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Twenty-first Report of the WHO Expert Committee on Insecticides

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ECOLOGY AND CONTROL OF VECTORS IN PUBLIC HEALTH

Twenty-first Report of the WHO Expert Committee on Insecticides

The twenty-first WHO Expert Committee on Insecticides met in Geneva from 7 to 11 October 1974. The meeting was opened by Dr J. Hamon, Chief Vector Biology and Control, on behalf of the Director-General. He pointed out that six years had elapsed since the last meeting of a WHO Expert Committee on Insecticide Resistance and Vector Control. During this period, considerable advances had taken place in vector control, and several new concepts had emerged and were being tested. At the same time, fresh problems had arisen and others had become aggravated, thereby impeding the progress of vector control and jeopardizing the success of many disease control programmes. Since disease control operations are still to be launched in large areas of some continents, especially Africa, a change in strategies is required to take account of such problems as insecticide resistance, the increased cost and scarcity of some pesticides, and the increase or the recrudescence of vector-borne diseases. The recommendations of the Expert Committee would be of great value to the World Health Organization.

1. INTRODUCTION

The control or eradication of many widespread vector-borne diseases of man and animals became a practical proposition with the advent and use of modern pesticides during and immediately after the Second World War. The availability of several effective, safe, and low-cost pesticides, coupled with vast improvements in the techniques of their application, made it possible for many governments in both the developed and the developing countries to embark on extensive — sometimes countrywide — programmes for the control or eradication of such diseases as malaria, filariasis, plague, viral encephalitis, dengue, and leishmaniasis. Spectacular results have accrued from many of these programmes and an enormous reduction in morbidity and mortality has been achieved. In a few programmes, attempts have even been made to eradicate the vectors themselves. However, for several reasons—chiefly the development of vector resistance to insecticides, the limited number and high cost of alternative compounds to combat resistance, the rapidly increasing cost of all pesticides, and the consequent shortage in some of the countries where they are most needed—there is now a need to reassess the place of insecticides in vector control programmes. Besides the technical and financial difficulties, there is growing concern about the environmental contamination that results from the use of persistent pesticides.

Though there are vast areas of the globe where one or more of the known and tested insecticides are still effective against particular vectors of disease, the problems posed by the development of insecticide resistance in a number of species are in many countries serious enough to warrant consideration of a partial or even a total discontinuance of the use of some compounds. Refinements of technique, and the development and application of new techniques, not only for conserving the compounds that are still effective but also for ensuring their more efficient and economic utilization, are urgently required. Research on newer insecticides and better methods of application and management practice have to be strengthened and expanded. Biological and genetic methods are already being tested, both from the theoretical aspect and as regards the feasibility of their practical application, but newer concepts in integrated vector control have to be developed and tested.

A careful review and analysis of the impediments to progress in vector control as practised currently or in the past are prerequisites for the consideration and testing of new developments in the future.

It is recognized that the development and implementation of vector control programmes have to be backed by investigations on many subjects, but the Committee emphasized that since both national and international resources are always limited, the requirements for vector control should in the first instance be viewed in relation to the competing requirements for other public health programmes, and, whenever possible, the costs and the benefits of a programme should be described in socioeconomic terms. Annex 2 of the report describes the steps to be taken and the factors to be considered during the planning and implementation of vector control. The aim has been to state the principles involved, in the belief that these will be applicable to small-scale programmes as well as to large-scale, international programmes.

2. PROBLEMS IMPEDING PROGRESS IN VECTOR CONTROL PROGRAMMES

2.1 Vector resistance to insecticides

Resistance to insecticides has already appeared in 108 species of arthropods of public health importance and it seems certain that this process will continue and increase. Not only have resistant populations spread over wide geographical areas, but some species have become, in the same area, resistant to almost all available compounds, and many others are susceptible only to compounds that few of the developing countries can afford.

The severity of the resistance problem is illustrated by the large number of species resistant to organochlorine insecticides (91 to dieldrin and 61 to DDT), and the hope that the problem might be overcome by the use of organophosphorus and carbamate compounds has already been proved overoptimistic by the appearance of resistance to these insecticides in 27 vector species. In some species of mosquitos (*Anopheles albimanus* in Central America, *Culex tarsalis* and *Aedes nigromaculis* in California), in houseflies (*Musca domestica* in Europe and the USA) and in a few species of ticks (in Australia) resistance has appeared to all three main groups of compounds, and control by insecticides is no longer fully effective. In the case of many other species, alternative insecticides are fortunately still effective, although even this solution is now threatened by a world shortage of raw materials and high costs. In some vectors in which resistance levels are low and the problem is geographically localized, control can still be maintained.

Resistance in a vector is sometimes the result of campaigns carried out against other vectors, and is frequently caused by the widespread use of agricultural pesticides. The extent of resistance problems would become much greater if organized control programmes were carried out on an "area-wide" basis, thus exerting an enormous selection pressure over the vector populations in large areas. Although agricultural pesticides are used only to a moderate extent at present in most developing tropical countries, the amount and variety of insecticides being applied are steadily increasing. This trend will continue as the food and cash crop production is increased to face the growing demand of the world population. Since resistance is often non-specific, this use of insecticides in agriculture further enlarges the resistance problem.

A threatening aspect is that resistance in most insects is due to generalized detoxication mechanisms, and these mechanisms may make the application of some new insecticides of limited value. This factor emphasizes the need for the use of alternative control measures for the control of insect vectors of disease wherever possible and feasible.

The Committee recognized the implications of all these problems for the planning of future programmes and considered four possible methods of mitigating the difficulties :

(*a*) use of alternative insecticides ;
(*b*) environmental control ;
(*c*) genetic control ; and
(*d*) biological control.

None of these alternatives by itself is likely to provide a solution in all situations, but a combination of two or more, planned in an integrated programme, offers the best prospect for overcoming the resistance problem. The alternative methods and integrated programme planning are discussed below.

2.2 Environmental contamination

Since the last WHO Expert Committee on Insecticides met there has been a great increase in public concern over environmental contamination by pesticides used in agriculture and public health; this has led to increasing restrictions on the manufacture and use of many compounds, particularly the organochlorine compounds. DDT and dieldrin, for example, have been completely banned in some countries and their use restricted in others.

The Committee pointed out that pesticides are purposefully introduced into the environment under the strong presumption that the benefits from their use are much greater than the risks to human health and environmental quality (*1*). The responsibility for permitting their use rests with governments, and decisions are made according to national priorities. The Committee emphasized, however, that every effort must be made in vector control programmes to reduce to the lowest possible level the risk of environmental contamination. A sound knowledge of the ecology of the target species would make it possible to design programmes in such a way that pesticide application is focused in both space and time so as to achieve maximum control with minimal amounts of chemical and hence of environmental contamination.

