JOINT FAO/IAEA DIVISION

of Isotope and Radiation Applications
of Atomic Energy for Food and Agricultural Development

INTERNATIONAL ATOMIC ENERGY AGENCY
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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REPORT OF THE

ADVISORY GROUP MEETING

ON

GENETIC METHODS OF INSECT CONTROL

9 - 13 November 1987

Vienna, Austria

EXECUTIVE SUMMARY

Despite the availability of a range of modern pest control techniques, insects remain a major cause of production losses in agriculture and contribute significantly to diseases of man and livestock. The increasing incidence of pesticide resistance, and concerns over the environmental impact of residues, have highlighted the need for improved technologies. As a result, genetic methods of pest control, including the use of irradiation sterilized insects, have become of increasing importance. It is therefore essential that the Joint FAO/IAEA Division continues to promote the development and application of this method of pest control.

The advisory group concluded that the opportunities for genetic control might be widened by the application of new techniques, particularly recombinant DNA technology. The scope for integration of genetic control methods with other control measures, and its use as a temporary suppressive measure on an area-wide basis was also recognized. Examples are given from representative groups of insect pests to illustrate how these concepts can be applied.

The advisory group regarded the Seibersdorf laboratory as a unique facility for the conduct of tactical research related to mass-rearing and release procedures for major pests such as medfly and tsetse spp. Associated research on genetic sexing of medfly, diet recycling and the development of more environmentally acceptable alternatives for pre-release suppression of medfly were considered to be important research projects. The advisory group concluded that the laboratory should continue to remain a centre of excellence for mass-rearing technologies for medfly and tsetse spp., and for training scientists and technicians from developing countries.

The Joint FAO/IAEA Division currently plays a major co-ordinating and supportive role for those areas of international research which impinge on genetic control. The advisory group believes that the Joint FAO/IAEA Division should maintain its initiative in bringing together leading genetics and molecular biology laboratories and continue to support their research on general gene transfer techniques and the development of genetic sexing methods for insects that are amenable to genetic control. The action of the Joint FAO/IAEA Division in co-ordinating the use of F-1 sterility for the control of lepidopteran pests was also regarded as an important initiative. The advisory group strongly supports the continuance of the Joint FAO/IAEA Division's activities in co-ordinating research programmes, promoting information flow through the newsletter and in providing training fellowships.

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I. INTRODUCTION

The Joint FAO/IAEA Division's research and development activities in the area of insect control has, since the inception of the programme in the mid-1960s, emphasized the development of methodologies and capabilities for applying the Sterile Insect Technique (SIT) to eradicate or control major insect pests, especially in developing countries. Periodically, specific subject areas under the programme are reviewed by invited consultants who advise on and recommend activities for improving the programme. The first advisory group meeting in the field of genetic control of insect pests was convened in July 1975 to consider the potential of genetic control in resolving agricultural and veterinary insect problems. At that time, the SIT had been demonstrated as a practical and preferred method for controlling the screwworm fly in the U.S.A., and similar programmes were under investigation for agricultural, veterinary and medical insect pests. By 1975, there also had been extensive discussion and research on other methods of genetic control, but only limited field testing to validate the ideas proposed.

The following report presents the findings and recommendations of an advisory group convened in Vienna from 9 - 13 November 1987, some 12 years after the 1975 meeting. The advisory group was requested to:

(1) review progress in the development of genetic methods of control;

(2) assess new technologies which are relevant to genetic control and determine their availability;

(3) establish whether the current status of alternative control measures has lessened or increased the need for genetic control measures since 1975;

(4) assess the likely course of development in the field of genetic control over the next 5 to 10 years;

(5) examine the role of the Joint FAO/IAEA Division in extending the application of genetic control measures in order to increase agricultural output and production efficiency in developing countries; and

(6) make recommendations to guide relevant genetic research in support of the SIT.

A. Definition of genetic control

For purposes of this report, genetic control of insect pests is defined as any approach involving the introduction of genetically-altered insects into a population with the objective of population suppression or a reduction in pest status. Generally, the released insects will have been reared in the laboratory and treated with irradiation or chemosterilization or have been manipulated genetically, or be the progeny of crosses between strains which exhibit some type of incompatibility. Genetic control could include the release of both sexes, or males only, in which (1) all gametes contain dominant lethals induced by irradiation or chemosterilization; or (2) all gametes will give rise to dominant lethals in later generations through some inherited effect, e.g. delayed or hybrid sterility in lepidopteran pests; or (3) released individuals carry chromosomal rearrangements which result in lethal chromosomal imbalance; or (4) other genetic traits such as recessive lethal genes that cause inviability in subsequent generations, lead to a reduction in numbers of the target pest. In some instances, a genetic transporting mechanism such as meiotic drive or negative heterosis could be incorporated into the system to introduce conditional lethal traits or genetic information aimed to replace a noxious form with some non-noxious form.

