CONSULTANTS GROUP MEETING

ON

PRODUCTION SYSTEM ANALYSIS AND ECONOMICS FOR TSETSE FLY MASS-REARING

AND

THE USE OF THE STERILE INSECT TECHNIQUE IN ERADICATION PROGRAMMES IN AFRICA

23 September - 3 October 1991

Vienna and Seibersdorf, Austria

CONTENTS

EXECUTIVE SUMMARY

A consultants' group met in Vienna from 23 September - 3 October 1991 to explore "Production System Analysis and Economics for Tsetse Fly Mass-rearing and the Use of the Sterile Insect Technique in Eradication Programmes in Africa". This report is based on their observations during working visits to the Entomology Unit of the IAEA Agricultural Laboratory at Seibersdorf, and on information supplied by the tsetse team and staff of the Joint FAO/IAEA Division's Insect & Pest Control Section.

The consultants conducted a technical, operational and financial review of present rearing methods, equipment, philosophies and production capacities, taking into account one of the recommendations made at the 6th Session of the "FAO Commission on African Animal Trypanosomiasis" held in June 1991 in Harare, Zimbabwe. This recommendation, related to the use of the Sterile Insect Technique (SIT), states that "FAO, through the Joint FAO/IAEA Division, should further investigate and improve the use of sterile insects to strengthen the efficacy of tsetse surveys and, where applicable, consider the use of the SIT to support eradication campaigns where other techniques on their own will not achieve this objective".

In investigating the potential for improved tsetse mass-rearing and analyzing the present costs of pupa/distributable sterile fly production, the consultants noted that:

1. The Seibersdorf Tsetse Unit is conducting an effective research and development programme which strives to emulate a production facility while continuing to pursue R&D. The capacity of the present facility in Seibersdorf is practically limited to a colony size of about 150,000 breeding females. The release of sterile males in an eradication campaign of economical relevance would require a colony containing more than 500,000 female flies. Such a population can only be maintained in an organizational, operational and financially justifiable manner if the rearing technology is transferred from an R&D philosophy to one of large-scale production.

2. At the current status of the programme, the main cost of production is staff cost, accounting for over 50%. Operational costs are approximately US$ 0.40 per usuable pupa and US$ 0.60 per sterile male pupa. These costs are in line with other studies on production and are quite good for an R&D operation.

3. Estimations of field operation costs, including sterile male release for eradication and sterile female release for detection, indicate the feasibility of SIT programmes in a West African situation, but also show the value of a lower cost of mass-produced flies as an important consideration in making decisions regarding eradication programmes.

The group concluded that:

1. The Tsetse Unit at Seibersdorf should focus its structure and activities to R&D with respect to mass-rearing techniques for the SIT in Africa.

2. A number of experiments should be conducted which might help to overcome problems and limiting factors of the present rearing methods. An emphasis on improvements in mass-rearing is justified given the economic indicators shown as a result of the present study.

3. Written documentation should be generated immediately so that the current production process is defined, controllable, transferable and easily discussed.

4. In order to assess more rigorously the actual overhead costs to the production colony (i.e. the Glossina tachinoides model) and the scope for targeting cost reductions, it is necessary to identify, quantify and accurately cost the actual overheads of the production unit. Similarly, disaggregation of the consumable usage is necessary in order to carry out constructive cost analysis.

In addressing criteria for the development of a successful mass-rearing facility for the SIT in Africa, the group commented on the relative merits of tsetse production contracted to private industry or performed by an agency, regional or national facility, and made a comparison of the advantages of a mobile versus a fixed production facility, also emphasizing the modular system design.

1. INTRODUCTION

The increased public concern regarding chemical pesticide use by international organizations and their commitment to non-chemical means of insect management, have resulted in emphasis on those methods available to control insects that are environmentally sound.

The International Atomic Energy Agency (IAEA) and the Food and Agriculture Organization (FAO) of the United Nations have long been working on certain alternatives to chemical pesticide use. The work of the Joint FAO/IAEA Division in the SIT dates back to the mid-1960s. Most recently, the joint efforts of FAO, IAEA, IFAD, UNDP and the Libyan Government have resulted in a very successful programme to combat the spread of the New World Screwworm which had been established in North Africa. The method of accomplishing this task was in a large part by the screwworm SIT, originally developed to eradicate this insect pest in the United States [1].

The tsetse fly, Glossina spp., comprising 30 species and sub-species, is a major insect pest throughout large parts of Africa. It is the vector of trypanosomiasis, sleeping sickness in humans and nagana in domestic livestock. At the World Food Conference in 1974, the Food and Agriculture Organization (FAO) of the United Nations declared the tsetse and trypanosomiasis problem to be one of the most serious constraints to livestock development on the African continent.

Various methods of control are available, including the use of trypanotolerant cattle, chemotherapy, vaccine development (with limited progress), trapping, insecticidal targets, conventional insecticidal treatments and biological techniques. No one method has proved technically and economically effective against all species of tsetse in the wide range of agro-ecological zones of Africa. Methods which were previously used widely, such as ground spraying with DDT, are now considered unacceptable on environmental grounds. Newer techniques relying on odour attractants used with traps or insecticide treated screens are promising but have, to date, proved more effective against the savannah species than against riverine and forest tsetse species.

A programme involving the release of sterile male insects, called SIT, for this variety of insect pests has been developed for many years. The use of SIT as part of an integrated control programme has been endorsed by international agencies and affected countries alike. Research and development by the IAEA and others has resulted in the ability to mass-produce and apply tsetse SIT methods in Tanzania (mainland and Zanzibar), Burkina Faso and Nigeria.

Despite its environmental advantages and technical feasibility, the technique's main disadvantage is generally considered to be its high cost. Prospects for wider utilization of SIT for tsetse control in Africa in support of sustainable rural development will be improved by addressing this key issue: Can the cost of the technique be substantially reduced? These programmes offer the opportunity to evaluate large-scale production techniques that may be applied in a successful fashion to provide necessary insects for utilization in the integrated pest management programme for this serious African insect pest.

2. BACKGROUND

Self-perpetuating tsetse colonies have been held under laboratory conditions since 1959 [2]. The IAEA Agricultural Laboratory at Seibersdorf became involved in this subject in 1967 [3]. Breeding of tsetse colonies became significantly more successful in 1975 due to the development at Seibersdorf of an artificial feeding system utilizing a silicon membrane. This method, and other essential related techniques of preparing conservable diets of fresh and lyophilized bovine and porcine blood, made it possible to start two pilot SIT programmes. These programmes, one in Burkina Faso and one in Nigeria, proved the feasibility of SIT for riverine tsetse species with laboratory bred sterile males.

The present capabilities of the technology developed in Seibersdorf is illustrated by Appendices II.1. and II.2. They demonstrate the status and performance of tsetse species held in colony during the period January - June 1991.

The total colony size of all species combined consists of more than 130,000 females of seven different Glossina species. Of those seven species, 83% of the production was due to Glossina tachinoides: 1,690,000 total puparia were produced in the first six months of 1991, and 530,000 were dispatched to consignees in Europe and Africa for either research or ongoing eradication work. This figure is quite impressive when considering that the production facility was never designed as a mass-rearing operation. Its objective is to be a service unit of the Joint FAO/IAEA Division in order to undertake research and development in the context of the IAEA's programmes and objectives.

Over the past two decades many papers and reports have been published regarding the use of SIT for control of tsetse in Africa. The more recent publications ([4], [5], [6], [7], [8] and [9]) have expressed that:

A. SIT has been proven as an effective method for control and/or eradication of various insect pests; and

B. SIT against tsetse is considered as one aspect of an integrated pest management programme involving the Joint FAO/IAEA Division, participating national governments and several donor countries.

The Joint FAO/IAEA Division's activity related to tsetse/ trypanosomiasis control was recently addressed at the "FAO Panel of Experts on Ecological and Technical Aspects of the Programme for the Control of African Animal Trypanosomiasis and Related Development" and at the 6th Session of the "FAO Commission on African Animal Trypanosomiasis" held in June 1991 in Harare, Zimbabwe. With regard to SIT, the following recommendations were endorsed:

A. The use of SIT in combination with trapping and target devices is justifiable when the objective for its use is eradication and when this can be achieved at an acceptable cost.

B. The production capacity of existing tsetse rearing facilities should be strengthened so that at the sub-regional level (e.g. West African countries) biological products can be used for field release and bioassay work on a cost-sharing basis.

C. The release of sexually sterilized female tsetse flies should be explored as sentinel insects for the detection of low-level native populations and for use as a complimentary entomological method to monitor the progress of control operations where this does not exacerbate the trypanosomiasis situation.

In addition, it was generally recommended by the commission that "FAO, through the Joint FAO/IAEA Division, further investigates and improves the use of sterile insects to strengthen the efficacy of tsetse surveys, and where applicable, considers the use of SIT to support eradication campaigns where other techniques on their own will not achieve this objective".

3. CONDUCT OF CONSULTANCY - IAEA HEADQUARTERS AND SEIBERSDORF

The Consultants' Group Meeting on "Production System Analysis and Economics for Tsetse Fly Mass-rearing and the Use of the Sterile Insect Technique in Eradication Programmes in Africa" was conducted from 23 September - 3 October 1991 at the IAEA Headquarters in Vienna and Seibersdorf Agricultural Laboratory. The list of participants is included as Appendix I.

The objectives of the consultancy as described by the IAEA was to:

A. carry out a technical, operational and financial review of present rearing methods, equipment, philosophies and production capabilities;

B. investigate the potential for improved mass-rearing at Seibersdorf and the use of sterile insects in control and eradication operations in Africa;

C. propose suggestions for implementation of a tsetse mass-rearing facility intended for use in Africa; and

D. assess opportunities for improving the prospects for use of SIT in an integrated pest management programme for tsetse in Africa.

Time was split equally between IAEA Headquarters in Vienna and the Agricultural Laboratory at Seibersdorf. Comprehensive materials relating to all aspects of the programme were presented orally and in written form by personnel. No materials were provided beforehand. Written materials included reports, publications, tables, sketches and summary lists. Actual flow charts, standard operating procedures (SOPs) and organizational charts were not available. However, a clear idea of these areas was communicated to us during the working sessions. As a result, a flow chart was constructed and is attached as Appendix III.

Due to the limited time available, the group of consultants had little opportunity to personally perform each operation of the production process. However, the data accumulated for each step in production were reviewed and the process was seen in operation. In addition to the Entomology Unit, the group met with the Agrochemicals and Residues Unit and the Animal Production and Health Unit of the IAEA Agricultural Laboratory at Seibersdorf for discussions and review of their work related to tsetse and trypanosomiasis control. A summary of that information is included as Appendix IV. Co-operation from all staff involved was outstanding which was greatly appreciated by the consulting team.

4. FINDINGS (OBSERVATIONS)

The consultants know that the present methods of rearing and production of sterile males in Seibersdorf are the result of more than twenty years of research and development by its laboratory staff, visiting experts and researchers. The improvements over that time frame have been marked, in particular the development of the membrane feeding system. A large number of well-designed experiments were performed which aided in the positive development of current knowledge.

Application of that research and development in actual operating situations requires a different look at procedures, one more in tune with commercial production standards. The next challenge for the IAEA is to transfer that technology and provide a viable support group for one or more large-scale mass-rearing facilities.

A production facility is, by definition, a facility in which a known amount of product can be produced in a given time. It is thought by some that this definition cannot be applied to living organisms. This is not correct. Living organisms can be used as a "production vehicle" to manufacture a known quantity in a predictable manner. The keys to success include:

A. a stable production process that is never varied unless an improvement is well documented and only then by proper procedure;

B. written procedures (SOPs);

C. constant environmental conditions;

D. reliable employees and/or an automated system;

E. a well-designed facility (including flow of materials); and

F. contingency planning in advance.

Production facilities are designed to manufacture a specific substance. This concept is the overriding consideration in setting the specifications during design for all aspects of the building. Often a company will tear down and re-build a facility when the product line changes in order to get the best efficiencies of production. It will not usually adapt an old building to a new process. A well-designed building will possess a logical flow of materials and workers as well as some degree of adaptability for new systems or processes.

In companies designing new production processes, one is taught to rarely believe the conclusions of the scientific literature until one has reproduced the experiment to his own satisfaction in his own laboratory. Some general principles which should be explored include determination of what factors impact mortality. For example: Are heavier pupae really an indication of better survival in the wild?