The Committee emphasized that these considerations are equally applicable to biological control agents, particularly since some of these are self-replicating and they may include potential hazards that cannot be recognized at present.

The systematic introduction of any chemical or agent into an ecosystem carries the threat of environmental contamination, and it is important that everyone with any responsibility for vector control programmes that might involve such introductions should be fully aware of this danger. Since pesticides must remain the foundation of vector control programmes for some considerable time to come, there will inevitably be some risk of environmental contamination. Therefore, much more planned ecological research is necessary in order to understand the fate of control agents (chemical and biological) in the environment. With this knowledge, it will be possible to evaluate thoroughly their impact on individual species and on ecosystems in general and to assess whether environmental modifications do occur and the levels of change that are acceptable in relation to the benefits gained. The use of the model ecosystem technique (*2*), which has provided a great deal of information on the fate of insecticides in food chains, is encouraged, and additional techniques should be developed to evaluate the effect of pesticides on non-target species under experimental and natural conditions. An example of such an approach at the operational level is to be found in the environmental monitoring procedures built into the WHO Onchocerciasis Project in West Africa.

2.3 Ecological information

Successful vector control is based upon an understanding of the ecology of the target species and its relation to man so that the control method employed can be applied in the most selective manner for maximum effect. Specific ecological information is required on populations, movement and activity patterns, and a wide range of other behavioural features. These features vary in space and time for the numerous species of vectors and within many broadly distributed species there are also local variations.

There is a considerable body of knowledge on many vector species, but too often this information is not well organized and has been collected by methods that are neither systematic nor comparable. There is often not enough planning in the collection of ecological data and, as a result, time and resources are often wasted. It is important to define why data are collected and how these data are to be used. This is one of the main reasons for the encouragement of ecological and mathematical modelling, i.e., to define the ecological linkages in transmission cycles and the data needed to understand how control measures might be most effectively and judiciously used to break them. As was recognized earlier by the WHO Scientific Group on Vector Ecology (*3*), ecology is rapidly developing into a quantitative science with predictive potential, and it is necessary that ecological studies of vectors take advantage of recent innovation and continue to advance from the descriptive stage.

The Committee noted that the use of different control methods requires various types of ecological data for which there is no composite method of study or analysis. In all situations the distribution of the target species in time and space is of crucial importance. It will therefore be necessary to undertake studies that will more closely define the relationship between vector species and their habitats; wherever possible, indices or indirect measures should be developed that will specify vector habitats and thereby facilitate the application of the available and prospective forms of vector control.

It was noted that many of the major vector problems today are associated with man-made changes in the environment. Urban disease problems associated with *Ae. aegypti* (yellow fever and dengue haemorrhagic fever) and *C. pipiens fatigans* (Bancroftian filariasis) are well recognized (*4*). The importance of human activities will continue to grow as populations increase, urbanization continues, and land is opened up for agriculture to meet the additional food needs. Hence, studies of the ecology of many important vectors of disease must take account of man-made environmental conditions as well as sylvatic conditions.

The Committee recommended that future studies be designed to quantify the relationships between vector populations and the human populations at risk in order that the role of human behaviour patterns in disease transmission can be better defined.

2.4 Personnel training

As with any other complex public health programme, the planning and implementation of vector control programmes requires a diversity of specially trained personnel. The Committee felt that this requirement has not always been sufficiently recognized by various authorities and consequently the programmes have sometimes been inadequately staffed. The central role of the entomologist has often been ignored and the efficacy of vector control programmes has suffered accordingly.

Moreover, existing training facilities in several developing countries have not been fully utilized, and sources of professional knowledge and competence within the country have been overlooked. Amongst the factors responsible for this situation is the failure of many public health authorities to appreciate the importance of vector-borne diseases and the necessity for their control, and hence the need for adequate personnel training in this field. The lack of proper status, incentives, and opportunities for ontinued study and advanced training, both for the junior and professiona grades, is also a contributory factor.

Since it is certain that vector control planning and execution will become more complex, the Committee noted with concern the lack of recognition of the need for specialized, academic training in this important field. In countries where vector control is important, there is also a need for the training of technical and supervisory grades. By providing a better understanding of the problems and goals of the programmes, such training will also improve the motivation of these grades.

2.5 Operations and management

Large-scale programmes of disease control based on reducing vector populations demand a high degree of efficiency in the operational activities, backed by good management. Procurement of supplies and equipment at the proper time, and their adequate storage and distribution, are very important steps in the operation of such programmes. Equally important are the actual operations themselves, whether insecticides or alternative methods of control are employed. In the past, the lack of coordination of these activities has led to poor results. Quite often, it has meant that the procurement of supplies and equipment has been very much delayed, either owing to administrative defects or to a failure to appreciate the absolute necessity of having them reach their destination at the proper time. The consequences are particularly serious when insecticides arrive at the target site late or in inadequate quantities.

In the planning of insecticide applications close attention should be given to the reactions of the people in the target area ; in particular they should be prevented from plastering recently treated surfaces, which effectively stops the vector from contacting the insecticide.

The use of inappropriate measures has often led to poor results in vector control. For example, *C. p. fatigans* has at no time been highly susceptible to organochlorine compounds, yet in the past these insecticides have been extensively used for their control. Such inappropriate use has led not only to failures, but to a lack of confidence in an otherwise useful insecticide. Operational features have to be more specifically attuned to the actual needs than has been the practice.

Most of the problems are technical, and the solutions lie in a better understanding, by those directly involved in managing the programmes, of the ecology and bionomics of the vectors, the potential and the limitations of the methods to be employed, and the human factors that influence the success of vector control. In some areas operational problems have been created by an indifference or hostility to insecticide application on the part of those whom the programmes were designed to benefit.

Management includes administration and supervision, and many vector control programmes have suffered because of inadequate supervision and training. Quite simple operational procedures, such as periodic cleaning or insecticide treatment of drains or containers harbouring larvae, may be neglected or carried out badly because the methods themselves are so simple and uninteresting that the senior vector control officials have not planned work quality checks. Most problems of this kind can be overcome by better management practices.

2.6 Economic considerations and funding

Too little attention has been given in the past to project costing and to assessing the economic as well as the health benefits of control programmes. However, with the increasing demand and competition for world resources, particularly finance and expertise, national authorities and donor organizations are likely to be increasingly critical of the funding of such programmes as vector control. The Committee therefore stressed the great importance, in the planning and development as well as in the operational stages of future projects, of a thorough socio-economic appraisal, including a cost-benefit analysis. The project costing must take into account not only estimations of the expenditure on actual control operations but the consequences of any environmental contamination or degradation that might occur, and, whenever appropriate, the cost of related programmes to obviate or correct such consequences.

