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FAO PLANT PRODUCTION AND PROTECTION PAPER 205

The FAO/IAEA Spreadsheet for Designing and Operation of Insect Mass Rearing Facilities

IAEA

Cover Photo: The Mediterranean fruit fly mass-rearing facility in "El Pino", Guatemala.
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The FAO/IAEA Spreadsheet for Designing and Operating Insect Mass-rearing Facilities

Procedures Manual

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Sponsored by the Joint FAO/IAEA
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Content

Foreword

The interactive FAO/IAEA Spreadsheet for Designing and Operating Insect Mass-rearing Facilities is generic. Even though this first version (V 1.0) was developed for facilities using Mediterranean fruit fly *Ceratitis capitata* genetic sexing strains (GSS) based on the *temperature sensitive lethal* mutation (*tsl*), the default settings can be changed so that it can be used for other pest insects. The Spreadsheet assists in technical and economic decision making associated with design, costing, construction, equipping, and facility operation.

The spreadsheet is user friendly and thus largely self-explanatory. Nevertheless, it includes this basic instructions manual that has been prepared to guide the user, and thus should be used together with the software. Ideally the model should be used as a support tool by consortia assessing facility design, investment and possible economic returns of different facility size and production scenarios. A consortium should include an entomologist with experience in mass-rearing management and facility design, an architect, a civil engineer and an A/C expert.

The officer responsible for developing this software and procedures manual is Mr. Carlos Cáceres of the Joint FAO/IAEA Programme of Nuclear Techniques in Food and Agriculture. The IAEA wishes to acknowledge Mr. Pedro Rendón of the USDA / APHIS / PPQ CPHST, Guatemala, for his significant contributions to the development of the spreadsheet.

The information included in Appendix 1, Site Selection, Physical and Biological Factors to be Considered gives useful ideas on pre-construction factors not covered by the Spreadsheet for Designing and Operating Insect Mass-rearing Facilities. These include some of the requirements for obtaining approval by both the Government and the community, the types of insect to be mass-reared, the types of buildings needed, work flow patterns, hygiene and waste management.

Appendix 2, Criteria Relevant for Location and Establishment of Mass-rearing Facilities should also be consulted prior to building a mass-rearing facility. Important issues such as site selection incorporating site characteristics, climate and environment, manpower and infrastructure and social and political support are discussed. Issues are ranked and scored according to their criticality.

The information in Appendices 1 and 2 provide useful check lists of necessary and useful issues that should be addressed in designing, building and using mass-rearing facilities.

Appendix 3 is a Glossary of terms used in the Spreadsheet for Designing and Operating Insect Mass-rearing Facilities.

The FAO/IAEA Spreadsheet For Designing And Operating Insect Mass-rearing Facilities — Procedures Manual

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1. INTRODUCTION

The FAO/IAEA interactive Spreadsheet for Designing and Operating Insect Mass-rearing Facilities V.1.0, (SDIMF) is an Excel 2000 Windows-based programme, for which all standard Windows and Excel conventions apply. A glossary of terms used in this Manual is presented in Appendix 3.

1.1. Simple guidelines

a. The only cells that may be added to or edited are highlighted in yellow. Other cells that the user attempts to edit will return an Excel warning window containing: 'Protected Cell or Block'.
b. The programme is controlled by clicking the left mouse button when the cursor is positioned over the appropriate part of main menu. It is also possible to navigate between pages of the menu by positioning the cursor on any part of the spreadsheet on the bottom of screen window.
c. To close the SDIMF programme, single click the left mouse button when the cursor is positioned over the 'x' square in the top right corner of the screen or press the ALT and F4 keys at the same time.

1.2. Installation requirements

What you need:

d. Windows version XP or later.
e. Microsoft Office 2003 or later.
f. Personal computer with at least 800 MHz microprocessor and at least 256 MB RAM.
g. CD ROM Drive.

The CD you have received has everything you need to run the SDIMF programme. Before installing the programme please make a backup copy of the SDIMF folder so that all links work properly. If you do not know how to do this consult your Windows manual.

1.3. To install the programme

h. Start Windows.
i. Insert SDIMF CD into the appropriate drive.
j. Access the File Manager or Windows Explorer and double click on the SDIMF folder.
k. Start Excel 2000 (or later version) and open the file called SDIMF from the File menu.

1.4. Objective of manual

This manual is **not** designed to teach the reader how to design mass-rearing facilities but rather to guide the user through the programme, indicating where inputs are required so that the essential information for facility design and facility management could be easily derived. Use the manual **simultaneously** with data input; moving from section to section in the manual as you move from page to page through the spreadsheet model.

1.5. Suggested reading

Cáceres C. and P. Rendón, 2008. The FAO/IAEA Interactive Spreadsheet for Design and Operating Insect Mass-rearing Facilities, pp. 307–312. In: Sugayama, R.; Zucchi, R.; Ovruski, S. and Sivinski, J. [ed.], *Proceedings of the 7th International Symposium on Fruit Flies of Economic Importance*. Bahia, Brazil; 2006.

Oborny, J. 1998. Design concept of HVAC-system for fruit fly mass-rearing facilities. Final report IAEA Technical Contract Number 10276, July – November 1998. York Austria, York International Ges. M.b.H., Vienna, Austria. IAEA, Vienna, Austria.

2. SYSTEM OVERVIEW

The SDIMF was designed based on experience accumulated in the mass-rearing of the Mediterranean fruit fly *Ceratitis capitata* (Wiedemann) using genetic sexing strains (GSS) based on a *temperature sensitive lethal* (*tsl*) mutation. The spreadsheet takes into account the biological, production and quality control parameters of the species to be mass reared, as well as the diets and equipment required. All this information is incorporated into the spreadsheet for user-friendly calculation of the main components involved in facility design and operation.

Outputs of the spreadsheet are size of the different rearing areas, rearing equipment, volumes of diet ingredients, other consumables, as well as personnel requirements. By adding cost factors to these components, the spreadsheet can estimate the costs of facility construction, equipment and operation. All the output parameters can be easily generated by simply entering the target number of sterile insects required per week. This spreadsheet is a powerful tool for project and facility managers as it can be used to estimate facility cost, production cost, and production projections under different rearing efficiency scenarios.

The spreadsheet was created using Microsoft® Office Excel. It uses the workbook/page- calculation Microsoft® Office Excel structure to present a series of inputs/outputs related to the different aspects of the insect mass-rearing process. The spreadsheet model is set out in a series of 'sheets' that contain individual components of the model. These are kept in separate pages to make editing and use easier and more understandable. The user will be able to input information at different levels of complexity depending on his/her own needs. Outputs are calculated based on simple formulas constructed by the combination of the critical inputs involved in the rearing process.

3. OPENING THE FILE

When first opening the original file it is very important that it is saved under a new name so that the empty original document is kept in an unaltered form so that it can be used for future projects. It is also important to make back-ups of the original file and also files that are being worked on so that in the event of accidents there is always an up to date copy of the work available.

From Excel open the file SDIMF from the directory into which the programme was copied (File/Open/). Immediately save this file as a new name by using the File/Save As.

4. DATA ENTRY

Some cells are shaded yellow. These are input cells into which information must be added. The manual will address each spreadsheet page as a separate section. Clicking on the tabs at the bottom of the screen allows the user to move between pages.

5. SPREADSHEET STRUCTURE

The following sub-sections (i.e. 5.1 to 5.23) refer to pages (Excel tabs and corresponding worksheets) in the SDIMF.

5.1. Introduction

In this page there are two boxes. Both have a hyperlink, the right box connects to the main menu while the left box goes to the instructions manual.

5.2. Main menu

The main menu contains all the options for manipulating the spreadsheet view. It is only available when the spreadsheet view is the active window. It contains the following main menu items.

5.3. Start-up parameter

This item refers to the target number of sterile insects required per week. All the output calculations are easily generated by simply entering this information.

5.4. Production parameters

This option contains information of the production profile and quality standards based on average data from operational facilities. It also contains information of load capacity for rearing equipment or other components. Users can modify this information according to the characteristics of the strain or species in question and according to the characteristics of rearing equipment or components.