Findings are separated between Seibersdorf (R&D) and mass-rearing in Africa (production). Economic factors have been detailed and reviewed for each of the topics. Recommendations and discussions regarding the issues of concern are addressed in detail.

4.1. SEIBERSDORF (R&D)
(see Appendix V for floor plan)

4.1.1. Technical/operational

Seibersdorf's current management is highly efficient. The facility is well organized and the staff works together in a spirit of co-operation. The fact that an R&D project can achieve the levels of production such as this one has, is testimony to the quality of its personnel.

The Seibersdorf Tsetse Unit is conducting a programme which strives to emulate a production facility while continuing to pursue R&D. Instead, Seibersdorf should focus on performing all the necessary R&D experiments so that a predictable and optimized production process can be created. Once a production process has been optimized, it should not be changed without good reason, and all potential problems should be considered before they are implemented. The changing of the production process is the final step in the implementation of new procedures, and should only be done when there are clear improvements in the economic or production efficiencies.

The Seibersdorf Unit is a good R&D facility and a poor manufacturing facility. This is not due to the quality of the personnel or the direction of the laboratory. This is a reflection of insufficient dedicated space, faulty building design (poor flow of materials), an inadequate ventilation system, lack of documentation (SOPs - see below), and other production related factors. It makes the best of a non-perfect situation.

In biological production systems, the <u>environmental systems</u> are a critical component and should be constructed in a manner that repairs are automatic (or self-repairing). It is preferable that systems be designed with "off-the-shelf" items so that they can be easily obtained. Each room should have a "known" positive pressure in order to limit the potential for contamination (see section 4.2. on Mass-rearing for Tsetse SIT in Africa). We have been told that one system like this is operational and others are in process.

4.1.2. Financial analysis of the Seibersdorf operation

There are several reasons for analyzing the present costs of production of large-scale rearing operations at Seibersdorf:

A. To obtain an accurate true cost for the pupae which are currently being distributed outside the laboratory.

B. To examine the structure of production costs in order to identify priority areas for targeting cost reductions by either scientific research or management changes.

C. To improve the basis for planning and appraising possible future mass-rearing SIT programmes in Africa and possible use of sterile tsetse for purposes such as entomological monitoring.

The financial analysis of costs of production at Seibersdorf is presented in Appendix VI. The costing is a partial one, including only the extra costs incurred by the laboratory over and above its normal R&D budget. Taking into account annual charges for buildings, equipment, staff, consumables and other overhead costs, it is estimated that in 1991 prices the average cost of production is in the order of US$ 0.40 per distributable pupa. This is not equivalent to the price per distributable sterile male fly as distributed pupae include both male and female flies. Taking this into account, it is estimated that the cost per distributable sterile male (ex-Seibersdorf) is approximately US$ 0.60 per fly.

The main cost of production is staff cost, accounting for over 50% of the cost of production. Sixty per cent of this time is allocated to diet preparation/feeding and fly separation procedures, which underlines the need to focus efforts on improving these two parts of the production process.

Detailed data were not immediately available to analyze overhead costs accurately, which, according to the Seibersdorf accounting procedures, are charged to the Entomology Unit directly in relation to staff numbers. Using this way of calculating overheads, they amount to 24% of the cost of running the G. tachinoides colony. In order to assess more rigorously the actual overheads to the colony and the scope for targeting cost reductions, it is necessary to identify, quantify and accurately cost the actual overheads of the production unit. Similarly, disaggregation of consumables usage is necessary in order to carry out constructive cost analysis. It was outside the scope of the present consultancy to carry out this detail of analysis. It is recommended that data on weekly consumption of consumables (by inventory recording) and other services/utilities provided to the production colony be routinely recorded in order to facilitate financial management and evaluation of the unit.

4.1.3. Recommendations

Written documentation (SOPs - see below) should be generated immediately so that the current process is defined, controllable,

transferable and easily discussed. SOPs should be written in the following format:

A. The title of the specific operation to be performed (for example: Emergence or Sexing or Preparing the Blood Supply).

B. A list of all equipment to be used in this specific operation, including the name of instrumentation, manufacture, serial number, model number and quantity of the item used.

C. A detailed explanation (including environmental parameters) of how to perform the tasks so that someone unfamiliar with the process could duplicate it without difficulty. This section should be written by the employee performing the task and not by the management. It should be re-checked for accuracy by employing inexperienced personnel who should duplicate the task without supervision. Management should oversee this operation and assess its performance.

D. A document control number and date of revision. A document control number is simply a numerical code to identify individual SOPs and to separate distinct processes (for example: mass-rearing of insects versus preventative maintenance of equipment).

The building design, ventilation system and other deficiencies are not consequential at Seibersdorf since it is an R&D facility. They would be important in a facility dedicated to production. However, the process development aspects of the R&D operations should be similar to production scenarios. Therefore, Seibersdorf should concentrate on optimizing the production and economic efficiencies of the production process. This concentration should focus on the physical plant currently used as the Glossina tachinoides production unit, since it is clearly the most efficient one.

Seibersdorf needs to clarify and update much of the scientific information that has been generated since the programme's inception. This material basically falls under three categories:

A. Sound documented published research which is valuable.

B. A number of trials which, because of design or other reasons, do not answer the questions which need to be answered.

C. Information which was generated pre-membrane feeding and is based upon the systems which were not in place as of 1 October 1991.

Seibersdorf needs to thoroughly review all of the scientific research results which currently form the basis for production design and

management decisions, as there are several reasons why certain areas of the existing information base need re-validation:

A. Some experimental results were obtained on species different from those currently being mass-reared.

B. Results may have been obtained under in vivo feeding regimes where transferability of results to in vitro feeding systems may need to be demonstrated.

C. Results may have been obtained under other experimental conditions where transferability to tsetse-rearing on a large-scale may give different results.

D. In some cases, information required for production management decisions is slightly different from that required in scientific studies.

The staff are very much aware of the need for this type of re-validation: it is strongly recommended that the entire information base be systematically re-checked as a specific exercise.

The relevance of particular data can be evaluated by using the economic model and mathematical algorithm that has been included within this report as Appendix VII.

The format for all future experiments needs to be standardized. The best format for data reliability is to:

A. run an experiment with at least three samples of 60 or more insects/sample;

B. perform three separate experiments on different days; and

C. do a statistical analysis on every set of experiments.

Experiments will need to be done at Seibersdorf to optimize production. Besides the ones itemized below, experiments recommended for the mass-rearing section of this report would also be carried out at Seibersdorf and should begin as soon as possible.

A. Test whether antibiotics should be incorporated into the diet. Some antibiotics decrease fecundity and should not be used. However, antibiotics are known which can stimulate growth, increase survival rates and not decrease fecundity. It may be possible to selectively incorporate antibiotics using data from blood contamination tests to minimize mortality. This may reduce colony epidemics and lessen the risk of antibiotic resistance. Perform the same experiments with fungicides.

B. Test the quality of SOPs by hiring temporaries with no biological experience and assess their success.

C. Re-do every experiment relevant to mass-rearing which is based upon insufficient data. Remove all procedures from SOPs that are not relevant. For example, if one measures biological contamination, then one must use the data in some fashion. If one includes ATP (or other phagostimulants) in the blood source, then one needs to know what effect they have in the production setting. If radiation treatment of blood until all micro-organisms are killed results in a 10% decrease in pupae weight, then one needs to know if that 10% decrease has any effect on mortality or field efficacy (the true measure of success).

D. Re-design the forms used by employees to include information relevant to costing, and to ensure that only relevant data is being collected. Do not distract or waste employee time by requiring the collection of irrelevant data.

E. All experimental data (especially mortality counts) should be posted in a common area so that every employee has access to the data. A training course should be implemented so that employees can understand the implications of the data as well as the statistical manipulation. It is important that the staff realizes that a little change in production can make a significant difference in the results.

4.2. MASS-REARING FOR TSETSE SIT IN AFRICA

4.2.1. Technical/operational

The first critical decision that needs to be made is whether production of tsetse is contracted to private industry or performed by an agency, regional or national facility set up in Africa. An argument can be made for either case.

The advantage of involving private industry in general is that the Joint FAO/IAEA Division gets out of the production business and concentrates on research and development. It also provides technology transfer from the public sector to the private. There could possibly be competition for the contract which might further lower costs. Industry generally would be able to provide the facilities and operation in a more efficient manner. A contract could be let with clear parameters for quality control that must be met before any product payments are authorized.

Other factors may favour the operation of the facility by non-private organizations mentioned above. These include, but are not limited to, such things as continuity of financial support, organizational agreements and philosophies, political necessities and timing. It may well be that no private industry interest will make the decision moot. In either case, the following issues must be considered.

The development of a successful mass-rearing facility in Africa will have two basic differences from the operation of the facility at Seibersdorf:

A. It will be situated in an area with a different climate, political stability, access to scientific equipment, work regimen and personnel. This necessitates preparation and operations that have to be more able to deal with hardships.

B. The production facility does not do research and development. It would depend upon Seibersdorf for research and development, initial pupae production and as a back-up in the case of difficulties.

Given the fact that in either case the basic equipment and staffing would be the same, the real question is one of what type of facility to utilize. The choices are really two, fixed or mobile operations. A fixed site would require a permanent structure built most likely by local contractors with local standards. A mobile site would be constructed of modular units that are pre-built, shipped to the site and organized in the proper fashion. Advantages and disadvantages of mobile versus fixed production facility are listed in Appendix VIII.

4.2.2. Financial analysis

It is outside the scope of the present very short consultancy based at Seibersdorf to undertake a detailed analysis of the economics of mass-rearing tsetse flies in Africa. Brandl [10] has published a detailed economic study of experience with SIT for tsetse control in Burkina Faso, but similar evaluations do not appear to have been carried out in relation to BICOT in Nigeria or for SIT operations in Tanzania.

Costings will depend greatly upon the choice of country for which a project might be considered, the size of the project, number of species to be controlled and other factors.

It was felt that the most constructive way to develop an economic perspective on the economics of integrating SIT into tsetse and trypanosomiasis control operations would be to examine a hypothetical model of a plausible scenario somewhere in West Africa, examine the cost structures of such an operation, and examine whether there are any obvious implications for future prospects of SIT and related research programmes that might be developed under the auspices of the Joint FAO/IAEA Division and the IAEA Agriculture Laboratory, Seibersdorf.

Appendix IX presents a cost analysis of a hypothetical integrated tsetse control programme against a riverine species of tsetse, in which SIT is being used to achieve eradication after the tsetse population is suppressed using odour-baited insecticide treated screens (preferably odour-baited targets). This is closely similar to situations that have been experienced in the pilot programmes in Burkina Faso and Nigeria.

In this cost model, the cost of the direct field operations (excluding entomological monitoring, provision of access roads, and project overheads) amounts to just over US$ 1,500 per linear kilometre of riverine habitat.

The first observation is that the suppression phase (maximum duration: 4 months), which achieves 90-95% elimination, costs only a fraction of the SIT phase (maximum duration: 8 months), which is required to achieve the final eradication of the tsetse. This shows that in general, SIT is likely to be viable only in conjunction with other tsetse control techniques and that the Joint FAO/IAEA Division is correct in viewing SIT as only one potential component of an integrated operation. The cost analysis also demonstrates that where other methods are technically feasible, SIT, with current systems of pupae production and operational design, is not likely to be cost-competitive.

The second observation concerns the overall cost structure. The cost of the sterile males represents just under 50% of the total field operation cost. This confirms that research and development to improve mass-rearing of flies, from both a technical and financial viewpoint, could have a significant impact on the potential role of SIT in tsetse control programmes. On the other hand, it should be noted that manpower and vehicle costs represent some 40% of the total cost of field operations.

In order to substantially reduce the costs of such programmes, it will be necessary to give attention to reducing manpower and vehicle requirements for field operations. This is not a new area of research: in Zimbabwe, the use of targets is also constrained by high manpower and vehicle requirements, and research in that country is now giving increased attention to changes in target design and operational logistics to reduce manpower/vehicle overheads, sometimes at increased cost in terms of odour and insecticide used per target.

In the context of using SIT in tsetse control programmes, thought should be given to operational aspects of the use of sterile males. Is it possible to achieve eradication with fewer field visits, perhaps by releasing more flies per visit? Such questions may require appropriate field investigation.