While ethical and humanitarian considerations must continue to play a part in decision making on project funding, the Committee felt that, in assessing the benefits for the purposes of this analysis, it was now imperative for project managements to produce estimates of the gains that would result from the attainment of project objectives, such as conservation of a work force, or its improved performance, both of which would be reflected in an increase in gross national product. Other benefits might include the release or better utilization of natural resources—for example, by the control of tsetse fly in Africa in areas suitable for ranching. In addition, any direct savings should also be included. For example, a rodent control project, either rural or urban, will not only stop transmission of many diseases that debilitate the work force, but will also reduce the direct loss of growing or stored food that results from rodent infestations. There may, in addition, be further benefits not susceptible to economic quantification, including the social benefits that affect the quality of life.

Where appropriate and possible, such an analysis should also take into account the cost of alternative long-term solutions to the vector-borne disease problem. In a number of tropical cities mosquito-borne diseases could be reduced by the provision of adequate piped water supplies and of sewage and refuse disposal facilities. In other cases, the alternative of prophylactic medical treatment to a population should be considered and costed.

In the future it seems likely that project funding, particularly for large-scale projects, will depend largely on the presentation of a socioeconomic cost-benefit analysis that shows a realistic balance on the credit side. Accordingly, the Committee felt it important that steps be taken to develop expertise and methods to ensure that socioeconomic appraisals become an integral component during project formulation.

Besides these general economic considerations, the Committee noted the specific funding problems facing on-going and projected vector control programmes. These include general cost inflation, affecting all aspects of a project, and the more direct and serious threat of world shortages and rising costs of, pesticides, some of which have doubled in price in the last year. Consequently, project costing must allow for inflationary pressures, for only in this way can funding be maintained at the correct level for the duration of a project.

After considering the increasing cost and shortage of insecticides and the current difficulty of many national control programmes in maintaining adequate funding, the Committee concluded that there was a real possibility of serious interruptions in some vector control programmes. Any suspension of control could lead to a recurrence of epidemics of vector-borne diseases. The Committee therefore proposed that WHO and its associated international agencies together with national governments at risk should urgently examine the need for and the problems related to maintaining stock-piles of vector control equipment and insecticides for use in an emergency.

The success of a programme may bring its own problems. As a long campaign becomes increasingly successful, less attention and financial support may be given to it. Administrative and funding authorities must therefore be kept aware from the outset of a programme of its progress, possible duration, and financial requirements.

2.7 Information exchange

Both from field reports and field observations, it is clear that an obstacle to the success of many vector control programmes is the shortage of information on new developments available to the officials in charge. Most of the new information that would be of value is published in scientific journals, which are not always easily available, and many of the articles are in a form that does not allow the field worker to relate the findings to his problems.

As the volume of information on new compounds and methodologies increases, the burden of ensuring that relevant information reaches the appropriate individuals in different countries becomes greater. It is often true, unfortunately, that useful information may be filed, or lost altogether, before reaching the person who could make most use of it. Sometimes when new compounds and equipment become available to the vector control official, he may hesitate to utilize them owing to uncertainty over the efficacy or the safety of the compound, or because he has inadequate guidance on the operation and maintenance of equipment.

In most of the developing countries, the official in nominal charge of local vector control may be a health officer, who has neither the time nor the training to judge the merits and demerits of the wide range of pesticides and equipment at present available on the market.

Additional problems may be raised by delays in publishing the results of field trials of new compounds and techniques and by the non-publication of many valuable field observations.

In many countries much of the information that would be helpful is not in the local language. This barrier can be a major one, and every effort should be made at national and international levels to ensure that it does not stop the free exchange of information on vector control. Arrangements should be made for the translation of important publications into local languages and for their wider distribution.

3. PRESENT TRENDS AND PROSPECTS FOR VECTOR CONTROL

3.1 Environmental control

The improvement of the environment, both in urban and in rural areas, should be the first priority in all development programmes. The elimination or control of vectors of disease is as important as the provision of water supplies and sewage disposal facilities or schools and health centres. Whereas chemical and biological methods may provide only temporary control of vectors and pests, environmental improvements may lead to permanent control. The initial costs may be high, and programmes may require a period of years to implement, but governments and local authorities should be urged to include environmental changes relating to vector control in all their long-term planning.

Knowledge of the ecology of the vectors and their breeding habits will in many instances make a high level of control possible by manipulation of the environment. As such measures are likely to produce definitive and permanent results they should be the basic approach to effective vector control. Source reduction by elimination of breeding-places and measures to reduce the man-vector contact are proven methods for limiting the spread of arthropod-borne diseases and for nuisance abatement.

Filling, drainage, carefully planned water management, and the removal of containers providing larval habitats are most important measures for reducing the urban mosquito problem (*5*). Correct disposal of sewage water and installation of an adequate and continuous piped water supply can lead to permanent reductions of vectors of filariasis, yellow fever, and dengue haemorrhagic fever to levels at which disease transmission is interrupted. Construction of solid and rat-proof houses without cracks and fissures will largely prevent the breeding of reduviid bugs, fleas, and rodents. Cleanliness, both in and around houses, proper disposal of refuse and waste water, and adequate protection of stored foodstuffs are of fundamental importance for the suppression of urban fly and rodent populations and the diseases they can spread. The use of bed-nets and the screening of houses are effective measures of defence against mosquitos and other flying pests. Personal hygiene, in particular frequent change and washing of clothes, can prevent infestations with body lice.

Where applicable and justified, the elimination of animals, such as rodents, which are hosts of vectors and reservoirs of disease, has a marked effect on vector propagation and disease transmission, e.g., in the control of leishmaniasis and plague. However, in the case of game animals this method can be counter-productive and must be used with caution.

In the rural environment, vector densities may often be increased by such agricultural and industrial activities as the construction of dams, large-scale irrigation projects, and deforestation. These can lead and have led to the spread of schistosomiasis, onchocerciasis, and mosquito-borne diseases, such as malaria and Japanese encephalitis. To minimize the risk of spread of disease, close consultation and cooperation between the authorities responsible for agriculture, engineering, and public health are essential at the planning stage.

Environmental hygiene is of fundamental importance for ensuring that vector control efforts have a lasting effect, and it contributes in many ways to human well-being, but to achieve a steady improvement the cooperation of the local population is indispensable. For this reason, intensive health education of the public, which will need political support as well as close cooperation between the various authorities concerned, is an essential prerequisite.