5.5. Male only and colony pages

These are automatic calculations that are generated on the basis of the production parameters and the target production level. They calculate the number of immature and adult stages required to produce the target number of sterile insects.

5.6. Diet formulation

This option allows the introduction of specific diet components and their amounts (in %).

5.7. Larval diet requirements

This page calculates the amount of larval diet required per day.

5.8. Adult diet requirements

This page provides the amount of adult diet required per day.

5.9. Larval and adult diet ingredient

This page calculates the quantity (weight or volume) for each specific diet ingredient.

5.10. Rearing equipment

This page calculates the quantity of each specific type of equipment required.

5.11. Summary page

This page summarizes the quantity of mature and immature stages and the quantity of diet and rearing equipment for each specific developmental stage required to produce the target number of sterile insects.

5.12. Holding time and environment conditions

This page gives information about the time that immature stages should be held in each specific rearing room plus specific environmental conditions for each room.

5.13. Air conditioning (A/C) requirements

This AC page of the spreadsheet uses as a basis the average requirements of the air conditioning load in tons/m^3 or BTU/m^3 from reference operational facilities. These are applied to estimate the cost and the total A/C load required for the whole facility. As this is not an exact calculation a separate case study will be necessary, conducted by an expert, to produce the final A/C system specifications.

5.14. Electricity

This is the average consumption of electricity per m^3 in each rearing room from reference operational facilities and is used mainly to estimate the total electricity load required and the costing.

5.15. Water

This is the average consumption of water per million sterile pupae produced from several operational facilities and is used to estimate quantity of water required and costing.

5.16. Area calculation

This page calculates the space required for each specific rearing room and auxiliary areas taking into account specific equipment characteristics.

5.17. Construction cost

The user can input the local cost per m^2 of construction to estimate the cost of the facility.

5.18. Personnel

This page calculates the number of supervisors, technicians and operatives; the number of operative staff is calculated on the basis of the average number of operatives required to produce one million sterile insects. Automation of some of the steps of the rearing system will affect this initial calculation.

5.19. Equipment list and cost

The rearing equipment quantity is calculated automatically. However, the cost of all equipment and the quantity of auxiliary equipment should be added manually by the user and the rearing expert according to local availability and characteristics.

5.20. Diet cost

The user should provide the local cost of diet ingredients to be able to calculate the cost of adult and larval diets. The spreadsheet provides the user with a basic list of equipment that is regularly required for rearing Mediterranean fruit fly genetic sexing strains based on the *tsl* mutation.

5.21. Personnel cost

Users should provide and input the values for the local salary costs for each staff category.

5.22. Total investment and rearing cost

Rearing costs can be determined by adding the annual cost of equipment and building depreciation, personnel, diet, electricity, overheads, and consumables. This output can then be divided by the number of sterile insects produced per year.

5.23. Floor plan

Design example for facility with capacity to produce 250 million Mediterranean fruit fly sterile pupae per week

6. FINAL CONSIDERATIONS

This spreadsheet is a powerful tool for project and facility managers. It provides managers with practical information regarding the list of items that should be considered when planning the establishment of rearing facilities of any insect species. Once facilities are established, they can also be used to estimate facility and production costs, as well as production projections under different rearing efficiency scenarios.

During the design process it is very important that a local specialist provides the required inputs for the air conditioning (A/C), heat and electrical load assessments as the cost for theses important components vary according to facility size and location. As a reference point, the model uses the production of 2500 million sterile male Mediterranean fruit fly pupae per week at the 'El Pino' mass-rearing facility in Guatemala. The estimation and preliminary calculations of the A/C system required for each specific rearing environment for fruit fly mass-rearing facilities can be found in Oborny (1998).

The estimation of auxiliary areas and waste water treatment plant are also not subject to automatic calculation since these areas can be standard for a given facility size. Nevertheless, the spreadsheet also includes examples of sizes for each specific auxiliary area for facilities capable of producing between 100 to 250 million of male only sterile Mediterranean fruit fly pupae per week.

The spreadsheet will continue evolving, taking into account user-feedback and new technological developments.

Appendix 1
Site Selection, Physical and Biological Factors to be Considered

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1. BACKGROUND

The first insect mass-rearing facility was built in Florida for the New World screwworm fly in the late 1950s. Over these last five decades the sterile insect technique (SIT) has progressed for other pest insects from the laboratory bench to the large scale 'factory' level of sophistication. One example is the El Pino facility in Guatemala which has the capacity to produce close to 3000 million sterile Mediterranean fruit fly per week. Other facilities around the world have also been built for different pest insects (http://www-ididas.iaea.org/IDIDAS/default.htm) and they are all designed to produce mass-reared, sterile insects but each one differs from the other in design and resource usage. Unfortunately, some facilities have been found to be deficient in design and resource use and, therefore, they need considerable redesign or their cost-effectiveness for SIT has been less than optimal.

Despite this undesirable occurrence, SIT has been demonstrated to be very successful in the suppression, containment, eradication or prevention of selective target pest insect populations. Consequently a number of national authorities are now looking for advice on building their own facilities for SIT programmes against a wide range of pest insect species. They need to know, among other related issues, how to determine the optimum size, the best location and the most cost-efficient design and equipment. The answers to these queries vary considerably with location, climate and the environment, the scale and the target pest, the funding available and the government's objective, and many other variables.

When national or regional authorities, who wish to build their own SIT mass-rearing facilities approach existing facilities for advice on how to start they are confronted with a very wide range of different styles of planning and design, and types of construction and energy efficiencies. In addition, each existing facility will list a series of deficiencies of which to be aware.

Considering the cost to build, run and maintain such a facility, a standard format for planning and design of mass-rearing facilities for SIT purposes would be extremely useful for FAO (Food and Agriculture Organization of the United Nations) and IAEA (International Atomic Energy Agency) Member States.

Based on the experience of managers of existing mass-rearing facilities, there are some common, but important, considerations that should be taken into account to facilitate the task of designing a cost-effective mass-rearing facility. There are many, but some of the main concerns are:

- Site selection;
- Design of buildings for optimal process, product and staff flow;
- Safe storage of equipment and consumables;
- Appropriate warehouse space for sufficient stocks;
- Backups for key equipment, processes, and utilities;
- Balancing requirements and costs for automation and manual labour;
- Balancing investment and future energy efficiencies and maintenance costs;
- Waste treatment, disposal and impact on the environment;

- Requirements for research, quality control, hygiene, staff amenities and occupational health and safety;
- Others.

2. PRE-CONSTRUCTION FACTORS THAT NEED TO BE CONSIDERED

2.1. Planning, Permits, and Legal Requirements

- *Site selection criteria* – These are critical, important and useful factors that need to be considered. Refer to Appendix 2.
- *Building permits and environmental impact assessment, and other legal requirements/certification obtained/satisfied (e.g. ISO 14000 for environmental accreditation)* — Essential to be obtained before building commencement. Must ensure that the likelihood of future activities around the facility will not adversely impact on the SIT programme.
- Note: For many factors described here ISO certification may be useful.

2.2. Biological Parameters

2.2.1. Basic Biological Information

- *Target pest insect species* - Different species have variable life cycles, diets, temperature needs, cage type, etc. and so will impact on factory design.
- *Number of species* — Mass-rearing one or several species in one facility will impact on facility design.
- *Scale of production* — laboratory vs industrial – Moving from small to large scale rearing is difficult as simple up-scaling is not possible. This is due to such factors as personnel, management, manual activities vs automation, insect diets, contamination and heat load, and related air conditioning, etc.
- *Production level required, including colony stock and number of sterile insects for release* — Maximum production level needs to be known so that target release areas (release densities will vary between rural areas, urban areas and dense native forests) will obtain sufficient sterile flies for an effective SIT programme. This production capacity should be estimated using realistic average efficiencies to avoid future production shortfalls.
- *Production schedules driven by customer orders* — As far as economically feasible the facility should be designed to accommodate likely current and future fluctuations in demand for eggs, sterile pupae, and possibly fertile pupae.
- *Forecast volumes for each of the products (egg, larvae, pupae and adults)* — Once the required production level has been determined these volumes will be calculated by the spreadsheet.
- *Seasonal vs year-long production* — SIT activities are generally based on a year round supply basis. However there may be some need to reduce output during winter in temperate regions or in high summer. This also depends on the species being targeted.