While cost of production needs to be kept as low as possible, it may be more important to try to research and develop stable production systems rather than maximum output systems which may be less stable. This may mean accepting higher costs of production of the pupae in order to make production more robust and less sensitive to factors such as inconsistency in supplies of blood.

4.2.3. Considerations of SIT other than for control operations

The above analysis has concentrated on the use of sterile insects for achieving eradication. There are several other potential uses of sterile insects, particularly in the context of entomological monitoring [5] and possibly also in the protection of eradicated areas from re-invasion by tsetse.

Appendix X deals with the economic analysis of using sterile female tsetse to detect relic populations of wild tsetse. Objective methods for assessing the relative technical and cost effectiveness of different methods of fly surveying have not been developed. The appendix provides an example of how this problem can be tackled, and shows that it is plausible that entomological monitoring using sterile females could be cost-effective in comparison with existing methods. It is recommended that further research in this direction be considered.

4.2.4. Recommendations

In order to operate a production facility in Africa, it is imperative that Seibersdorf develops SOPs. Companies which wait until the last moment to collect written procedures from research and development routinely have significant difficulty implementing the process. The SOPs should be complete and an effort should be made to make them simple and efficient. The employees that one will hire may not have a predictable educational background. Every effort should be made to do contingency planning concerning problems that can arise from implementation of the SOPs using unskilled workers, and to try to design safety mechanisms into the procedures to circumvent potential problems (for example: implement on-the-job training, design equipment so that it works in only one way).

Since the African facility will not have quick access to spare parts and repair, it should do contingency planning and have back-up and/or duplication of important equipment. There should be spare parts which can be installed when needed, automatic back-up of key services (for example: back-up electrical generator) and duplication of critical equipment using switches so that when the first unit fails power is automatically shunted to the second unit. Obviously, this requires that the primary and secondary units are permanently installed at the outset. For example, the air-conditioning compressor should be constructed and connected in this manner. If this concept is not used, then the first air-conditioning failure will destroy most of the colony.

The facility should be under positive pressure so that contamination by micro-organisms is limited. In a simple positive pressure system a high volume air-conditioning (HVAC) system is regulated by variable air volume (VAV) control elements to achieve approximate levels of positive pressure. A good quality air filter is added to HVAC to limit contamination from outside sources. A system of this sort should be adequate for mass-rearing of tsetse flies based upon the data we have seen, but it should be confirmed by Seibersdorf. If microbial contamination (or cross-contamination) becomes a problem, then a more stringent set of isolation conditions should be considered, including air locks, interlocks, and more sensitive air volume monitoring equipment.

Electronic instruments are very stable except when subjected to high temperatures or variable currents. It is very important that power to the facility be filtered through a voltage regulator. It may be necessary to design two units in the same building with an automatic switch-over device so that non-regulated power is <u>never</u> used in this facility. Also, it may be necessary to go so far as to erect one or more lighting towers to protect a building in a remote setting.

A preventative maintenance programme for equipment should be written as an SOP and used to prevent equipment failure. This may require a full-time employee if the facility is in a hostile environment.

Extreme care should be taken to ensure that the design of the facility includes state of the art safety features to ensure protection for all personnel from injury or accident.

The IAEA should consider designing the production facility in modules so that expansion is simplified. A modular system may have inherent advantages in a mass-rearing system which could expand or contract depending on funding or political decisions. The rooms within a module should be connected in a logical manner so that materials and product "flow" through the facility. Materials and product should be transported the minimal distance possible. Rooms should be designed and positioned to limit the potential for microbial contamination. It is critical to decide ahead of time on key questions which impact facility design (for example: should the facility be mobile, should there be a backup water supply on site, fire protection schemes, etc.?).

A cost factor to consider is that a facility designed to rear multiple insects under mass-rearing conditions need not be twice as expensive as a facility designed to rear a single species. There will be common areas (food preparation, offices) and equipment (HVAC) which may be able to be shared in a well-designed mass-rearing facility.

The supervisors (or managers) who will oversee production in Africa should be hired at least 6 months in advance, and begin a structured training programme at Seibersdorf. It is imperative that these managers be instilled with the idea early on that a production process is a fixed process and must be dictated by the SOPs. If possible, the IAEA should consider hiring someone with prior industry experience.

In order for proper progression to follow the transition from R&D to mass-production, certain steps should be taken, including:

A. Determination of parameters to make decision-making possible regarding mass-production design strategies (for example: will a hypothetical cage size, shape and operation really work? How efficient is emergence control and utilization in sexing insects for breeding purposes? Can an inexpensive artificial media be developed?, etc.).

B. The following experiments or subjects for experimentation are suggested in order to answer critical questions in that regard. Answers to the questions raised by this work will allow the next stage of design and construction to occur. This would of course include final decisions on automation systems. None of those decisions can logically be made at this time.

Experiments which need to be done at Seibersdorf and which apply to mass-rearing in Africa, include the following:

A. Efforts to convert production to an artificial diet. The main thrust to successful production in biological systems is to eliminate variables. As long as the food source contains a number of variable agents, production will not achieve attractive economic results or predictable production quantities. In the past, synthetic diets have been formulated at Seibersdorf using crude haemoglobin extracts [11]. Since these extracts were contaminated with a mixture of insect components the results are not reliable. This group of consultants recommends that Seibersdorf uses outside industrial biotechnology expertise to develop a synthetic diet. A number of companies are in this business, and bring years of experience in a variety of animal systems. Moreover, the Kabayo protocols and results should be reviewed.

B. Ensure that food source is 100% aseptic (this is best achieved through an artificial diet). If tsetse are as sensitive to contamination in their food source as indicated, then the food source must be aseptic in order to manufacture predictable levels of insects.

C. Investigation of the possible correlation between mortality and handling. It is safe to assume that, as is the case in other insect systems, there is also a correlation in tsetse flies. Seibersdorf needs to concentrate on developing a system that limits the handling of insects. The best place to start is in the sexing operation (which takes up to 40% of total time spent in the process).

D. Plan and implement a series of experiments to separate females and males during emergence. One example would be the development of a cage that would be a closed system after pupae have been introduced. After a known interval of time, the pupae could be manually or automatically moved to a separate compartment in the same cage so that males and females could be separated without physical contact.

E. If blood must continue to serve as the primary food source, then an attempt should be made to determine if insects should be fed from the top, bottom or inside of the cage. Most animals use the presence of indicator chemicals to dictate when feeding should start or stop. If tsetse are not receiving the molecular indicators in their diet, they may starve or feed until they die and contribute to observed mortality rates.

F. Production will not be able to be performed in an efficient manner in the present cages. It is important that an attempt be made to increase the size and production of cages. Since personnel will be of uncertain educational background, this study is of particular importance. The cage should be designed as a closed system that limits handling. For example, one cage with three compartments could be envisioned. The first compartment would contain females (from the early emergence phase), the second would contain males (from the terminal phase), and the third section would contain a mixed population (from the intermediate phase of emergence). The third section should be detachable so that it may be used for release without having to move the insects to another cage. The barrier between the first and second section could be removed when the flies are old enough to be mated. The cage should be designed so that one day's complete production of pupae can exist in one cage. The less complicated the production procedures, the more likely they will be successful. In addition, it would be appropriate to incorporate into the cage a mechanism to remove dead flies without having to open the cage to the outside environment.

G. Examine male and female pupae shells for molecular differences, as an alternative method to be used for separating the sexes. Analyze the immunogenic fractions (proteins, glycoproteins, glycolipids) between males and females for any differences. These differences could be used to produce monoclonal antibodies, which when linked to colorimetric re-agents could easily be used for sex discrimination.

H. Test whether pupae or larvae (in an early stage) can be frozen immediately after collection. This would eliminate a lot of variability and allow one to stockpile pupae. One potential experimental design is to freeze pupae at one degree per hour until at -70°C. Thaw quickly after a few weeks of storage and determine mortality. Other experiments might include the use of cryogenic agents (glycerine, dimethylsulfoxide).

I. Investigate chilling (and other temperature incubations) as a method of increasing the difference in pupal emergence rates in females versus males.

J. If other insect populations can be manipulated (for example: medfly pupal coloration selections or male/female emergence rates affected by temperature and genetic sub-population isolation), then these procedures should be modified and applied to tsetse flies in an attempt to optimize production. In addition, work could commence on the search

for a "maleness gene", as in medfly, if it exists. Since there is a need for tsetse females for stock colony replenishment, the selection for pupal colour separation would be sufficient to cause a great increase in efficiency of production. A machine similar to the one used for medfly pupae colour separation could be used.

K. There is a remote possibility of inducing additional births per female or a quicker gestation period using fertility drugs or hormones. Although there is no work on this except in insects with multiple ovulation, it might be a worthwhile consideration given the difference an increase in egg production might create.

L. An attempt should be made to decrease the frequency of feeding. Does reduction of feeding regimes to 2 or 3 times per week have an effect on overall mortality rates (not pupae weights). Production scheduling could be simplified if one could lower feeding frequency to 3 times per week (half the colony could be fed on Mondays, Wednesdays and Fridays and the other half on Tuesdays, Thursdays and Saturdays). This standardizes feeding so that personnel are doing the same job every day.

The group strongly recommends that additional independent work be conducted in a timely fashion on:

A. engineering/design of automation systems, equipment and facility;

B. experimental formulation of artificial media substrates by biotechnology industry; and

C. economic analysis of Bicot operations.

Appendix I

LIST OF PARTICIPANTS

Consultants

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Mr. Detlef Luger	Tsetse Sub-unit
Mr. Harald Baumgartner	Tsetse Sub-unit
Dr. Chris Doku	(Ghana: scientific visit)
Ms. Loyce Alungat Okedi	(Uganda: fellowship)
Ms. Lucia Kruzic	Secretary Insect and Pest Control Section
Ms. Maria Hallqvist	Secretary Insect and Pest Control Section

Performance and status of Glossina spp. colonies at the Entomology Unit, FAO/IAEA Lab. Seibersdorf, in 1990

species	country of origin	% EM rate (mean + std)	% daily mortality (mean + std)	No. pupae/ fem./10 d (mean + std)	No. pupae produced Jan. to Dec. 1990	Mean No. colony females Dec.'90	status of colony
G. tachinoides	Burkina-Faso	91.6 2.8	0.57 0.20	0.87 0.09	1,831,379	109,597	production colony to provide 50,000 pupae per month to BICOT, Nigeria
G. p. palpalis	Nigeria	89.8 3.3	0.94 0.15	0.89 0.07	279,960	15,125	stock colony to provide 6,000 pupae pupae per month for experiments
G. f. fuscipes	Central African Republic	90.9 3.4	0.45 0.22	0.76 0.11	51,963	1,225	maintenance stock colony, adapted to mass-rearing conditions
G. brevipalpis	Kenya	90.3 5.8	0.32 0.11	0.83 0.08	50,441	1,213	maintenance stock colony, adapted to mass-rearing conditions
G. austeni	Zanzibar, Tanzania	94.9 2.6	0.64 0.23	0.94 0.04	67,006	1,187	maintenance stock colony, adapted to mass-rearing conditions
G. pallidipes	Uganda	84.8 4.5	0.85 0.26	0.84 0.09	31,350	1,080	colony under adaptation to mass-rearing conditions
	Zimbabwe		0.75 0.33	0.71 0.12	2,897	354	colony under adaptation to mass-rearing conditions
G. m. submorsitans	Burkina-Faso	94.6 2.4	0.97 0.24	0.52 0.07	6,064	965	experimental colony
					2,321,060		

Performance and status of Glossina spp. colonies at the Entomology Unit, FAO/IAEA Lab., Seibersdorf, January to June 1991