3.2 Chemical control

For the past 30 years, since the advent of DDT, reliance has been placed almost exclusively on chemical pesticides for vector control programmes. Although it was originally hoped that reliance on the broad spectrum organochlorine insecticides, such as DDT, HCH, and dieldrin, could lead to the control or even eradication of many vector-borne diseases, this has not been the case. The appearance of second order problems of steadily increasing severity, such as vector resistance, environmental contamination, and increasing costs, has seriously jeopardized successful vector control operations in large areas, which are inhabited by many millions of people. These setbacks, coupled with the demand for vector control of such diseases as onchocerciasis, schistosomiasis, and African and American trypanosomiases, which will involve the treatment of far vaster areas of the environment than the presently conducted programmes, make it imperative to re-examine strategies for the use of chemicals in vector control. The objective is to plan sounder programmes for the use of pesticides within an ecological framework of integral vector and disease management. If this objective can be achieved, the result should be a decrease in insecticide treatment rates and a reduction in environmental contamination. At the same time, sounder strategies offer the hope of slowing the emergence of catastrophic resistance problems.

3.2.1 *Present-day insecticides*

Most of the chemicals available for vector control today, excluding inorganic chemicals and larvicidal oils, can be classified conveniently into three groups : Group I—organochlorine compounds ; Group II—organophosphates ; and Group III—carbamates. The organochlorine compounds include DDT, HCH, dieldrin, chlordane, endosulfan, and methoxychlor. The first three of these compounds have had the widest use in malaria eradication programmes as residual house sprays. They are persistent in the environment and can accumulate or become concentrated through food chains (bioconcentration). Vector resistance to these compounds is an increasingly serious problem (section 2.1).

The rising costs of the organochlorine insecticides are jeopardizing vector control programmes in many areas. For example, the price of DDT has risen 125 % during the past year. This factor and restrictions on the production of the organochlorine insecticides because of their role in environmental contamination is making it very difficult to obtain adequate supplies.

It is most important to reassess the techniques used for application of organochlorine insecticides in vector control programmes in order to increase the efficiency and economy of their use. Estimates suggest that losses in application, based on the amounts reaching the target sites, range from 40% to 80%. Investigations of the use of DDT and HCH, for example in integrated pest control programmes might result in more efficient applications to restricted locations, with very substantial savings in the amount of insecticide required.

The Group II organophosphorus insecticides malathion and fenitrothion are being used as substitutes in residual house spraying against DDT-resistant and dieldrin-resistant *Anopheles* species. Malathion is one of the insecticides of choice as a louse powder and for ultra-low-volume (ULV) spraying, and fenthion, chlorpyrifos and Abate are most effective larvicides. All these compounds are readily biodegradable and cause only limited environmental contamination. However, vector resistance to organophosphorus insecticides is becoming widespread and is now found in 27 species (section 2.1). The increasingly high cost of the organophosphorus insecticides is also limiting their use.

The Group III carbamate insecticide propoxur has been used in residual house spraying against resistant *Anopheles* and shows promise for the control of triatomine bugs. However, resistance to propoxur has already appeared in *An. albimanus* and its high cost is a discouragement to wider use. Carbaryl is effective as a louse powder.

3.2.2 *New insecticides*

As mentioned above, insecticide resistance, environmental contamination, and economic problems are prejudicing the continuation of many vector control programmes. It must be remembered that at present such programmes protect more than 1 billion of the world's inhabitants from insect-borne diseases. Although the more precise use of present-day insecticides in integrated vector management programmes may obviate some of the present dilemmas, it is certain that current standards of vector and disease control cannot be maintained without the development of new compounds. WHO has pursued a successful programme for the evaluation and testing of new insecticides for vector control.[a] From 1960 to 1974, approximately 2 000 candidate chemicals have been examined under this programme and approximately 30 have been selected as useful for vector control operations. Candidate chemicals have been supplied from some 50 firms and laboratories in nine countries. One disturbing feature is the decline in the number of chemicals being submitted, from approximately 200 in 1963 to an average of some 44 compounds a year

[a] *Bulletin of the World Health Organization*, **44**: 11–22 (1971).

for the last three years (1972–74). Increased efforts must be made to interest the world chemical industry and research scientists in submitting new chemicals with novel modes of action for evaluation.

Although the flow of new chemicals has declined, two new groups of compounds—in addition to the three already in use (see section 3.2.1)—show special promise. Group IV includes the synthetic pyrethroids, such as resmethrin, bioresmethrin, and prothrin. These compounds are as much as 10 times as effective against vector species as previously available insecticides, and they show better residual properties than the naturally occurring pyrethrins from *Chrysanthemum* flowers. The relative safety to man and higher animals of resmethrin, bioresmethrin, and prothrin, and their biodegradability, together with their very high target species toxicity, make them very attractive candidates for integrated vector control. An integrated approach to control will be essential because of the very high cost of these complex compounds, at present estimated at US $23–27 per kg.

Group V compounds, the insect growth regulators, such as methoprene and OMS 1804, offer more specific toxicity to target species. However, since they act by inhibition of growth and maturation or of cuticle development, applications of these compounds must be timed precisely to expose the vector at a critical developmental period. For example, in the case of methoprene, the critical time is a relatively short period within the last larval instar of the mosquito. The inhibitor of cuticle development, OMS 1804, is effective only when ingested prior to the time of moulting. The proper utilization of these very expensive compounds in vector control will require development of new techniques in formulation, such as slow release granules or microencapsulation, and more precise entomological knowledge to determine the most sensitive period in the insect life cycle. The Group V compounds present some potential problems with regard to environmental contamination and, unfortunately, evidence of vector resistance to them has already appeared.

The effective and economical use of Group IV and V compounds in vector control will require a variety of ecologically sound and innovative methods for application. Their 10-fold to 100-fold higher cost compared with Group I-III insecticides clearly precludes large-scale environmental applications at conventional dosages.

The greatest value of the programme for evaluation and testing of new insecticides lies in the large body of computerized information made available on about 2000 potential insecticides. It will become increasingly important to reinvestigate promising compounds that were by-passed at various levels of the programme because of marginal failure to meet specific criteria of performance. Many of these compounds, such as endosulfan, methoxychlor, dicapthon, ronnel, and various safer and more readily biodegradable variants of conventional organochlorine, organophosphate, and carbamate insecticides, may be required for specific vector control operations.

3.2.3 *Synergists*

At various times in the programme for evaluation and testing of new insecticides synergists for various insecticides have been evaluated for use, especially against resistant vectors. Particular difficulty has been encountered in matching satisfactorily the residual properties of insecticide and synergist to give a sufficiently long-lived combination. In addition, some of the synergists evaluated were much more expensive than the insecticide with which they were intended to be used. However, a variety of newer and cheaper synergists have been developed, and the use of these in combination with such well-established insecticides as DDT, HCH, malathion, propoxur, and carbaryl deserves serious study. The use of such insecticide-synergist combinations offers another rational approach to combating various resistant strains of insect vectors. To date, however, the use of combinations found promising in the laboratory has been disappointing in the field.

