit tick-bite fever. The floor, baseboards, and wall crevices, as well as dogs and their quarters, should be treated. Suitable acaricides for surface treatment are listed in Table 16 and dust formulations can be used as well as liquids. For animal treatment, see Table 11. In addition, amitraz (oral LD_{50} for rats 800 mg/kg) may be used as a 0.25-0.5 g/l (0.025-0.05%) wash for control of ticks and mites on dogs.

Hand-operated compression sprayers or pressurized containers are generally used for surface treatment. Animal treatments are applied directly from the container to the animal. A single treatment will be sufficient for light infestations, but weekly retreatment may be required for severe infestations. Note should be taken of the remarks in the footnotes to Table 11 concerning the treatment of animals.

9.1.2 Exterior residual treatment

In areas where tick borne diseases are endemic, treatments are directed to outdoor areas frequented by people and pets such as gardens, recreational areas, camp sites and the borders of footpaths. Large-scale applications may be required if the risk of infection is high, but this is generally too expensive for routine control. Some of the acaricides listed in Table 16 can also be used for exterior residual treatments, for example carbaryl and propoxur at 2 kg a.i/ha, deltamethrin and lambda-cyhalothrin at 0.003-0.3 kg a.i./ha, permethrin at 0.03-0.3 kg a.i./ha and pirimiphos-methyl at 0.1-1 kg a.i./ha. Liquid formulations are best applied using hand-operated compression sprayers, back pack or vehicle-mounted power sprayers. Pellet formulations should be used where ground cover is extensive because they penetrate the vegetation and reach the microhabitats of the ticks. Exterior residual treatments remain effective for about one month. Care must be taken to avoid contamination of watercourses and adjacent areas, and to prevent hazard to non-target organisms.

9.2 *Ornithodoros* and related argasid ticks

These are generally called soft ticks and are vectors of relapsing fever. Several species are domestic and hide in cracks and crevices during the day. They are intermittent feeders and can survive long periods without food. Interior residual treatment is the main method of their control. The floors and walls of mud houses, stables and other shelters should be treated with the insecticides listed in Table 16.

9.3 *Leptotrombidium* and other trombiculid mites

Larval trombiculid mites are commonly called "chiggers", their natural hosts are principally non-commensal rodents living in "scrub" ecotypes. The chigger feeds on its host only once and thereafter is non-parasitic. Any infection transmitted by the chigger is therefore conveyed by ovarian transmission in the parent state. The two most important vectors of scrub typhus are *L. akamushi* and *L. deliense*. They are difficult to control because of their wide and patchy distribution in the environment. However, if mite islands can be identified, it is possible to remove the scrub vegetation mechanically or with herbicides to destroy their habitat, although It is often easier and more acceptable to spray mite-infested areas with insecticide. Where chemical application to the environment is not feasible, personal protection using repellents applied to socks and the bottoms of trouser legs is recommended (see chapter 14).

Treatment should be applied to woodland or bush areas where chigger infestations have been identified. Diazinon, malathion and propoxur are effective and may be applied as emulsions, suspensions or dusts. Pyrethroid insecticides generally have a short residual effect and are therefore not very suitable for outdoor chigger control in the long term. The insecticide can be applied using knapsack sprayers or from vehicle mounted aerosol or fog generators. Hand-operated or power-operated dusters can also be used for application of propoxur at 1.1 kg ai./ha. A single application of residual pesticide should last several weeks and retreatment need only be carried out when reinfestation is detected. Non-residual applications will need to be repeated every week. Care must be taken to avoid contamination of ponds and other watercourses. Dimethoate (2 g/kg (0.2%)) has been used in rodent bait as a systemic acaricide in oil palm plantations.

9.4 *Sarcoptes*

The causative agent of scabies affecting man is the acarid mite *Sarcoptes scabiei hominis*, which burrows and breeds in the human epidermis, particularly in the more humid areas of the skin. It causes intense itching, and constant scratching by the infested person may lead to streptococcal and/or staphylococcal sepsis of the infested areas.

The entire life-cycle occurs in man and extends over 10-15 days, with the adult *Sarcoptes* normally surviving 3-5 weeks. The mode of transmission of the parasite is principally by direct skin-to skin contact and to a lesser extent through contact with infested garments and bed-clothes. Improved personal hygiene therefore plays an important part in the control of scabies, in addition to treatment of the patient and infested clothing with acaricides.

Treatment with acaricide ointment should be preceded by a hot bath with liberal use of soap. Infested clothing should be sterilized or washed in hot soapy water. The acaricide preparation should then be applied to the infested parts of the body or over the entire body if the infestation is extensive. Sulfur ointments, 20-25% benzyl benzoate emulsions or permethrin 10-20 g/l in liquid paraffin are effective for skin applications. It may be necessary to treat simultaneously all members of the family in which the scabies case occurred. A single treatment should eradicate the mite infestation, but a repeat treatment after three days may be advisable. Bedding, mattresses, sheets and clothes may require dusting with an acaricide such as temephos 20 g/kg (2%).

Useful references

Arlian, L.G. (1989) Biology, host relations and epidemiology of *Sarcoptes scabiei*. Ann. Rev. Entomol., 34: 139-161.

World Health Organization (1986) Mites of public health importance and their control. Unpublished document WHO/VBC/86.931.

Table 16. Suitable acaricides for indoor residual treatment

Insecticide	Chemical type[a]	Concentration g/l or g/kg	Toxicity:[b] oral LD_{50} of a.i.[c] for rats (mg/kg of body weight)
Alpha-cypermethrin	PY	0.3-0.6	79
Bendiocarb	C	2.4-9.6	55
Bifenthrin	PY	0.48-0.96	55
Carbaryl	C	50	300
Chlorpyrifos	OP	5	135
Chlorpyriphos- methyl	OP	5	>3000
Cypermethrin	PY	0.5-2.0	250
Deltamethrin	PY	0.25	135
Diazinon	OP	5	300
Lambda-cyhalothrin	PY	0.25	56
Malathion	OP	20	2100
Permethrin	PY	2.5	500
Propoxur	C	10	95
Pirimiphos-methyl	OP	10	2018
Zeta-cypermethrin	PY	0.4-0.8	106

[a] C = carbamate; OP = organophosphate; PY = synthetic pyrethroid

[b] Toxicity and hazard are not necessarily equivalent; the factors influencing the latter are discussed in section 17.1.1.

[c] a.i. = active ingredient

10

HOUSE DUST MITES

Mites that form viable populations in house dust are commonly referred to as house dust mites. Certain species of these mites, especially a few from the family Pyroglyphidae, are important producers of allergens which can induce asthma, rhinitis and atopic dermatitis (eczema) in susceptible people. The most commonly studied species of dust mite are *Dermatophagoides pteronyssinus* and *D. farinae*.

House dust mites have a cosmopolitan distribution and are found in almost every house. In temperate regions, allergy to dust mites is increasing and is closely associated with housing features such as double glazing, fitted carpets, poor ventilation and central heating. Conditions in such houses are suitable for dust mite proliferation. They are particularly abundant in mattresses, pillows, carpets, rugs and upholstered furniture. Most of the mites feed on skin scales and/or fungi growing on the scales. Humidity and temperature are important factors regulating the growth of house dust mite populations. They can only absorb water vapour from unsaturated air if humidity is above their Critical Equilibrium Humidity (CEH), which is approximately 71% for *D. farinae* and 75% for *D. pteronyssinus*; below this level they are prone to desiccation.

A number of allergens of house dust mites have been isolated and characterised. A few groups of these allergens are found in large concentrations in mite faecal pellets. These allergens are highly water soluble and are heat labile. There are other groups of allergens which are non-faecal in origin and some of these are stable at high temperatures.

House dust mite densities above 100 mites/g of dust from mattresses and carpets is considered a risk factor for sensitisation and development of asthma and 500 mites/g dust is considered a major risk factor in the development of acute asthma in those mite allergic individuals.

10.1 Control of house dust mites.

Control of house dust mites alone is usually not sufficient to achieve clinical benefits; mite allergens in house dust must be removed as well. There is evidence to show that reducing mite-allergen levels can cause a major improvement in asthma symptoms. Mite control options include physical, environmental and chemical interventions but for effective control, these approaches need to be integrated.

Dry vacuuming of carpets has little effect on removing live house dust mites, as they are able to attach themselves firmly to fabric fibres. In fact, traditional vacuuming may increase allergen exposure by pumping clouds of fine dust into the air. The negative effect of this can be reduced by opening windows while vacuuming and changing the collection bag regularly. In some vacuum models, a filter can be fitted which removes significant amounts of dust and allergen. This effect can be further enhanced with the use of motorised nozzles. Similarly, wet vacuuming does not remove live mites, although it does significantly reduce dust and allergen levels, especially if applied in association with detergents or surfactant solutions.

Due to the high density of dust mites in mattresses and pillows, allergen exposure is often greatest while sleeping. Plastic covers for mattresses and pillows may be used to provide a physical barrier between the mite infestation and the sleeping person. Such covers, however, do not permit air circulation so may be uncomfortable to sleep on. There are more expensive materials containing micropores which allow a degree of air to circulate without permitting the passage of allergens.

Live mites, dust and allergens can be removed from bedding and pillows by domestic laundry processes using a minimum water temperature of 55^{0}C or by dry cleaning. Mite numbers in mattresses can also be reduced by leaving electric blankets switched on for 7 hours during the day when beds are not being slept on. In general, maintaining low humidity through use of air conditioners or other means will reduce the density of house dust mites.

10.2.1 Chemical control methods

An application of liquid nitrogen or acaricide to the household habitats of dust mites will destroy them. The dead mites must then be removed or the mite allergens in the dust chemically denatured.

(a) Target area. Application of acaricides or allergen denaturing compounds to mattresses, carpets, rugs, mats, curtains and other soft furnishings, particularly in bed rooms, can temporarily reduce house dust mite and allergen levels. All sites to be treated should be vacuumed prior to application of acaricide and again 2-3 hours after, when treated surfaces are dry.

(b) Acaricides. Benzyl benzoate dust (5%) can be applied to carpets at a rate of 60 g/m^2. The dust should be left for 12-24 hours before vacuuming. For mattresses and soft furnishings, a liquid formulation is available and one treatment remains effective for up to a year. An alcohol based formulation of benzyltannate can be applied to control mites and denature allergens at the manufacturer recommended rate using a hand sprayer. d-Phenothin (0.4%) can be applied to mattresses, carpets, curtains and soft furnishings using hand sprayers supplied with the product at a rate of 20 sprays per m^2. Pirimiphos-methyl applied at a rate of 2 g/m^2 on carpets using a carpet shampooer, or as an aerosol applied to soft furnishings, can reduce both mite counts and allergen levels to below pre-treatment levels for up to 2 months. Tannic acid applied as a 3% spray at 20 ml/m^2 may not kill mites but can reduce allergen levels for 1-2 months.

Cotton sheets impregnated with a special formulation of benzyl benzoate are available in some countries. When placed on the upper surface of mattress and below the bed sheet, they are reported to reduce mite counts for at least 12 months.

*(c) **Precautions.*** Care should be taken not to inhale spray mists or dusts during application. Food should be covered and surfaces on which food is prepared should not be treated. Benzyl benzoate is toxic to cats if eaten.

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11

VENOMOUS ARTHROPODS

Scorpions, spiders and wasps are not disease vectors but their poisons can cause serious discomfort and occasionally death to humans. Control measures are confined to the particular dwelling or area where these arthropods constitute a nuisance. So far, they have not developed any resistance to insecticides.

11.1 *Centruroides* and other scorpions

Scorpions are easily recognized by their two lobster-like pincers and long tail terminating in a bulbous sting. They rarely sting humans and then only when provoked. The victim of a scorpion sting should have immediate medical attention. Placing a piece of ice over the wound site may reduce pain and slow down absorption of the venom. Scorpions are active at night, hiding during the day beneath loose stones, bark, fallen trees and other debris, as well as under houses and in attics. Therefore, elimination of the hiding places would greatly reduce the risk of scorpion stings. If removal of scorpion hiding sites is not possible, chemicals may be employed for residual treatment.

(a) Target area. Inside dwellings, pesticides should be applied to the sites where scorpions are apt to enter or hide, such as baseboards (skirtings), closets, inlets for plumbing and under furniture, as well as in attics and basements. For outdoor treatment, pesticides should be applied to any portion of the structure (foundation, siding, porches, etc.) in contact with the soil, to a height of 0.6 m above ground level. Accumulations of stone, lumber and firewood should also be treated, but not shrubbery.

(b) Insecticides. Solutions, suspensions or emulsions of azamethiphos 10 g/l (1%), bendiocarb 2.4-4.8 g/l (0.24-0.48%), chlorpyrifos 2-5 g/l (0.2-0.5%), deodorized malathion 50 g/l (5%) or propoxur 20 g/l (2%) can be applied as indoor residual sprays. Dusts of bendiocarb 10 g/kg (1%), carbaryl 20-50 g/kg (2-5%), pirimiphos methyl 20 g/kg (2%) or propoxur 20 g/kg (2%) can also be used. The same insecticides at the same dosages are used for outdoor residual sprays, while for dusting, carbaryl 100 g/kg (10%) can be applied. Granules of diazinon 100 g/kg (10%) are also effective for area treatment. Pyrethroid insecticides are not usually recommended, since they might irritate the scorpions, causing more danger to the residents. Hand-operated or power-operated sprayers are used for spraying and the surface of the infested areas should be thoroughly wetted. Hand-operated dusters are used for dusting.