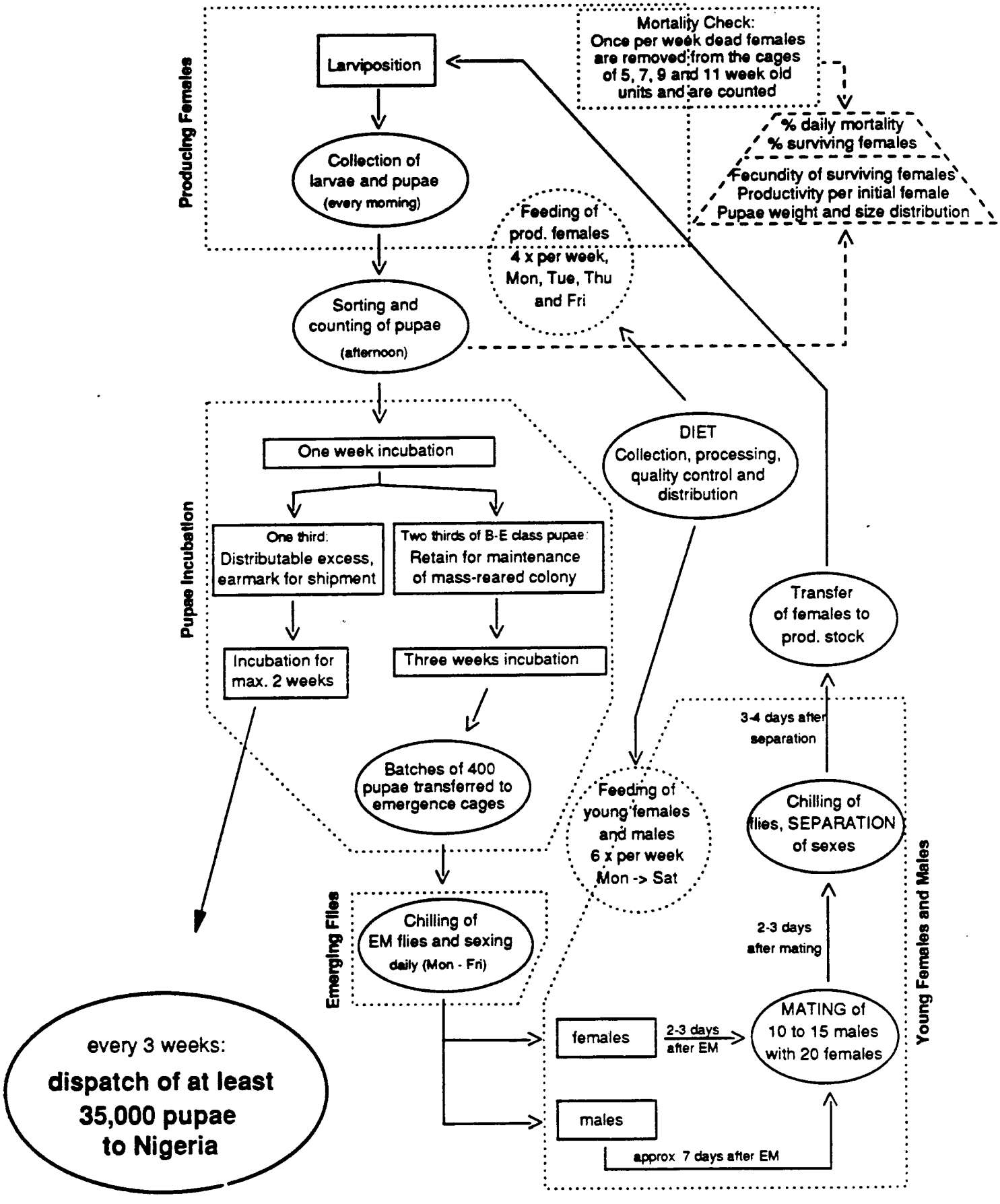
species	country of origin	% EM rate (mean ± std)	% daily mortality (mean ± std)	No. pupae/ fem./10 d (mean ± std)	Mean No. colony females June '91	No. pupae produced Jan. to June 1991	No. pupae despatched Jan. to June 1991	status of colony
G. tachinoides	Burkina-Faso	93.0 1.9	0.66 0.35	0.94 0.11	108,337	1,363,197	446,800	production colony to provide 50,000 excess pupae per month to BICOT, Nigeria
G. p. palpalis	Nigeria	92.3 1.1	0.98 0.24	0.97 0.64	10,832	185,472	81,720	stock colony to provide 5,000 pupae per month for experiments and for use in projects
G. f. fuscipes	Central African Republic	92.5 2.0	0.25 0.06	0.71 0.10	1,574	11,850	120	maintenance colonies, adapted to mass-rearing conditions
G. brevipalpis	Kenya	94.3 2.2	0.25 0.04	0.78 0.12	1,077	10,907	700	
G. austeni	Zanzibar, Tanzania	95.2 3.0	0.30 0.06	0.85 0.65	3,197	23,238	20	
G. palliditpes	Uganda	83.3 2.0	0.82 0.18	0.88 0.48	1,808	15,501	2,220	colonies under adaptation to mass-rearing conditions
	Zimbabwe	89.3 3.5	0.60 0.22	0.46 0.90	932	3,725	0	
G. m. submorsitans	Burkina-Faso	94.8 1.7	1.19 0.23	0.64 0.74	2,810	14,151	0	experimental colony
					130,567	1,628,041	531,580	

The emergence rate, the daily mortality and the female fecundity are averages from monthly gross-calculations. The %EM-rate summarizes results from three to four representative groups of pupae per month. The % daily mortality refers to the mean number of colony females each month, and the No. of pupae per female per 10 day period refers to the average number of producing females which is assumed to be two thirds of the total number of females in the colony.

Appendix III

Colonization of 100,000 female *G. tachinoides* at the Entomology Unit,Seibersdorf, 1991

Flow Chart of Routine Maintenance



Appendix IV

TSETSE TRYPANOSOMIASIS-RELATED ACTIVITIES IN THE AGROCHEMICALS AND RESIDUES UNIT AND THE ANIMAL PRODUCTION AND HEALTH UNIT

The consultants visited two units of the Seibersdorf Laboratory which are, in addition to the Entomology Unit, involved in the tsetse and trypanosomiasis programme of the Joint FAO/IAEA Division.

IV.1. AGROCHEMICALS AND RESIDUES UNIT

Dr. M. Hussain, Unit Head, gave a summarizing report about the ongoing co-ordinated research programme entitled "Development of Controlled-Release Formulations of Pesticides using Nuclear Techniques". The main objectives are to:

A. develop and test organic formulations and solvents (carriers) which protect or hinder pyrethroidal insecticides from decay and/or washing off under field conditions;

B. develop technically and financially reliable techniques of impregnating fabric targets with these materials; and

C. test insecticidal effectiveness of impregnated targets against tsetse under laboratory conditions.

Substantial progress has been achieved during the last decade which is well documented.

IV.2. ANIMAL PRODUCTION AND HEALTH UNIT

The Head of the Animal Production and Health Unit, Dr. P. Wright, explained in his report that the essential concerns of the unit, in close co-operation with FAO, WHO and OIE, are to:

A. establish and standardize biological kits (based on ELISA technique, radioimmunoassay and other biologically reacting methods) for the diagnosis of globally most important animal diseases (foot and mouth disease, brucellosis, rinderpest, etc.); and

B. design prototype production of these kits and prepare future full production.

With regard to African animal trypanosomiasis, the Animal Production and Health Section of the Joint FAO/IAEA Division and the unit at Seibersdorf co-ordinate and technically backstop activities conducted under the FAO/IAEA co-ordinated research programme on "Improving the Diagnosis of African Trypanosomiasis and other Vector-borne Diseases of African Livestock using Immunoassay Methods".

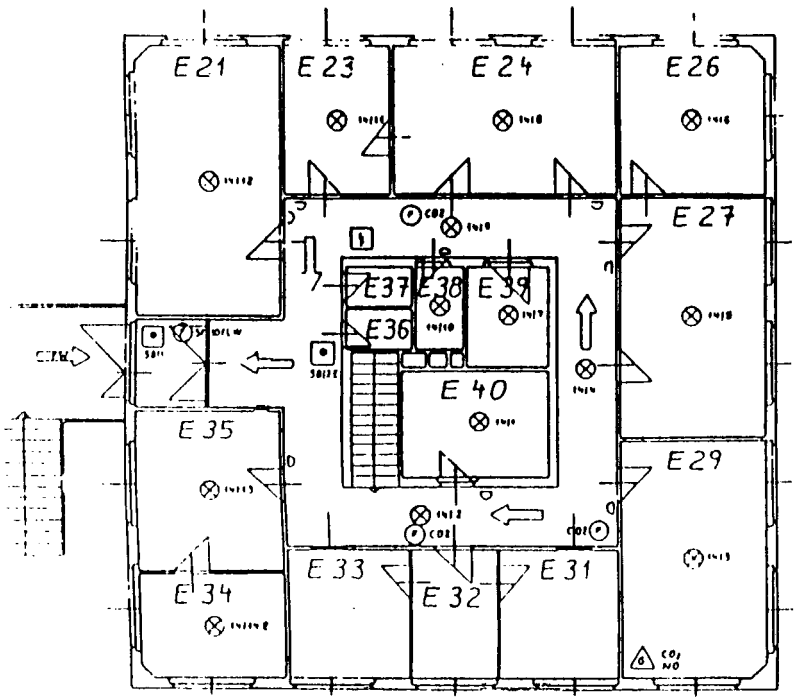
It seems clear that the Seibersdorf Laboratory has the ability to examine a broad spectrum of integrated pest management for tsetse. It is equally clear that there is not a strong focus by these two units to concentrate on tsetse/trypanosomiasis due to different programmatic influences.

E 31 HEAD OF ENTOMOLOGY, GINGRICH
E 35 COMPUTER ROOM
E 34 BAUMGARTNER
E 29 FELDMANN
LUGER
BARNOR

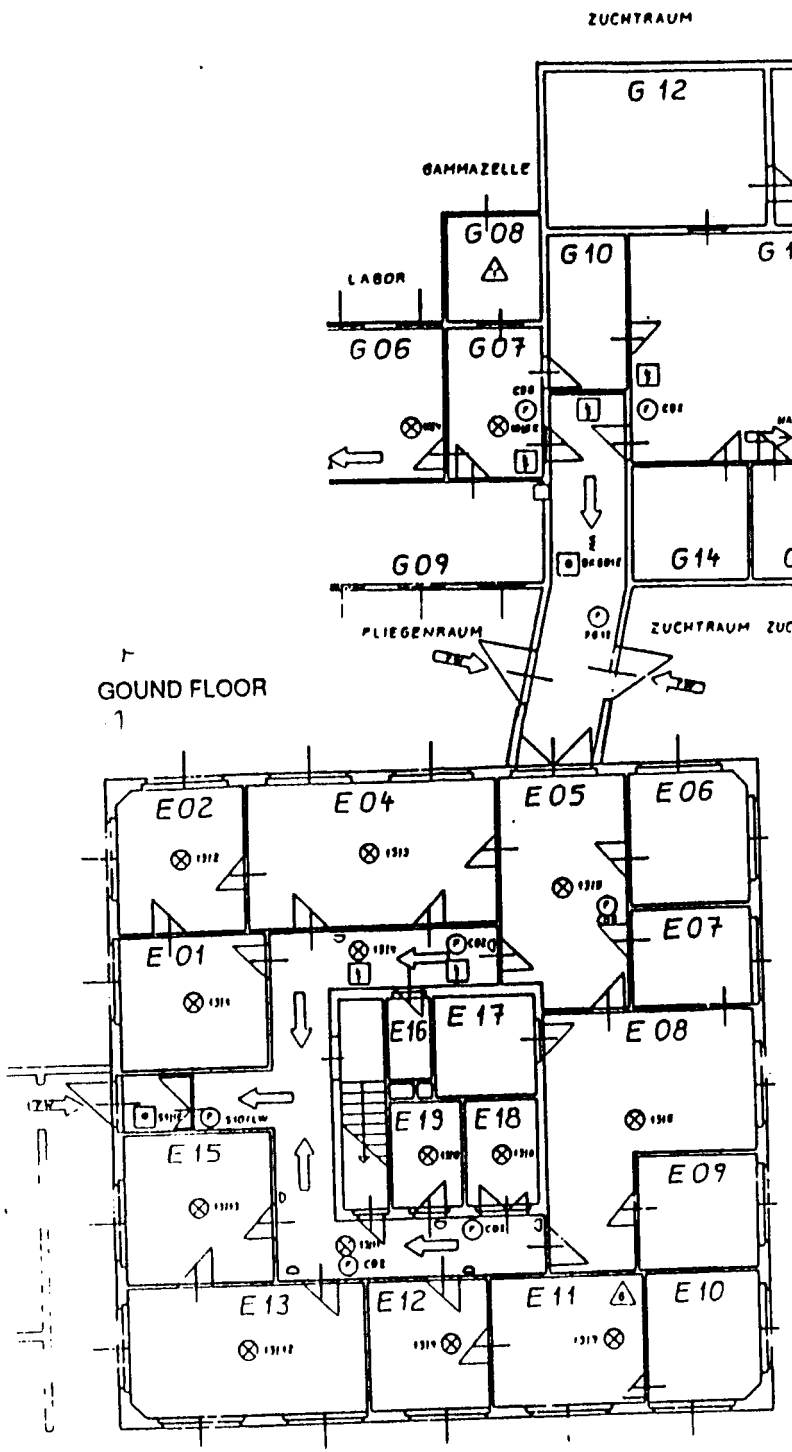
E 01 INSECTARY B
E 02 FEEDING ROOM B
E 04 GENERAL LAB.
E 05 FEEDING ROOM C
E 06 INSECTARY C1
E 07 INSECTARY C2
E 08 MICROSCOPY
E 09 HANDLING ROOM
E 10 MACHINE ROOM
E 11 BLOOD PREPARATION
E 12 CLEANING ROOM

E 13 FEEDING ROOM A
E 15 INSECTARY A
G 11 HANDLING ROOM D
G 12 INSECTARY D1
G 13 FEEDING ROOM D
G 14 INSECTARY D2
G 15 INSECTARY D3

FIRST FLOOR



GOUND FLOOR



Appendix V
FLOOR PLAN OF THE SEIBERSDORF TSETSE REARING FACILITY

Appendix VI

FINANCIAL ANALYSIS OF PRODUCTION COSTS FOR A 100,000 Glossina tachinoides COLONY AT SEIBERSDORF

VI.1. INTRODUCTION

This appendix reviews and evaluates available information concerning the establishment and operating costs of the Glossina tachinoides colony at the Seibersdorf Laboratory.