B. Rationale for genetic control

Despite the development and availability of a wide variety of techniques for controlling insect pests of agricultural, veterinary and medical importance, insects remain a major cause of food and fibre shortage, and a major contributor to diseases of man and livestock in both developed and developing countries. Synthetic pesticides, in particular, have enjoyed a pre-eminent place since the 1940s in the control of insect pests, and will remain an important component of pest control measures for the foreseeable future. However, four factors have led to the need for changes in the ways synthetic pesticides are used: the widespread development of resistance, increasing costs of developing and registering new pesticides, greater consumer awareness of pesticide residues in foodstuffs and other commodities, and the enactment of legislation in many countries to minimize residues and restrict the use of broad spectrum pesticides. Thus, more than ever, there is a need to find alternative methods of pest control that avoid resistance problems and are environmentally less damaging. A number of alternative and novel methods of pest control are being developed and implemented throughout the world. These include biological control, integrated pest management which aims to combine the positive features of chemical and biological control, vaccines, biorational compounds such as growth regulators and pathogen toxins, neuropeptides and synthetic sex pheromones, insect pathogens, and genetic methods of pest control. This report focuses on genetic control but does acknowledge the need to combine whatever means become available to control insect pests safely and effectively.

One form of genetic control, the sterile insect technique (SIT), rose to prominence with the successful eradication of the screwworm fly from the U.S.A. during the 1950s and, more recently, with the elimination of this livestock pest from Mexico. The SIT has also been used to eradicate populations of other species of dipteran and lepidopteran pests, including tsetse spp., old world and new world screwworm, various tephritids, and several lepidopteran pests.

Despite the important successes with SIT and other methods of genetic control indicated in the preceding paragraph, it would be fair to say that the level of success is below the expectations of the early 1970s and a number of programmes have been abandoned because of lack of progress (e.g. olive fly, Culex spp., Anopheline spp., Aedes aegypti, selected medfly trials). Reasons for this lack of achievement include the existence at that time of effective chemical control options, technical limitations in the methods available for treating or manipulating insects prior to mass-rearing and release, inadequate knowledge of the general biology, ecology and behaviour of the target pest, and, finally, social and political problems associated with area-wide eradication programmes. Genetic control can be a difficult concept to "sell" to laypersons, who become bemused when the pest manager releases individuals of the same species. Regionally based control programmes which run across political boundaries can also cause problems for the successful development of genetic control programmes as in the extension of the screwworm fly and medfly projects from Mexico into Central America.

During the past 10 years, co-incident with increasing pesticide usage problems, there have been important advances in the techniques available to the practitioner of genetic control, especially with the advent of molecular biology and recombinant DNA technology. There has also been greater emphasis placed on development of area-wide management programmes based on the principle of preventing large outbreaks through localized suppression. These developments emphasize the need to seek ways of optimizing the effectiveness of genetic control and integrating it with other management tactics.

This report reviews developments that have occurred over the past decade in relation to genetic methods of pest control and provides a set of recommendations to the Joint FAO/IAEA Division concerning the likely directions of research and development in the area of pest management and the key role that the Joint FAO/IAEA Division can play in promoting and supporting this research and its application to developing countries.

II. THE NEED TO INTEGRATE GENETIC CONTROL WITH OTHER PEST CONTROL MEASURES

A. Availability of other pest control measures necessary for genetic control implementation

An important component of successful SIT programmes has been their intelligent integration with a range of traditional methods to ensure effectiveness. For example, chemicals were used before and during the SIT programmes for the screwworm fly in North America. Husbandry and quarantine measures were then deployed to maximize and sustain the impact of SIT in the U.S.A. and Mexico. Similarly, integration measures were a conspicuous feature of successful SIT programmes for *Dacus dorsalis*, medfly, gypsy moth and the pink bollworm. Indeed, the need for more environmentally acceptable means of reducing the abundance of the medfly in Central and South America, and in the Mediterranean region, before initiation of a medfly SIT programme, is now a major concern to pest control authorities and the Joint FAO/IAEA Division.

Recommendation:

The advisory group recommends that the Joint FAO/IAEA Division should continue to identify specific operational conditions under which genetic control will be deployed for key pests and those cases where genetic control is dependent on availability of other pertinent information or control procedures which are currently not available. Where such a deficiency is identified, the Joint Division should inform the research community, through its existing information network and newsletters, and seek ways to actively promote relevant research through various funding mechanisms. If such measures do not lead to the necessary research being carried out, the Joint Division should consider establishment of the relevant research programme in its own laboratory at Seibersdorf (see section V).