11.2 *Latrodectus*, *Loxosceles* and other spiders

All spiders possess venom, but only a few are dangerous to man, among them *Latrodectus mactans* (the black widow spider). Some species of *Loxosceles*, *Cheiracanthium*, *Atrax* and *Phonentria* are also of concern to man. In treating spider bites, the general principle is the same as for scorpion stings. Dusting spiders, their egg masses and webs with pesticide, applied by mechanical means, is a useful method of control. Pesticides can also be applied to spider resting places such as walls, corners, cracks, spaces under furniture, privies, rubbish heaps and stacks of old lumber. Suspensions or emulsions of the insecticides listed in Table 17 can be used, while dust formulations of bendiocarb or malathion 10 g/kg (1%) are also appropriate. Hand-operated sprayers are employed for spot treatment in dwellings and a treatment may remain effective for 2-3 weeks. Care should be taken in spraying overhead surfaces, as *Latrodectus* spp. irritated by the spray may drop down and bite.

11.3 *Vespula*, *Polistes* and related wasps

Wasps, hornets and cidada killers are easily distinguished from bees by their simple, unmodified legs. Unlike bees, wasps have unbarbed stings and are able to sting their victims repeatedly without losing their stings and dying. Male wasps do not possess stings. Wasps may build nests on the branches of trees and shrubs, in the attics of buildings, beneath eaves, or underground.

Direct treatment of wasp nests with insecticide is the method most commonly used and can also be used against bees when necessary. Suspensions or emulsions of the insecticides listed in Table 17 can be used as well as carbaryl 20 g/l (2%), chlorpyrifos 5 g/l (0.5%), deltamethrin 0.15 g/l (0.015%) and dichlorvos 10 g/l (1%). Dusts of bendiocarb 10 g/kg (1%), carbaryl 50 g/kg (5%) and pirimiphos-methyl 20 g/kg (2%) are also suitable. Hand-operated or power-operated equipment is used for spraying and dusting the nest. Wasp nests are most safely destroyed at night, when all the wasps are inside. The spray mixture is directed at the entrance of the nest in a continuous jet. A single treatment should be sufficient to destroy it. If nests are treated during the day, sting-proof suits, hard gloves and thick rubber boots should be worn for protection.

Table 17. Suitable insecticides for control of spiders

Insecticide	Chemical type[a]	Concentration (g/l or g/kg)	Toxicity:[b] oral LD_{50} of a.i.[c] for rats (mg/kg of body weight)
Alpha-cypermethrin	PY	0.3-0.6	79
Azamethiphos	OP	10	1010
Bendiocarb	C	2.5-4.8	55
Bifenthrin	PY	0.48-0.96	55
Chlorpyrifos	OP	2-5	135
Cypermethrin	PY	0.5-2.0	250
Deltamethrin	PY	0.3	135
Diazinon	OP	5	300
Fenthion	OP	10	586
Lambda-cyhalothrin	PY	0.7	56
Malathion	OP	30	56
Permethrin	PY	1-2	500

[c] C = carbamate; OP = organophosphate; PY = synthetic pyrethroid

[b] Toxicity and hazard are not necessarily equivalent; the factors influencing the latter discussed in section 17.1.1.

[c] a.i. = active ingredient

12

SNAILS

Schistosomiasis (bilharzia) affects around 200 million people in 74 tropical countries and is caused by five *Schistosoma* species. Medically, the three most important species are *S. japonicum*, transmitted by aquatic snails of the genus *Oncomelania* in Eastern Asia, *S. mansoni* by *Biomphalaria* in Southwestern Asia, Africa and the Americas and *S. haematobium* by *Bulinus* in Southwestern Asia and Africa. Less important, because of their limited distribution, are *S. intercalatum*, transmitted by *Bulinus* in West-Central Africa, and *S. mekongi* by *Neotricula* along the Mekong River in South-East Asia. In most areas, transmission is seasonal, occurring when human water contact, snail populations and larval schistosome development rates are all high. The frequency and intensity of such seasons may contribute to the severity of disease in the local communities. Moreover, the focality of transmission sites complicates control of the intermediate host snails. Snail control is just one intervention in integrated morbidity control, now dominated by population-based chemotherapy.

The truly aquatic *Bulinus* and *Biomphalaria* are the snails most amenable to chemical control using molluscicides, but control of the more amphibious *Oncomelania* should be coupled with environmental modification. Mollusciciding is not considered feasible against the riverine *Neotricula*. *Biomphalaria* and *Bulinus* inhabit stable waterbeds but may invade less stable transmission sites seasonally during periods of favourable conditions, so such sites should be kept under regular surveillance. Molluscicides should be used primarily to reduce seasonal *Schistosoma* transmission peaks by eliminating at least 95% of the local snail population throughout the transmission season.

12.1. Suitable molluscicides for snail control

The older molluscicidal compounds have long since been abandoned, are no longer recommended by WHO in view of their toxicity to man and other adverse environmental effects. Currently, niclosamide (oral LD_{50} in rats, 5000 mg/kg) is the only effective, commercially available molluscicide. There have been no confirmed reports of resistance in field snail populations since it was introduced in the early 1960s.

Niclosamide is available as a wettable powder (WP) (70% active ingredient) and as an emulsifiable concentrate (EC 25% active ingredient), both of which are highly effective. The WP is diluted in water for field application by sprayers or dispensers at not less than 1:20 (wt/vol) and the EC at 1:15 (vol/vol). In practical use, concentrations of 1 mg/l a.i. in the water for eight hours or 0.33 mg/l a.i. for 24 hours both give the recommended dose of 8 mg/l for aquatic snail control. Lower concentrations may be applied to stagnant water where the a.i. decays slowly over several days. The manufacturer recommends 0.6 and 1 mg/l a.i. for stagnant and flowing waters respectively for the WP, with equivalent figures of 0.4-0.6 and 0.6 mg/l a.i. for the EC. An excellent spreading effect in standing water, with or without vegetation, is given by mixing the EC with diesel oil (8.5 EC:1.5 diesel oil). It is essential that the specified concentrations should be maintained in the treated water for the full time to achieve the required dose. Home-made granules of WP, sand and gum, and gelatin capsules of WP have been used successfully in certain situations. When used focally and/or seasonally, in judicious combination with other control measures, niclosamide can be cost-effective with no serious adverse effects on the environment.

12.2. Where to apply molluscicides

The distribution of snails in their habitats is non-random, reflecting the whereabouts of food resources (e.g., water plants, algae, decaying vegetation) and physical features (e.g., water flow patterns, substrate) which attract or repel them. For cost-effective mollusciciding, pre-control surveys are essential to identify potential transmission sites favoured by snails both geographically and seasonally.

Selective mollusciciding applications are usually restricted to sites with high human water contact (e.g. due to activities such as swimming, bathing and laundry) and adjoining snail habitats. Water contact sites are well known to local people and are easily verified by evidence of frequent access and use. Basic maps should be prepared showing the location of transmission sites and, if possible, the local human population, as molluscicides do not normally need to be applied to practically unpopulated areas. These maps should be updated regularly. Drinking water sources are often separate and play little part in transmission. Likewise, large rivers and lakes are not in themselves important to transmission, but may have transmission sites. Snails are often associated with specific vegetation (e.g., water lilies, floating algae), especially if it is not too dense, and special attention should therefore be given to such microhabitats. The situation may alter following the construction of dams across both small and large rivers due to ecological changes which favour transmission.

With regard to irrigation schemes, transmission is usually most intense at sites near human dwellings where water contact and contamination with urine and faeces are frequent. Transmission sites and seasons are likely to vary from one scheme to another, but they can usually be identified by experienced personnel in carefully conducted pre-control surveys.

12.3. When to apply molluscicides

The timing of mollusciciding should, if possible, be linked to and precede the delivery of population-based chemotherapy, especially during periods of intense transmission. The application(s) of molluscicide should be geared to reduce the intensity of such seasons to insignificant levels. Three molluscicide applications or more may be necessary in each transmission season (e.g., towards the end of a rainy season when flooding has ceased, about six weeks later during the early dry season, and again if water persists well into the dry season). Molluscicidng is most efficient in small, still water bodies (e.g., ponds, borrow pits and small dams) when they are relatively full, but may be inappropriate when they have nearly dried out. More frequent applications may be needed where transmission is continuous and, especially in flowing sites, if rapid reinvasion from upstream snail colonies is anticipated.

12.4. How to apply molluscicides

A simple calculation of the volume and, where appropriate the flow, is needed for all sites to calculate the correct dosage for treatment. Great precision is not essential except to avoid waste of the expensive chemical when treating large habitats. Watering cans, hand-operated compression sprayers and motorised sprayers may be used to apply molluscicide to moist soil or still water. Focal applications must extend to a radius of at least 15 metres around a transmission site and any adjoining snail reservoirs. Preliminary removal of aquatic vegetation may improve penetration by the molluscicide.

Flowing water is treated by drip feeding molluscicide for a predetermined time (e.g., 8 or 24 hours) from automated dispensers made from plastic or metal containers that empty their contents at fixed time (e.g., every 30 or 60 minutes). Dispensers must incorporate some form of agitation to prevent settling of WP formulations and, if possible, a constant head device. They should be placed upstream above a stretch of turbulence to ensure even delivery of the molluscicide to the transmission site or sites. Clearing away of vegetation will improve penetration by the molluscicide, but supplementary hand-spraying of stagnant backwaters may be needed.

12.5. Evaluation of mollusciciding operations

The manufacturers produce a field chemical analysis kit to test the concentration in the treated site, but it is difficult to use in turbid water. The simplest assessment of the effectiveness of mollusciciding is to compare counts from standardised field snail collections immediately before and a week after mollusciciding. A more precise evaluation is possible by placing small nylon mesh cages containing 10-20 locally caught snails in several places around the site before treatment and recovering them 24 hours after its completion. All snails in the test cages should be dead whereas high survival rates should be obtained from control cages placed in nearby untreated ponds or, in flowing sites, upstream of the dispensers.

12.6. Precautions

Protective clothing (masks for WP, gloves for EC) are recommended during the preparation and mixing of solutions for field use. Niclosamide at molluscicidal concentrations (1 mg./l) is not toxic to humans, domestic animals or crops and treated water may be drunk without risk. Such concentrations kill crustaceans, amphibians and fish but, as niclosamide is biodegradable, these mobile species rapidly repopulate treated sites within a few weeks of focal application. Crustaceans and fish killed during mollusciciding can be eaten by local people, if collected immediately.

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13

RODENTS

There are 35 families of rodents comprising some 389 genera with about 1700 species. They make up about 40% of the known mammal species in the world. Many rodents are carriers of a variety of infectious organisms which can be transmitted to humans and domestic animals. The causative agents of these rodent-borne zoonotic diseases include viruses, rickettsiae, bacteria, protozoa and helminths.

13.1 Rodent-borne diseases

13.1.1 Viral diseases

Only the more important viral diseases carried by rodents will be discussed here. Tick-borne encephalitis is endemic in Asia and the field mouse *Apodemus flavicollis* and the bank vole *Clethrionomis glareolus* are the most important reservoirs. Venezuelan equine encephalitis involves mosquito vectors and rodents such as the cotton rat *Sigmodon hispidus*, the cotton mouse *Peromyscus gossypinus*, the rice rat *Oryzomys palustris* and the black rat *Rattus rattus*.

The causative viruses of the rodent-borne haemorrhagic fevers (Argentine, Bolivian, Venezuelan, Lassa and Haemorrhagic Fever with Renal Syndrome (HFRS)) are transmitted to humans through direct contact with faeces, urine, nasal or oral secretions of a wide range of infected rodents, depending on the virus and locality.

13.1.2 Rickettsial diseases

The most important of these is murine typhus, which is flea-borne with a world-wide distribution. *Rattus norvegicus* and *R. rattus* are the primary rodent reservoirs. Rocky mountain spotted fever is transmitted by ticks, with the rodent reservoir belonging to the genera *Microtus*, *Peromyscus*, *Sigmodon* and *Spermophilus*. Scrub typhus (tsutsugamushi disease) is transmitted by mites of the genus *Leptotrombidium* (see chapter 9). It is widespread in the western Pacific and Southeast Asia and its principal rodent hosts are species of the genus *Rattus*.

13.1.3 Bacterial diseases

Lyme disease is caused by *Borrelia burgdorferi* and occurs in North America, Europe and Australia. It is transmitted by ticks of the genus *Ixodes* (see chapter 9). The most important rodent reservoir in the USA is the white-footed mouse *Peromyscus leucopus*.

The causative agent of leptospirosis is transmitted to humans through exposure to water contaminated with urine of infected animals. Rats, particularly *R. norvegicus*, are the most common reservoirs. Plague is caused by *Yersinia pestis* and the most frequent source of disease in humans has been the bite of infected fleas (especially the Oriental rat flea *Xenopsylla cheopsis*, see chapter 4). The disease occurs in Asia, Africa and the Americas and the reservoir hosts include many species of rodents. *Rattus norvegicus* and *R. rattus* are the most common urban rodent hosts. The causative agents of tick-borne relapsing fevers are transmitted to humans by Argasid ticks from a variety of rodent hosts. Rats are also an important reservoir for *Salmonella typhimurium*.