The following analysis is based entirely on cost information provided by the Seibersdorf Laboratory except where otherwise stated. The approach adopted is to examine the marginal cost of the production colony, i.e. the costs incurred by Seibersdorf in addition to those of its research programme. This means that facilities (such as toilets, offices) which would in any case be provided for staff are not considered. Only staff time (at fully overheaded cost) directly allocated to running the colony will be included.

The analysis is confined to costs and outputs at full production, i.e. the costs associated with the phase in which the colony is being brought up to full size are not considered, although these are likely to be significant and would increase the overall average cost per distributable pupa.

In order to simplify the cost model, a discounted cash flow method is not used since the cash flows are assumed to be constant. Instead, annual charges are derived by amortizing the cost of buildings and equipment. An interest rate of 10% is used.

The objective is to obtain a working figure for the approximate true cost of producing pupae at Seibersdorf. The cost will not necessarily reflect accurately the cost of producing puparia in Africa within a mass-rearing facility, partly because this approach is a partial cost analysis, and partly because a mass-rearing facility in Africa would be designed quite differently and unit costs for inputs (especially labour) are likely to be very different.

The main aim is to identify the relative importance of different components of the production cost with a view to focusing attention on those areas where cost improvement appears most needed or feasible. This may be feasible through attention to either management or by initiating appropriate research.

VI.2. BUILDING REQUIREMENTS

The space requirements for the Seibersdorf G. tachinoides colony are shown in Table VI.1., amounting to a total of 161 m^2. While a small contingency allowance is included to allow for unproductive building space, the area requirement is based only on the production facility and excludes many facilities which would be necessary if the colony were not part of an existing facility (see notes to Table VI.1. The annual charge for the buildings is calculated at US$ 22,171.

VI.3. EQUIPMENT REQUIREMENTS

Table VI.2. provides a list of the equipment used in the G. tachinoides colony at Seibersdorf with current costs. The most important item omitted from the equipment list is a radiation source for sterilizing flies, pupae and blood, since the laboratory is able to make use of radiation sources elsewhere on site. The type of unit requires costs in the order of US$ 150,000, which amortized over 25 years at 10% interest would generate an annual charge of some US$ 16,500. This compares with the total annual charge for equipment estimated at US$ 26,026 in Table VI.2.

VI.4. STAFF COSTS

Table VI.3. presents an estimate of the total time spent by staff involved in running the Seibersdorf G. tachinoides colony in 1991. For staff not involved full-time in colony operations, only that part of their time allocated to the colony is considered.

The total hours per week spent running the colony amounted to 163 hours. Taking into consideration time losses due to leave, sickness and holidays, the average time worked per employee averages 32 hours per week over the whole year. Thus, the colony could be operated by just over 5 people on a full-time basis, although 10 people are actually involved. The proportion of time spent working on the colony ranged from 9-95% for different individuals.

The time spent by management represented only 10.6% of the total time spent, but accounted for 23.7% of the total cost. For a routine production facility this appears to be a high proportion.

Fig. VI.1. shows how the staff time disaggregates between different activities. Forty per cent of the time is spent on chilling for separating flies after emergence and mating. Twenty per cent of time is spent on diet preparation. Both of these activities may be reduced substantially in a mass-rearing unit with an appropriate design.

VI.5. CONSUMABLES

At the time of preparing this draft, a detailed breakdown of the direct running costs of the colony was not available. The annual budget for running the colony was given as US$ 20,000, to include purchase of blood, chemicals used in diet preparation, miscellaneous laboratory chemicals and glassware.

VI.6. OVERHEADS

Within the Seibersdorf Entomology Unit as a whole the overhead costs are estimated by the Accounting Office at US$ 14,600 per year per staff member. This includes the provision of utilities (water, electricity, sewage, telephone), general administration, security, maintenance, cleaning, transport, and so on. At the time of drafting this report, information was not available to disaggregate this figure, neither into the different items contributing to those costs, nor to the allocation of the overhead to different parts of the Entomology Unit.

Calculated pro rata of time spent by the staff on the facility, the overhead cost is calculated at US$ 74,460 per year. In effect, this is directly a function of staff time and is not a very satisfactory way of estimating the real overhead cost.

VI.7. SUMMARY OF COSTS

Table VI.4. summarizes the costs discussed above. The working capital tied up in the facility is not considered, and is assumed to be lost in the overhead costs.

The total cost of running the Seibersdorf G. tachinoides colony is estimated to be some US$ 310,000 per year. The main component is staff cost, representing 54% of total cost. The second cost component appears to be the overhead costs. These may be over-estimated and it will be important to try to identify and quantify these in more detail in future costings.

Buildings, equipment and consumables together appear to represent only 22% of the cost of production.

VI.8. COSTS PER OUTPUT OF PUPAE

According to production data of the G. tachinoides colony over the last year, the average size of the colony was 112,006 breeding flies. Gross pupal production was 49,361 per week. Of these, the average retention for colony replacements was 34,263 per week. The distributable excess was thus 15,098 per week, equivalent to 785,096 per year.

As shown in Table VI.4., the "factory gate" cost of production amounts to US$ 0.39 per distributed pupa.

For comparison, Brandl (1988; p. 29) [10] calculated the cost of producing sterile males in Burkina Faso in 1984 at 45.9 FCFA (for a colony of 120,000 G. palpalis gambiensis), equivalent to DM 0.3029 per pupa at the then prevailing exchange rate. Doubling this figure to allow for inflation averaging 10% per year (estimate), the current cost in Burkina Faso might be in the order of DM 0.6 per fly, equivalent to approximately US$ 0.35 per pupa at the current exchange rate (US$/DM - 1.68). This is only a "back-of-the-envelope" calculation, but suggests that the costing of the Seibersdorf production is in the right order of magnitude.

Williamson et al. (1983) [12] reported that in 1979 the cost of production of pupae at Tanga, Tanzania, was US$ 0.22 per pupa. Adjusted to current prices (perhaps by a factor of 4) this would be significantly more expensive than calculated above for Seibersdorf. This reflects that the colony was smaller (60,000 breeding female flies) and was fed in vivo on goats. On the other hand, the Tanga cost analysis does not include the costs of capital investments in buildings, equipment and animals.

VI.9. DISCUSSION

As emphasized at the outset of the appendix, the cost structure of the Seibersdorf G. tachinoides colony is not comparable with that of an autonomous mass-production unit that might be established in Africa. There are two areas in which lessons are to be learned from the above analysis; firstly, in relation to the Seibersdorf operation itself, and, secondly, in relation to problems and prospects for future SIT operational facilities for tsetse control in Africa.

VI.9.1. LESSONS FOR SEIBERSDORF

The main cost of production is staff inputs, of which 60% is accounted by fly separation and diet preparation. This is a crucial area for cost reduction. Changes in fly separation techniques which may appear technically sub-optimal will be financially advantageous if there are significant savings in labour costs. These procedures need to be designed for financial optimality and not technical optimality.

Similarly, the scope for moving away from blood diets needs re-thinking. Synthetic diets have been researched, but the prevailing view is that these are likely to be too costly in comparison with blood. It is unclear whether previous cost comparison has taken account of the fully overheaded cost of staff inputs to blood processing and diet preparation. It has now been accepted that the colony does not suffer from a feeding regime of 4 days per week compared with 5 days. The scope for moving to feeding 3 times per week needs more investigation as this could further reduce labour inputs.

VI.9.2. LESSONS FOR DEVELOPING A MASS-REARING PRODUCTION PROCESS FOR APPLICATION IN AFRICA

Costs of production in an African country are likely to be different for several reasons:

- Capital costs for equipment will be much higher because of delivery costs from Europe, the need for a high level of spare parts and back-up units, and need for ancillary equipment not included in Seibersdorf costing (see notes to Table VI.2.). Also, some items of equipment are likely to wear out more quickly in Africa and have a higher maintenance cost than in Europe.

Labour costs are likely to be very much lower per individual employed but a facility in Africa may need a higher number of staff. In the Seibersdorf costing, only the time allocated by individuals directly to the colony operations has been considered. In a mass-rearing operation in Africa all of the staff time would have to be charged against production.

- Staff training will be a substantial expense in Africa.

- Establishment and commissioning of a project in Africa is likely to involve expatriate staff whose costs are substantially higher than if the same people were employed in a European facility such as Seibersdorf.

Because of these differences in costs and cost structures between Seibersdorf and African institutions, caution is required in transferring findings from the analysis in this appendix.

Brandl (1988) [10] has made an economic evaluation of the tsetse and trypanosomiasis control operations carried out in Burkina Faso which involved a SIT component. It appears worthwhile that the Joint FAO/IAEA Division commissions an economic study of the data generated by the BICOT project in Nigeria and by the project in Tanzania (Tanga and Zanzibar) to assess the actual cost of production of pupae during project implementation and to appraise the likely cost reductions that could be achieved given the present state of knowledge.

TABLE VI.1. BUILDING OVERHEAD FOR THE SEIBERSDORF G. tachinoides COLONY

Room	Area (m^2)
Main breeding room for adult females	30
Holding room for young flies	10
Feeding room	25
Fly handling room	45
Blood preparation room	10
General storage	10
Washing room	10
Sub-total	140
Allowance for corridors, halls, etc. (15%)	21
Grand total for building requirements	161
Establishment cost at US$ 1,250 per m^2	201,150
Amortization factor, 25 years, 10%	9,077
Annual charge for buildings	22,171

Notes:

1. There is no charge made for land rent.

2. Design and commissioning costs are not included.

3. Requirements for offices, toilets, workshop, generator room, and meeting/lecture rooms are not included.

4. The total space required for a mass-rearing facility specifically designed as a production unit would be significantly greater (at least factor 2) than the space currently used at Seibersdorf.

TABLE VI.2. EQUIPMENT REQUIREMENTS FOR G. tachinoides COLONY AT SEIBERSDORF (COSTS IN US$, 1991 PRICES)

Item	No. Reqd.	Unit Cost	Life (yrs)	Annual Charge	% of Total
Fly holding trolleys	16	700	15	1,473	6.2
Air-conditioners	5	3,000	10	2,441	10.3
Humidifying systems	3	3,000	10	1,465	6.2
Climatic control system	3	1,500	10	732	3.1
Standard fly holding cages	1,600	5	5	2,110	8.9
Cages for young females	5,000	2.5	5	3,297	13.9
Male holding cages	2,500	2.5	5	1,649	7.0
Silicone membranes	100	20	1	2,200	9.3
Aluminium feeding trays	100	20	10	325	1.4
Washing machines	3	1,000	5	791	3.3
Heat sterilizing machines	2	1,200	10	391	1.7
Pupal sorting machine	1	7,000	10	1,139	4.8
Fly chillers	3	1,650	5	1,306	5.5
Pupal counting machine	1	3,500	10	570	2.4
Laminar air flow bench	1	15,000	15	1,972	8.3
Electric blood stirrer	2	800	15	210	.9
Blood collection equipment set	2	480	5	253	1.1
Freezing cabinets	2	1,000	10	325	1.4
Refrigerator	2	600	10	195	.8
Laboratory and insectary furnishings		5,000	10	814	3.4
Sub-total				23,660	100.0
Contingencies allowance at 10%				2,366	
Grand total cost for equipment				26,026	

Notes:

1. The above costs exclude the following items which are likely to be necessary in establishing a similar colony in Africa:

   (a) Office equipment (phone, fax, computer, printer, photocopier, desks, cupboards, typewriters, filing cabinets, and other minor items).