B. Integration of genetic control with other control measures

Regulatory programmes can be effective in preventing introduction and artificial movement of pests, but new introductions of exotic species do occur from time to time. Provided these introduced populations are detected early (when they are still localized) eradication is a justifiable objective. Likewise, eradication is necessary when total elimination of the pest from localized areas frees those lands for needed agricultural production which is not feasible in the presence of the pest. It is in settings such as these that genetic methods of eradication should be further developed and support systems for their operational deployment maintained. Restricted eradication, either in time or space, may also be attractive when it results in pest containment at a cost less than that needed for continual suppression.

Genetic control methods should also be considered for use in integrated pest management programmes where eradication is not sought. Generally, it is believed that key pests (annually economic) are the best targets for genetic control. Currently, seasonal increases in density of these species trigger the initiation of control activities at a local (field) level. Pest management programmes are being developed for countering these pests on an area-wide level. Genetic control methods are ideally suited for early intervention in a population cycle to forestall later pest densities which would exceed the treatment threshold. In an area-wide programme, this preventive approach is feasible, but on a field by field basis it probably is not practical.

Genetic control methods are generally most useful against small populations, particularly in isolated islands or inland ecological enclaves. Most insects of economic importance, however, may occupy large areas within their normal species range, or may be migratory. In such situations, a more comprehensive approach, incorporating other control components, would be necessary to reduce the population to levels manageable by genetic control methods like SIT. Moreover, such large areas are unlikely to have obvious natural barrier zones and these can only be effectively created by resorting to other control measures like insecticide spraying.

The suitability of genetic control for management of intermittent pests is generally discounted because costs of developing and maintaining necessary technology appear unattractive relative to the simplicity of using chemical control when a pest becomes a problem. However, some of these species may offer great promise for genetic control. By utilizing genetic control methods for intermittent pests when populations are increasing, larger scale outbreaks may be averted. Viewed from a wide geographical perspective, a relatively modest rearing facility could serve a large geographic area.

Insecticide resistance has led to the rapid multiplication of pests to pre-control levels and even beyond. Genetic control methods, integrated with minimal use of chemical insecticides, could facilitate resistance management while contributing to the control of target pests. In recent years, biological control agents have been identified which may replace the use of chemicals against certain pests, particularly the aquatic stages of some insects in the tropics. The integration of genetic control methods into a general control scheme incorporating biological agents would help achieve the overall aim of environmental protection.

The creation of large water bodies to facilitate irrigation farming in certain tropical countries has resulted in the build-up of large populations of insect pests. This is particularly so in irrigated rice fields where the upsurge of medical vectors, mainly mosquitoes, has, by their effect on man, impeded agricultural production. The control of such insects would not only be of medical importance but would also lead to increased food production.

Clearly, there is a wide array of current pest control problems that exist because control practices are flawed or incomplete. Research on genetic control should proceed concurrently with development of other management technologies as integrated pest management strategies (IPM) are devised to meet those needs.

Recommendation:

Recognizing that genetic control could be incorporated into IPM strategies, the Joint FAO/IAEA Division should identify suitable opportunities where this philosophy could be adopted and should encourage research and development to ensure that genetic control is implemented in the broadest possible scope.

III. THE APPLICATION OF NEW TECHNOLOGIES IN GENETIC CONTROL

Interest in the use of novel techniques of relevance to genetic control has been stimulated by the rapid development of recombinant DNA technology, predominantly in *Drosophila melanogaster*. A major breakthrough is the development of gene transfer techniques using a particular transposable element, the P-element, to mediate transformation, thereby making possible inter-specific gene transfer. There are now many laboratories actively engaged in the development of general gene transfer systems suitable for a wide variety of pest organisms. There is little doubt that in the near future gene transfer systems will be developed for pest insects and thereby provide an important new dimension for genetic control.

Gene transformation could be exploited directly to produce novel control mechanisms or it could be used as an adjunct to support and strengthen conventional genetic control methods. It is therefore encumbent on pest managers to seek ways of using this powerful new tool in applied entomology.

Species-specificity, one of the virtues of genetic control, can also be one of its limitations, especially where a species comprises a number of cryptic sub-species. If relevant gene constructs could be developed in one particular species then these could also be used to transform related species. This capability obviously broadens the application of the genetic control approach and permits its extension to insect species where there is little genetic information available. The implications of this concept should not be underestimated. The following two cases will serve as examples as to how these new techniques can be applied:

- as recommended in the 1975 advisory group's report, genetic sexing of the medfly remains a high priority because of the advantages it provides for SIT control of this species. The development of genetic sexing using classical methods has faced significant difficulties. Gene transfer techniques could open up new possibilities. These are listed in the report of the IAEA Consultant's Meeting, Vienna, December 1985.