13.1.4 Protozoal diseases

Chagas disease is caused by *Trypanosoma cruzi* and transmitted to humans by triatomine bugs (see chapter 6) from many vertebrate hosts. The rodent reservoirs include *Rattus rattus* and the guinea pig *Cavia porcellus*. Leishmaniasis is transmitted by phlebotomine sandflies (see chapter 3) from hosts such as the gerbil *Psammomys obesus*, *Arvicanthis niloticus*, and species of *Meriones*, *Oryzomys*, *Proechimys*, *Akodon* and *Rattus* as well as dogs. Toxoplasmosis is caused by the intracellular protozoan *Toxoplasma gondii*. Transmission is through consumption of contaminated food or water. The domestic cat is the definitive host, but rodents such *as Rattus rattus*, *R. norvegicus*, *Mus musculus* and *Peromyscus maniculatus* constitute a source of infection for cats.

13.1.5 Helminth diseases

Rats, such as *Rattus rattus* and *R. exulans* serve as reservoir hosts for schistosomiasis caused by *Schistosoma japonicum*. Rodents are also reservoir hosts for nematodes such as *Angiostrongylus cantonensis*, *Trichinella spiralis* and *Capillaria hepatica* and the tapeworms *Hymenolepis diminuta*, *H. nana* and *Echinococcus granulosis*.

13.2 Rodent control

Control of rodents may be divided into chemical and non-chemical methods. The importance of non-chemical methods such as environmental sanitation, rodent exclusion, rodent proofing, electrical barriers, trapping and use of biocontrol agents is increasing. Such methods are recommended when applicable although chemical methods (rodenticides) are the mainstay of most rodent control programmes.

13.2.1 Repellents, chemosterilants and fumigants

Repellents, although effective in keeping rodents away from specific areas, are also toxic. Among the most commonly used are thiramcycloheximide, tributyltin salts and R-55. Chemosterilants or chemical inhibitors of reproduction can target either the male or female rodents. Alphachlorohydrin is the only male antifertility compound that has been widely marketed. The problem with male sterilisation is that for polygynous species, a high proportion of males must be treated to have any effect on population density. The synthetic oestrogen BDH 10131 appears promising, as a single dose makes a female rat infertile for one year, but there are problems with palatability.

Fumigants can be effective in eliminating rodent infestations in small, restricted areas. Application is hazardous and personnel must be carefully trained in the technique. The most commonly used fumigants are calcium cyanide (to produce hydrogen cyanide), methyl bromide, chloropicrin and aluminium phosphide (to produce phosphine). In addition, carbon dioxide, carbon monoxide and carbon disulphide are sometimes used.

13.2.2 Rodenticides

Rodenticides are generally administered as poisoned food baits, liquids or dusts. Acute rodenticides are fast acting (often a single dose suffices), while anticoagulant rodenticides are slow acting (multiple doses) and cause death through chronic internal bleeding. Generally, anticoagulant rodenticides are preferred because of efficacy and safety. A list of rodenticides is found in Table 18.

13.2.2.1 Acute rodenticides

These compounds are administered at high concentrations in baits, but are relatively cheap to produce. However, they are highly toxic to non-target animals, including humans, and few of them have a specific antidote. In addition, they cause poison or bait shyness, which disinclines rats from returning to consume more bait after initial exposure. The advantage of acute rodenticides is their rapid effect while using the minimum amount of bait. This is an asset when rodent infestation is very high.

13.2.2.1 Anticoagulant rodenticides

These compounds act by interrupting the vitamin K cycle in liver microsomes, causing fatal internal haemorrhages. In terms of human safety, unlike acute rodenticides, their chronic mode of action allows enough time for an antidote to be administered. Vitamin K1 is the specific antidote for accidental poisoning. Anticoagulant rodenticides are classified into first generation and second generation anticoagulants. All of them are either hydroxycoumarins or indane-dione compounds.

Generally, the first generation anticoagulants are effective against most rodent species. The second generation anticoagulants were developed to combat species resistant to the first generation compounds. Warfarin has been the most widely used rodenticide, but resistance has been established in *Rattus norvegicus* and *Rattus rattus* in parts of Europe, North America and South East Asia. Some xerophilous rodents of North Africa and the Middle East show natural tolerance to warfarin. Calciferol is suitable for use against anticoagulant resistant rodents although it is very toxic to non-target mammals, including humans.

13.2.3. Application of rodenticides

Most rodenticides are employed as food baits, although some are applied as liquid baits or as contact poisons (dusts). A good-quality cereal is normally used as the base material in food baits. A coloured dye is incorporated to prevent accidental human consumption or feeding to livestock or non-target animals. In addition, various attractants, additives and preservatives may be added to facilitate preparation or to improve the efficacy of baits. If perishable baits are used, they should be applied in the early evening to ensure their freshness overnight. Baits should be laid in suitable containers, which allow access to rodents but reduce scattering. For sewer treatment, baits mixed with wax, that will remain effective for a longer duration and will not mildew are recommended.

For effective control using acute rodenticides, prebaiting is normally carried out. This involves leaving unpoisoned bait for several days until the rodents are used to the new source of food and are feeding freely. The poison is then added and one or two nights exposure to the poison is enough to kill most of them. The problem with prebaiting is that the main advantage of acute rodenticides, i.e. rapid control, is lost if several days of prebaiting are required. Therefore, where immediate control is essential, the prebaiting period can be omitted and although incomplete control may result, anticoagulants can be used to eliminate the remaining rodents.

When anticoagulants are employed, the baits should be placed under cover and protected from the weather and non-target animals. Surplus amounts of baits should be provided throughout the poisoning cycle, and excess baits removed subsequently. All dead rodents should be recovered and disposed of appropriately (e.g., incineration, deep burial).

In arid areas and in habitats where water is scarce, water baits are an efficient technique for control. Water-soluble salts of anticoagulants are most commonly used for this purpose. Poisoned water baits should be placed at ground level only, and should be inspected regularly. Extra care should be taken to prevent access to non-target species.

Where acceptance or other baiting problems arise, the use of poison dusts may prove successful. Such application is usually wasteful, as only a small amount of the poison on fur and feet is consumed by the rodents while grooming. This technique cannot be used if there is risk of affecting non-target species or contaminating food supplies.

13.2.4. Rodent control strategy.

Control strategy can be broadly based on an initial survey, followed by application of control methods and maintenance of control and hygiene practices. The survey defines the severity of the infestation. The most common cause of control failure is underestimating the extent of an infestation. The surveyor can use signs and traces such as droppings, runs and holes to identify the species present and estimate population density. The survey should include examination of roof spaces, walls, floors, basements, drains, sewers and outdoor shelters.

If chemical control is indicated, the choice between acute rodenticides or anticoagulants must be made. In general, anticoagulants are more effective except where rapid control of a large population requires the use of fast-acting compounds. Sub-lethal doses of anticoagulants will not lead to bait shyness which may occur with sub-lethal doses of acute compounds. Baits should be placed in areas of rodent activity as defined by the initial survey. Open bait trays may be more attractive to rodents, but for safety reasons access to bait should be restricted to prevent accidental poisoning of non-target mammals. Bait consumption rates may increase if unpoisoned water is placed next to the bait.

It is important that control efforts are maintained until the desired level of control is reached. If local eradication is the aim, weekly visits to treated areas should be carried out to monitor rodent activity and replace bait. As a general rule, if no bait has been taken for two weeks, then the infestation has been cleared. During and after implementation of control, environmental hygiene should be practiced to reduce sources of food and shelter and hence the likelihood of reinfestation.

13.2.4 Precautions

When handling rodenticides, gloves should be worn and hands should be thoroughly washed afterwards. Rodenticides which rapidly break down in the bodies of rodents should be used, where possible, to prevent secondary toxicity to predators scavenging on dead rodents. Because rodenticides are often applied in the domestic environment, accidental poisoning of humans and non-target animals sometimes happens. In rodent control programmes it is important that specific antidotes against the compounds being used are readily available. The advantage of using slow acting rodenticides is that the symptoms of accidental poisoning can be recognised in time and the antidote administered.

Useful references

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World Health Organization (1987) Commensal rodent control. Unpublished document WHO/VBC/87.949.

Table 18. Acute and anticoagulant rodenticides for control of rodents

Rodenticide	Formulation	Effect	Concentration (%)	Tocicity[a]: oral LD50 of a.i.[b] for rats (mg/kg of body weight)
Alphachloralose	bait	acute	2-4	200-400
Brodifacoum	bait, wax block	anticoagulant	0.005	0.22-0.27
Bromadiolone	bait, oil-based, wax block, powder	anticoagulant	0.005	1.12-1.8
	concentrate			
	tracking powder		0.1-2.0	
Bromethalin	bait	acute	0.005-0.01	2.0-2.5
Calciferol	bait	subacute		43.6-56.0
Chlorophacinone	bait	anticoagulant	0.005-0.05	20.5
	oil-based concentrate		0.25	
	tracking powder		0.20	
Coumachlor	concentrate	anticoagulant	0.025-0.05	900-1200
	tracking powder		1.0	
Coumatetratyl	wax block, bait	anticoagulant	0.0375	16.5
	tracking powder		0.75	
Difenacoum	wax block, bait	anticoagulant	0.005	1.8
Difethialone	wax block, bait	anticoagulant	0.0025	0.56
Diphacinone	powder concentrate	anticoagulant	0.1-0.5	2.3-4.3
	water soluble oncentrate		0.1-2.0	
	bait		0.005-0.05	
Flocoumafen	wax briquette	anticoagulant	0.005	0.25-0.56
Fluoroacetamide	bait	acute	1-2	13.0
Pindone	bait	anticoagulant	0.005.0.05	50.0-280
Red squill	bait	acute	0.015-0.05	0.4-2.6
Sodium (mono) fluoroacetate	bait	acute	0.08-0.5	0.2-5.0
Warfarin	concentrate	anticoagulant	0.5-1.0	10.0-20.0
	tracking powder, bait		0.025-0.05	
Zinc phosphide	bait	acute	1-5	27-40.5

[a] Toxicity and hazard are not necessarily equivalent; the factors influencing the latter are discussed in section 17.1.1.
[b] a.i. = active ingredient

14

REPELLENTS

Repellents are products which when applied to the skin, clothing, or in some cases to screens and netting, prevent or deter arthropods from attacking humans or other animals. They are used in particular against outdoor biting insects and in situations where individual protection is the priority and treated mosquito nets, vaporising mats or other chemical control methods are not appropriate.

14.1 Compounds used as repellents

The following chemical compounds are among the most effective against one or more groups of arthropods: benzyl benzoate, butyl ethyl propanediol, deet (N,N-diethyl-3-methylbenzamide, formerly N, N-diethyl-*meta*-toluamide), dibutyl phthalate, dimethyl phthalate, ethyl hexane-diol, butopyronoxyl, 2-chlorodiethylbenzamide, and acylated 1,3-aminopropanole derivatives. A number of alicyclic carboximides of heterocyclic amines are also available and are effective on clothing as well as on skin. Impregnating clothing with permethrin has also proved to be an effective and long lasting strategy for repelling biting insects. Permethrin has low dermal absorption, low mammalian toxicity, no odour and does not irritate the skin. In recent years, several natural products based on plant extracts have become commercially available. The most important of these is qwenling. This originated in China and is derived from the lemon eucalyptus plant and contains the active ingredient p-menthane-3,8-diol (PMD). Other natural products with repellent activity include neem oil and citronella.

Deet is the most commonly used, commercially available repellent as it is effective against a wide range of biting arthropods. Deet feels less oily on the skin than the other chemical repellents and is sufficiently effective to allow some dilution with alcohol, which increases its cosmetic acceptability. Recently, however, concern has been expressed by some over the safety of long term skin exposure to deet. Qwenling offers a natural alternative which is almost as effective as deet in repelling many types of nuisance insect. Where the superior activity of deet is required against mosquitoes, blackflies, or biting midges, then treated mesh jackets with hoods can be used to provide good protection without deet coming in contact with the skin. Recent work on the acylated 1,3-aminopropanole derivatives shows that they may be as effective as deet without the side effects.

14.2 Application methods

Repellents are available as liquids, lotions, solid waxes (stick-type formulations), creams, foams and impregnated wipe-on towelettes and can be dispensed from tubes, squeeze bottles, pressurized cans, roll-ons and hand pump containers. The repellent may be applied directly to exposed skin from the container or first applied to the hands and then rubbed over the skin. Repellent sprays from pressurized cans should not be sprayed directly at the face. Repellent soaps containing deet or permethrin are much cheaper than other commercially available repellents and if applied to the skin (and not washed off) may give protection for several hours.

Impregnating clothing with a repellent provides extra protection, and temporary treatment can be achieved with a spray-on application. However, for maximum protection against certain arthropods, clothes should be dipped in a solution of repellent at a concentration of 0.65-1 g a.i./m^2 for permethrin and for other repellents at a dose of 20 g/m^2 or a total of 70 g of active ingredient(s) for a jacket (or shirt), trousers and socks. Either emulsions or solutions of the repellents, or repellent mixtures, are suitable for treating clothing. As an alternative to impregnating clothing, anklets (sweat bands worn on the ankles) can be impregnated with permethrin or deet to deter mosquitoes or other biting insects which attack the lower leg. If the treated anklets are kept in a sealed plastic bag when not in use, they may remain effective for several weeks before reimpregnation is required. In severe insect biting conditions, a combination of deet applied to the skin and permethrin impregnated clothing will provide maximum protection, but this is not recommended for children. A 0.5% permethrin spray is now available for occasional rapid treatment of clothes.