   (b) General laboratory equipment, such as microscopes, balances, hot plates, dissection tools, etc.

   (c) The cost of the radiation source.

(d) Requirements for spare units of key equipment.

(e) Special utility requirements, such as a standby generator, constant voltage supply unit, water filtration system, air-conditioning units (apart from the insectary units).

(f) Basic maintenance tools and equipment.

(g) Costs of freight, insurance and installation.

2. These costs may include Austrian taxes which would not be payable on an export consignment.

TABLE VI.3. STAFF COSTS FOR THE SEIBERSDORF G. tachinoides COLONY (US$, 1991 PRICES)

Staff	Hourly Cost (AS)	Hours per Week	ANNUAL COST AS	ANNUAL COST US$	%
Management	391	17.3	351,176	29,265	23.7
Technicians (7)	150	145.6	1,133,128	94,427	76.3
Sub-total		162.9	1,484,304	123,692	100.0
Social overheads (see Note 1) at 35%			519,506	43,292	
Grand total salary and wages			2,003,810	166,984	

Notes:

1. Social overheads include employer's contributions to health insurance and superannuation schemes.

2. Other staff costs associated with the facility (e.g. cleaning, office staff, security guards, maintenance staff, and so on) are subsumed in the "overhead costs" (see text).

TABLE VI.4. SUMMARY OF ANNUAL COSTS OF OPERATING THE SEIBERSDORF *G. tachinoides* COLONY (US$, 1991 PRICES)

Item	Annual Charge	%	Source
Buildings	**22,171**	**7.2**	**Table VI.1.**
Equipment	**26,026**	**8.4**	**Table VI.2.**
Staff	**166,984**	**53.9**	**Table VI.3.**
Consumables	20,000	6.5	Note 1
Other overheads	74,460	24.0	Note 2
Total	309,641	100.0	
Calculation of costs per pupa			
Pupal production per year:			
Gross	2,565,038		Note 3
Distributable excess	785,096		
Cost per pupa (US$)			
Gross	.121		
Distributable excess	.394		
Calculation of costs per sterile male			
Proportion of gross pupal output which will be available for release as sterile males	.20		
Cost per sterile male (US$)	.60		

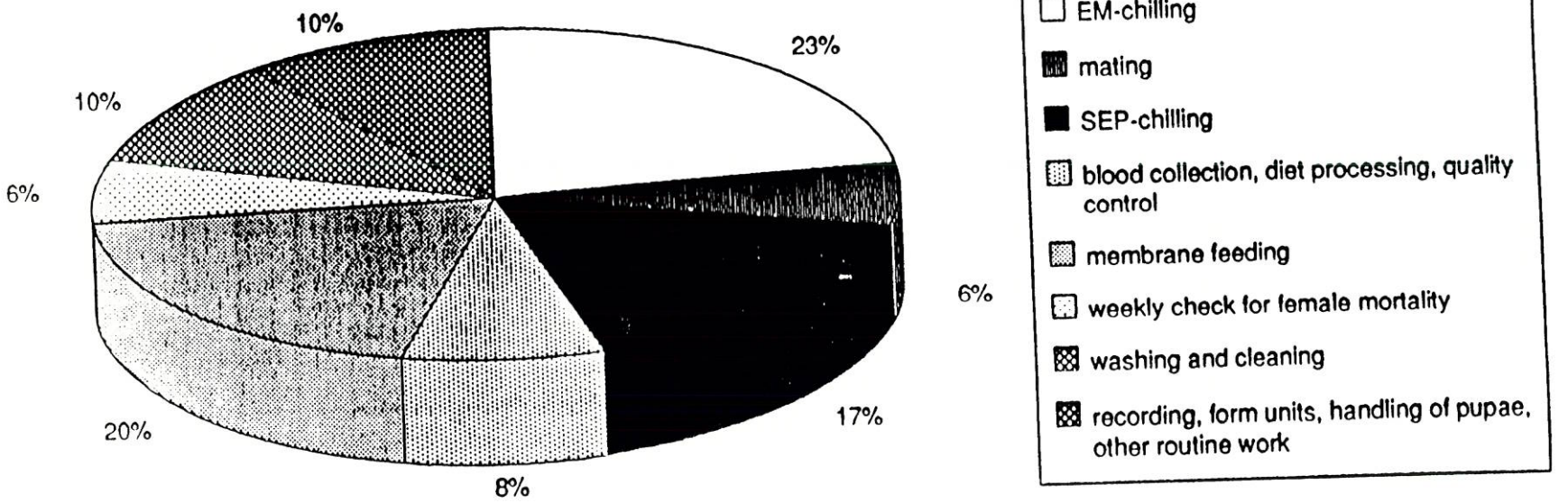
Notes:

1. This figure, provided by U. Feldmann, is based on the budgeted total expenditure for the G. tachinoides colony. At the time of preparing this schedule a detailed breakdown was not available. The budget includes blood, ATP, glassware, etc.

2. The overhead costs are as calculated by the IAEA Accounting Office and represent an average charge on the staff of the Entomology Unit calculated at US$ 14,600 per year. This was not available in a disaggregated form.

3. This number is based on figures provided by U. Feldmann for the last year of operation. The number includes female as well as male puparia, and does not represent the cost per sterile male potentially available for release.

FIG. VI.1. Workload distribution in the Glossina tachinoides production colony at the Entomology Unit, 1991



Appendix VII

PRODUCTION MODELLING

VII.1. INTRODUCTION

This appendix discusses the need for developing a production model for mass-rearing of tsetse flies in order to improve the design of the production system and to optimize management decisions once a production unit is operational.

There are several objectives in designing and managing a mass-rearing unit to produce tsetse flies for use in SIT programmes. Sterile males must be produced:

- in sufficient, reliable numbers to meet the needs of the associated SIT project;

- of sufficient, reliable quality so that they will live long enough and compete effectively with wild males; and

- as cheaply as possible.

If only the first two of these objectives were important, then decisions about design and management of the production unit would become easier. The aim would be to achieve the best possible technical specification and maximum possible biological performance. If technical feasibility had to be achieved at any cost, then cost could be ignored, but this is not the case in tsetse mass-rearing. At present, cost is probably the main constraint to wider use of SIT in tsetse control programmes.

The starting point in this appendix is therefore that design and management decisions about tsetse mass-rearing must take full account of cost issues.

Design and management decisions which take cost into account will be concerned with optimizing rather than maximizing production, which is crucially different. The concept of optimizing will apply to both quantity and quality of output, as shown in the following examples:

- To produce the required number of flies it may be more cost-effective to have a larger colony with lower productivity per breeding female than to achieve higher productivity in a smaller colony if this can be done only at high cost.

- Similar arguments can apply to fly quality: it may be cost-effective to produce larger numbers of lower quality flies if this will achieve the same end result as a lower number of high quality flies produced at higher cost.

Optimization will take into account not only the quality, quantity and cost of production, but also production characteristics such as ease of management and reliability of supply.

In many biological production systems there is an inverse relationship between productivity and stability of production. Low-input-low-output systems are often robust, with only minor fluctuation in productivity caused by disturbances to the production routine. By comparison, high-input-high-output production systems tend to be more unstable in that minor perturbations can cause serious loss in productivity. Hence, such systems tend to require a higher level of management than low-input-low-output production systems.

This is illustrated in Fig. VII.1 where volume of output (V) is plotted against an unspecified production parameter (P), for two hypothetical production systems.

A small perturbation (A to B) causes little change in the output from system 1, which is stable in comparison with system 2, where the same perturbation causes a substantial drop in output (C to D).

The preference for system 1 versus system 2 depends on the confidence of managers in being able to closely control potential perturbations in the production environment, and to accommodate any fluctuations in output which can be anticipated because of the production method.

There are various different methods or "tools" by which decision-making can be improved. One method which appears likely to be useful in the context of a tsetse mass-rearing unit involves the development and use of production models.

VII.2. THE CONCEPT OF A PRODUCTION MODEL

A production model is a simplified representation of the real production system. In the case of tsetse mass-rearing, the potential application for such a model is to simulate and thereby try to optimize different design and management decisions.

Such a model could also be used to simulate the consequences of changes in biological productivity parameters, such as mortality and fecundity rates. This can help to identify those parts of the production process where improvement in performance (to be achieved by research or better management) is most likely to have the greatest effect on the overall productivity of the tsetse colony - in both technical and financial terms.

VII.3. AN APPROACH TO PRODUCTION MODELLING OF A TSETSE COLONY

At Seibersdorf the breeding females in the tsetse colony are kept from between 10 to 13 weeks after which time they are killed and replaced. The flies which survive to this age are still capable of producing pupae although it is suggested that the pupae of older flies tend to be smaller and therefore correspond to weaker flies.

With the present production system at Seibersdorf, it is also considered worth replacing the flies at this stage since cumulative mortality means that by 10 to 13 weeks as many as 50% of the flies in each cage have died.

On the other hand, the breeding females are expensive to produce and ideally they should be kept as long as possible, since surviving flies will still go on producing pupae for some time. An objective decision on the optimum age for disposal needs to take account of the implications of varying this parameter. A decision with regard to the optimum age at which a production unit should be terminated, can best be made by making use of a simple spreadsheet model. Key biological parameters included in such a model are: the average age at which females produce their first larvae, the average interlarval period, the mortality before females reach the first larviposition day and the post-larviposition mortality. Using data available at Seibersdorf, it would be feasible and probably worthwhile to specify different mortality rates for each weekly or 10-day age group. The management parameter which is variable in the model is the age at which a production unit is terminated.

From the parameters specified above, and assuming a constant input of 100 freshly emerged flies, the spreadsheet model should estimate how many flies survive day by day up to the age of termination. From a set of collected data (age group of flies by day) and calculated ones (numbers of flies surviving to the given day according to the daily mortality rate, the proportion of the total colony represented by the daily age group, and the average pupal production from flies surviving to the specified day), the spreadsheet calculates some simple parameters of productivity of the colony. This includes the proportion of producing flies, daily pupal output, percentage occupancy of the colony, average mortality rates, and hence daily requirements for replacement females as a percentage of the colony size.

As the age of termination of the flies increases, the proportion of the colony which is producing pupae increases over the range 60 to 100 days termination age.

The occupation rate is defined as the number of living flies divided by the space in the colony, i.e. the total number of cages multiplied by the potential fly occupancy. This figure takes into account the mortality in the colony: this is an important figure as the amount of work and some other direct production costs are dependent upon the number of cages and not the number of living flies. As the age of termination of the flies increases, the occupation rate decreases slowly but steadily.

Average daily pupal production per living fly takes into account the non-producing as well as the producing flies. Daily production per living fly increases steadily as the age of termination increases from 60 to 100 days. However, the pupal production per unit of space in the colony hardly changes at all, reflecting that increase in the proportion of the colony larvipositing is almost exactly offset by decrease in the occupation rate. Indeed, for the higher mortality rate of 0.8% per day, average daily pupal production per unit of fly space actually decreases over the interval 90 to 100 days termination age. What this suggests is that for a given

production facility, the gross pupal output is likely to be relatively insensitive to decisions about age of termination where daily mortality rates are in the order of 0.6% to 0.8%. In other words, this may not be a particularly important management decision to the extent that it affects pupal production.

On the other hand, there is an important relationship between age of termination and daily requirement for replacement breeding females. The proportion of the colony needing to be replaced daily decreases steadily as the age of termination increases. Since the requirement for breeding females diverts both male and female flies from net output from the colony, it appears advantageous to extend the age of termination as far as possible.