- genetic control through modification of the vectorial capacity of insect pests is a concept which has received considerable attention. At the moment the production of non-vector strains is limited by difficulties related to classical selection techniques. However, the molecular cloning, or synthesis, of genes for proteins which suppress the development of parasitic disease organisms, and the subsequent transfer of such genes into vector species, offers an alternative route for the production of non-vector strains.

These are just two examples of how molecular techniques could be of direct relevance to genetic control. However, besides the direct approach, molecular techniques can be of great significance in the supportive research necessary for both the preparation of a genetic control method and the monitoring of its effect.

Among the key requirements in genetic control, is an understanding of the population structure of the target species. Where a population is sub-divided either into sibling species or at the intra-specific level, as is common in mosquitoes, then it is essential to have practical methods of identifying the various taxa. The methods most widely used to date have been hybridization crosses, polytene chromosomes, allozymes and cuticular hydrocarbons analysis. Not only are these technically complex but interpretation of the results can require considerable skill, and the conclusions can remain ambiguous.

Where these methods are inappropriate or inadequate, then the use of recombinant DNA probes should be considered. Species diagnostic probes derived from repetitive genomic DNA sequences have been developed for a number of mosquito and simuliid vectors. ^{32}P or chromagen labelled probes can be used in relatively simple, dot-blot hybridization procedures. The target species DNA used for such studies need not be of high quality, and alcohol preserved material has proved wholly adequate. Such techniques are of value in both the initial survey and in the monitoring phases of control programmes. During initial surveys, southern blots of restriction enzyme digests of mitochondrial DNA may help determine the existence of sibling species.

There is a need for further development and use of molecular genetic markers in the monitoring of released insects. One crucial aspect of monitoring in most genetic control programmes is determination of the mating success of released males. It has already proved possible to identify the source of sperm from DNA-DNA hybridization in the form of dot-blots of individual mosquito spermathecae. It may soon prove possible to use introduced molecular markers to tag sperm of the release strain for detection by such techniques.

The laboratory rearing of insects prior to release requires the use of a number of techniques for monitoring and conserving genetic variability, mating competitiveness and fitness. By permitting regulation of sex ratios during laboratory rearing, modern recombinant DNA techniques might be used to improve the efficiency and economics of rearing programmes. Molecular transformation techniques could be used to introduce genes for insecticide resistance into insects for release to confer fitness superiority in the field.

In genetic control programmes directed against insect vectors of disease, it is important to monitor disease transmission. Some of the new technologies are of considerable value in detecting the presence of disease organisms and in quantitation of the infection. Techniques based on recombinant DNA probes are now available for the detection of vector stages of malaria, trypanosomes, *Leishmania*, filaria and rickettsial infections. Monoclonal antibodies have proved useful in identifying sporozoites in malaria vectors.

Recently developed biochemical techniques offer relatively simple methods for determining the insecticide resistance status of individual insects. These techniques have obvious relevance to genetic control programmes which involve release of strains with introduced insecticide resistance genes. DNA probes are already available for one insecticide resistance gene and in the near future such probes may be of importance in this area.

Population movement and migration of the target species can seriously reduce the effectiveness of genetic control programmes. There is a need for the development of improved techniques for monitoring migrants. Radio-labelling, genetic and molecular markers offer possible approaches which should be explored.

The release of organisms which have been genetically modified by recombinant DNA techniques is the subject of legislation in a number of countries and may be the cause of some public concern. In view of the wide disparity in policy between countries and the rapidity with which such policies are being developed and modified, it is essential that the Joint FAO/IAEA Division should continue to monitor the situation. It would also be useful to maintain contact with the FAO Expert Panel on Integrated Pest Management which has already shown an interest in this topic. Further to the following recommendations, the Joint FAO/IAEA Division may wish to take additional action when it becomes clear that genetic engineering is a component of a specific genetic control field programme.

Recommendations:

(1) The Joint FAO/IAEA Division should co-ordinate and distribute information on the major laboratories and persons involved in research and development of molecular techniques relating to genetic control of insect pests and vectors. The advisory group noted the impending formation of an insect molecular genetics newsletter by the Royal Entomological Society in London. This may in part meet the need for exchange of information. The Joint FAO/IAEA Division could contribute to this exchange by broadening the scope of its existing newsletter and information circular.