- *Sexing strain or non-sexing strain* — Impacts on the size of the facility, the colony and the number and dimensions of rooms required, scheduling of operations, etc. and the complexity of the whole process.
- *Strain production profile* — Complete knowledge of the biological profiles (e.g. egg to pupae recovery) of each strain to be mass-reared needs to be available and understood. The profile defines the facility design.
- *Strain quality control specifications* — Minimum standards and testing methods for acceptable quality control parameters should be set up and followed for each strain. Will vary between strains and species and impact on facility design by affecting efficiencies and the size of facilities for quality control activities, storage of equipment, etc.
- *Life cycle for immature and adult stages* — Mass-rearing procedures and temperatures influence life cycle durations (e.g. rearing insects for male only lines and for colony lines reared under different temperature regimes) and will need to be addressed in facility design and scheduling. Also differences between species should be considered.
- *Type of insect diets required and specifications for nutritional and bulking ingredients* — Impacts heavily on production efficiency, insect quality and varies between species. Also affects storage needs and waste disposal requirements.
- *Origin of the diet components (local or imported)* — Locally available diet components are preferable if quality and production levels are not adversely affected, as it is cheaper and more easily obtained so storage space can be saved. When possible local bulking ingredients should be used.
- *Schedule and sequence of flow of biological materials through the facility* — These should be incorporated into the design plan to ensure efficient process flow (e.g. use of space, equipment usage, staff time, energy efficiency, contamination control).

2.2.2. Mother Colony

- *Mother colony management (pre filter, behaviour maintenance)* — This is an important component in addition to the filter rearing system. It is used to assist in the maintenance of the behaviour of colonized material to as close to the wild state as possible. It is established as a step prior to the filter colony stage of production.

A second use for the mother colony is as a means to select, under conditions as close to natural as is possible, for behavioural traits that would benefit these 'close-to-wild' flies' incorporation into the SIT rearing facility. This would result in less adverse impact on genetic makeup than would normally be the case under traditional colony establishment procedures.

In addition to these factors other traits that would enable the insect to survive longer in the field after release and mate more competitively with wild insects may be selected using the mother colony system. Such traits include:

  - Escape from predation;
  - Ability to find and access food, water;
  - Ability to find protection from wind, rain, heat, cold;
  - Early mating (if this is assessed to be beneficial);
  - Quicker adaptation to culture in captivity;
  - Examining the possibility of laboratory-cultured strains recovering natural traits by returning to natural conditions;
- *Setting up a mother colony* — Insects in the mother colony should be maintained under conditions as close as possible to those of wild insects. The following conditions should be considered:
  - Natural light;
  - Low insect density;
  - Sex ratio in favour of males to promote competition;
  - Use of natural vegetation (e.g. broad leafed evergreen trees);
  - Variable environmental conditions;
  - Heterogeneous fly populations (insects of different ages);
  - Limited or hidden food to select for ability to forage;
  - Selection for other traits (e.g. ability to escape predation, etc.).

Mother colonies can be established in several ways:
  - If the desire is to rejuvenate an existing laboratory culture by rearing under 'natural' conditions and selecting those with optimal traits suitable flies can be sourced from the existing laboratory strain;
  - Flies can be sourced from local wild populations;
  - If there are no populations of wild flies in the area then wild or laboratory flies could be imported from other areas / facilities.

Decisions will have to be made on how to collect eggs (using fresh fruit with or without punctures and artificial oviposition devices are some options), how to grow the larvae (in fruit, in artificial diets based on fruit or in totally artificial diets based on dried, diced or powdered carrot, wheat bran, etc), how to collect and hold pupae and how to rear the adults.

In the case that the mother colony is used for rejuvenating current strains additional decisions will have to be made on the types of methods or protocols to be used to select flies for optimal traits. These methods need to be scientifically robust. At present little research on this has been conducted.

- It should be remembered that production timing (e.g. pre-maturation and pre-oviposition periods), required environmental conditions, etc. will differ in the mother colony compared with normal mass-rearing procedures;
- The mother colony concept facilitates strain replacement/replenishment (colony replacement);
- The mother colony will produce insects continuously for the filter rearing system.

2.3. Facility Operational Requirements

- *Planning for facility operations (such as setting up site specific Standard Operating Procedures [SOPs]) to allow ISO accreditation* — SOPs are necessary and are used for assuring clients that quality control procedures have taken place and for facilitating trace back when troubleshooting. Aligning SOPs with ISO accreditation early is recommended because conversion to ISO accreditation after the facility has been built is very difficult and staff- and time-consuming, so pre-building SOPs aligned with ISO accreditation is important and more cost-effective.
- *Building design that facilitates preservation of equipment, ease of maintenance, reduction in contamination, energy use efficiency (linked to control of flow of people, biological material, equipment, etc) e.g. double roof for protection of AC equipment* — Addressing these issues at this planning stage is more cost-effective than corrective action and costly maintenance at later stages. Also facility production is affected if later correction actions are needed.
- *Auxiliary buildings and internal support areas* — Will be required for facility production (clerical staff offices, maintenance, utility rooms, workshop, warehouses, shipping/receiving rooms, cafeteria/coffee break rooms, locker rooms, restrooms). Should conform to Union, Health and Safety and also community requirements as much as possible. Ensure that facilities that do not need to be situated within the bio security confines of the facility are located outside the bio secure area.
- *Primary utility requirements, including electrical loads, compressed air, cold and hot water, steam, gas, fuel (e.g. diesel), communications, heat and A/C loads* — These utilities need to be designed, calculated and planned as they impact on the size, efficiency and ease of process flow of the facility — in line with recommendations from the spreadsheet. Consideration should be made on where these utilities (generation, storage, distribution and outlets) should be placed with respect to weather, exposure to sun, ease of movement of personnel and equipment, accessibility for maintenance, and proximity to associated activities. Must also conform to Occupational Health & Safety (OH&S) requirements.
- *Waste disposal* — solid and liquid.
  - *Solid* — e.g. spent diet, human waste, other process-related solid waste (e.g. bottles, paper), etc. Waste organic materials (e.g. larval diet, pupation substrate, dead adults and puparia) are eliminated from the facility. Treatment options for solids are steam sterilisation, exposure to dry heat (e.g. solar), freezing, irradiation to ensure elimination of all live stages of the insects. This issue is highly important in those cases where the mass-rearing facility is, or will be, in a target pest free area. Biosecurity issues are therefore very important in these cases. Treated solid waste can be disposed of as land fill, compost, as a complement to animal feed, combustion fuel, etc. If sold for feeding to stock care should be taken to ensure that the spent diet is suitable for stock feed (pH may need to

be modified). In the future there may be options for use as bio fuel or methane gas production. In a large facility around 15t or more per day of solid waste from larval diets is produced. This represents a significant cost and requires significant capital expenditure, so warrants careful consideration.

There should be systems in place for separating categories of solid waste product to facilitate recycling requirements.

- *Liquid* — Liquid waste, because of bacterial and particle loads and insect presence, must be treated on site and, if available and allowed, may be forwarded to municipal treatment works. Because of the volumes involved, there are generally legal regulations requiring on-site waste water treatment and disposal. Accurate calculations of the amounts of liquid waste likely to be produced and treated must be made to ensure efficient treatment and disposal. Options are to re-use some or all of the treated waste water (e.g. for on site WCs, fish farming), or to dispose of the treated waste in municipal waste disposal systems, use the water for irrigation on-site or off site, etc.
- *Consideration for elimination (or storage) of rain water run-off* — Rain water needs to be managed separately so that it does not enter the waste water drainage system. This is especially important during rainy seasons.