3.2.4 *Application techniques*

Control of vector species necessitates the use of a variety of types of equipment and of formulations comprising a variety of chemical types, depending on the nature of the habitat. Control may involve the application of a small quantity of a granular or liquid formulation to individual water-holding containers, applications to larger bodies of standing water, residual spraying inside homes, aerosol spraying of villages or cities, or aircraft applications over more extensive areas to curtail epidemics.

Significant progress has been made in the development of new equipment and the improvement of existing equipment. For example, hand sprayers used in malaria control programmes now have a life expectancy of 8 years compared with 2 years previously. New ground ULV aerosol equipment for mosquito control is highly effective against vector species and pest mosquitos. The ULV equipment eliminates the need for fuel oil diluents, mixing and storage tanks, and frequent reloading, increases speed of application, and reduces dosages and costs. The implementation of the Onchocerciasis Control Programme in the Volta River Basin area of West Africa has required the development of a new aerial application technique. Equipment is now available that will allow the accurate placing of measured volumes of insecticide into small rivers from an aircraft.

Recognizing that many improvements can yet be made in application equipment, the Committee recommended that work on developing and improving equipment be continued. There is a particular need for improved portable equipment capable of applying ULV aerosols to surfaces, especially for residual treatments.

The biological effectiveness of insecticides and their efficient use are related to the type of treatment under consideration. The droplet size of sprays is a particularly important factor affecting both biological effectiveness and economic use of insecticides ; there is a need for equipment and nozzles that will produce droplets within various narrow size-ranges for residual applications and aerosol treatments.

There is an increasing amount of information on slow-release type formulations and special formulations such as microencapsulation. Recognizing that such formulations are likely to extend the effectiveness of less persistent insecticides and to reduce environmental contamination, the Committee recommended that further developmental research on this subject be encouraged. The usefulness of some new insecticides, attractants, and growth-regulating compounds may depend upon the use of such formulations.

For the past 15 years, most vector control operations, especially in malaria eradication programmes, have been based on a firmly fixed schedule of treatment rate and dosage. Adherence to these has been judged essential for achieving maximum progress in disease eradication. The revision of the strategy of malaria eradication and the decision to implement malaria control projects provide opportunities for revising insecticide dosages and integrating the use of insecticides with other suppressive measures in a vector control or management programme. The rapidly increasing cost of insecticides provides an inducement for re-examination of application techniques.

Systems analysis of the ecology of the vector-disease system is urged as a means of understanding and integrating various environmental features involved in disease transmission (*3*). Such a computerized analysis provides a technique for re-evaluation of the relevant factors in disease control. Information based on vector control operations in many parts of the world suggests that dosages of insecticide sprays could be reduced substantially without a corresponding reduction in vector control. Increased attention must be given to the physiological and ecological responses of vector species to different insecticide treatments in order to establish the sites at which selective insecticide applications will have maximum effect. For example, very promising results in tsetse fly control have been obtained by treating the undersides of branches of appropriate size, height, and inclination so that only the preferred resting-places of the vector are treated. The savings in cost of insecticides and the reduction in environmental contamination resulting from such restricted applications cannot be over-emphasized. This phase of vector control research deserves the highest priority.

3.2.5 *Attractants*

The use of lures to attract insects into traps either for destruction or for estimation of population densities has been an important part of integrated pest management programmes for agricultural pests. This technique has been especially productive when the natural sex pheromones of the female or male of the pest species have been used as attractants. The use of lures for the control of insect vectors of human diseases has been much less successful. It is by no means certain that long-range pheromones are involved in the mating behaviour of the many Diptera that are the important disease vectors. Muscalure, a pheromone of the housefly, has been found to attract the insects to toxic baits and is especially useful in conjunction with sugar. Various species of cockroaches evidently secrete pheromones, but efforts to identify them have so far been unsuccessful. Chemical recognition factors or aggregating pheromones have been identified in tsetse flies, ticks, and several species of mosquito. Investigations of the pheromones of vector species are urgently needed.

Host attractant factors are clearly involved in the attraction of and attack by vectors but here again there is a scarcity of information. Warmth, carbon dioxide, and lactic acid seem to be the critical factors in stimulating attack by mosquitos. The host attractants for *Simulium*, *Phlebotomus*, *Glossina*, fleas, blood-sucking bugs, and mites and ticks seem quite unknown. Fermenting proteins are the attractants for the *Hippelates* " eye gnats ", and baits of fermenting egg protein mimic them and are useful in traps. Investigations in this general area are recommended as part of the need for increased understanding of vector ecology.

3.2.6 *Insect repellents*

During the past 30 to 40 years a large number of compounds have been tested for their ability to repel biting insects and acarines from human hosts. Following the development of mixtures of compounds that were effective against a wide range of species came the discovery of deet (diethyl toluamide), the most effective all-purpose repellent. Although other effective compounds are available, continued screening and evaluation have failed to identify repellents that offer sufficient advantages to warrant their use as replacements for deet. Attempts to extend the protection time given by standard repellents through the use of extenders, additives, and specialized formulations have been unsuccessful. Repellent-treated netting for use in bed-nets, head-nets, jackets, or trousers is a useful recent development.

Repellents are particularly needed in many large areas where other methods of control or protection are not available, and the pest species include mosquitos, ticks, chiggers, blackflies, and sandflies. The chief disadvantage of repellents is the short duration of protection time and the fact that all exposed areas of the body must be treated. Compounds offering an extended protection time and a wider range of repellent action are therefore required. However, owing to their high cost, repellents are unlikely to play a significant role in vector control programmes in developing countries.

3.3 Genetic control

The theoretical aspects of the various methods of genetic control are fairly well understood and they have been described in the literature. This information is too voluminous to review here, but has recently been reviewed by Pal & LaChance (*6*) and by Pal & Whitten (*7*). The methods fall into two general groups: (*a*) those leading to population control, reduction, or elimination through the release of partially or completely sterile insects in sufficient numbers to overcome the reproductive capability of the natural population, and (*b*) those leading to population control or population replacement through the release of partially sterile or fully fertile genetically altered insects. There are a number of potential genetic control techniques under study, and a considerable amount of research has been expended in their development, particularly in the laboratory. Among the insects of public health importance, some species of mosquito and tsetse fly have been investigated under field conditions; the results have confirmed the validity of the principles in special situations, but they also confirm the need for further developmental research. Field trials include the use of cytoplasmic incompatibility against *C.p. fatigans* in Burma, chemosterilized males against *C.p. fatigans* in Florida, and chemosterilized males against *An. albimanus* in El Salvador. A series of studies has been made on *C.p. fatigans*, *Ae. aegypti* and *An. stephensi* in Delhi, and experiments have been done on tsetse flies in Africa. Studies of the possibilities of genetic control of *An. gambiae*, *C. tritaeniorhynchus*, *Musca domestica*, *Rhodnius*, and *Ornithodoros* have begun.