(2) Through the fellowship training programmes, the Joint FAO/IAEA Division should promote the training of graduates from developing countries in the newer techniques of recombinant DNA technology as they apply to genetic control.

(3) Considering the crucial importance of germ-line transformation and noting the difficulties being encountered using P-element vectors, we recommend that the Joint FAO/IAEA Division, through its genetic engineering co-ordinated research programme, supports further research into transformation methods.

(4) Noting the importance of insect population movement and migration in limiting the effectiveness of genetic control programmes, we recommend that the Joint FAO/IAEA Division promotes the development of improved techniques for monitoring migrants, with particular emphasis on the potential of molecular markers.

(5) The Joint FAO/IAEA Division should continue to monitor the use of recombinant DNA techniques in genetic control programmes and keep itself informed of developments in the public debate and government regulation of the release of genetically-engineered organisms into the environment.

(6) The Joint FAO/IAEA Division should obtain and hold on file up-to-date copies of the guidelines produced by genetic manipulation advisory or monitoring committees of the various countries where such policies are well developed, such as in the U.S.A., Australia, U.K. and various other European countries.

IV. CRITERIA FOR SELECTING TARGET SPECIES FOR GENETIC CONTROL AND EXAMPLES OF TARGET SPECIES

A. Criteria for selecting target species

A number of criteria for selecting pest species as targets for genetic control were identified in the report of the FAO/IAEA Consultants' Meeting on "F-1 Sterility for Control of Lepidoptera Pests" (Vienna, 12 - 16 November 1984). This advisory group agreed with the earlier viewpoint and concluded that the selected species should fulfill as many of the following criteria as possible:

1. The species should be a key pest of a host plant or animal of major importance, the control of which would result in significant social and economic benefits.

2. It should have continuous, serious pest status.

3. It should be of importance to a number of countries or be present over a large area.

4. Isolated populations of the species should exist.

5. For the species selected, present control methods are difficult or inappropriate; genetic control techniques could be integrated with other measures.

6. The species is amenable to genetic control in terms of behaviour, biology, ecology and reproductive physiology.

7. The species is amenable to the technology associated with genetic control.

8. The species is present at low densities at certain times, either due to natural fluctuations or specific suppressive measures.

9. Both insect abundance and the impact of the genetic control measures on the target population should be easy to monitor.

10. The species should be well studied, or related to others that are well studied.

B. Examples

The advisory group selected four groups of insects as examples of pests which satisfy many of the criteria mentioned above. The species chosen reflect the particular experiences of some panel members and should not be necessarily regarded as the most important candidates for genetic control. These four groups are elaborated upon below.

1. Pest Lepidoptera

In the FAO/IAEA Consultants' Meeting on "F-1 Sterility for Control of Lepidoptera Pests" (Vienna, 12 - 16 November 1984) a number of lepidopteran pests were identified as species which merit consideration for research on F-1 sterility. The species were assigned to either group I or II, the former being of a higher priority in that they met most of the established criteria for selection. Since the criteria for selecting insects for genetic control are virtually the same, the same species deserve to be considered for genetic control. These species (in group I) are:

Heliothis virescens and H. armigera
Spodoptera littoralis and S. litura
Pectinophora gossypiella
Ostrinia nubilalis and O. furnacalis
Chilo partellus
Diatrea saccharalis
Plutella xylostella

The diamondback moth (P. xylostella) is an example of a lepidopteran pest in South-east Asia and the following points about the species are relevant:

a. The host plants are cruciferous vegetables, in particular the Brassicas. Crucifers are one of the more important vegetable crops throughout the world.

b. At least in South-east Asia, the diamondback moth is invariably present when the host plants are cultivated.

c. The pest is cosmopolitan and regarded as a key pest in many countries. The importance of the species in developed countries such as Australia and Japan should provide additional impetus to research on it. Although it is by no means the only major insect pest attacking crucifers, the successful control of the diamondback moth should rationalize current control measures and the expected reduction in the use of insecticides will have socio-economic and environmental benefits.

d. Because of its status as a major pest, the species is one of the better studied insects. Mass-rearing studies are being conducted and there have been investigations into genetic control.

e. The species is highly resistant to a number of different insecticides and chemical control is considered to be an ineffective option. However, other measures remain potentially useful. Two of these measures are the disruption technique employing pheromones and biological control.

f. In South-east Asia important areas growing cruciferous vegetables are located in the highlands and these represent ecological islands.

Recommendation:

Many important agricultural pests are Lepidoptera, e.g. Heliothis spp., Spodoptera spp., Ostrinia spp., and Plutella xylostella. The advisory group commends the Joint Division's initiative in establishing a co-ordinated research programme in F-1 sterility for control of lepidopteran pests and recommends that the Joint FAO/IAEA Division continues to support research into the potential of genetic control against this group of pests.