- *Work flow considerations* — These considerations need to be made for issues such as separation of irradiated and non-irradiated pupae. Ideally there is a system in place that the possibility of mixing irradiated pupae with non-irradiated (i.e. fertile) pupae is avoided. Options are irradiators with separate entrance and exit, or, preferably, a wall separating the pre- and post-irradiation areas (with no staff movement between these areas). This conforms to bio security needs, too (in addition to the required use of radiation indicator labels). The type of irradiator will determine the type of security system to be designed. (Note: Separate rooms [e.g. cold rooms] for holding pre-irradiated pupae and irradiated pupae will facilitate temperature management of different batches thereby facilitating also bio security.)
- *Control/exclusion of pests and contaminant organisms (e.g. ants, cockroaches, mice, rats, Drosophila, microbial contaminants such as moulds and bacteria)* — This is a very important consideration not only in terms of management of sanitation when operating the facility, but particularly during the planning stage for the facility to avoid future contamination management problems and expense. If any of these pests get out of hand the cost to control and the impact on production is very significant. These pests and contaminant organisms are not only a nuisance but also are disease vectors which will affect human health and the sanitation of facility processes. Some of these may also affect bio security. Water-filled channels, vermin wire, depth of foundations, floor treatment, pre-building ground treatment (taking care that chemicals that emit toxic volatiles will not impact on target insect

production). Also consider the effects of chemical soil treatments leaching into the environment.

- *Fire control/alarm systems/escape routes* — Need to follow local standard legal requirements. These requirements are essential (but must be designed to minimise compromising bio security) and often incorporate escape pathways, assembly areas, signage, placement of monitors, alarms, and other regulations.
- *Record keeping, production formats* — Systems need to be in place for collecting, storing, analysing all records (e.g. data on production, quality control, plans, drawings, temperature and humidity records). Back ups of all records should be stored in different locations. These systems are susceptible to acids, humidity, etc. within the facility and this issue needs to be covered.
- *Quality control of diet ingredients including water quality* — Systems and services should be included in the facility design in order to avoid future problems with inconsistencies in supply of quality ingredients and water. For example water quality can vary considerably between dry and rainy seasons. Bulking material may also vary in contaminant and chemical loads during the year. Note 1: Pre-purchase quality assessments may be necessary as well as assessments after long storage. Note 2: These systems and facilities should be outside of the bio secure sections of the facility.
- *Warehouse management / storage procedures and stock management systems* — These should be in place to effectively store products and preserve quality of ingredients and other perishables and to control pests, etc. This also involves inventory control so that oldest materials are used first. Plan for ISO accreditation requirements for this issue.
- *Air handling, air quality control procedures* — To guarantee the quality of the air with respect to microbial contamination and its spread, air filters have to be installed and regularly maintained (monitoring, cleaning, replacement). Microbiological loads need to be measured in all sensitive areas to confirm that filters are working properly.

2.4. Human Parameters

- *Level of automation* — To avoid or minimise future union problems, and for staff mental and physical health, automation should be considered as much as possible for very simple, repetitive processes. Automation will also reduce the likelihood of problems caused by human error and provide for more consistent quality. Initial investment in automation and maintenance may be high, but will still be cost-effective during the lifespan of the facility.
- *Number of technicians and operators required and worker skill levels* — This is linked to production level requirements, degree of automation, process efficiencies and worker skills. As the level of automation is increased, the need for labour is reduced but the skill level required of the workers is generally higher.

- *Work flow of personnel* — Facility design must minimise inefficient staff movement and avoid staff movement between dirty and clean areas to reduce risks of contamination. Staff levels must be sufficient so that staff in areas assigned to specific facility process sections can work and move independently from those in other sections (e.g. separate clean and dirty areas). If staff needs to perform both clean and dirty tasks, procedures should be set up to ensure that clean procedures are done before dirty activities. To achieve this, a gradient of clean to dirty activities / areas should be defined and established. Personnel flow is linked to the design of equipment and process flow systems. Personnel flow systems include entrance and access onto the site, bio secure areas, access to restrooms and recreational areas.
  Normally workers remain on-site (or inside designated bio security areas) during the whole working period and will require facilities for eating and recreation on-site. Bringing food into, or having cooking facilities within bio secure areas, need to be well planned and managed to reduce pest problems such as ants, cockroaches and without compromising bio security. Systems to minimise these possibilities should be considered.
- *Safety and health requirements* — Legal OH&S requirements need to be followed e.g. allowable weights, lifting heights, need for specialised equipment for OH&S.
- *Gender issues need to be considered* — These include restrooms, recreational and medical facilities. Child care facilities may also need to be considered. This is linked to the gender ratio.
- *Visitors* — There may be a need for public viewing areas to minimise disruption, to avoid contamination, compromising bio security and site security, and to increase the flow of visitors, which is good for community awareness and support. Such public viewing areas can be expensive, but their need will vary between sites and locations.
- *Medical services* — These must follow local legal requirements. Routine medical assessments of workers may be legally required, especially for workers dealing with irradiation, chemicals, particles, etc.
- *Off-street parking* — These should follow local regulations (if any). Roads, access to loading docks, parking areas, turning areas, re-enforced surfaces for heavy trucks, forklifts, etc. need to be included in the design.

2.5. Physical Parameters

2.5.1. Buildings

- *Design life* — The designed life of the rearing facility will be based on the purpose of the programme. For example, long term suppression programmes will require that the facility be designed to last many years depending on local building codes. In other programmes, eradication will be the goal and the required useful life of the facility may be only a few years.

- *One or multi-storey building* — Factors to be considered when deciding on whether a facility should be constructed as single or multi-storied include amount and topography of available land, geotechnical conditions at that location, energy efficiency and process flow.
- *Planning may need to be generic to facilitate adaptation to rearing other species* — A facility designed to mass-rear genetic sexing strains can easily be adapted to rear other species.
- *Modular design or single building* — If long-term production goals are known then a single building design may be the best option. For variable production requirements or rearing multiple species a modular design will provide flexibility. Modular building is more costly but allows for separate production units that facilitate disease control and management through competing production teams.
- *Planning to enable future expansion* — Modular design should facilitate expansion of facility capacity as well as rearing different species.
- *Energy saving, water conservation/recycling e.g. solar heating, installation of solar power panels* — These are capital investments required to reduce future running costs. Environment-friendly sources of energy require higher initial capital investment, but in the long term these will reduce operational costs. Energy conservation will become an increasingly important consideration in the future.
- *Detailed plans of plumbing, drains, power lines, steam lines, gas lines, etc. to enable safe maintenance procedures* — Detailed design drawings of the various systems within the facility have to be provided by the contractor upon completion of construction. These drawings should be updated when there are any changes made to the systems. They should also be readily available at all times, preferably in electronic format, with backup.
- *Electrical conduit — exposed or inside walls (may need to follow ISO requirements), ground fault circuitry for all wet areas* — If possible, surface mounted plumbing and electrical conduit should be avoided inside rearing rooms to facilitate cleaning and disinfection of wall and ceiling surfaces. Many rearing areas are wet and will require ground fault circuitry to wall outlets in order to prevent electrical shock hazard.
- *Plan all construction to allow future ISO accreditation* — Buildings construction and installations should adhere to technical local and, when applicable, international specifications.
- *Type of construction materials, insulation or not* — All interior surfaces in the rearing rooms should be constructed using corrosion-resistant material such as stainless steel, fibreglass, plastics, etc. All exterior walls and roof should be very well insulated. Interior walls may or may not require insulation depending on rearing conditions. Dimensions of the production rooms are calculated by the spreadsheet. Other areas not covered, such as filter rearing system, diet mixing, marking and bagging, irradiation and

packing, are not automatically calculated in the spreadsheet, and therefore should be directly correlated with the production level.