The conclusions from the numerous experiments can be summarized as follows. The application of the sterile male technique, cytoplasmic incompatibility, or genetic strains with translocations (leading to a high degree of sterility in the progeny) can be effective in small field trials. However, more developmental research is needed to show the applicability to larger and more difficult areas. New genetic control methods, such as those involving sex distortion mechanisms or the selection and release of strains refractory to pathogens, sensitive to selected ecological factors, or susceptible to insecticides, should be tested for feasibility under field conditions.

Before being considered potentially amenable to genetic control, a species should be suitable for rearing on a mass scale without serious effect on its behaviour and mating competitiveness. The target population should be either geographically or ecologically isolated, or should occur naturally in small numbers at some time during the year. If the target population is too large to tackle by genetic means, it may be reduced by non-genetic control methods. However, at the present time, unless some new and revolutionary ideas emerge, the genetic techniques are more useful for " management " and " manipulation " of populations than for complete suppression or overwhelming reduction in densities. It is, however, recognized that in completely isolated situations population suppression or reduction seems feasible.

In considering genetic control or manipulation of insect populations, the possible biological consequences of the actions taken must not be overlooked. Replacement strains could possibly create more problems than did the strain replaced, and the release of chemically treated insects may lead to a contamination problem.

The Committee recognized the advances made in research on genetic control and recommended that developmental research be emphasized and encouraged, particularly with tsetse flies and mosquitos, and that feasibility studies of genetic control of insect vectors of disease be expanded in close collaboration with such agencies as FAO and IAEA.

3.4 Biological control

As with other methods of vector control that are alternatives to the use of insecticides, the further development of biological control has been stimulated by the restriction placed on the use of certain insecticides, their increased costs, and by environmental contamination. Owing to the more immediate economic benefits and to the larger financial support given to the control of agricultural pests, biological agents for this type of pest control have been used for much longer and have been developed much further than those available against vectors of disease. In addition, the use of biological control agents in agriculture is related to monoculture systems, whereas disease vectors often exist in heterogeneous habitats where broad application is difficult.

In the field of public health, there are insufficient resources and manpower for increased research on and development of new agents, for the evaluation of promising agents in practical problem areas, and for obtaining the necessary safety testing data to assess effects on non-target organisms, man, and the environment. Nevertheless, significant research has been carried out, and although none of the available biological agents, other than larvivorous fish, are ready for operational use, several promising microbial isolates have been identified and are currently being tested. A systematic evaluation scheme for identifying the most promising agents has now been prepared (Annex 1).

There are areas and habitats where larvivorous fish can make considerable contributions to control, and the use of *Gambusia* and *Poecilia* is well documented in many countries. During 1974, WHO asked Member States for information on their experience with the use of fish for this purpose. The responses (from about 50% of the States) indicate that under certain conditions fish can be very effective in mosquito control. However, critical evaluation of their efficacy and of their possibly deleterious environmental effects is limited.

The release of large numbers of larvivorous fish at appropriate seasons ensures maximum predation rates, which contrast with the low but constant predation rates by local populations of larvivorous fish. This method is best applied where the species of fish to be released is already established and where resources are available for large-scale fish culture.

A study of the use of indigenous larvivorous fish for mosquito control has been made in Nigeria. Although only limited success was achieved, further trials with such species should be encouraged.

The variety of agents currently under study includes bacteria, fungi, nematodes, protozoa, and viruses. A strain of *Bacillus sphaericus* has been shown to be infective against certain *Culex*, *Aedes*, and *Anopheles* species in laboratory tests ; limited field trials are planned and attempts to extract toxins are in progress. A strain of *Metarrhizium anisopilae* has also shown promise in laboratory tests against *Anopheles*, *Aedes*, and *Culex* ; limited field trials are in progress and further trials should be encouraged. Fungi of the genus *Coelomomyces* are known to be pathogenic to mosquitos. However, recent research indicates that copepods are alternative hosts with an obligate infectious stage. The significance of this development on the future potential of *Coelomomyces* is yet to be evaluated.

Nematodes of the genus *Ressimermis* have been evaluated in small field trials against mosquito larvae. They can be reared in large quantities and more extensive trials should be undertaken. Nematodes infecting blackflies are also known, but further development is difficult because of problems in culturing both the agent and the host.

A large number of Microsporida (Protozoan) pathogens have been isolated. Of these, *Nosema algerae* appears to be the most promising so far. However, taxonomic studies and classification of the Microsporida are needed as a basis for safety testing. Research on spore production, storage and application is also needed.

Viral agents isolated from mosquitos have shown some efficacy against temperate *Aedes* in laboratory tests. Viruses have also been isolated from *Simulium*. Problems of identification, efficacy and safety have still to be resolved (*8*).

Where their larval habitat preferences coincide or overlap, the predaceous larvae of *Toxorhynchites brevipalpis* have been shown to reduce the numbers of *Aedes* larvae. *T. brevipalpis* can be easily colonized and the eggs travel well. In some areas this and related species may have a place in an integrated control programme. In rice-growing areas more attention should be paid to the role that other predatory insect larvae play in reducing vector populations. Some of these predators are being examined at present in Java.

Further study is required of the role of certain Hymenoptera in the biological control of triatomine vectors of Chagas' disease and of tsetse flies. Hymenopteran parasites already hold promise for the control of Muscoid flies and ticks and their potential should be further evaluated.

If possible, the response of natural and introduced predators to insecticide applications should be measured. If predators could be selectively eliminated in pilot areas, a direct measure might be obtained of the part they play in controlling vector populations.

It is obvious that the development of biological control agents requires considerable research, and the Committee stressed the importance of isolation, identification, production, formulation, and application techniques. It also stressed the need for biological field testing to demonstrate operational potential ; adequate safety testing should be undertaken concurrently.

4. PLANNING VECTOR CONTROL PROGRAMMES

The decision as to whether a vector control programme should be initiated must be made in the light of the socioeconomic importance of the disease and the resources that can be made available. A comprehensive approach should be followed, taking into account other public health problems and possible interactions with local, national, and international development projects, in order to judge priorities and to ascertain the highest possible benefit for the community from the investment made.

From the time a decision is made to carry out a vector control programme until a plan of operation is prepared and put into operation, information and data should be collected on a systematic basis, since these will be required to show that implementation can be technically and financially justified.