2. Livestock pests

In many regions of the world there exists a single key ecto-parasite of livestock whose suppression or eradication would provide an enormous benefit to mankind. Such pests include old world and new world screwworm flies, buffalo fly and hornfly, myiasis-causing blowflies, ticks, tsetse fly, and stable fly. Some of these pests have been controlled by SIT (new world screwworm fly and species of tsetse flies in defined areas of West and East Africa) or measures are in place to eradicate pest introductions should they occur (e.g. *Chrysomia bezziana* in Papua New Guinea and Australia). Considerable effort has been expended on developing genetic control programmes for other pests including the Australian sheep blowfly, which are now at the stage of large-scale field trials.

Information currently available on tsetse genetics is still too incomplete to postulate ways of making use of genetic methods other than SIT to facilitate control and/or eradication of the tsetse fly and/or trypanosomes transmitted by the fly.

Recommendation:

The group recommends that the Joint FAO/IAEA Division should co-ordinate and support further studies of tsetse genetics and genetic control related aspects (field and laboratory-reared populations) with the aim of utilizing the knowledge so gained to augment existing control methods.

3. Medfly and other fruit flies

The medfly is at present a target species for control by the SIT. Successful eradication programmes have already been run in California and Mexico using a combination of bait spraying and SIT.

The basic rearing technology used in these programmes has been largely developed in the Seibersdorf laboratory. The laboratory's staff and facilities have also played a key role in the training of scientists and technical personnel for current or planned field programmes. It is important that the above roles be maintained in the future.

The adoption of SIT for medfly control in developing and developed countries is facing two quite different problems. In the developed countries, for example in the Mediterranean Basin, the use of the SIT is impractical because of the problem of sterile stings by the released females. Recognizing this, the Joint FAO/IAEA Division has used its co-ordinated research programme and the training of fellowships to stimulate the development of genetic sexing techniques and has currently expanded the approach to genetic engineering techniques. This expansion has been paralleled by the development of molecular biological studies in other fruit flies, especially Anastrepha suspensa. It is crucial that these parallel developments are recognized and that every effort be made to co-ordinate this approach.

In the developing countries a different problem is faced, for example, in the expansion of the current programme in Central America to Guatemala, namely opposition to the area-wide use of malathion bait spraying: as bait spraying forms an essential component of this programme, it is recognized that the search for a more acceptable environmental alternative has an extremely high priority. Ways to reduce production costs by developing methods of recycling the food medium should continue to receive high priority.

Recommendations:

(1) Recognizing that one barrier to the expansion of the SIT for medfly control in citrus exporting areas is the problem of sterile stings, and considering that the effectiveness of SIT will generally be improved by the release of males only, it is recommended that genetic sexing techniques using both classical and molecular approaches continue to be pursued and actively supported by the Joint FAO/IAEA Division.

(2) Considering that the expansion of SIT for control or eradication of medfly in many areas is faced with the problem of the use of malathion in the bait spray the Joint FAO/IAEA Division should ensure that research to identify alternatives be actively conducted in the relevant laboratories.

(3) Considering the importance of mass-rearing technology for genetic control, it is recommended that the expertise at Seibersdorf in this field be fully exploited.

4. Mosquitoes

Mosquito-borne diseases (e.g. malaria, dengue, filariasis, etc.) are of significant medical and economic importance in the tropical regions of the world. The health and livelihood of the citizens of many developing countries are constantly threatened, and these diseases exact a heavy toll on manpower and productivity, including the production of food and fibre that are essential to economic prosperity. Concerns for environmental damage and the repeated development of resistance have curtailed the use and effectiveness of pesticides, which has been the primary means of mosquito control. The development of alternative control methods, including genetic mechanisms, have been encouraged and the appropriate research conducted for the past two decades. This work should be continued in the future.

In the past, several successful, but generally small-scale, research projects demonstrated that SIT was effective in causing a high level of sterility in natural populations of mosquitoes. Genetic sexing strains have been assembled for a number of the important species of mosquitoes, and this form of technology in support of SIT is a positive factor. A genetic sexing strain was employed successfully to produce one million males per day in a large-scale SIT project. For some important species of mosquitoes, a considerable body of genetic and cytogenetic knowledge has been collected, and this information provides a good base for applying genetic engineering methodology in the synthesis of future and the enhancement of current genetic control systems. Several laboratories are engaged in basic investigations of some of the critical aspects of genetic engineering, and significant progress is being made, especially in respect to the use of recombinant DNA techniques for the analysis of population structure.