- *Inventory or stock volume for nutritional and raw diet ingredients and consumables* — Amount of warehouse area should take into account the different ingredients availability (local or imported ones). A minimum stock of three months is recommended for imported ingredients.
- *Overall process equipment requirements* — Depending on the equipment required to rear the specific insect species, the areas should be designed to accommodate the respective equipment, working space around it and also the maintenance access. The level of automation should be considered.
- *Water supply and quality, well and/or mains, and storage capacity* — This includes the collection and storage of rain water from the roof and hard surfaces (may need a water purification plant if local water is contaminated, or is high in salts, etc). Available water sources could be rain, wells, or main. Depending on the source, the water may or may not require treatment to make it suitable for rearing purposes. The level of water treatment required depends on the quality of the water to be used and the intended use of the treated water.
- *Public or on-site production of electricity* — If publicly provided electricity is not available at the facility site it would be necessary to generate electricity locally. In either case a back-up system is required.
- *Electrical voltage requirements suited to applications and equipment. Location and number of power outlets* — The electrical requirements (voltage, phase-type, etc.) of the facility will depend on the electrical load of the facility systems and the type of automation and equipment used in daily operation. The transformers and electrical circuitry of the facility should be sized with consideration given to possible future expansion of the operation. It is recommended that each wall within all rearing areas have a minimum of two power outlets. Outlets should be located away, and protected, from water sources when possible and equipped with ground fault protection to prevent the risk of electrical shock to workers. Consider placement and style of power outlets away, and/or protected, from collision with moveable mass-rearing equipment.
- *Specialised plumbing for water supply and waste water, e.g. PVC instead of metal – considering corrosion, replacement costs, etc* — Plumbing for floor drains within the facility should be constructed only of corrosion resistant materials such as PVC. The plumbing should be accessible as much as possible for repair and replacement. Drains should be designed to avoid blockage from the volume of waste material handled in normal operation and be accessible for cleaning.
- *Waste water treatment plant, options for use of waste water, discard or re-use* — If waste water is to be re-used it may need extra treatment. The degree of waste water treatment will be dependent on the intended use of the treated water. In some instances, it is necessary to purify the water in order to reuse

it for diet preparation and other rearing activities. In most cases, the waste water will be treated only to the degree necessary for release into the local environment. This will vary depending on the local regulations. The capacity of the waste water treatment facility should allow for possible future expansion of the mass-rearing facility.

- *Biosecurity areas for quarantine/contamination control, e.g. showers, foot baths, changing rooms, airlocks, etc.* — In all cases, and not only when the facility will be located in a pest-free area, the facility should be designed to maintain security from insect escape. Air locks, air curtains, foot baths, shower rooms, air-tight doors, etc., are used to maintain security. The laundry and associated storage areas should be within the secure area and near the shower rooms.
- *Flexible production area through movable walls or partitions* — Movable walls within rearing areas are useful for conserving energy if variable levels of production are anticipated. The location of lighting, power outlets, air ducting and air handlers should be designed with consideration given to the location of movable walls.
- *Passages for flow of equipment through building e.g. separation of clean areas/routes from dirty areas/routes* — The movement of people and equipment along the process flow of the facility require a building design that avoids the cross contamination of clean and dirty areas. Passages (corridors) should therefore not be directly accessible to both clean and dirty areas. Doorways leading directly from clean to dirty areas should be avoided as much a possible.
- *Separation of sterile and fertile pupae* — The secure (pre-irradiation) area also containing the irradiator should be partitioned from the post irradiation area. Some irradiator designs allow for discharge of irradiated pupae on the post irradiation side of the partition. For other irradiators, it is necessary to provide a pass-through in the partition for manual movement of irradiated pupae.
- *Worker lunch / recreation areas* — The lunch and recreation areas should be sized for the number of employees. Additionally, the lunch area should be located within the secure area of a facility for eradication programmes to minimize staff movement into and out of the mass-rearing facility.
- *Accessory/auxiliary areas* — These include laundry, equipment washing, storage, warehouses, and others.
- *Offices: management, computer rooms, communications room, meeting rooms / areas* — The need for computer rooms, conference rooms, and other management areas will be dependent on the level of production. Depending of the size of the operation at least one room for office and computer will be required within the secure rearing area.
- *Quality and process control laboratories and microbiology laboratory* — A quality control laboratory is required for all production operations. The need for process control and microbiology laboratories will depend on

the scale of the operation, but the services will always be required and it will be necessary to contract for them when they will not be available on-site.

- *Public access requirements: viewing windows, public access only corridors, training / video rooms* — If a large number of visitors are expected to visit the facility on a routine basis, then consideration should be given to installing windows in the various rearing areas that allow for viewing operations without compromising biosecurity. The windows can be either in corridors or in a special visitors corridor on the ceiling of the facility (as in Mendoza Argentina). Other options include video monitoring of operations, or simulations of rearing activities.
- *Site security buildings* — In most operations it will be necessary to provide facilities for security personnel. This includes guard stations at entry points to the premises and in some cases, to the facility.
- *Medical service area* — In accordance with local regulations and proximity to public medical facilities, it may be necessary to provide medical service onsite. The degree of medical service may range from simple first aid stations to a designated area with beds and full-time medical staff.

2.5.2. Equipment

- *Level of automation* — The need for automation is dependent on the scale of operation, available technology, maintenance services, labour cost and skill level of available staff.
- *Irradiation equipment: gamma, electron beam, X rays* — The factors that need to be considered when choosing insect irradiation equipment include security risks and public concern associated with radioactive source irradiation equipment and its transport, need for thicker/denser walls and floors, cost of available equipment, access to commercial irradiation facilities and volume of insects to be irradiated daily.
- *Back-up generator/s, power supply protection, transformers, stabilisers, power generators* — All rearing facilities require back-up power generation to protect against the loss of production in the event of power outage. In addition, on-site electrical power generation may be required for normal operation if access to grid power is unavailable or if it is more cost efficient to do so. The power supply should be protected against power surge and phase failure in order to protect all electrical and electronic equipment within the facility. Transformers on incoming power should be sized to maximum capacity required for possible expansion of future operations.
- *Specifications of rearing and general type of equipment required to produce a specific target pest species* — Equipment for rearing a particular species can be adapted to local requirement. Provided the equipment has been used successfully elsewhere for the same species. In many applications, it will be necessary to develop specialized equipment through research and development or commercial fabrication.

- *Flow patterns of equipment through the facility* — The facility must be designed to minimize and accommodate the movement of all portable equipment used in the process flow. This includes the dimensions of doorways, corridors, ceiling clearances, etc. In addition, cross contamination of clean and dirty areas by equipment should be prevented as much as possible through proper design of the facility.
- *Communications infrastructure/systems, location and number of communication ports* — Specific areas requiring communication ports include irradiation, environmental systems control, quality and process control, offices, warehouse, meeting rooms and the mechanical room.
- *Environmental control and monitoring equipment* — This includes temperature (heating, cooling), relative humidity (humidifying and de-humidifying), lighting (100% on, then 100% off, or dawn/dusk needs), air pressure (e.g. to monitor for filter replacements), CO_2 monitors (if necessary) and other safety requirements. Each rearing room within the facility should be equipped with sensors to monitor the room environmental conditions including temperature, relative humidity and, in some case, levels of CO_2. A parallel and independent monitoring system is needed to ensure accurate readings provided by the primary system. In addition, the performance of air conditioning equipment including filtration can be monitored remotely through the use of sensors, such as air pressure differential between filtered and unfiltered air. All facilities require reference equipment to facilitate calibration of sensors.
- *Video surveillance for security* — Video surveillance to monitor access to the facility site and building is recommended.
- *Washing and disinfection equipment to wash/clean: trays, cages, clothing, filters, room walls and floors, cloth ducting, QC materials, etc.* — Automated washing equipment for washing rearing equipment such as trays, cages, etc, should be used in order to reduce labour cost and conserve water.
- *Extruder for biological waste products* — Spent larval diet must be heat treated in order to kill living insects that remain in it, before sending it outside the rearing facility. It is recommended that the diet temperature be elevated to 80°C to ensure total larval mortality. The volume of diet to be processed daily should be the basis for determining the size and through put of material of the cooking extruder. The equipment should be constructed of corrosion resistant materials such as stainless steel and be well insulated to conserve energy. There are many commercial sources for this type of equipment.
- *Steam boiler* — Steam will be required for several purposes in most rearing operations. It is used as a source of heat for the cooking extruder. It is also a very effective method of increasing the relative humidity in some areas of the facility. Steam can also be used for heating purposes. The intended uses of steam for a particular rearing application must be known before deciding on the size and number of steam boilers required.