14.3 Treatment sites

When applying repellent, the attacking habits of the different arthropod groups should be considered. For *Culex* and *Anopheles* mosquitoes repellent application should be concentrated around the feet and ankles. For general protection against mosquitoes, blackflies and other diptera, all exposed parts of the body, such as the legs, arms, face (except the eye area), ears and neck, should be treated. Since mosquitoes can also bite through light clothing it may be necessary, particularly when densities are high, to treat clothing as described above. Although blackflies do not bite through clothing, they tend to find their way inside collars, sleeves and trouser legs, rendering treatment of these areas necessary. In the case of ticks, maximum protection is afforded by impregnation of clothing as described above.

To repel chigger (Trombiculid) mites, all openings in the clothing should be treated by hand or with spray. Particular attention should be given to the cuffs, the front opening, inside the neck band and along the belt line of shirts, the fly and cuffs of trousers, and to socks above the shoes. Normally, a band of repellent 1.5 cm wide will suffice. As a further preventive measure, it is wise to tuck trouser cuffs in the tops of the socks when possible. Persons not exposed to chigger infested vegetation above the knee level can obtain adequate protection by treating socks and trouser cuffs. Under conditions of frequent exposure to chiggers, impregnated clothing provides the best protection. To repel fleas, the shoes, socks and lower trouser legs should be sprayed with repellent or the clothing properly impregnated.

14.4 Level of protection from different arthropods

The effectiveness of a repellent treatment depends upon the compound and its dosage, its method of application, the species of insect, the activity of the individual and climatic conditions (e.g., rainfall). Any figures for the duration of efficacy must therefore be subject to the reservation that the period of protection could be increased or decreased by alteration of these factors. Studies have shown that the principal loss of repellent from skin occurs through abrasion; absorption and sweat are also important factors. Loss through chemical degradation is of little importance with the compounds currently in use.

For mosquitoes and other biting diptera, deet is the most effective repellent in common use, but long term exposure to it is not recommended particularly for children,. For this reason, when repeated applications of repellent are required, one of the natural products, such as qwenling, should be used. Neem oil has shown a good repellent effect against *Anopheles* mosquitoes. Other repellents effective against certain mosquito species are dimethyl phthalate, ethyl hexanediol and buto-pyronoxyl, each of which can be applied to the skin. Treatment of clothing with permethrin can also provide good protection against mosquitoes.

Tick repellents are not ordinarily applied to the skin. For treatment or impregnation of clothing the best product is permethrin, but deet and butopyronoxyl are also effective. For repelling chiggers, benzyl benzoate, dibutyl phthalate or permethrin are the best materials for treatment of clothing because some efficacy remains, even after one or two washings. Deet is effective on clothing, but is not wash resistant. For protection from fleas, deet is the best repellent and is applied either to the skin or to the clothing. Benzyl benzoate and permethrin are highly effective for impregnating clothes against flea bites.

14.5 Precautions

Apart from the plant based products and permethrin, the repellents discussed above may have a softening action on plastics, some types of rayon and other synthetic fabrics (but not nylon), paint and varnish, but will not damage cotton or wool. Ethyl hexanediol has the least adverse effect, and deet is less injurious than the other materials. Benzyl benzoate should not be applied to the skin for regular use as a repellent and long term skin exposure to deet should be avoided for adults, and deet should not be used at all on young children. Benzyl benzoate and dibutyl phthalate are the only repellents that will withstand leaching by water. Clothing treated with other repellents must be retreated if the garments become wet and all repellent treated clothing should be retreated after each laundering. Repellents should not be applied to wet clothes, and impregnated garments should not be worn until the substance has dried completely.

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15

INSECTICIDE TREATED MOSQUITO NETS OR CURTAINS

15.1 Why treat nets or curtains with insecticide?

Nets have long been appreciated for providing protection against mosquitos, including malaria vectors. However, they are often torn or hung in such a way that mosquitos can enter or bite through them. It is mainly to prevent this that the concept of treating nets with an insecticide and/or repellent arose. With the discovery of synthetic pyrethroids with low mammalian toxicity but rapid insecticidal and excito-repellent impact on mosquitos, treatment of nets became a practical proposition. Pyrethroid treatment of nets gives added personal protection over an untreated net by irritating, repelling or killing mosquitos before they can find a place to bite through the net or, in the case of a damaged net, before they can find a hole through which to enter.

Apart from the improvement in personal protection due to the addition of a chemical barrier to the net, a mosquito net is a rational place to put a residual insecticide. Mosquitos 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 mosquitos are killed through a small investment in a residual insecticide. The area of the nets required to cover a family is much less than the area of the walls and ceiling of their house, which would require treatment in a conventional house spraying programme. Furthermore, netting, especially that made from synthetic fibre, is a favourable medium 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, sometimes such a "mass effect" has not been found and some of the most remarkable impacts recorded on malaria, e.g., on child mortality in The Gambia must be attributed only to the improved personal protection of children if their nets are treated. Only the pyrethroids have proved effective in treating 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 threat, although it is not currently a problem

Some of the same arguments about mosquito net treatment can be applied to the impregnation 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. Also, because the curtains would be in less intimate contact with people than would nets, a more toxic insecticide could be used. They would also provide indoor protection when people are not in bed. On the other hand, it is more difficult to seal all the apertures of a tropical rural house in order to give as a good protection as would a mosquito net to a sleeper.

Insecticide treated mosquito nets have been successfully used by people sleeping out of doors in the hot season, and they can be easily carried and used by nomadic people, migrant workers and refugees. Treated nets may be particularly relevant in situations of political unrest where national control programmes have been interrupted. People with treated nets can help protect themselves from malaria in the absence of a functioning national health system.

15.2 Types of mosquito net

If members of the community do not already own nets, it is important that the ones made available by a project fit the commonly used types of bed or sleeping mat. If they are too small, limbs are likely to protrude and if they are too large, gaps may be left which would allow mosquitos to enter. A prior survey of the sizes required in the community concerned should be made if nets are to be ordered. Strong preferences as to colour should also be noted. Rectangular nets are to be encouraged, rather than conical ones, as it is difficult to hang the latter so as to prevent mosquitos biting through them. They can be attached with strings to points on the walls or roof, to a frame attached to the bed, to four upright poles tied to the legs of the bed, or hung over chairs placed beside a sleeping mat. The net should be hung at a height which allows it to be tucked under the mattress or sleeping mat. Fixing eave curtains to prevent entry of mosquitos is quite easy where roofs are thatched, but more difficult where they are of galvanized iron, as there are few points for attachment and gaps tend to appear around the netting.

The purchase of flimsy mosquito nets is a false economy. Nets made of polyester or nylon fibres are now the preferred type in most countries and, for adequate durability, they should be made of 100 denier fibre (certainly not less than 70 denier). Borders of sheeting help to prevent tearing by bedsprings, rough wooden beds, etc. Good quality monofilament polyethylene is even more durable than polyester but unfortunately it does not appear to retain insecticide deposits for as long as does polyester. Cotton fibre is still widely used in some countries, but is more likely to rot than synthetic fibres and requires higher doses of some insecticides to achieve a given level of mosquito mortality. If conventional nets are unaffordable, it is possible to make treatable bed curtains from polypropylene sacking material, from which some of the horizontal fibres have been removed to provide ventilation.

Mosquito nets generally have a mesh size of approximately 1.5 mm (conventionally expressed as 196 meshes per square inch), but nets with a considerably larger mesh (e.g., 4 mm) are also quite effective at excluding mosquitos when provided with a pyrethroid deposit. Such nets are more comfortable for the sleeper in a hot climate because they are better ventilated.

15.3 Insecticides for net treatment

The pyrethroids listed in Table 19 can be used to treat mosquito nets and eave curtains. In experimental situations on synthetic netting, no extra benefit was proved by using doses at the higher end of the range listed and, for reasons of cost, the lowest effective dose should be used. However, given the variability in the doses actually achieved in routine dipping operations, as well as the washing habits of the people, a safety margin should be considered by programmes to reduce the number of nets that receive an ineffective dose. In general, higher doses of pyrethroids on nets are required to kill *Culex* mosquitos than *Anopheles*.

Permethrin was the first synthetic pyrethroid to be recommended by the WHO for use on nets, and reports of adverse side effects using permethrin treated nets are rare. Retreatment is required every six months as long as the nets are not washed. A single wash reduces the insecticidal activity by more than half.

The alpha-cyano pyrethroids (e.g., alphacypermethrin, deltamethrin, lambda-cyhalothrin, cyfluthrin) are rather more toxic than permethrin to mammals, but this is compensated by their much greater toxicity to insects. For this reason, very small quantities are needed on a net (see Table 19). The residual activity of some of these compounds can last for one year, even with one or two washings. This is a major advantage, especially in places where the malaria transmission season lasts for more than six months per year. The alpha-cyano pyrethroids are cheaper per individual net treatment than permethrin. Their main disadvantage is that skin exposure during treatment can cause transitory side effects, such as tingling or burning. This may cause discomfort, but poses no other danger. Also, people sleeping under freshly treated nets sometimes report cold-like symptoms such as nasal irritation and sneezing.

Etofenprox is structurally different but functionally similar to the conventional pyrethroids. It is used in doses similar to permethrin and performs similarly in experimental conditions. Its main advantage is its very low toxicity, much lower even than permethrin. However, in spite of its different structure, pyrethroid-resistant mosquitos also showed resistance to etofenprox under experimental conditions.

15.4 Treating mosquito nets and curtains

Only one manufacturer produces a net made of polyethylene fibre into which the pyrethroid permethrin has been incorporated before the fibre is extruded. The insecticide inside the fibre is intended to provide a reservoir from which a surface layer is maintained so that the net is more wash and wear resistant and does not need to be retreated so frequently. In all other cases, the insecticide is applied after manufacture and is re-applied at intervals of 6 months to one year. In Sichuan Province, China, and in some West African projects, the insecticide is applied by spraying the nets *in situ*, using the same methods as for house spraying. In other countries, net treatment is carried out by dipping in pyrethroid emulsions or suspensions in water.

15.4.1 Bulk treatment

Dipping different types of netting in the same mixture gives deposits on the dry netting proportional to the uptake of liquid by each piece of netting. Several nets made of the same material may be dipped successively in a bulk mix and it does not matter if the nets are of different sizes as they will naturally take up volumes of liquid proportional to their areas. Thus it is not necessary to measure the size of each net when bulk dipping. A more absorbent material such as cotton would take up more insecticide per square metre than a polyester net dipped in the same mix, while a polyethylene net would take up less. Thus, for the same target dosage per square metre, a more dilute mix should be used with cotton than with synthetic nets. However, as indicated above, for the same insecticidal effect of permethrin or lambda-cyhalothrin, a higher dose per square metre is required on cotton than on synthetic netting. These differences between cotton and synthetics tend to balance out, and where a mixture of light cotton and synthetic nets have to be dipped a single mixture could be used - the cotton nets would absorb more insecticide, but need more for the same effect. Heavy cotton is so absorbent, however, that a more dilute mix would be appropriate. Synthetic nets with cotton borders should be dipped in a mix which would give an appropriate dose on the netting, recognising that a wastefully high dose would go into the border where few mosquitos would encounter it.

The volume of insecticide concentrate in ml (M) required per square metre of netting for a target dose of active ingredient chosen from Table 19 may be calculated as follows: $M = T/(C \times 10)$ ml/m^2 of netting, where T is the target dose in mg/m^2 and C is the strength of the concentrate as a percentage (gm active ingredient/100 ml). Where the strength is given on the label in g/l this should be divided by 10 to convert it to a percentage.

Examples

(i) For a target dose of 200 mg/m^2 from a 50% EC of permethrin, $M = 200/(50 \times 10) = 0.4$ ml of EC is required per m^2 of netting.
(ii) For a target dose of 20 mg/m^2 from a formulation labeled "100 g/l" (=10%), $M = 20/(10 \times 10) = 0.2$ ml of the formulation is required per m^2.

To determine the retention of liquid in litres per square metre of netting (R) a measured area of the netting (which could be a whole mosquito net measuring 2 m long, 1 m wide and 1.5 m high, whose area, by the formula given below, is 11 m^2) is dipped in a measured volume of liquid (e.g., 2 litres) in a bowl. After wringing and allowing the excess liquid to drip back into the bowl, in the manner which will be used in the operational programme, the volume of liquid left in the bowl is measured. If, from an initial 2 l, 1.56 l was left after dipping and wringing an 11 m^2 net, this would indicate that 11 m^2 had retained 0.44 l, i.e., the R is 0.44/11 = 0.04 l/m^2. Thus M ml of concentrate must be diluted to R litres with water to produce the desired dose on the netting.