The planning of control may be a relatively simple task when the problem is limited to a small area, but can be complex and time-consuming when national or international problems are involved. At all levels, planning is a continuing process and the plan of operation, even when based on the best available expertise, needs to be revised and updated periodically. A flexible machinery should therefore be incorporated into each vector control operation to permit the periodic adjustment of the plan to field observations and new technical developments, as well as to the changing context within which it operates. Annex 2 describes all the main requirements to be taken into account during the construction of a plan of vector control operations. Their relative importance and the precise use of the data gathered will depend on the scale and nature of each programme.

While it might be much simpler to organize and establish specialized services devoted only to one type of control operation, such a course may result in excessive rigidity. The long-term objective of any vector control operation should, therefore, be the development of a multipurpose vector control unit forming an integral component of the public health service.

5. INFORMATION EXCHANGE AND TRAINING

Having defined the problems impeding the exchange of information on vector control (section 2.7), the Committee discussed how best these could be overcome. WHO plays a central role in transferring information on all new developments in vector control from research groups to those responsible for control programmes. At the same time, there is a great need to ensure that information flows in both directions so that account can be taken of field experience in future research and development planning.

There are already close links between the Organization and commercial and research groups, and the information flow to the Organization can be considered satisfactory. However, the transfer of information to and from the field needs improvement. It was agreed that the series of information documents on vector ecology and control being prepared by the Organization would, with some modifications, provide one means of resolving the problem. It was stressed that these documents should be written in as simple terms as possible, first in order to ensure that readers of different nationalities find the contents easily intelligible and, secondly, in order to facilitate translation into national languages.

The Committee considered that in addition to general reviews of the ecology and control of individual vector groups, the series should include the results of trials of new insecticides and new spraying equipment. However, since costs of materials, especially those imported, are increasingly proving a major constraint in vector control programmes, the series should also give guidance on the merits of local materials and of alternative control methods, even when these are less satisfactory than those usually recommended. The aim throughout the series should be to provide the reader with up-to-date and practical information that he can relate without difficulty to his own interests, and, in order to provide the essential feedback to the Organization, each of the documents should have a prominent notice requesting readers to give comments on their experience of the subject reviewed.

After the documents have been prepared and circulated, they should be reviewed and, if necessary, revised annually to ensure that they remain up-to-date.

The Committee considered that the problem of ensuring that the information documents reach the appropriate individuals in different countries was not insuperable and recommended that WHO should compile and maintain an up-to-date distribution list of all government organizations and institutes concerned with vector control.

There are a number of Government organizations and bilateral agencies that provide information to developing countries on recent developments in pest control. Cooperation between WHO and these organizations should be encouraged and strengthened.

The distribution of technical information within countries is most often inadequate. Governments should therefore be encouraged to formalize their systems of distribution and, where necessary, to strengthen health and technical education units.

Training and instruction in vector control methods form an important part of the programme of WHO, and the Committee recommended strengthening these activities whenever possible. Every effort should be made to ensure that those being trained are encouraged to provide the Organization with relevant information on their vector control work and thus take an active part in the information exchange programme.

6. RESEARCH NEEDS AND RECOMMENDATIONS

In the past the relatively uniform, and largely effective, measures applied in vector control programmes, such as the application of 10% DDT dusting powder for typhus control and 70% DDT water-dispersible powder for residual spraying in antimalaria programmes, have resulted in minimal expenditure on further research and development. A dramatic change in the situation has occurred recently, however, as a result of the world shortages and rising costs of pesticides and restrictions on their use, which have added to the problems already posed by the development of insecticide resistance. Furthermore, extensive new vector control programmes are being planned for campaigns against onchocerciasis, African trypanosomiasis, and schistosomiasis. A new outlook is therefore needed to encourage and finance research related to vector control. In the body of this report the Committee has emphasized the need to take the widest possible view of the strategy of vector control and to relate programmes to socioeconomic conditions. The translation of this approach into practical and economical control techniques will require greatly intensified research and improved expertise. The following specific recommendations should be viewed within that context.

The Committee recommended:

1. The development of the systems analysis approach to vector-borne diseases in order that a variety of suppressive measures—environmental, biological, genetic, and chemical—can be integrated and the effects of changes in strategies assessed.

2. Detailed planning of all phases of a projected vector control programme and the implementation of pilot programmes to simulate all phases of large-scale programmes well in advance of the start of operations.

3. The development of systematic studies to evaluate the effects of control agents and techniques on the components and dynamics of different ecosystems.

4. The subjection of new vector control approaches and programmes to realistic cost-benefit analyses, which should include appraisal of the cost of environmental contamination and the merits and demerits of socioeconomic changes resulting from the techniques employed and the results achieved.

5. Every encouragement should be given to the world chemical industry to intensify the search for new, selective insecticides, rodenticides, and molluscicides with novel modes of action.

6. Reinvestigation of promising insecticides and insecticide-synergist combinations not previously utilized because of marginal failure to meet specific criteria.

7. Further development and improvement of spraying equipment, particularly portable equipment for ULV aerosol applications, and of formulations and dosage rates in order to make insecticide applications more effective and species-specific.

8. Stringent requirements for the evaluation of the safety of all proposed biological, genetic, and chemical control agents.

9. A review by WHO and other appropriate international agencies together with selected national governments of the need for and the problems related to maintaining stockpiles of vector control equipment and insecticides that could be utilized during epidemic outbreaks of vector-borne diseases.

10. Support for increased and improved training for vector control personnel of all grades.

11. Encouragement of scientists of related disciplines, such as insect physiology, ecology, and genetics, to play a part in the solution of vector-borne disease problems.

12. More efficient and rapid means for the exchange of technical information on vector control progress and problems, with special attention to the critical problem of conveying research findings to field workers.

13. Intensive efforts to strengthen research and development of non-chemical methods of control and to integrate alternative methods within vector control programmes.

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Annex 1

PRELIMINARY SCHEME FOR SCREENING AND EVALUATING THE EFFICACY AND SAFETY OF BIOLOGICAL AGENTS FOR CONTROL OF DISEASE VECTORS

STAGE I *Laboratory*	*STAGE II* *Laboratory*		*STAGE III* *Preliminary field trials*	*STAGE IV* *Laboratory*		*STAGE V* *Large scale field trials*
A. Identification and characterization [a] B. Assessment against selected target vectors C. Preliminary evaluation of ease of rearing in quantity	A. Mammalian infectivity tests to ensure safety to laboratory & field personnel [b] B. Preliminary assessment against certain non-target species	RESULTS OF REVIEW OF STAGES I AND II	Strictly regulated pond tests under WHO supervision [c] to determine efficacy against disease vectors under natural conditions	More detailed tests on mammalian infectivity, using appropriate techniques *Laboratory & field trials* Detailed studies on non-target range—especially other fauna in habitats where Stage V trials may be conducted	REVIEW OF STAGES I, II, III AND IV BY INFORMAL CONSULTATION GROUP	To be conducted under WHO auspices. Not presently defined, and will vary according to target vector, habitat(s), mode of application, etc.