2..6. Environmental Parameters

- *Thermal loads of different diets, equipment and activities in different areas* — These should be determined as the heat load from different raw ingredients, microbial loads, types of equipment, insect species and stage of development, number of trays, human activity levels, etc. They vary considerably and will impact on the size, type and design of the heating / cooling systems, size of rooms, ventilations requirements, etc.
- *Air conditioning system* — The chill water cooling system is recommended for all mass-rearing operations. Heating should be either hot water circulation or, in special cases, steam. Electrical resistance heating is too costly and should be avoided if at all possible. Thermostats should be electronic digital and maintain temperature within one degree of set point. Condensation on chilled water pipes, inside ceiling, etc. should be minimised. Chilled water pipes should be outside of rearing rooms. This precaution will minimise contamination problems. Sufficient room sealing will reduce this problem and assist in energy conservation. Consideration should be given to placing rooms set to similar temperatures adjacent to each other and in a gradient from warm to cool as far as that applies to process control. Consideration should also be given to the use of cloth ducting for air distribution (for temperature control) within each room. Advantages are that these are easily removed for washing and replaced with a spare. This reduces problems with microbial contamination and overall facility cleanliness.
- *Humidity* — Humidity production within air conditioning ducting, which is commonly used, is not recommended for SIT facilities due to condensation inside the ducting leading to microbial contamination and corrosion problems. To avoid this problem, a second ducting system dedicated to steam delivery is recommended. Another option is free standing humidifiers installed in each room as required. An alternative is to deliver humid air via micro-nozzles with fans used to disperse humidity.
- *Environmental characteristics for each operation in the process: temperature, RH, lighting, etc* — Specific range of operation for the different rearing room should be defined according to the target species. Technical experts will supply these biological parameters for incorporation into the design specifications.
- *Requirement for natural lighting e.g. for mother colony, filter colony, and possibly some corridors and passages* — This ensures conditions as close to nature as possible as well as saving on energy costs. Ensure this is done in a quarantine and biosecure way.
- *Air filtration* — It is recommended that HEPA (High Efficiency Particulate Air) filtered air should be injected into at least the seeding and initiation rooms, which should be under positive atmospheric pressure, with the minimal air exchange rate of three air changes per hour. Positive pressure reduces the entrance of microbial contaminants via air inlets. Areas which are designated as dirty should be under negative pressure. Dirty air can be

drawn from the building to the outside. Air outlets from these areas should be separate from air inlets for designated clean areas.
- *Air exchange rate* — Recommendations are 3 to 10 air changes per hour depending in the rearing area, corrosion risk, and environmental requirements.

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Appendix 2
Criteria relevant for Location and Establishment of Mass-rearing Facilities: A Protocol for Selecting the Optimal Location for Tsetse Fly Mass-rearing Facilities Current Status

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The construction of rearing facilities for tsetse SIT represents a major investment. The costs of facility construction and of its operation over the expected 30-year plus life of the facility are significant financial commitments. It is the purpose of this protocol to provide a framework for planning the creation of such new facilities. Decision-making on the physical location of the planned facility must be as objective as possible and based on the best information. It is envisioned that rearing facilities may be established that are permanent or relocatable. Permanent facilities will have an operating life for tsetse rearing of at least 30 years. Relocatable facilities are designed to be more mobile and will be established in a location for 2–5 years after which they will be dismantled and components redeployed elsewhere.

The protocol presents 56 separate factors arranged into 4 broad categories to consider in choosing a location for establishing a mass-rearing facility:

- Site Characteristics — This category includes factors concerning the suitability of the site from an engineering and construction standpoint.
- Climate and Environment — This category addresses implications of extreme climatic conditions on facility operation and how the surrounding environment may be favourably or unfavourably impacted by the presence of a facility.
- Manpower and Infrastructure — Critical to the operation of a facility is access to adequate manpower, transportation systems, municipal services, utilities and communication means.
- Social and Political Support — Factors in this category address the compatibility of the facility with the surrounding community and emphasizes the vital nature of strong political support in making the venture successful.

The various factors in each category are scored in relation to their criticality to the successful performance of the facility in providing rearing support to tsetse programmes.

- Critical — Those factors characterized as critical must be satisfied at the location under consideration. These factors are so important that the facility cannot be successful if those factors are not affirmative.
- Important — Factors that are characterized as important deserve special consideration because they tend to have a bearing on the cost of constructing or efficiency of operating the facility.
- Useful — Factors characterized as useful convey certain advantages that should be taken into account, but do not indicate barriers to using a location for the facility.

Site Characteristics

Category	Factor	Level	Comments
Topography	Land area	Critical	At least 5 times projected final building area must be available to provide for a buffer area and some space for future expansion
	Drainage	Important	If no main sewerage is available, high soil percolation is required for effluent dispersal Implication for building design and cost
	Slope	Useful	Greater than 5% slope may impact building costs, less than 1% may result in higher drainage costs
	Orientation	Useful	Consider solar heat load, solar energy availability
Geotechnical	Soil condition & stability	Important	Engineering evaluation of the site may dictate that special construction methods be used to mitigate site condition problems, thus increasing the cost
	Water table level	Important	Unusually high or low water table may have construction cost impact for drainage or water acquisition
Hazards	Earthquake	Critical	Low risk of earthquake; facility design to accommodate maximum predicted earthquake severity over projected lifespan
	Possible previous chemical contamination	Critical	Chemical residue testing demonstrates no residual insecticide, chemical or heavy metal contamination from previous uses
	Neighbouring land use	Critical	Adjacent land uses do not generate chemical emissions damaging to tsetse operations
	Lightning strike	Important	Power conditioning may be required
	Eradication zone	Important	Facility that will be operated in a tsetse free zone will require bio-security
	Forest fire	Important	Frequent fires will compromise air-handling system and threatens direct building damage
	Flood risk	Important	Above 20 year flood maximum. Cost implications
	Low erosion	Useful	High levels of erosion of soil at the site from wind or water may have maintenance cost implications over the life of the facility
	Low risk of landslide	Useful	Landslides could threaten the consistent long-term functioning of the facility

Climate and Environment

Category	Factor	Level	Comments
Environmental impact	EIA/EIS	Critical	To avoid conflicts with other interests, it is vital that establishing a tsetse facility at the location will be in compliance with local and national environmental and threatened and endangered species regulations
Climate impacts on facility efficiency and bio-security	Air quality (dust, pollution)	Critical	Air quality is sufficiently high such that no extraordinary air purification and handling systems are required to protect the facility from airborne dust, particulates and chemicals
	Temperature	Important	High and low temperatures increase environmental control costs
	Humidity	Important	High and low humidity increase environmental control costs
	Local environment not conducive to tsetse survival	Important	Provided the site is close enough to field operations to be logistically viable, this factor reduces requirement for bio–security
	Non-corrosive environment	Critical	Remote to sea & industrial plants

Manpower & Infrastructure

Category	Factor	Level	Comments
Transportation links	Roads	Critical	Roadways must be passable by commercial vehicles year around to ensure timely delivery of equipment and supplies as well as shipment of flies
	International/ Regional airport	Critical	Commercial airport must be within 2 hours of the facility to ensure timely delivery of supplies and shipment of flies
	Distance to current and future release sites	Critical	Total transit and release time to any projected release site must be cost effective and not result in unacceptable loss of quality
	Local public transportation	Important	Important for workforce commuting
	Airstrip in vicinity of facility	Important	Facilitates transport of flies, supplies and equipment
	Rail	Useful	Of potential occasional value in transport of heavy equipment
	Navigable waters	Useful	Of potential occasional value in transport of heavy equipment
Population proximity	Labour availability	Critical	Proximity (within reasonable commuting distance for the local area, e.g. 1 hour by bus) to population centre is vital to supply employees to the facility workforce