It is convenient to dip nets in a large plastic bath marked with adhesive tape at the level reached when 10 l is added by measuring cylinder. (Subsidiary marks at 2 and 5 l allow for smaller numbers of nets to be treated without too much waste of insecticide). The volume of concentrate to make up a 10 l batch in the bath is: (M x 10) / R, which would be (0.4 x 10)/0.04 = 100 ml for example (i) above, or 50 ml for example (ii) (in these two examples, the insecticide concentrations in the mixes may be re-stated as 0.5% and 0.05%). The necessary volumes of concentrate can conveniently be measured out with an appropriately marked plastic measuring cup. Pipettes or glass measuring cylinders are not needed for accuracy in this kind of operation, and are easily broken in the field.

After dipping and wringing a net and allowing it to drip back into the bowl for a minute or two, it should be put to dry. This can be done by hanging it for a short time in the open air. It was thought that dripping from the bottom of the net or the action of sunlight might harm the uniformity or strength of the pyrethroid deposit, but there is no strong evidence that this is so. Where many nets are to be hung up for drying, a sheet of plastic may be suspended underneath to collect the drips for re-use. It may be preferred to dry each net on the mattress of the bed for which it is intended. Insecticide dripping into the mattress presumably helps to kill any bedbugs which may be present.

15.4.2 Individual treatment

As an alternative to dipping in a bowl, some people prefer to treat nets individually in a plastic bag. To assess the amount of insecticide, concentrate and water to add to the bag, the area (A) of a rectangular net could be calculated from the formula: A = (2 x H x W) + (2 x H x L) + (L x W), where H, L and W are the height, length and width in metres. For a conical net, A = 0.5 x distance up the slope x circumference at the base.

The volumes of concentrate and water to be added to the bag could be calculated as (A x M) ml and (A x (R - M)) litres respectively. In practice, however, a team who are treating several nets individually would not need to measure many, as they would soon learn the amount of water necessary to just saturate each size of net used by the community and the corresponding amount of insecticide concentrate for each. To speed up the procedure, a large volume of insecticide of the correct concentration can be mixed in a bucket and the volume required to just saturate a net can be poured into each bag.

After adding the insecticide/water mixture to the bag, it should be thoroughly "kneaded" to ensure even distribution of the insecticide over the net. A possible objection to the bag method, as compared to the bowl method, is uneven wetting of the net. Nets treated in bags may be dried in the same way as those treated in a bowl.

15.5 Retreatment of nets

Washing nets removes some of the pyrethroid deposit. People vary greatly in their feelings about the need to wash nets frequently. Some seem quite willing to delay washing and drying nets until the day before re-treatment after 6 months of use. While others feel the need for much more frequent washing.

Guidance about when re-treatment should be carried out may be obtained by bioassaying nets which are in operational use. This is done by making mosquitos walk on the net for a standard time (e.g., 3 minutes) and then observing the percentage knocked down after 1 hour and the mortality after 24 hours. During the exposure period the mosquitos may be confined in WHO bioassay cones attached to the net, or the net may be wrapped round a spherical structure made of wire and the mosquitos introduced into the sphere of netting for their exposure period. Nets freshly treated with the doses of pyrethroids listed in Table 19 should give 80-100% mortality in bioassays. After several months of use, and especially after washing, mortality is observed to decline markedly. It seems reasonable to recommend re-treatment in areas where the mosquito and malaria problem is perennial when mortality in bioassays has dropped to about 50%. This is likely after 6 months with permethrin, but not for 12 months or more, even after washing, with the alpha-cyano pyrethroids. In areas with only a short annual mosquito and malaria transmission season, all that is required is that nets are freshly re-treated in anticipation of that season.

15.6 Precautions

During net dipping, strong rubber gloves should be worn to avoid the risk of skin irritation. The gloves should be checked for holes which would render them useless. Goggles or other eye protection are recommended for those who will be close to the dipping bowl to protect the eyes. A wide shallow dipping bowl is preferable to a tall narrow one as the vapour from insecticide formulations can accumulate in the latter and cause unpleasant symptoms in people who have to dip many nets.

Pyrethroids are toxic to fish. Therefore, any surplus insecticide should not be disposed of where it might enter a pond or stream. Pouring it into a pit latrine it would be useful in killing fly or mosquito larvae. On dry soil it would be harmlessly degraded. As with all insecticide containers, when these are emptied they should be cut up and buried so that there is no risk of their being re-used to store food or drink.

Useful references

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Lengeler, C., Cattani, J., de Savigny, D. (1996) Net gain - Operational aspects of a new health intervention for preventing malaria death. International Development Research Centre/World Health Organization.

Table 19. Suitable pyrethroid insecticides for the treatment of mosquito nets or curtains

Insecticide	Formulation[a]	Dose[b] (mg/m^2)	Toxicity:[c] oral LD_{50} of a.i.[d] for rats (mg/kg of body weight)
Alpha-cypermethrin	SC	20-40	79
Bifenthrin	SC	25	55
Cyfluthrin	EW	30-50	250
Deltamethrin	SC	15-25	135
Etofenprox	EC	200	>10000
Lambda-cyhalothrin	CS	10-20	56
Permethrin	EC	200-500	500

[a] These formulations are recommended, but others may also be appropriate. SC= suspension concentrate; EW=oil-in-water emulsion; CS= capsule suspension; EC=emulsifiable concentrate

[b] These doses refer to synthetic netting. For cotton netting higher doses may be needed (see section 15.4.1).

[c] Toxicity and hazard are not necessarily equivalent; the factors influencing the latter are discussed in section 17.1.1.

[d] a.i. = active ingredient

16

HOUSEHOLD INSECTICIDE PRODUCTS

Household insecticide products are a common and popular mode of personal protection against household insect pests in all parts of the world. These products include aerosols, mosquito coils, fumigation mats, liquid vaporisers and baits.

16.1 Types of household insecticide product

A wide range of products are available to combat household insect pests. In temperate climates, the most important household pests are cockroaches, ants, fleas and, in the summer months, flies, mosquitoes and wasps. In tropical climates mosquitoes are the most important household insect pest, in addition to houseflies, cockroaches, ants, sandflies, bed bugs and in parts of Latin America, triatomine bugs. The active ingredient used in household insecticide products should be cheap and effective with low mammalian toxicity. The most common insecticidal products available are discussed below and a summary of the active ingredients used is shown in Table 20.

16.1.1 Aerosols

Aerosol sprays are the most widely used household insecticide product. They can be divided into flying insect killers (FIK) for use against mosquitoes, flies and wasps and crawling insect killer (CIK) for use against cockroaches, ants, fleas, bed bugs and triatomine bugs. Dual action products also exist. FIKs can be either oil-based or water-based, with the latter generally more popular with consumers because the smell is less unpleasant. The main differences between FIKs and CIKs are the active ingredients used, the concentration of actives and the aerosol droplet size. The active ingredients for FIKs are predominantly pyrethroid knockdown agents and in CIKs the active ingredients are usually residual pyrethroids. Sometimes the same active ingredients are found in FIKs and CIKs, but concentrations tend to be higher in the latter in order to leave a residual deposit on surfaces. Non-gas propellent delivery systems such as trigger sprayer are gaining more importance due to their higher safety.

16.1.2 Mosquito coils

Mosquito coils are most commonly used in Asia, Africa and the Western Pacific region. Coils are made from a mixture of active and inert ingredients (e.g., saw dust or coconut husks and pigment). The active ingredients commonly used in mosquito coils are from the class of pyrethroids which provide quick knockdown action. The active ingredients in the smoke, produced when the coil is burnt, deter mosquitoes and other flying insects from entering houses. Mosquito biting rates can be reduced by up to 80% in the presence of a burning coil depending on the size of room in which it is used and the active ingredient in the coil.

16.1.3 Electric vaporising mat

Electric vaporizing mats have become increasingly popular since the early 1980s and consist of a mat heater and vaporising mat. The mat is made from fibre board impregnated with insecticide, stabilizers, slow-releasing agents, perfumes and coloring agents. The heater is plugged into an ordinary household electric socket and heats up to an optimum temperature of between 110°C and 160°C, depending on the type of heater and its accompanying mats. When the mat is heated, insecticide vapour is released to provide a low aerial concentration of insecticide. This induces behaviour changes in flying insects through a sequence of sub-lethal effects including deterring them from entering the room, bite inhibition and knock down. Continued exposure results in death of the insect. The size of the mat is compatible with the associated brand of heater for easy insertion and removal. The advantage of using mats over coils is that with the former, there is no unpleasant smoke. The disadvantages are that electricity is required and replacement mats, are generally more expensive than coils.

16.1.4 Electric liquid vaporiser

The principle of this product is similar to that of the electric vaporising mat. It consists of a heater and a bottle of liquid insecticide. The liquid (typically a hydrocarbon solvent mixture with a dissolved pyrethroid insecticide) is drawn up through a wick made from a variety of materials (e.g., carbon, ceramic or fibre). The end of the wick is positioned within a heating element. When heated, the insecticide vaporises from the wick. A bottle of liquid insecticide with its wick will last 360 hours with normal usage. With the vaporising mat technology, a new mat has to be inserted every day, whereas the liquid in a liquid vaporizer only needs to be replaced every one or two months.

16.1.5 Baits

Baits can be formulated to control ants, cockroaches and houseflies. They can be in the form of a loose granular bait, a purpose-built bait station or a gel bait. Baits consist of a food attractant (e.g., glucose) and an insecticide. For cockroach and ant baits, the active ingredients used include abamectin, boric acid, chlorpyrifos, dichlorvos, fenitrothion, hydramethylnon, propoxur and sulfluramid. (See section 3.1.4 for fly baits.)

16.2 Household insecticide products and public health

Household insecticide products are a popular, user-friendly and cost-effective mode of personal protection against household insect pests. World-wide surveys have shown that consumers spend a considerable amount of money each year on such chemicals. The use of household insecticide products are a form of active community participation in household insect pest control. As the main targets for household insecticides are mosquitoes and other disease vectors, emphasis should should be on promoting the use of safe and effective household insecticide products as an integral part of vector-borne disease control programmes.

Table 20. Active ingredients used in household insecticide products

Product	Active ingredient	Concentration range %	Toxicity[a] : Oral LD50 of a.i.[b] for rats (mg/kg of body weight)
Aerosol	bendiocarb	0.1-0.5	55
	bioresmethrin	0.04 - 0.2	>7000
	chlorpyrifos	0.1-1.0	135
	cyfluthrin	0.01 - 0.1	250
	cypermethrin	0.1 - 0.35	250
	cyphenothrin	0.15 - 0.5	318
	deltamethrin	0.005 - 0.025	135
	dichlorvos	0.5 - 1.0	56
	d-phenothrin	0.05 - 1.0	>10000
	d-allethrin	0.1-0.5	500
	d-trans allethrin	0.1 - 0.5	500
	etofenprox	0.5 - 1.0	>10000
	fenvalerate	0.05 - 0.3	500
	permethrin	0.05 - 1	500
	prallethrin	0.05 - 0.4	460
	propoxur	0.5 - 2	95
	pirimiphos methyl	0.5 - 2	2018
	S-bioallethrin	0.04 - 0.7	700
	tetramethrin	0.03 - 0.6	>5000
Mosquito coil	d-allethrin	0.1 - 0.3	500
	d-trans allethrin	0.05 - 0.3	500
	transfluthrin	0.02 - 0.05	>5000
	prallethrin	0.03 - 0.08	460
Electric vaporiser mat	d- allethrin	25 - 60 mg/mat	500
	d-trans allethrin	15 - 30 mg/mat	500
	prallethrin	6 - 15 mg/mat	460
	S-bioallethrin	15 - 25 mg/mat	700
	transfluthrin	6 - 15 mg/mat	>5000
Liquid vaporizer	d-allethrin	3 - 6	500
	d-transfluthrin	1.5 - 6	500
	prallethrin	0.6 - 1.5	460
	S-bioallethrin	1.2 - 2.4	700
	transfluthrin	0.8 - 1.5	>5000
Bait	abamectin	0.005 - 0.1	10
	boric acid	1.0 - 52	-
	chlorpyrifos	0.1 - 2	135
	fenitrothion	1 - 5	503
	hydramethylnon	1 - 2.15	1200
	propoxur	0.25 - 2	95
	pirimiphos methyl	0.5 - 2	2018
	sulfluramid	0.5 - 2	543

[a] Toxicity and hazard are not necessarily equivalent; the factors influencing the latter are discussed in section 17.1.1.

[b] a.i. = active ingredient

17

SAFE USE OF PESTICIDES

The following recommendations are intended as a guide to those responsible for the use of pesticides in public health programmes for vector control. They are based mainly on recommendations made by several WHO expert committees on Vector Biology and Control.

17.1 General principles of safety measures

All pesticides are toxic to some degree. Care in handling pesticides, particularly by spraymen and people living in sprayed houses, should be a routine practice and form an integral part of any programme involving the application of pesticides. The general principles on which safety measures are based are discussed below, with special consideration being given to the indoor use of residual sprays.