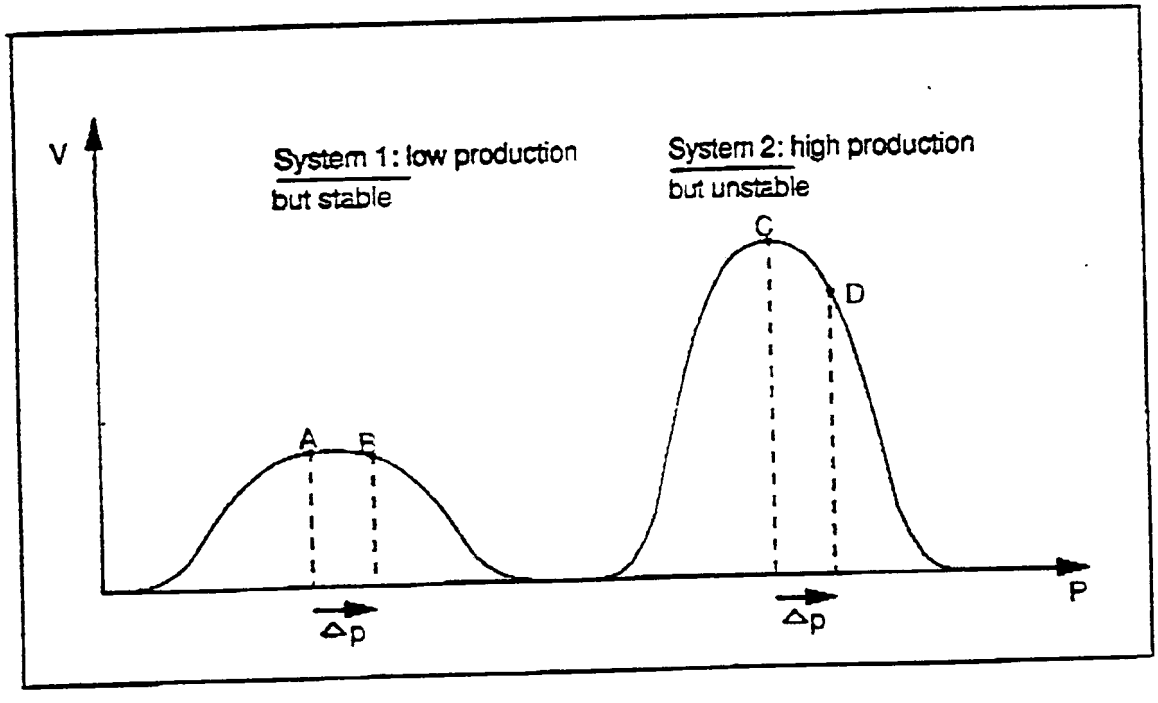
To examine this issue in more detail would involve further development of the production model to look at the relationship between age of termination and the requirement for replacement flies. Extension to the model would in due course also take into account the cost aspects of the decision options.

It would also be interesting to run the model for termination ages from 100 days upwards, and with a wider range of daily mortality rates.

VII.4. CONCLUDING COMMENTS

The model discussed above shows how design and management decisions can be investigated through simulation using a production model. It is recommended that the Seibersdorf staff explore this approach for optimizing a production system for mass-rearing of tsetse flies.

FIG. VII.1. Production output



Appendix VIII

COMPARISON OF ADVANTAGES AND DISADVANTAGES OF 185 m^2

MOBILE VERSUS FIXED PRODUCTION FACILITY

	Characteristic	Advantage	Disadvantage
1.	Mobility	Mobile	Fixed
2.	Construction cost	Mobile	Fixed
3.	Structural integrity	Mobile	Fixed
4.	Operational cost	Mobile	Fixed
5.	Modifications	Mobile	Fixed
6.	Variable production	Mobile	Fixed
7.	Quality of construction	Mobile	Fixed
8.	Design cost	Mobile	Fixed
9.	Politics	Mobile	Fixed
10.	Transport costs	Fixed	Mobile
11.	Size constraints	Fixed	Mobile
12.	Completion time	Mobile	Fixed

1. Mobile units can be securely anchored to emulate a fixed facility with the advantage of being able to be moved with little difficulty to another location. They also could be set up initially at Seibersdorf for trial runs before being sent to Africa. A fixed facility has no ability to be moved and provides a financial liability in the case of differing programme needs or political situations.

2. Prefab steel shipping containers are approximately US$ 40,000 finished per 8 x 40 unit (x 7 units) = US$ 280,000. General construction of facility in Africa is estimated at US$ 2,175 per square metre which is equal to a total cost of US$ 400,000.

3. Mobile facility constructed according to western standards and specifications. Mobile facility will have a steel frame and walls.

4. Mobile facility will be better constructed using modules which can be added onto and removed from central structure. A fixed facility has fixed costs and quality problems.

5. Modular system is completely variable in how units are assembled. A fixed facility needs additional construction to make modifications which may be expensive.

6. A modular structure can be easily scaled up or down. A fixed facility is more difficult to change.

7. A fixed facility will be more problematic in quality and construction costs than a mobile one.

8. Modular structures are structure designed and standardized. A fixed structure will have additional design costs.

9. A mobile structure can be moved if a political or biological decision requires it. There is no need to permanently commit to one country. However, a fixed facility would possibly generate financial support from the country in which it is located.

10. A fixed structure has none.

11. A fixed structure can be designed to meet the size constraints. A modular structure has some size limitations.

12. A mobile structure can be completed quickly. A fixed facility may have some inherent problems.

Appendix IX

COST ANALYSIS OF A MASS-REARING COLONY IN THE CONTEXT OF A POSSIBLE TSETSE ERADICATION PROGRAMME INVOLVING SIT IN WEST AFRICA

IX.1. INTRODUCTION

This appendix looks at the likely costs of producing tsetse within a mass-rearing programme in an African country. The exercise is in the nature of a pre-feasibility study as no specific country is being considered where such a unit might be established. The role of SIT within an overall integrated tsetse eradication and related land use development programme will vary according to situation. The example costed out in this appendix is not intended to be typical or representative, but rather a plausible example of the type of situation that can be envisaged. This is possible on the basis of experience gained on tsetse SIT programmes in Burkina Faso, Nigeria and Tanzania.

IX.2. APPROACH TO THE COST MODEL

There is a wide range of situations in Africa in which very different tsetse and trypanosomiasis control operations can be envisaged. For the present exercise, the example chosen is an operation against riverine tsetse, probably somewhere in West Africa.

The hypothetical situation is one where riverine forest is of a width ranging from 5 to 50 m, mostly about 20 to 30 m. Initial fly population is in the order of 1,000 tsetse per linear kilometre of river. It is assumed that there is an average of 6 km^2 of land area per linear kilometre of tsetse-infested riverine habitat.

Initially, there would be a "tsetse population suppression" phase lasting approximately 4 months, in which insecticide-treated screens (i.e. preferably odour-baited targets) were deployed along the riverine habitat at a density of 4 to a maximum of 10 per linear kilometre. After 3-4 months, this target phase should achieve a 90-95% reduction in fly numbers, to approximately 100 per kilometre, of which it is assumed 50% are male. In practice, it is found that there is differential catching out of the sexes and the proportion of females is likely to be higher than the males. With the objective of maintaining an effective ratio of sterile to wild male flies, it is estimated that the required number of flies to be released will total 1,600 sterile males per linear kilometre during an eradication phase lasting a maximum of 8 months.

The possible costs of this exercise are shown in Tables IX.1. to IX.3., which include field operations for the suppression phase, the cost of sterile males and the field operations for the SIT phase. The costings do not include entomological monitoring, construction of access roads where required, or expatriate assistance in the overall programme.

IX.3. TSETSE SUPPRESSION PHASE

As shown in Table IX.1., the total cost of field operations in the suppression phase is calculated at US$ 535 per linear kilometre of riverine habitat, of which 47% is accounted by the cost of the targets and 53% by manpower and vehicle costs.

It is assumed that gadgets can be recovered at the end of the suppression phase and used again, so that the costing is less than the full initial price. On the other hand, no allowance is made for repairs and replacements. It is assumed that local farmers are participating in some of the routine work involved in deployment and servicing of targets. This community participation is not costed.

Vehicle charges are calculated on the assumption that each team requires a 4-wheel drive vehicle, such as a landrover. The cost per kilometre is a rough estimate based on a vehicle life of four years plus petrol costs.

IX.4. THE SIT PHASE

A budget costing for the SIT phase is given in Table IX.2. A key assumption is the number of sterile males to be released per kilometre in order to achieve eradication. On the basis of IAEA/Seibersdorf experience in BICOT, Nigeria, this number is estimated at 1,600 per linear kilometre. This is the total number of flies to be released over the whole SIT phase.

A second key assumption is the cost per fly. In Table IX.2., the Seibersdorf costing is used. It would be possible to argue that this is either too low or too high, but it is of the correct order of magnitude.

Under the above assumptions, the SIT phase would cost in the order of US$ 1,530 per linear kilometre of riverine habitat, of which 63% is accounted by the cost of the sterile males and 37% by vehicle and manpower costs.

IX.5. DISCUSSION

As shown in Table IX.3., the total cost of the direct field operations for the hypothetical eradication programme amounts to just over US$ 1,500 per linear kilometre. The suppression phase accounts for 26% and the SIT phase for 74% of these costs.

The cost of the sterile males accounts for just under 50% of the overall cost, and this finding underlines the importance of achieving significant economies in the mass-rearing of tsetse if the use of SIT in integrated tsetse control programmes is to be cost-competitive with other control measures and if tsetse eradication is to be economically justifiable. Having said this, it is also important to observe that manpower and vehicle costs account for over 40% of the costs summarized in Table IX.3. While serious attention is required in the area of improving the economics of mass-rearing, there is scope and need to examine possibilities for achieving significant economies in manpower and vehicle costs.

Such economies may be feasible by basic re-thinking of the design of the SIT phase, which may have implications for appropriate R&D investigations that need to be carried out.

For example, there is likely to be a cost saving if eradication can be achieved over a shorter time period by increasing the ratio of sterile to wild flies, thus reducing the manpower and vehicle inputs needed to achieve eradication. This may prove financially worthwhile even if this approach is technically sub-optimal, for example, possibly requiring an increased total number of flies to be released per linear kilometre.

The balance of effort between the suppression and SIT phase could also be re-examined. The cost-optimal point at which to intervene with SIT may be earlier than the point of maximal population suppression. Indeed, there may be advantages in commencing the SIT phases concurrently with the later stages of population suppression. This would work better if traps were replaced with targets treated with juvenile hormone analogue, which would have a synergistic action on population depression by SIT. There may be a case for the Joint FAO/IAEA Division supporting research into the use of juvenile hormone treated targets for use against riverine species of tsetse.

However, all of these suggestions may prove premature as they are based on a rather simple and hypothetical cost model. Given the significance of the analysis which derives from the model, it does appear worthwhile to investigate the assumptions involved. It is recommended that the Joint FAO/IAEA Division commissions a detailed economic study of the BICOT and Zanzibar project data to improve the information base available for this kind of analysis.

TABLE IX.1. INPUTS REQUIRED TO ERADICATE 100 LINEAR KILOMETRES OF RIVERINE HABITAT INFESTED WITH G. tachinoides

SUPPRESSION PHASE

	Value	Note
Target Requirements		
Targets per linear kilometre	10	1
Length of riverine habitat to treat	100	
Number of targets required	1,000	
Cost per target (US$)	25	2
Total cost of targets	25,000	
Manpower/Vehicle Requirements		3
Number of staff in team	3	
Salary charge per team member	5,000	
Salary of supervisor	8,000	
Teams per supervisor	3	
Salary charge per team	17,667	
Kilometres per team per year (4WD vehicle)	15,000	
Cost per kilometre (US$)	1.2	
Vehicle charge per team per year	18,000	
Annual manpower/vehicle charge per team	35,667	
Teams per 100 kilometres	2	
Percentage of year spent on suppression phase	.4	
Manpower/vehicle charge per 100 linear kilometres	28,533	
Total Costs		
Total cost of suppression phase per 100 linear kilometre of riverine habitat	53,533	
of which: targets	46.7%	
manpower/vehicles	53.3%	

Notes:

1. Requirement as estimated by A. Van der Vloedt, including extra targets for hot spots (confluences, cattle crossings, etc.).