Category	Factor	Level	Comments
Population proximity (continued)	Technical support for repair and maintenance	Critical	In the event that facility engineers are not able to perform repairs necessary to keep the facility functioning, trade/technically (environmental control services) skilled personnel must be available within 3 hours for emergency service and within 24 hours for non-emergency repair
	Scientific expertise availability	Important	External scientific and management expertise (university, other government facilities or international organizations) is necessary to support the facility and must be accessible for advice, research and methods development, trouble-shooting and consultation
Municipal services	Fire protection	Important	Municipal fire protection service is highly desirable; if not, it must be provided by the facility, but at an undesirable increased cost of operation
	Medical facilities	Important	Within commuting distance for accident/ emergency services and routine health care
	Police	Important	These services are important to employees recruited to work in the facility
	Schools	Important	These services are important to employees recruited to work in the facility
	Means of public relations	Important	Mechanisms exist to keep the local public informed of activities of the facility
	Staff accommodation and housing	Important	If not available locally must be provided by facility
	Shopping, recreation facilities	Useful	Amenities useful for recruiting employees and visiting scientists
Utilities	Electrical power	Critical	Refer to engineers for requirements – back-up generators always required, but rating will depend on local supply reliability
	Water supply	Critical	Obviously, a ready and adequate supply of water is vital to the functioning of the facility. Possibly supplied from bore holes and/or require additional treatment
	Blood source	Critical	The source(s) of blood for feeding must be stable to ensure uninterrupted supply and economical delivery
	Waste disposal	Important	Lack of public means for disposal of waste entails constructing own facilities
	Off-site industrial scale irradiator	Useful	If irradiator not available it will have to be provided by the facility
	Potable water	Useful	Municipal potable water would be convenient, but alternative means of supply can be employed, perhaps at greater cost
	Proximity to abattoir	Useful	Serve as backup in case the established sources of supply are disrupted
	Gas service	Useful	Gas is cheaper than electricity for heating – bottle gas much more expensive than mains

Category	Factor	Level	Comments
Communications	Phone (mobile and fixed) and fax	Critical	Commercial service is available in the area and interruptions in service are infrequent
	Internet	Critical	Commercial service is available in the area and interruptions in service are infrequent – preferably broadband, 128 kB or more
	Courier services	Critical	Dependable daily courier service is available
	Postal services	Important	For non-critical communication
	Satellite communication	Useful	As backup to primary communication means

Social & Political Supports

Category	Factor	Level	Comments
Political support	Local and central government support	Critical	Political commitment to provide support for the life of the program
	Land tenure, ownership/use	Critical	Legal arrangements have been made to ensure that the land will be available for the life of the project and support for expansion is guaranteed
	Zoning	Critical	Current and future use of land adjacent to the facility (buffer zone) must be regulated by zoning laws to ensure that land uses inconsistent with tsetse operations are prohibited. Impact assessment of future land use on tsetse rearing required
	Legal authorization for using radioactive sources	Critical	Government agencies have established procedures to regulate and authorize the use of radioactive sources for SIT ('Milestone 2'), thus ensuring the uninterrupted use of irradiators for the life of the program
	Fiscal incentives	Important	Government accommodations to the costs of establishing and operating the facility could be important in choosing a location
Public support	Social acceptance by the local population	Critical	Evidence can be presented that the local community is supportive of the establishment of the facility

The following worksheet is for use in assessing a location or comparing several candidate locations for the establishment of a tsetse fly mass-rearing facility. Each location under consideration is scored by the same assessment committee and ranked according to the following formula:

- Any unfavourable response to one of the 23 'critical' factors eliminates a location from consideration. Only those eligible locations with favourable responses to all 23 critical factors are included in the ranking.
- 'Important' factors receive 5 points for each favourable response and 0 point for each unfavourable response.
- 'Useful' factors receive 1 point for each favourable response and 0 points for each unfavourable response.

Locations are ranked according to the total points tallied for each and this result, along with any further explanatory information is forwarded to the decision-maker.

Worksheet for Scoring Factors Pertinent to the Selection of a Location for a Tsetse Fly Mass-rearing Facility

Category	Factor	Level	Favourable	Unfavourable
Site Characteristics				
Topography	Land area	Critical		
	Drainage	Important		
	Slope	Useful		
	Orientation	Useful		
Geotechnical	Soil condition & stability	Important		
	Water table level	Important		
Hazards	Earthquake	Critical		
	Possible previous chemical contamination	Critical		
	Neighbouring land use	Critical		
	Lightning strike	Important		
	Eradication zone	Important		
	Forest fire	Important		
	Flood risk	Important		
	Low erosion	Useful		
	Low risk of landslide	Useful		
Climate & Environment				
Environmental impact	EIA/EIS	Critical		
Climate impacts on facility efficiency and bio-security	Air quality (dust, pollution)	Critical		
	Temperature	Important		
	Humidity	Important		
	Local environment not conducive to tsetse survival	Important		
	Non-corrosive environment	Critical		
Manpower & Infrastructure				

Category	Factor	Level	Favourable	Unfavourable
Transportation links	Roads	Critical		
	International/ Regional airport	Critical		
	Distance to current and future release sites	Critical		
	Local public transportation	Important		
	Airstrip in vicinity of facility	Important		
	Rail	Useful		
	Navigable waters	Useful		
Population proximity	Labour availability	Critical		
	Technical support for repair and maintenance	Critical		
	Scientific expertise availability	Important		
Municipal services	Fire protection	Important		
	Medical facilities	Important		
	Police	Important		
	Schools	Important		
	Means of public relations	Important		
	Staff accommodation and housing	Important		
	Shopping, recreation facilities	Useful		
Utilities	Electrical power	Critical		
	Water supply	Critical		
	Blood source	Critical		
	Waste disposal	Important		
	Off-site industrial scale irradiator	Useful		
	Potable water	Useful		
	Proximity to abattoir	Useful		
	Gas service	Useful		
Communication	Phone (mobile and fixed) and fax	Critical		
	Internet	Critical		
	Courier services	Critical		
	Postal services	Important		
	Satellite communication	Useful		

Category	Factor	Level	Favourable	Unfavourable
Social & Political Supports				
Political support	Local and central government support	Critical		
	Land tenure, ownership/use	Critical		
Political support (continued)	Zoning	Critical		
	Legal authorization for using radioactive	Critical		
	Fiscal incentives	Important		
Public support	Social acceptance by the local population	Critical		

FACILITY DESIGN & SUPPORT SERVICES

General

This section describes the various buildings and associated facilities required to design a Tsetse Fly Mass-rearing Facility.

The buildings required for the facility are generally as follows:

- Production (Rearing) Module/s (Number of modules depending on the rearing capacity required of the facility),
- Common Production Facilities,
- Male Module,
- Staff Facilities,
- Maintenance Workshop,
- Utilities Building,
- Guardhouse.

Rooms and Functions

The various rooms and their function required in the various buildings are as follows:

Production (Rearing) Module/s	
Room	*Function*
Production Room Rearing	Main rearing
Pupal Incubation Room	Pupal incubation
Pupal Emergency (SSPC)	Emergence- self stocking into production cages (for separation of male and female flies)
Blood Preparation & QC	Preparing blood for feeding and blood quality assurance
Blood Store	For storage of blood required for feeding at the module
Store	For storage of equipment, stationary, etc.
Production Office	Office for production module supervisor
Tray & Membrane Washing	For washing of tray and membrane

Production (Rearing) Module/s	
Room	*Function*
Cage Empty (Female disposal) & Oven	To remove dead female flies from cages and tray drying
Toilet	For use by production workers

Common Production Facilities	
Room	*Function*
Cage & Trolley Washing	For washing used cages and trolleys from production modules
Central Equipment Store	For storing cleaned cages and trolleys after washing
Hotroom	For drying of cages and trolleys
Cage Making	Area where cages are made
Membrane Making/Preparation	Area where membranes are made and prepared for use at each production module
Blood Preparation & QC	Preparing blood for feeding and blood quality assurance
Blood Processing	For sieving and batching in containers and blood sample testing
Irradiation #1	Area where flies (males) are sterilized
Irradiation #2	Second irradiator may be needed to sterile blood supply
Walk-in Freezer Blood Store (Pre-Test)	For long term storage of blood supply after blood processing
Packing & Despatch	Area where sterile flies are packed into boxes
Male Chilling	For chilling sterile flies in boxes before despatch

Male Module	
Room	*Function*
Male Pupal Incubation	Area for male pupae to incubate
Male Emergence	Area for emergence of male flies
Blood Preparation & QC	Preparing blood for feeding and blood quality assurance
Blood Store	For storage of blood required for feeding at the module
Store	For storage of equipment, stationary, etc.
Office	Office for male module supervisor
Holding & Feeding — Male Flies	Area for Male flies to mature (2–3 days duration)

Staff Facilities	
Room	*Function*
Officess	—
Conference room	—
Canteen/Lunchroom/ Tearoom	—
Restroom	—
Changerooms & Toilets — Male & Female	For staff, production workers & visitors
First Aid	—

Maintenance Workshop, Utilities Building, Guardhouse	
Room	*Function*
Maintenance Workshop	For engineering/maintenance works
Utilities Building	For accommodating standby power generator/s and Electrical Substation and Fire/Water Services Pumphouse as and where required
Guardhouse	—

The ceiling height throughout the whole facility should generally be 3000 mm with probably higher ceilings in areas like mechanical & electrical services plantrooms and store or warehouse.