17.1.1 Toxicity and hazard

In recommending safety measures it is necessary to take into account both the nature of the pesticide, including its formulation, and the proposed method of application. A measure of the potential toxicity of pesticides to man and other mammals is obtained from the acute oral and/or dermal LD_{50} values,[1] which provide a statistical estimate of the number of mg of active ingredient per kg of body weight required to kill 50% of a large population of test animals. While these figures represent the relative acute toxicities of various compounds to the test animals, they do not measure the actual hazard involved when a pesticide is used in the field. Factors that influence hazard are: type of formulation, type of packaging, concentration of the pesticide in the finished formulation, method of application, amount of surface or area to be treated, dosage required, association of human or animal populations with treated surface or area, and the species of animals exposed, their age, sex and condition. In selecting specific pesticide formulations from manufacturers, the oral and dermal LD_{50} for rats should be checked because the variety of available formulations may have values which differ markedly from those for the active ingredient which are quoted in the tables of this guide.

Since the last revision of this guide in 1984, pyrethroid insecticide use has increased dramatically. Pyrethroids have relatively low values for oral LD_{50} for rats which indicates a relatively high intrinsic toxicity but are, in fact, very safe insecticides. They are effective against insects at extremely low doses and therefore have a high

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[1] Oral LD_{50} values for rats have been included in the tables listing chemicals used for controlling particular vectors and pests. The values given are taken from World Health Organization (1996) The WHO recommended classification of pesticides by hazard. Unpublished document WHO/PCS/96.3.

ratio of insect to mammalian toxicity. Even with frequent exposure to low concentrations (e.g., when handling treated mosquito nets), the risk of toxicity is remote because any pyrethroid reaching the systemic circulation will be metabolised rapidly to less toxic metabolites. It is therefore concluded that field use of pyrethroids, in recommended concentrations and with the precautions necessary for the application of any chemical, poses little hazard to applicators. However, to avoid discomfort, skin should be protected when handling pyrethroid concentrates.

17.1.2 Supplies and equipment

The planning of a vector control campaign must include provision for the safe transport and secure storage of the pesticide concentrates. These should not be stored in rooms in which people live or in which food is kept. They should be stored out of direct sunlight and protected from rain and flooding. Protection against theft, misuse, and access to them by children must be provided. Those in charge of programmes using pesticides must ensure that suitably qualified people take full responsibility for the custody of stocks and the disposal or treatment of empty or nearly empty containers (see section 17.1.8).

Pesticides which have satisfactorily completed the WHO Pesticide Evaluation Scheme (WHOPES) and for which either interim or final specification has been recommended should be used in preference to compounds which have not been assessed.

All pesticide containers should be adequately labeled to identify the contents and show, in a form comprehensible to the operator, the nature of the material and the precautions to be employed. All equipment used to distribute the pesticides should conform to the general and specific recommendations with regard to design and maintenance published by WHO. There must be regular, systematic inspection of all equipment to ensure that there is no leakage from faulty valves, gaskets or hoses.

17.1.3 Responsibility for safety

Any authority approving the use of a pesticide, including the substitution of a new material for one already in use, must ensure that the application is carried out under appropriate supervision. In some instances, consultants or technical experts will have to be recruited to provide specialized training and give advice. Their function should be to inform the local medical and other specialized staff in the public health programmes on such matters as the proper training of spray teams, the setting up of any special diagnostic measures, and the organization of facilities for treatment, including the provision of antidotes in cases of accidental poisoning. While the ultimate responsibility for the health of spraymen and those living in treated premises must rest with a medical officer, the day-to-day responsibility for ensuring that sound and safe techniques of application are practiced can be given to any competent field operator. The foreman and other responsible field operators should receive pertinent instructions on rates of application to ensure that correct dosages are applied.

17.1.4 Safety training

Training in the safe use of pesticides should be on two levels: (1) for the medical specialist, entomologist, engineer or sanitarian, instruction should be given on the mode of action of the new pesticide, the significance of any diagnostic measures, recognition of the signs and symptoms of any toxic effects, and the necessary facilities for treatment of cases of poisoning; and (2) for the foreman and other responsible field operators, training should be given in the techniques of spraying, safety precautions, protective equipment, recognition of the early signs and symptoms of poisoning and first aid measures, including resuscitation (see section 17.3.2). Handbooks for primary health care workers and doctors on how to manage poisoning cases have been published by Bayer[1] and WHO[2].

The staff who will carry out the work must be organized into squads in which each person knows precisely what their duties and responsibilities are. Before toxic materials are used, a training period is essential, during which the spraymen should work in the required protective clothing, to ensure that it is acceptable to the operators and that work can be carried out properly while it is being worn.

17.1.5 Medical surveillance

Arrangements must be made to ensure that any exposed person can easily report any symptoms to a supervisor who will then bring the complaint to the attention of a medical officer. Any undue prevalence of illness not associated with well-recognized signs and symptoms of poisoning by the particular pesticide should be noted and reported to the appropriate health authorities. Apart from clinical surveillance, quantitative biochemical tests may be carried out in an attempt to assess the degree of exposure. The significance and importance of regular determination of blood cholinesterase activity when organophosphates are used are discussed in section 17.2.2. Detailed procedures have been described for measuring the exposure of spray operators[3].

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1 Bayer (1993) Treatment of pesticide poisonings - a guide for doctors.

2 World Health Organization. Management of poisoning, A handbook for health care workers (In press).

3 World Health Organization (1982) Field surveys of exposure to pesticides. Standard protocol. Unpublished document VBC/82.1.

17.1.6 Protective equipment

The various items of protective clothing that may have to be used are described below, with notes on their proper care.

- *Hats.* These should be of impervious material with a broad brim to protect the face and neck and should be able to withstand regular cleaning or be replaced regularly.
- *Veils & visors.* A plastic mesh net will protect the face from larger spray droplets and permit adequate visibility. Alternatively, a transparent plastic visor can be used.
- *Capes.* Short capes of light plastic may be suspended from the hat to protect the shoulders.
- *Overalls.* These should be of light, durable cotton fabric. They must be washed regularly, with frequency depending on the pesticide being used. Washing with soap, detergent or washing soda is adequate in the case of organophosphate and carbamate compounds. A rinse in light kerosene may be needed for organochlorine compounds, which should be followed by washing.
- *Aprons.* Rubber or poly vinyl chloride (PVC) aprons will protect from spills of liquid concentrates.
- *Rubber boots.* These will complete the protection afforded by the apron.
- *Gloves.* PVC or rubber gloves or gauntlets should be used when handling concentrates. When handling pyrethroids PVC gloves should not be used as pyrethroids are absorbed by PVC. Rubber gloves should be used when handling concentrates with an organic solvent base. Cotton gloves offer some protection for hands when regularly washed. Impervious gloves must be cleaned regularly, inside and out.
- *Face masks.* Masks of gauze or similar material are capable of filtering the particles from a water-dispersible powder spray and may be worn to reduce inhalation of the spray and dermal exposure of the face, if such protection is considered desirable. They must be washed regularly and, in some instances, fresh masks may need to be used for the second half of the day's spraying, so that the face is not contaminated.
- *Respirators* (masks with cartridge or canister). These are designed to protect operators fogging with very toxic powder formulations. The cartridge or canister must be renewed regularly according to usage. To be effective, the respirator must fit the face closely, and must be cleaned regularly. Respirators are not usually required for normal vector control operations.

17.1.7 Personal hygiene

Scrupulous attention to personal hygiene among spray operators is an essential component in the safe use of pesticides. For professional spraymen operating in the tropics, safety precautions may depend largely on personal hygiene, including the washing and changing of clothes. A drill for carrying out and supervising personal hygiene, the regular washing of protective clothes and cleaning of equipment should be organized along the following lines:

- Spraymen should be provided with at least two uniforms to allow for frequent changes.
- Washing facilities with sufficient water and soap should be made available in the field at appropriate locations.
- All working clothes must be removed at the end of each day's operations and a shower or bath taken.
- Working clothes must be washed regularly, the frequency depending on the toxicity of the formulation used.
- Particular attention should be given to washing gloves, as wearing contaminated gloves may be more dangerous than not wearing gloves at all.
- Spray operators must clean themselves before eating.
- Eating, drinking and smoking during work must be strictly forbidden.
- When work involves insecticides of relatively high toxicity, the hours of work must be arranged so that exposure to the material being used is not excessive; transport should be arranged so that there is not a long delay between the end of the day's operations and the return to base for washing.

17.1.8 Disposal of empty or nearly empty containers

It is important to ensure the safe disposal of empty or nearly empty containers. As far as possible, they must not be removed by unauthorized people who might use them as containers for food or drinking water, especially in areas where such containers are scarce. It is understood that some pesticide containers will inevitably be reused, so it is important to ensure that risk of poisoning is minimised. Used containers can be effectively decontaminated by rinsing two or three times with water and scrubbing the insides thoroughly. If a drum contained an organophosphate, an additional rinse should be carried out with washing soda 50 g/l (5%) and the solution allowed to remain in the container overnight. Rubber gauntlets should be worn during this work and a soakage pit should be provided for the rinsings. All containers should be indelibly marked "not for storage of food or water for human or animal consumption".

17.2 Operative procedures

17.2.1 Preparation of spray materials

The greatest degree of exposure occurs during handling of pesticide concentrates and appropriate facilities for this must be provided. When compounds of relatively high mammalian toxicity are to be used by non-commercial operators, these compounds should be supplied in diluted form for safety reasons. In preparing concentrates of water dispersible powders, use must be made of deep mixing vessels and long handled mixers to protect the operator from splashing and to permit stirring from a standing position.

For the dilution of solid pastes, power appliances are most appropriate and permit the dilution to be prepared in a closed vessel. Where such appliances are not available, long handled mixers and tall vessels should be provided. No vessel should be filled to the point where the operator risks being splashed. Long-handled dippers or scoops should be used for transferring the insecticides from one vessel to another. The concentrates may be subdivided into bags or small containers suitable for safe mixing by the spraymen in the field. All smaller containers should be secured and packed to withstand transport to the periphery of the area of application. Adequate protective clothing (see section 17.1.6) should be available for those handling concentrates and adequate washing facilities must be immediately accessible so that spills on the skin can be quickly removed.

17.2.2 House treatment with residual sprays

It must be recognized that spraymen will inevitably be exposed to insecticide spray and that absolute protection of the skin and respiratory tract would impose physical limitations that would make such work impossible in hot climates. The skin can be protected to a considerable degree by cotton clothing and by regular washing with soap and water.

Inhabitants of houses to be sprayed should be told the purpose and the times of insecticide applications and should be given clear instructions as to what they have to do before and after their houses have been treated (e.g., remove all foodstuffs and cooking utensils, stay out of the house during spraying, children may enter the house only after the floors have been swept or washed).

When handling pesticide concentrates (both water dispersible powders and emulsifiable concentrates), appropriate facilities must be provided. Workers must use protective clothing and equipment as indicated below. When weighing the insecticide powder and during preparation of the suspension, workers should avoid contact with the insecticide powder and should stand in such a position that the wind blows the dust away from them. If the concentrate comes into contact with skin it should be washed off at once. Work should be performed away from food and utensils.

Any spillage of insecticide on the ground during mixing should be removed, in particular for the protection of chickens and domestic animals. Concrete surfaces should be washed and earth surfaces should be cleaned by scooping up the damp earth and burying it. Large numbers of insects, such as flies, moths and bed-bugs, may be killed and fall on the floor during indoor spraying operations, thereby presenting an insecticide hazard, particularly to chickens. Floors should therefore be carefully swept and the sweepings safely disposed of.

17.2.2.1 Specific precautions for particular insecticides

The degree of mammalian toxicity of an insecticide, in particular its dermal toxicity, greatly influences its hazard to people during indoor residual application. The specific precautions required, in addition to those outlined above, are summarized for several commonly used insecticides.

For organochlorine compounds such as DDT, operators should wear protective clothing and some form of head covering. After completion of the day's work, they should wash and change into their ordinary clothing. For organophosphate application, spraymen should wear clean, regularly washed overalls, broad-brimmed hats and shoes or boots (not sandals) while spraying. The mixers and baggers and any other spraying personnel handling the concentrate should also wear this protective clothing and rubber gloves while working. They should wash, preferably by taking a shower, at the end of a day's work.

In the case of fenitrothion and diazinon, strict precautionary measures should be observed, including daily washing of overalls, use of cloth face masks, broad-brimmed hats and shoes or boots. When handling the concentrate, mixers and baggers should also wear rubber boots, gloves and aprons. Any concentrate getting on to the skin should be washed off at once. Whenever clothes become wet from the insecticide, they should be changed immediately. Operators should not be exposed to the insecticide for longer than the predetermined working hours (usually 5-6 hours application). Transport should be arranged to minimize delays between the end of a day's operations and return to base for showering, which should be mandatory. Once a week, all personnel exposed to the insecticide should be examined. The examination should include a determination of cholinesterase, as operators may have to be withdrawn from exposure if cholinesterase activity decreases significantly (to 50% of a well-established pre-exposure value). The tintometric method is a suitable and simple technique for determining blood cholinesterase, and the commercially available field kit[1] contains an instruction sheet.

For the carbamate insecticides, ordinary precautionary measures should be taken in the application of carbaryl, but stricter precautions are required for propoxur. The spraymen should wear clean overalls, cloth face masks, broad-brimmed hats and shoes or boots. Mixers and baggers should wear the protective clothing described above as well as rubber gloves and aprons. Emphasis should be on hygiene (e.g., a bath or shower should be taken after the day's work and clothes should be washed after each pump charge). Cholinesterase monitoring is not indicated when carbamate insecticides are applied since the inhibited enzyme reactivates too rapidly for this technique to be of operational use. For bendiocarb, precautions to be taken are as for propoxur except that the insecticide should be mixed in the sprayer. The outer sachet is opened and the inner soluble sachet is added to the sprayer containing the required amount of water. The sprayer should be closed, pressurized and shaken well. The empty outer sachet should be returned to the supervisor for disposal.