[a] This study may vary from routine taxonomic determination (fish, nematodes, predatory insects) to the detailed serotyping necessary for microorganisms, especially viruses.

[b] Not required in predator–prey situations, but more detailed tests on effects on non-target organisms could be substituted in trials of larvivorous fish, predatory insects, etc.

[c] Especially where the biological control agent is not indigenous.

Annex 2

PLANNING AND IMPLEMENTING VECTOR CONTROL PROGRAMMES

A. PLANNING

Identification of the problem and the need for control

In most cases information will already be available on the endemicity of vector-borne diseases and on the ecology of the vectors or the intermediate hosts. There may also exist data on the basis of which their relative public health and socioeconomic importance can be assessed. Where such information is not available, or is inadequate, surveys and field investigations should be organized to fill this need.

To establish the priority of a control programme relative to other public health problems of the area, it is essential that the assessment activity should be extended to cover as far as possible other major communicable diseases of the area. In the later stages, such information could also be useful for the selection of methods of control that would be beneficial to other health problems.

Feasibility survey

The feasibility survey consists of a set of preliminary studies to determine the practicability of accomplishing a project with the methods and resources available, taking into consideration the local technical, operational, administrative, and socioeconomic conditions. The study of feasibility should cover the different phases and stages of a programme until its completion. Feasibility surveys, therefore, can be directed towards ascertaining the following:

1. *Technical feasibility*

Technical feasibility is determined by assessing the efficacy of the available methods of control in reducing the vector population or the intermediate hosts to a level required by epidemiological criteria, which have first to be established. A thorough knowledge of the epidemiology of the disease is therefore essential. Small-scale field trials of various control methods may be needed to confirm the technical feasibility.

2. *Operational feasibility*

Determination of operational feasibility requires a study of the practicability of applying various control methods under the local geographical, physical, social, and climatic conditions. The study should take account of communications, housing, agricultural practices, human habits and customs, water resources, and the existing and planned health infrastructure.

3. *Administrative and financial feasibility*

An assessment should be made of the available or potential government and local facilities needed for the organization of the campaign. This involves a study of the administrative and financial structure, the rules and procedures on allocation of funds and accounting of expenditure, recruitment of personnel, procurement of supplies and materials, maintenance and repairs of transport, legislation and legal support, as well as any other administrative and managerial matters related to the programme.

Socioeconomic studies

Socioeconomic studies are required to permit establishment of the priority of the programme and to provide data to support applications for funds from the government or assisting agencies. It may be necessary to make a study in depth of the adverse effects of the disease on development and production in agriculture, industry, commerce or in any other sector where the working capacity of the individual may be impaired. The study should also take into account the savings that might be made in health services after the disease has been controlled.

Pre-planning detailed survey

When the feasibility survey has been completed and data and limited field tests have demonstrated the possibility of organizing a vector control campaign, the government or the executing agency may decide to embark on a programme. A detailed survey may then be needed to compile the information required for the development of a programme proposal.

In large-scale vector control projects, detailed surveys may be required in a number of areas, each representing different ecological and epidemiological conditions. In selecting such areas, account should be taken of the various geographical, physical and climatological conditions that may exist in the country or in the operation area. The information collected, together with the results of pilot field trials, will constitute the basis on which the plan of operations will be prepared.

lot field trials

There are rarely two vector control situations that are exactly identical. Consequently, vector control activities cannot be carried out in accordance with rigid, stereotype guidelines. The correct solution of each operational problem will require imagination and competence.

In many cases, a very effective control methodology that has been developed and tested under a variety of situations may require only minor modifications for adaptation to local conditions. More often, however, there are several promising lines of approach, the relative cost-effectiveness of which requires evaluation. In some cases, the problem has no simple known solution, and the development of a new methodology is essential.

Whatever the situation, adjustments, comparisons, and developments should be made during pilot field trials under operational conditions. In the simplest situations, these trials may involve only the comparison of several combinations of insecticide dosages and application schedules, whereas in more complex ones, new methodologies and equipment may need to be developed and assessed during large-scale field operations.

When integrated control programmes are being planned, adequate allowance should be made for extended and extensive field trials. Decisions should be made on a cost-effectiveness basis, taking full account of the existing operational and socioeconomic parameters as well as their probable future evolution.

Toxicological hazards

An assessment must be made of the possible toxicological hazards of insecticides for operators and for the general population. Hazards depend on the toxicity of the chemical used, the mode of application, and the likelihood of man–insecticide contact after application. They can be lessened by choice of the most suitable insecticide with the lowest toxicity, by the provision of protection for operators, by emphasis on personal hygiene and, if necessary, by surveillance by biochemical tests of the applicators to ensure that they can be withdrawn from contact with the insecticide before symptoms of intoxication appear. If hazards to applicators can be controlled, and insecticides are properly applied, hazards to the general population are most unlikely.

There are practical limits to the toxicity of the insecticides that can be used for indoor residual spraying by current methods. At present, these limits appear to be represented by the toxicities of compounds like fenitrothion in the organophosphorus group (LD_{50} (rats) : oral 504 mg/kg, dermal 3500 mg/kg) and propoxur in the carbamate group (LD_{50} (rats) : oral

95 mg/kg, dermal 1600 mg/kg). More toxic insecticides, such as fenthion can be applied to highly polluted water as larvicides, but strict supervision and surveillance of the applicators is necessary.

Care should be taken to ensure that toxic and highly toxic pesticides are applied only by trained applicators and that they are not available to the general public for household use. Recommended safety precautions have been discussed in detail in the twentieth report of the WHO Expert Committee on Insecticides (*9*).

The plan of operations

The data compiled from the surveys and pilot trials and from previous experience, where available, should form an adequate basis for planning the detailed activities of the programme and its operational and administrative organization and needs. The document thus prepared is a programme proposal, which, after review and approval by the various parties concerned, becomes the plan of operations.

B. IMPLEMENTATION

The implementation of vector control operations should be considered only when appropriate provisions have been made to comply with all the technical, administrative, and logistic requirements of the plan of operations and when firm commitments for the long-term funding of the programme are assured. The last of these requirement is especially important when the objectives can be achieved only after an extended, uninterrupted period of operations, as is the case for malaria eradication and onchocerciasis control.

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