On two previous occasions, the Joint FAO/IAEA Division convened consultants' meetings for the purpose of evaluating the possibility of using SIT for the control/eradication of species in the *Anopheles gambiae* complex. In the first meeting in September 1982, the consultants recommended that appropriate ecological and genetic data should be collected on isolated populations of *Anopheles arabiensis* in Kenya as a prelude to the use of the SIT as a primary part of an IPM field trial. Recent studies in the Mwea Rice Irrigation Scheme in Kenya have provided background data on this 150 km^2 area suggesting that it may be a suitable site for consideration.

In the second meeting (January 1984), the island of Mauritius was proposed as an isolated site for evaluation of SIT against A. arabiensis, the primary malaria vector on the island.

Recommendation:

Considering that the proposed projects in Kenya and Mauritius received generally favourable reviews by the consultants and others, the advisory group recommends that further research be undertaken to develop genetic control of A. arabiensis.

V. THE ROLE OF THE AGENCY IN RESEARCH, DEVELOPMENT AND IMPLEMENTATION OF GENETIC CONTROL PROGRAMMES

A. The research capability of the Joint FAO/IAEA Division and the research objectives of the Seibersdorf laboratory

Other sections in this report have concluded that there exists considerable potential for genetic control as an eradication or suppression measure for internationally important pests, including medfly and other fruit flies, tsetse spp. of veterinary and medical importance, mosquito spp. in the developing and developed world, and coleopteran and lepidopteran pests of significance in agriculture and forestry.

The Joint FAO/IAEA Division has played a key role in tactical research, development, implementation and training over the past 20 years, particularly in relation to medfly and tsetse spp. The advisory group believes that there is a continuing need for this research and extension capability if genetic control is to be more widely used.

In particular, the Seibersdorf laboratory has been a centre of excellence for mass-rearing and general biology of both medfly and tsetse spp. It has extensive facilities and a unique capability for pursuing R&D in this area. Much of the successful development of SIT for medfly and tsetse species can be traced back directly to the tactical research, development and training conducted at Seibersdorf. The advisory group saw good evidence of effective interaction between the Joint FAO/IAEA Division's entomologists and scientists implementing large-scale SIT programmes for medfly in Central America. Improved production efficiency by diet recycling was considered important by the project operators and significant advances were observed at Seibersdorf on this problem.

The advisory group was aware that the development of genetic sexing techniques for medfly was proceeding in a number of laboratories around the world as well as at Seibersdorf. However, the advisory group considered that it was prudent to maintain this research initiative at Seibersdorf because of the difficulties and high risk of developing a practical system for mass-rearing conditions. Once one or several genetic systems were developed, it would be necessary to evaluate these under mass-rearing conditions. The advisory group felt that the comprehensive mass-rearing facility and the experience of the staff at Seibersdorf placed the laboratory in an excellent position to translate the genetic sexing procedures into a practical reality and to train operators from user countries in the new technologies. Furthermore, there were important questions relating to improved competitiveness of released males which are best done at Seibersdorf. Greater emphasis could be given to this area when resources permit. Consequently, the advisory group regarded it as essential that the Seibersdorf laboratory maintains in active form its medfly and tsetse rearing and tactical research facility at Seibersdorf.

Bearing in mind the outstanding technical advances made in recent years on tsetse rearing at Seibersdorf, the advisory group reached a similar conclusion concerning the tsetse operations at Seibersdorf. The tsetse component of the R&D activities was considered all the more important as tsetse is primarily a problem of developing countries and enjoys lesser research effort in developed countries than does medfly.

Notwithstanding the above observations, the group believes that the Joint FAO/IAEA Division will need to exercise its judgement carefully to select those R&D topics most likely to have the widest spin-off such as rearing methods and quality control and deployment methods for medfly and tsetse fly, or specific research addressing problems which are unlikely to be tackled effectively by other R&D organizations. The selection of environmentally acceptable substitutes for malathion to assist in pre-release suppression exercises would fit comfortably into this category. Consequently, the advisory group supports the Bacillus thuringiensis initiative at Seibersdorf. However, this problem could also be solved by evaluating other compounds, such as boric acid. The laboratory should maintain close contact with other groups currently addressing this problem or which have a capability to address the problem.

Recommendations:

(1) The advisory group strongly recommends that the Joint FAO/IAEA Division continues to play a leading role in the development of SIT procedures for medfly and tsetse fly spp., and that the Seibersdorf laboratory continues to play a major role in training of applied entomologists in developing countries and in the transfer of SIT technology to both developed and developing countries.

(2) The advisory group regarded it as essential that the Seibersdorf laboratory maintains in active form its medfly rearing and tactical research facility.