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[1] Produced by Tintometer Sales Ltd, The Colour Laboratory, Salisbury, England.

For the pyrethroids, ordinary precautionary measures, such as wearing clean overalls, canvas shoes or rubber boots and hats, and washing body and changing clothing after a day's work, should be observed. The wearing of disposable face masks is also recommended. Whenever feasible, exposure should be limited to fewer than seven pump charges per day and the operators should comply strictly with the hygiene regimen (washing of hands and face after the spraying of a pump charge).

17.2.3 Larvicide treatments

Persons applying larvicides are generally liable to a much lower degree of exposure than spraymen engaged in indoor house treatment, with exposure confined mainly to the hands and arms.

For the majority of larvicides, care must be taken to avoid contamination of drinking-water and waters inhabited by non-target organisms of value, such as fish and crustaceans. Temephos, methoprene, *Bacillus thuringiensis* and permethrin may be used to control mosquitoes that breed in drinking water containers (see section 2.2.3). Such treatment should always be made with pesticide formulations that ensure accurate and reliable dosage.

17.2.4 Rodenticide treatments

Compounds which are toxic to rodents are usually also toxic to non-target mammals, including humans. The ratio of pest to human toxicity is understandably lower for rodenticides than insecticides. When handling rodenticides, gloves should be worn and hands should be thoroughly washed afterwards. In enclosed areas, the bait should be placed on trays or plates, while in open areas, bait stations (wooden box, tube, etc.) should be used. Rodenticides which rapidly break down in the bodies of rodents should be used where possible to prevent secondary toxicity to predators scavenging on dead rodents. Where rodenticides are applied in the domestic environment, specific antidote should always be available, as accidental poisoning of humans and non-target animals can occur. Unfortunately, very few of the acute rodenticides have a specific antitode, and due to their rapid action there is seldom sufficient time to administer one. The slow mode of action of the anticoagulants is highly beneficial for safety reasons as the symptoms of poisoning can be recognised and the antidote, vitamin K_1, applied.

In order to reduce the risk of unintentional poisoning, anticoagulants should be used in preference to acute rodenticides. Toxic compounds should be stored safely and applied in a manner which reduces access to non-target animals. For instance, placing the rodenticide tray under a weighted wooden crate with small openings in it will help prevent access to it by larger animals.

17.2.5 Herbicide applications

Particular attention is required during herbicide applications to avoid spray-drift onto crops and other non-target vegetation. As these compounds may be non-specific and highly phytotoxic even at very low concentrations, spraying should be performed under as near windless conditions as possible.

Dalapon-sodium has a low oral toxicity and breaks down in the environment within a few weeks, but can cause skin irritation. Diquat is generally safe if applied at the rate of 0.6-0.8 kg of a.i./ha using a non-toxic wetting agent. It has a short persistence and drinking and irrigation water is safe to use 1-2 days after application. 2, 4-D has a wide spectrum and is effective as a contact herbicide against broad-leaved weeds. It is not harmful to wildlife if used at rates of 2-4 kg of a.i./ha, and there is no evidence of accumulation of residues. The ester formulation is harmful to fish.

17.2.6 Application by motorized equipment and aircraft

The main hazards are to those who handle bulk concentrates in loading the machines and to the pilots, operators and ground staff. Specialised equipment, including pumps and pouring devices for transferring liquids, must be available to them. The cleaning and maintenance of machines, including hoses and connections, should be done with care to ensure that mechanics do not accidentally contaminate themselves with concentrates during routine maintenance. Washing facilities to deal with large spillages of concentrate must be available at loading points.

Aircraft and machinery must be properly designed for the purposes for which they will be used and pilots must be given a specific training course in the use of toxic pesticides. As large tracts of land and urban areas may be treated, there must be prior consultation with the health authorities responsible for the residents and for the food and water supplies in these areas. Any limits they lay down must be strictly adhered to. Residents should be told the purpose and times of the pesticide applications.

17.2.7 Application to people

Liquid or dust formulations may be applied directly to people, clothes and cattle to control external parasites. Special care must be taken to ensure that the correct formulation is used, as mistaken use of a concentrate may have disastrous results.

17.2.8 Special devices

These include vapour release devices, baits and impregnated cords and cloth. In operations using these devices, the materials will normally be commercially available and will have been prepared by mixing pesticide concentrates with the appropriate food for the pest. Such baits should not be prepared or used inside dwellings, and should be freshly prepared for each application or stored in clearly labeled containers, out of reach of children and animals.

17.3 Diagnosis and treatment of insecticide poisoning

17.3.1 Symptoms of poisoning

Symptoms of exposure to organophosphate and carbamate insecticides are similar, but the signs of poisoning may appear more rapidly in the case of the latter. For organoposphates, the signs may not appear until after the individual has left work, and their association with occupational poisoning may not be recognized immediately. Early symptoms of poisoning include excessive sweating, headache, blurred vision, narrowed pupils, weakness, dizziness, nausea, hypersalivation, excessive bronchial secretion, vomiting, stomach pains, slurred speech and muscle twitching. Later there may be diarrhoea, convulsions, coma, loss of reflexes and loss of sphincter control. The symptoms of pyrethroid poisoning may include paraesthesia (cold burning), particularly of the face and hands, irritation of the upper respiratory tract, salivation and occasionally, allergic reactions.

17.3.2 First aid and decontamination

Once poisoning has been diagnosed, it is important to collect the following information which will be needed once a doctor or medical officer is available: the name of the toxic substance (see packaging of product), amount and route of exposure (skin, mouth, etc.), time of poisoning, reason for poisoning (intentional, accidental, overexposure while spraying) and any other information related to the circumstances of poisoning.

It is important that the person administering first aid is protected from the solvents and active ingredient. Therefore, gloves should be worn and if mouth-to-mouth respiration is required, all vomit and saliva should be removed from the patients mouth and a clean handkerchief placed between the mouth of the patient and the mouth of the person giving first aid. At the onset of symptoms, all contaminated clothing should be immediately removed, affected skin should be washed with soap and flushed with large quantities of water. If insecticide has been swallowed, give plenty of water (no milk or alcohol) to drink and, if available, a suspension of 10 g of medical charcoal in 150-200 ml of water. Vomiting should only be induced by a qualified person unless the compound swallowed is highly toxic and medical assistance is not readily available. The risk associated with inducing vomiting is that aspiration of the solvent could induce pneumonia. Only in fully conscious people should vomiting be induced, and this by stimulating the back of the throat with a finger tip. Give large quantities of water to drink after inducing vomiting. If eyes are contaminated, open the lids with fingers and wash the conjunctivae with running water for several minutes.

The patient should be transported as soon as possible to a doctor to receive an antidote. For organophosphate and carbamate poisoning, 2-4 mg of atropine should be given intravenously (for children 0.5-2 mg, according to weight). Depending on symptoms, further doses of 2 mg should be given every 15 minutes for 2-12 hours, longer in severe cases. Slight atropine overdose can be recognised by dilated pupils, heart rate over 140 beats/minute, reddening of the face and a dry mouth. Oximes, such as obidoxime chloride (Toxogonin) or pralidoxime chloride (Protapam, 2-PAM) must not be given in cases of carbamate poisoning. Automatic injectors are available for administration of atropine[1]. It is recommended that these devices should be at hand where organophosphate or carbamate insecticides are being applied, but should not be issued to the individual operators. Instead, where a doctor or medical officer is not available, field supervisors should be trained in the emergency treatment of insecticide poisoning (including atropine injection) and resuscitation. WHO has developed a suitable training course for public health workers[2].

In treating of pyrethroid poisoning, vitamin E oil preparations can be given for prolonged paraesthesia. To treat irritation of the upper respiratory tract, inhalation of water vapour aerosol or cough relieving medicines should relieve symptoms. Only in cases of definite allergic symptoms should corticosteroids be administered. On occurrence of convulsions after severe intoxication, intravenous injections of 5-10 mg Diazepam (or other benzdiazepine derivatives) should be given.

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1 For example, "Atropen" auto-injector (containing 2 mg of atropine in solution), produced by Duphar, PO Box 7005, Amsterdam, The Netherlands.

2 World Health Organization (1994) Multi-level course on safe use of pesticides and diagnosis and treatment of pesticide poisoning. Unpublished document WHO/PCS/94.3.

18

PESTICIDE APPLICATION RATES AND CONVERSION FACTORS

The information given in this section is to enable the operator to prepare formulations properly and to convert the specific percentage concentrations of spray or quantities to be applied for a given area into metric, US or UK equivalents. For practical purposes, the conversion rates used are rounded off.

18.1 Preparation of spray suspension from wettable powders

Table 21. Amount of wettable powder (WP) or water-dispersible powder (WDP) required for the preparation of approximately 380 litres (100 gal (US); 83 gal (UK)) of spray suspensions of various concentration[b].

Concentration of a.i.[a] in WP (%)	Concentration of spray suspension (%)				
	5	2.5	1	0.5	0.25
90	21.0 (46.3)	10.5 (23.1)	4.2 (9.3)	2.1 (4.6)	1.0 (2.3)
75	25.2 (55.6)	12.6 (27.8)	5.0 (11.1)	2.5 (5.6)	1.3 (2.8)
50	37.8 (83.3)	18.9 (41.7)	7.6 (16.7)	3.8 (8.3)	1.9 (4.2)
25	75.6 (166.7)	37.8 (88.3)	15.1 (33.3)	7.6 (16.7)	3.8 (8.3)

[a] active ingredient
[b] Weights are given in kg (lb).

The general formula is:

$$X = \frac{A \times B \times D}{C}$$

in which X = amount of water-dispersible powder required
A = percentage concentration desired
B = quantity of spray desired
C = percentage concentration of water-dispersible powder
D =
1 if X and B are expressed in kg and litres, respectively
8.33 if X and B are expressed in lb and gal (US), respectively
10 if X and B are expressed in lb and gal (UK), respectively.

Example: 380 litres (100 gal (US)) of 1% spray suspension are to be prepared from 50% powder:

$$X = \frac{1 \times 380 \times 1}{50} = 7.6 \text{ kg} \quad \text{or} \quad X = \frac{1 \times 100 \times 8.3}{50} = 16.7 \text{ lb}$$

7.6 kg (16.7 lb) of water-dispersible powder are required.

18.2 Formulation of emulsifiable concentrates and sprays

Table 22. Preparation of emulsifiable concentrates from technical material

Concentration desired (%)	Weight of technical material required to make the given volumes of concentrate[a]		
	100 litres	100 gal (US)	100 gal (UK)
35	35 kg	292 lb	350 lb
25	25 kg	208 lb	250 lb
15	15 kg	125 lb	150 lb
12.5	12.5 kg	104 lb	125 lb
6.25	6.25 kg	52 lb	62.5 lb

[a] To every 100 parts of concentrate, 2 parts of emulsifier should be added.

The general formula is:

$$X = \frac{A \times B \times C}{100}$$

in which:

X = amount of technical material required
A = percentage concentration desired
B = quantity of emulsion concentrate desired
C =

1 if X and B are expressed in kg and litres, espectively
8.33 if X and B are expressed in lb and gal (US), respectively
10 if x and B are expressed in lb and gal (UK), respectively.

Example: 190 litres (50 gal (US)); 41.5 gal (UK) of 25% concentrate are to be prepared from technical grade material:

$$X = \frac{25 \times 190 \times 1}{100} = 47.5\ \text{kg} \quad \text{or} \quad X = \frac{25 \times 50 \times 8.33}{100} = 104\ \text{lb}$$

47.5 kg (104 lb) of technical material are required.

Formulation of emulsifiable concentrates should be undertaken by professional formulators.

Table 23 Preparation of emulsions from emulsifiable concentrates (EC) of different strengths

Percentage of a.i.[a] in EC	Parts water to be added to 1 part of EC for given final concentration				
	5%	2.5%	1%	0.5%	0.25%
80	15	31	79	159	319
60	11	23	50	119	239
50	9	19	49	99	199
25	4	9	24	49	99
10	1	3	9	19	39

[a] active ingredient

The general formula is:

$$X = (A/B) - 1$$

in which

X = parts of water to be added to 1 part of emulsifiable concentrate
A = concentration of the emulsifiable concentrate (%)
B = required concentration of the final formulation (%)

Example: A 0.5% formulation is to be prepared from a 25% concentrate:

$$X = (25/0.5) - 1 = 49$$

49 parts of water to 1 part of concentrate are required.

18.3 Amount of formulation required to give a specific weight of active ingredient per unit area

Table 24. Requirements for spray formulations

Dosage	Litres[a] of spray required per 100 m^2 (1000 ft^2) using given concentrations of technical insecticide				
(Weight/unit area)	0.25%	0.5%	1.0%	2.5%	5.0%
2 g/m^2 (200 mg/ft^2)	-	-	20	8	4
1 g/m^2 (100 mg/ft^2)	-	20	10	4	2
0.5 g/m^2 (50 mg/ft^2)	20	10	5	2	1
0.2 g/m^2 (20 mg/ft^2)	8	4	2	0.8	0.4

[a] 1 litre is approximately equivalent to 0.25 gall (US) or 0.2 gal (UK). For more precise equivalents, see section 18.7.