2. Includes costs for insecticides and odour baits.

3. Estimate based on Zimbabwe experience. Team comprises three staff with annual salary cost estimated at US$ 5,000 per person. Supervision is assumed to be 20% of the time of a senior officer salaried at US$ 10,000 per year.

TABLE IX.2. INPUTS REQUIRED TO ERADICATE 100 LINEAR KILOMETRES OF RIVERINE HABITAT INFESTED WITH G. tachinoides

SIT PHASE

	Value	Note
Number of sterile males per 100 kilometres	160,000	1
Cost per sterile male (US$)	.60	2
Total cost of flies per 100 kilometres	96,000	
Team-years per 100 kilometres	1.6	3
Cost per team-year	35,667	
Team cost per 100 kilometres	57,067	
Total cost of SIT phase per 100 kilometres	153,067	
of which: sterile males	62.7%	
manpower/vehicles	37.3%	

Notes:

1. Based on releases of flies every two weeks for up to 20 visits until eradication is achieved. Initial releases are in the order of 12,500 per visit, decreasing as eradication proceeds. Total requirement calculated assuming an average release of 8,000 flies on 20 visits.

2. Based on the Seibersdorf cost of production.

3. Assuming eradication can be achieved in 8 months.

TABLE IX.3. INPUTS REQUIRED TO ERADICATE 100 LINEAR KILOMETRES OF RIVERINE HABITAT INFESTED WITH G. tachinoides

SUMMARY OF COSTS

	US$	
Suppression phase	**53,533**	**25.9%**
SIT phase	**153,067**	**74.1%**
Total	206,600	
of which: sterile males		46.5%
targets		12.1%
manpower/vehicles		41.4%
Total cost per linear kilometre of river	2,066	
Total cost per km^2 of project area	344 (Note 2)	

Notes:

1. The above cost breakdown is for direct operation inputs only. Entomological monitoring, building of access roads, operational planning and general overheads for field operations are not considered.

2. Assuming an overall ratio of 6 km^2 of land area per linear kilometre of river in the project area.

Appendix X

ECONOMIC ANALYSIS OF PROSPECTS FOR USING STERILE FEMALE FLIES FOR ENTOMOLOGICAL MONITORING IN TSETSE SURVEY OPERATIONS

X.1. INTRODUCTION

Entomological monitoring forms an important part of tsetse and trypanosomiasis control programmes. If the control phase is to be successful, it is crucial to establish the perimeters of the tsetse-infested area prior to commencing operations. After control operations have been carried out, it is equally important to know that no residual pockets of flies exist which are viable and able to re-infest the area which has been otherwise cleared of flies.

The objective in this type of entomological monitoring is straightforward to determine whether or not a tsetse fly population is present or not. This is a very different situation from trying to measure the size or structure of a population which is known to exist, which has tended to be a more interesting subject of research.

Simply knowing whether or not a fly population exists has been more of interest to tsetse control practitioners than researchers. In practice, the planning of tsetse surveys has been on an empirical basis and is often based on what resources are available plus the subjective experience of the entomologists involved in operations. This situation makes it difficult for tsetse control organizations to take an objective view of new techniques which become available for entomological monitoring. For example, the use of odour-baited traps for surveying fly populations was not widely adopted for tsetse surveying for some years after the technique had been well proven.

It has been suggested (Van der Vloedt, 1984 [5]) that entomological monitoring of relic populations of wild tsetse could be achieved quickly and effectively by release-recapture of sterilized female tsetse flies, by examination of the reproductive tract of recaptured females for evidence of insemination, and/or examination of the females' abdomen for evidence of mating scars (e.g. palpalis group).

This idea has been frequently discussed and endorsed at international meetings of the tsetse and trypanosomiasis control and research community, but has not, to date, been widely investigated under field conditions.

The objective in this appendix is to examine the financial aspects of the proposed technique to provide further evidence on which to evaluate the potential for the use of sterile female tsetse in entomological surveying.

X.2. APPROACH TO THE ANALYSIS

In order to compare one technique for monitoring with another, it is necessary to develop a framework for meaningful comparison - in simple terms, comparing like with like. In this analysis, the basis for comparison is:

- to identify and quantify the resources required to establish that tsetse flies are <u>not</u> present in an area.

Given the nature of biological systems, the absence of tsetse flies from an area can be expressed in terms of probability, for which a confidence level will be defined in comparing one technique for surveying with another.

In the present analysis, the use of sterile females for entomological monitoring (SFEM) will be compared only with the use of odour-baited traps, by way of an example. Other alternatives for direct or indirect entomological monitoring include the use of sentinel herds, ox fly rounds, and parasitological monitoring of local cattle (blood smears, BCT, ELISA). Analysis of these other techniques is outside the scope of the present study, but would be a useful future exercise.

X.3. THEORETICAL APPROACH

The analysis is based on the assumption that there exists a minimum population density (MPD) below which a tsetse population is not viable, as the rate of successful mating falls below the level necessary to maintain the population under natural mortality rates. It is assumed that for savannah species, MPD is typically in the order of one fly per square kilometre, varying according to other stress factors on the fly population apart from population density.

In order to assess the likelihood that there is no tsetse fly population present, it is appropriate to examine the "null hypothesis" that there <u>is</u> a viable population present at a density equal to, or greater than, the MPD.

X.4. SURVEYING USING TRAPS ONLY

The following assumptions (which may or may not be valid) are used in assessing the trap approach to surveying. Firstly, the fly population is assumed to be dynamic and effectively homogenous throughout the surveyed area, so that sooner or later the fly will come into the vicinity of the trap. The probability that a fly which encounters a trap will enter it, is assumed to be independent of the fly population density. The effectiveness of the trap is defined as a parameter E, which is equivalent to the proportion of the population within one kilometre of the trap which will be caught in the trap per day of deployment. This is closely equivalent to the percentage probability that any given fly present in the block will be caught each day. Experimental work in various African countries suggested that with a range of different designs of trap, according to species, it is realistic to expect E values in the order of 1% per day. This can be increased in practical terms by deploying more than one trap per square kilometre.

Given a known value of E, what is the necessary time period for which a trap must be deployed, recording zero catches, before it can be safely assumed that no flies are present in the area?

Testing the null hypothesis that there is one fly per square kilometre, the probability that this fly is not caught on day 1 is (1-E). There is an equal probability that it will not be caught on day 2. The probability of not catching the fly for n successive days is $(1-E)^n$.

The value of $1-(1-E)^n$ is therefore a measure of the confidence level that the null hypothesis can be rejected, and that there is, in fact, no residual fly population present.

This confidence level can be improved by increasing the number of traps which are deployed in an area which is to be surveyed. For the present exercise, it is assumed that the minimum viable population is expected to exist only over an area of 10 km^2, and that 10 traps are deployed uniformly throughout this area.

Using these figures, it is possible by simple arithmetic (a spreadsheet algorithm was used for the present analysis) to calculate the number of days for which the 10 traps must be deployed in order to reach 95% and 99% confidence levels that there are indeed no flies present. These values are shown in Table X.1. For example, with E = 1.0% per day, it would be necessary to deploy the traps for 46 days with zero catch in order to be 99% sure that there were no residual flies.

X.5. SURVEYING BY USE OF THE SFEM

Again, the null hypothesis is that there is a residual tsetse population close to the MPD, i.e. in the order of one fly per square kilometre. The male/female ratio is assumed to be 50:50. The objective is to release a number of sterile females such that a sufficient number can be recovered to assess the likelihood of there being a wild, unsterile male remaining. This probability is only partly dependent on the number of sterile females which are released, as there is an absolute limit to the number of times which the wild male will be able to mate. Release of larger numbers of sterile females will tend to increase the number of potentially inseminated females, as statistically there will be a lower probability of the wild male mating more than once with the same sterile female.

On the basis of discussion with A. Van der Vloedt, it is estimated that a single wild male might mate between 2-10 times with the released females. For the present analysis, and without detailed scientific evidence from the field, it is assumed that release of 10 sterile females per square kilometre could lead to insemination of perhaps 2-4 of the released females over a period of one week.

The calculation now becomes one of calculating the minimum trapping time required to reject the new null hypothesis that there are two or four (both cases are considered) sterile females per kilometre which have been inseminated.

The results of this calculation, along similar lines to the previous table, are shown in Table X.2. Taking the same example as given above, with E = 1.0% per day, it would take only 23 days to achieve 99% confidence that wild flies were present if two released females were inseminated, or 11 days if four were inseminated.

In essence, the SFEM technique involves amplifying the wild population and the degree of amplification is the main determinant of the time-saving in the trapping requirement. At present, there is very little information available upon which to assess accurately the likely amplification factor (AF). If AF is between 2 to 4, then with trapping regimes of the type used in this example, the SFEM would result in savings in the order of 23 to 35 days per operational area.

X.6. FINANCIAL IMPACT OF THE SFEM

The cost-effectiveness of the SFEM depends on the trade-off between the cost of the sterile flies, against the savings in manpower and vehicle costs of survey teams in the field. As shown elsewhere in this report, these manpower and vehicle costs can be very substantial. The manpower/vehicle cost per square kilometre of area surveyed depends on the size of the area which one survey team is able to cover. This is highly variable from one situation to another.

The cost of releasing 10 sterile females per square kilometre approximately one week prior to the start of a trapping phase would cost in the order of US$ 5 per square kilometre additional to the normal costs (on the basis of US$ 0.50 per pupae as a budget costing). It seems highly plausible that this level of cost saving would be feasible in reduced manpower and vehicle costs.

X.7. CONCLUSIONS

Apart from the potential financial advantages of using sterile females for entomological monitoring, there may be operational advantages in that the method may allow tsetse control organizations to respond quickly and effectively when suspected residual foci are identified and limited staff, vehicles and traps are available to carry out emergency survey work. It is often highly advantageous to be able to characterize a fly distribution quickly so that urgently required "mop-up" operations can be planned accurately and with minimal overkill.

There does appear to be a sound basis for recommending further research investigation of aspects of tsetse ecology necessary for a more detailed technical appraisal of the SFEM technique, with a view to improving the basis for assessing practical application by tsetse control organizations in Africa.

TABLE X.1. NUMBER OF TRAPPING DAYS NEEDED TO BE CONFIDENT THAT THERE ARE NO TSETSE PRESENT IN A GIVEN AREA IN SUFFICIENT NUMBERS TO FORM A VIABLE POPULATION

Fly density at which population collapse is assumed to occur	FDC
Trapping efficiency, defined as the percentage of the population within 1 km^2 of the trap that will be caught in one day	E
Number of days trapping with zero catch to have a 95% confidence that the fly density is below the viable level	D95
Number of days trapping with zero catch to have a 99% confidence that the fly density is below the viable level	D99

FDC	E	D95	D99
.5	.5%	120	184
	1.0%	60	92
	1.5%	40	61
	2.0%	30	46
	3.0%	20	30
	5.0%	12	18
1.0	.5%	60	92
	1.0%	30	46
	1.5%	20	30
	2.0%	15	23
	3.0%	10	15
	5.0%	6	9

The above probabilities are calculated on the assumption that 10 traps are set out over a hot spot covering 10 km^2.

TABLE X.2. NUMBER OF TRAPPING DAYS NEEDED TO BE CONFIDENT THAT THERE ARE NO TSETSE PRESENT IN A GIVEN AREA IN SUFFICIENT NUMBERS TO FORM A VIABLE POPULATION, USING THE SFEM TECHNIQUE

Density of sterile females reflecting a viable wild population	SFV
Trapping efficiency, defined as the percentage of the population within 1 km^2 of the trap that will be caught in one day	E
Number of days trapping with zero catch to have a 95% confidence that the fly density is below the viable level	D95
Number of days trapping with zero catch to have a 99% confidence that the fly density is below the viable level	D99

SFV	E	D95	D99
2.0	.5%	30	46
	1.0%	15	23
	1.5%	10	15
	2.0%	<7 days	10
	3.0%	<7 days	<7 days
	5.0%	<7 days	<7 days
4.0	.5%	15	23
	1.0%	<7 days	11
	1.5%	<7 days	<7 days
	2.0%	<7 days	<7 days
	3.0%	<7 days	<7 days
	5.0%	<7 days	<7 days

The above probabilities are calculated on the assumption that 10 traps are set out over a hot spot covering 10 km^2.

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