(3) Due to certain technical limitations in the mass production and distribution of sterile males for SIT, research and development for greater automation of aspects of mass-rearing and handling medfly is required in order to promote efficiency. The Joint FAO/IAEA Division should include this objective in its R&D programme at Seibersdorf. Research on diet recycling should continue at Seibersdorf because of the economic importance of this to mass-rearing of medfly in Central America.

(4) Conscious of the limited resources available to the Joint FAO/IAEA Division's Seibersdorf laboratory, the advisory group recommends that the Joint FAO/IAEA Division continues to monitor research developments elsewhere to ensure that work was not being duplicated.

(5) Should robust genetic sexing systems be developed at Seibersdorf or elsewhere the laboratory should regard as a high priority their development into practical operational systems for transfer to mass-rearing facilities in other countries.

B. <u>The role of the Agency in research and development of genetic control</u>

The Joint FAO/IAEA Division occupies a unique position in overviewing the extensive fundamental, strategic and tactical research being conducted in both developed and developing countries which is pertinent to the development of practical methods of genetic control of key insect pests which will assist developing countries in increasing the level and efficiency of food and fibre production. In particular, as many of the newer technologies such as molecular biology and recombinant DNA technology are very costly in terms of human resources, facilities and general supplies, and being essentially basic research, it is difficult to identify which areas will have the greatest relevance and spin-off for genetic control. The balance of effort and the direction of much of this research can and has been strongly influenced by the efforts of the Joint FAO/IAEA Division. The application of genetics and molecular biology to genetic control of the medfly is one outstanding example.

The consultants believe the Joint FAO/IAEA Division has already taken several initiatives or has in place mechanisms, which should enable it to capture the benefit of the new technologies for improving or extending the application of genetic control methods in developing countries.

1. The co-ordinated research programmes

The Joint FAO/IAEA Division has already invited a number of laboratories to participate in a scheme which will promote greater awareness and interaction between the workers concerned with research addressing problems of importance in genetic control. The Joint FAO/IAEA Division's current co-ordinated research programmes are the following:

a. "Development of methodologies for the application of the SIT for tsetse eradication or control";

b. "Development of genetic sexing mechanisms in fruit flies through manipulation of radiation-induced conditional lethals and other genetic measures";

c. "Standardization of medfly trapping for use in sterile insect technique programmes";

d. "Radiation-induced F-1 sterility in Lepidoptera for area-wide control"; and

e. "Genetic engineering technology for the improvement of the sterile insect technique".

By this means, and at relatively little cost, the Joint FAO/IAEA Division keeps itself informed of relevant research and places itself in a position where it can co-ordinate and influence both the direction and rate of progress of research pertinent to genetic control methods.

Recommendation:

The advisory group strongly recommends that the co-ordinated research programme scheme be continued by the Joint FAO/IAEA Division.

2. The fellowship training programme

The advisory group recognizes the enormous contribution to date of the Joint FAO/IAEA Division's programme in providing fellowship training for scientists and technicians from developing countries who are involved in insect and pest control operations.

Recommendation:

Considering that such training is vital for transferring new pest control technologies to developing countries, the advisory group recommends that the Joint FAO/IAEA Division should continue to support and promote training in all aspects of genetic control including basic insect genetics and molecular biology, wherever appropriate.

3. Information on genetic control

The group took note of the existence of a newsletter and information circular for disseminating information on pest control methodologies. Recently, a new information circular was initiated by the Joint FAO/IAEA Division specifically on medfly genetics.

Recommendation:

The advisory group recommends that the Joint FAO/IAEA Division continues to support and expand the scope of these publications to include R&D topics that are relevant to genetic control in general.

ANNEX 1

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ANNEX 2

WORKING PAPERS

1. The use of Y-autosome rearrangements and conditional lethals for controlling the Australian sheep blowfly, and gene transfer techniques in pest insects.

   Dr. M.J. Whitten

2. Prospects for genetic control of fruit flies in Brazil.

   Dr. J.M.M. Walder

3. Possible use of a genetic mechanism in the control of *Anopheles arabiensis* in East Africa.

   Dr. T.K. Mukiama

4. Prospects for genetic control of pest Lepidoptera in South-east Asia.

   Dr. Khoo Khay Chong

5. Research and development of genetic sexing techniques for the Mediterranean fruit fly, *Ceratitis capitata*.

   Dr. A.S. Robinson

6. The application of molecular techniques in insect vector control

   Dr. H. Townson

7. Inherited sterility in Lepidoptera: Principles and applications.

   Dr. C.P. Schwalbe

8. Genetic methods for control of mosquitoes and biting flies.

   Dr. J.A. Seawright