Table 25. Requirements for emulsifiable concentrates and dusts

Dosage		Amount of 25% concentrate[a] required		Amount of 5% dust[b] required	
kg/ha	lb/acre			kg	lb
4.54	10	18.2 litres	4.8 gal (US) 4.0 gal (US)	90.8	200
2.27	5	9.1 litres	2.4 gal (US) 2.0 gal (UK)	45.4	100
1.36	3	5.5 litres	1.4 gal (US) 1.2 gal (UK)	27.2	60
1.0	2.2	4.2 litres	1.1 gal (US) 0.9 gal (UK)	20.0	44
0.45	1	1.8 litres	1.9 gal (US) 1.6 pt (UK)	9.1	20
0.23	0.5	900 ml	1.9 pt (US) 1.6 pt (UK)	4.5	10
0.045	0.1	200 ml	6.1 fl oz (US) 6.4 fl oz (UK)	-	-

[a] Containing 0.25 kg/litre (2.1 lb/gal (US); 2.5 lb/gal (UK)
[b] Containing 50 g of active ingredient per kg.

The general formula are:

for concentrates: $$X = \frac{A \times 100}{B \times C}$$

for dusts: $$X = \frac{A \times 100}{B}$$

in which

X = amount of concentrate or dust required
A = dosage (kg/ha or lb/acre)
B = percentage concentration of the product used
C =
- 1 if X and A are expressed in litres and kg/ha, respectively
- 8.33 if X and A are expressed in gal (US) and lb/acre, respectively
- 10 if X is expressed in gal (UK)

Examples: For a dosage of 4.54 kg/ha (10 lb/acre):

(a) Using a 25% concentrate:

$$X = \frac{4.54 \times 100}{25 \times 1} = 18.2 \text{ litres} \quad \text{or} \quad X = \frac{10 \times 100}{25 \times 8.33} = 4.8 \text{ gal (US)}$$

18.2 litres of concentrate per ha or 4.8 gal (US) of concentrate per acre are required.

(b) Using a 5% dust:

$$X = \frac{4.54 \times 100}{5} = 90.8 \text{ kg} \quad \text{or} \quad X = \frac{10 \times 100}{5} = 200 \text{ lb}$$

The amount of dust required is 90.8 kg/ha or 200 lb/acre.

18.4 Conversion tables for dosages in parts per million

Table 26. Concentrations of active ingredient equivalent to one part per million

1 part per million (ppm)	=	1 mg (0.015 grain) per kg
	=	1 g (15.4 grain) per tonne
	=	0.007 grain (0.45 mg) per lb
	=	1 ml (0.035 fl oz (UK) per 1000 litres
	=	0.16 fl oz (UK) (4.5 ml) per 1000 gal (UK)
	=	0.13 fl oz (US) (3.8 ml) per 1000 gal (US)

Table 27. Dilution factors for a 25 % concentrate

Required concentration	Volume of 25% concentrate[a] needed for the given volumes of water		
(mg/l)	1 million litres of water	1 million gal (US) of water	1 million gal (UK) of water
1	4 litres	4 gal (US)	4 gal (UK)
0.1	400 ml	3.2 pint (US)	3.2 pint (UK)
0.01	40 ml	5.1 fl oz (US)	6.5 fl oz (UK)
0.001	4 ml	0.5 fl oz (US)	0.6 fl oz (UK)

Table 28. Relationship between concentration, treatment dosage and water depth

Treatment dosage		Concentration (ppm) at given depth[a]	
g/ha	lb/acre	2.5 cm (1 In)	30 cm (1 ft)
2240	2.0	8.8	0.74
1120	1.0	4.4	0.37
560	0.5	2.2	0.18
280	0.25	1.1	0.092
112	0.10	0.44	0.037
56	0.05	0.22	0.018
28	0.025	0.11	0.0092
11	o.01	0.044	0.0037

[a] The concentration (ppm) at other depths or other treatment dosages can be obtained by simple proportion. For example, the mg/l concentrations at depths of 10 and 20 cm are 1/4 and 1/8 respectively of those at 2.5 cm.

18.5 Area measurements for space applications

Table 29. Number of hectares in areas of different linear dimensions[a]

Length (m)	Number of hectares in rectangle with given width			
	25 m	50 m	100 m	500 m
1600	4.0	8.0	16.0	80.0
1000	2.5	5.0	10.0	50.0
600	1.5	3.0	6.0	30.0
400	1.0	2.0	4.0	20.0
250	0.63	1.25	2.5	12.5

[a] Other values can be determined by simple proportion or by the following formulae:

$$\text{area (hectares)} = \frac{\text{length (m)} \times \text{width (m)}}{10000} \quad \text{or} \quad \frac{\text{length (km)} \times \text{width (ft)}}{10}$$

$$\text{area (acres)} = \frac{\text{length (ft)} \times \text{width (ft)}}{43560} \quad \text{or} \quad 0.121 \times \text{length (miles)} \times \text{width (ft)}$$

Table 30. Aerial spray coverage in relation to speed of aircraft and swath width

Speed of aircraft[a]		Aerial spray coverage per minute for given swath width[b]				
km/h	mile/h	15.2 m (50 ft)	22.9 m (75 ft)	30.5 m (100 ft)	61.0 m (200 ft)	152.5 m (500 ft)
128	80	3.2 ha	4.9 ha	6.5 ha	12.9 ha	32.4 ha
		8 acres	12 acres	16 acres	32 acres	80 acres
144	90	3.6 ha	5.5 ha	7.3 ha	14.2 ha	36.4 ha
		9 acres	13.5 acres	18 acres	36 acres	90 acres
160	100	4.0 ha	6.1 ha	8.1 ha	16.2 ha	40.5 ha
		10 acres	15 acres	20 acres	40 acres	100 acres
192	120	4.9 ha	7.3 ha	9.7 ha	19.4 ha	48.6 ha
		12 acres	18 acres	24 acres	48 acres	120 acres
240	150	6.1 ha	9.1 ha	12.1 ha	24.3 ha	60.7 ha
		15 acres	22.5 acres	30 acres	60 acres	150 acres

[a] 1 knot = 1.85 km/h = 1.15 mile/h.

[b] Other coverage values can be determined by simple proportion or by the following formulae:
hectares per minute = (swath width in m) x (speed in km/h) x 0.00166;
acres per minute = (swath width in ft) x (speed in mile/h) x 0.002.

Given the area an aircraft covers per minute, the spray system is calibrated to disperse the desired amount of pesticide per unit area. To find the rate of pesticide dispersal required per minute, multiply the area covered per minute by the amount of pesticide to be applied per unit area.

Example: A volume of 220 ml/h is to be applied from an aircraft which covers 4.0 ha/min.

220 x 4.0 = 880

The spray system is calibrated to deliver 880 ml/min.

18.6 Dosages in relation to space applications

Required concentration (g/m^3)	Quantity (g) of active ingredient required for treatment of given volumes[a]				
	0.5 m^3 (17.7 ft^3)	1.0 m^3 (35.3 ft^3)	5.0 m^3 (176.6 ft^3)	10.0 m^3 353.1 ft^3)	100.0 m^3 (3531.5 ft^3)
0.1	0.05	0.1	0.5	1.0	10
0.15	0.075	0.15	0.75	1.5	15
0.2	0.1	0.2	1.0	2.0	20
0.25	0.125	0.25	1.25	2.5	25
0.3	0.15	0.3	1.5	3.0	30
0.35	0.175	0.35	1.75	3.5	35

[a] Volume sizes can be determined as follows:

cube or oblong = height x width x length
cylinder = height x π x $(radius)^2$
cone = (1/3) x height x π x $(radius)^2$
pyramid = (1/3) x height x width x length
sphere = (4/3) x π x $(radius)^3$

18.7 Approximate conversion factors: metric, imperial and American units

Length

1600m	=	1.6 km	=	1 mile	=	1760 yd = 5280 ft
10^5cm	=	1000 m	=	1 kilometre (km)	=	0.625 mile = 1100 yd
91.4 cm	=	0.91 m	=	1 yard (yd)	=	3 ft = 36 in
1000 mm	=	100 cm	=	1 metre (m)	=	1.093 yd = 3.28 ft =39.37 in
0.3048 m	=	30.48 cm	=	1 foot (ft)	=	12 in
25.4 mm	=	2.54 cm	=	1 inch (in)	=	1/12 ft
10000 µm	=	10 mm	=	1 centimetre (cm)	=	0.394 in = 0.033 ft
1000 µm			=	1 millimetre (mm)	=	0.0394 in
0.001 mm	=	0.0001 cm	=	1 micrometre (µm)	=	0.000039 in (about 1/25000 in)

Area

		259 ha	=	1 square mile (sq mile)	=	640 acres
		100 ha	=	1 square kilometre (km^2)	=	0.39 sq mile = 247 acres
10000 m^2	=	0.01 km^2	=	1 hectare (ha)	=	2.47 acres
4047 m^2	=	0.405 ha	=	1 acre	=	4840 yd^2 = 43560 ft^2
		10000 cm^2	=	1 square metre (m^2)	=	1.2 yd^2 = 10.76 ft^2 = 1550 in^2
		0.84 m^2	=	1 square yard (yd^2)	=	9 ft^2 = 1296 in^2
930 cm^2	=	0.093 m^2	=	1 square foot (ft^2)	=	144 in^2
		6.45 cm^2	=	1 square inch (in^2)	=	0.007 ft^2
		100 mm^2	=	1 square centimetre (cm^2)	=	0.155 in^2
		93 m^2	=	1000 square feet (ft^2)		

Volume

1000 litres	=	1 cubic metre (m^3)	=	1.307 yd^3 = 35.32 t^3
2.83 m^3	=	100 cubic feet (ft^3)	=	3.7 yd^3
0.77 m^3	=	1 cubic yard (yd^3)	=	27 ft^3
28.32 litres	=	1 cubic food (ft^3)	=	0.037 yd^3 = 1728 in^3
16.39 cm^3	=	1 cubic inch (in^3)	=	0.000579 ft^3

Liquid capacity

3.79 litres	=	1 US gallon (gal (US))	=	0.83 gal (UK) = 231 in^3
4.55 litres	=	1 UK gallon (gal (UK))	=	1.2 gal (US)
10000 ml	=	1 litre	=	0.26 gal (US) = 0.22 gal (UK)
32 fl oz (US)	=	1 US quart (qt (US))	=	0.9463 litres
Approx. 40 fl oz (UK)	=	1 UK quart (qt (UK))	=	1.136 litres
3 teaspoonsful	=	1 tablespoonful	=	0.5 fl oz (US)

Weight

1000 mg	=	1 gram (g)	=	0.0352 oz
28.35 g	=	1 ounce (oz)	=	1/16 lb = 437.5 grains
64.8 ng	=	1 grain	=	1/7000 lb
453.6 g	=	1 pound (lb)	=	16 oz
1000 g	=	1 kilogram (kg)	=	2.2 lb = 35.27 oz
1000 kg	=	1 tonne	=	2204 lb
907 kg	=	1 US short ton	=	2000 lb = 0.893 UK ton
1018 kg	=	1 UK ton = 1 US long ton	=	2240 lb = 1.12 US short tons

Weight of water in various volumes at 16.7°C (62°F)

1 ft^3	=	62.3 lb
1 litre	=	1000 g = 1 kg = 2.2 lb
1 gal (US)	=	8.33 lb
1 gal (UK)	=	10 lb

ANNEX I. PESTICIDE PRODUCTS WHICH HAVE PASSED THE WHO PESTICIDE EVALUATION SCHEME (WHOPES) AND FOR WHICH SPECIFICATIONS[1] ARE AVAILABLE.

Pesticide Type	Compound	Specification available for:
Insecticides	Bendiocarb	Technical, WDP, dustable powder
	Chlorpyrifos	Technical, EC
	DDT	Technical, WDP, EC, dustable powder
	Deltamethrin	Technical, WDP, EC, dustable powder, ULV liquid
	Diazinon	Technical, WDP, EC
	Dichlorvos	Technical, EC
	Diflubenzuron	Preconcentrate, WDP
	Dimethoate	Technical, EC
	Endosulfan	Technical, EC
	Fenitrothion	Technical, WDP, EC
	Fenthion	Technical, WDP, EC
	Iodfenphos	Technical, WDP
	Lambda-cyhalothrin*	Technical, WDP, EC
	Larvicidal oil	
	Lindane	Technical, WDP, EC, dustable powder
	Malathion	Technical, WDP, EC, dustable powder
	Methoxychlor	Technical, EC
	Permethrin	Technical, EC
	Phoxim	Technical, EC
	Pirimiphos-methyl	Technical, WDP, EC
	Propoxur	Technical, WDP
	Pyrethrum	
	Temephos	Technical, EC, sand granules
	trichlorfon	Technical, water soluble powder
Molluscicide	Niclosamide	Technical, WDP, EC
Repellent	Deet	Technical
Rodenticide	Brodifacoum*	Technical, concentrates, baits

* Interim specifications

[1] The specifications can be obtained on request from the Division of Control of Tropical Diseases, WHO, 1211 Geneva 27, Switzerland.