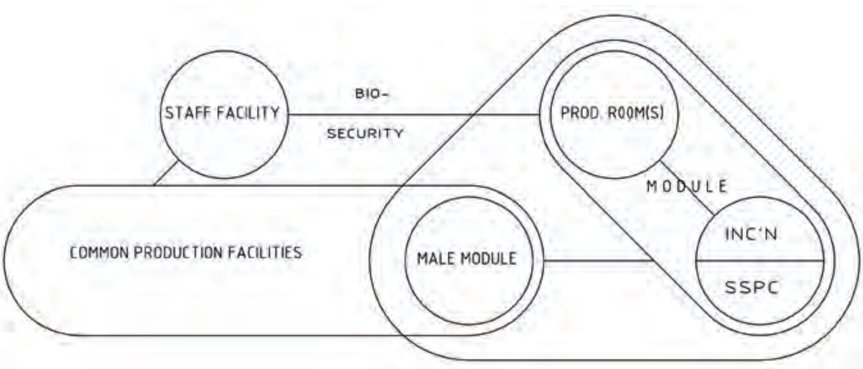
Design Concept

The building layout should take into consideration the following needs:

- Production capacity (generally in terms of number of flies per week);
- Bio-security;
- Personnel flow taking into consideration bio-security and personnel safety,
- Administration needs;
- Material flow for material supplies, cage preparation, process flow path, irradiation procedure and final despatch of sterile flies;
- Amenities for convenient use by various personnel;
- Cross-contamination control (i.e. need to segregate various rearing areas and production modules);
- Emergency evacuation;
- Shared support services – Common production facilities;
- Rack and tray cleaning, sterilisation, drying and storage needs;
- Utilities supplies;
- Road access-traffic flow;
- Landscaping needs;
- Staff accommodation where needed.

Production modules should preferably be positioned to facilitate easy and logical flow of personnel and rearing equipment to and from the common production facilities and to suit the logical transfer of flies to various rooms for processing. The following diagram serves to show the interaction of the various building units of the rearing facility. The type of construction should generally conform with the local building practices and methods. Local construction materials should be used as and where appropriate. The construction should also be in accordance with the recommendation of the Code of Good Manufacturing Practices (CGMP). Materials of construction used should therefore be durable and all walls and floor finishes should be hard, smooth and easily cleanable, using probably epoxy paint or self-levelling epoxy coating on concrete or cement plaster. Construction using

FIGURE 1
Interactive Bubble Diagram



modular sandwich panels consisting of two pre-finished steel skins bonded by rigid polyurethane foam and having smooth surfaces should also be considered.

The design of the facility and rooms should be adaptable, taking into consideration ease of future expansion and alterations, i.e. flexibility in partitions and room layout.

Support Services

The facility should be equipped with the following services:

- Controlled Environment Systems,
- Electrical Services,
- Lightning Protection,
- Communications,
- Fire Services,
- Potable and Process Water,
- Sanitary Waste,
- Trade Wastewater,
- Security.

Each of the above systems should be designed and documented by consultants who are qualified in the respective fields, taking into consideration the relevant local and international standards and codes that are applicable. In electrical services, particular attention should be given to selection of appropriate light fittings for the rearing rooms as tsetse would be sensitive to certain harmonic frequencies generated by certain types of fluorescent light fittings.

Controlled Environment System Design

The controlled environment systems should be designed to suit the following operating conditions taking into consideration the design ambient climatic conditions applicable to the country where the facility is located. This consideration should include the prevalent ambient conditions of wet and dry seasons.

Air-handling system serving each set of rearing/incubation/blood preparation rooms shall be separate. Bio-secure containment requirements dictate that ducting shall not penetrate the bio-secure boundary.

All exhaust discharges and outside air intakes should be fitted with stainless steel fly screen mesh.

Air-curtains shall be provided at the main entrance to bio-secured areas of the rearing facility, on the exterior side of the main bio-secure airlock entry and to operate when the door is opened.

The controlled environment systems should be designed to minimize initial and operating costs. To achieve this objective, the system should be simple in installation and psychrometrically efficient. The system should be designed to make 100% use of the favourable ambient conditions.

The system should be designed to control and maintain the desired conditions within the desired operating tolerances. Air-cooled split system has been used to serve the rearing facility. This system has been low in initial cost. Face and bypass system in conjunction with air-cooled split system should be considered to minimize the need for humidification which should be achieved with proprietary made humidifier only if deemed absolutely necessary to keep the rearing room within the desired conditions. Irrespective of the system adopted, the systems should be designed to maintain the stringent temperature and humidity tolerances required in the various rearing rooms, especially in the pupal incubation and emergence rooms.

Odour control should be considered in the controlled environment system design to minimize the odour within the production rearing rooms.

Desired Room Conditions

Area	Desired Room Conditions	
	°C Dry Bulb	% RH
Production (Rearing) Module		
Production Room — Rearing	24 ± 2	75±5
Pupal Incubation Room	24 ± 1	75±5
Pupal Emergence (SSPC)	26 ± 0.5	80±5
Blood Preparation & QC	22 ± 2	55 nominal
Blood Store	22 ± 2	55 nominal
Store	24 ± 2	55 nominal
Production Office	22 ± 2	55 nominal
Tray & Membrane Washing	24 ± 2	55 nominal
Used Female Fly Kill	24 ± 2	55 nominal

Area	Desired Room Conditions	
	°C Dry Bulb	% RH
Cage empty	Ventilation only, minimum 15 air changes per hour	
Membrane & Tray Sterilisation	24 ± 2	55 nominal
Toilet	Ventilation only, minimum 10 air changes per hour	
Common Production Facilities		
Trolley Washing	Ventilation only, minimum 10 air changes per hour	
Central Equipment Store	24 ± 2	55 nominal
Cage Making	Ventilation only minimum 15 air changes per hour	
Membrane Making/Preparation	22 ± 2	55 nominal
Blood Preparation & QC	22 ± 2	55 nominal
Common Production Facilities		
Blood Processing	22 ± 2	55 nominal
Irradiation #1 & #2	22 ± 2	55 nominal
Walk-in Freezer Blood Store (Pre-Test)	–20 ± 2	Not controlled
Male Chilling	4 ± 2	80 ± 5
Packing & Despatch	22 ± 2	55 nominal
Cage Empty Room (Female disposal)	Ventilation only minimum 15 air changes per hour	
Male Module		
Male Pupal Incubation	24 ± 1	75 ± 5
Male Emergence	26 ± 0.5	80 ± 5
Blood Preparation & QC	22 ± 2	55 nominal
Blood Store	22 ± 2	55 nominal
Store	22 ± 2	55 nominal
Office	22 ± 2	55 nominal
Holding & Feeding – Male Flies	24 ± 2	80 ± 5
Packing & Despatch	22 ± 2	55 nominal
Bio-secure Corridors	*22 ± 3*	*55 nominal*
Staff Facilities		
Female Changeroom	22 ± 2	55 nominal
Male Changeroom	22 ± 2	55 nominal
General Offices & Meeting Room	22 ± 2 °C Dry Bulb	nominal 55 %RH

Area	Desired Room Conditions	
	°C Dry Bulb	% RH
Staff Facilities		
Canteen/Lunchroom/Tearoom	22 ± 4 °C Dry Bulb	nominal 55 %RH
Guardhouse	*22 ± 4 °C Dry Bulb*	*nominal 55 %RH*

Outside Air

Outside air intake should be in accordance with the requirements of the local regulatory authorities or minimum of 10% of supply air (whichever is greater) unless otherwise stated hereinafter. Recirculation of room air will be permitted generally except for washrooms and toilets. All laboratory exhaust should be taken to discharge at not less than 3m above the roof. All other exhaust roof discharge should be kept at least 1m above the roof and kept at least 6m from any thoroughfare and outside air intake.

Area	Outside Air Intake
Generator Room	Ventilation rate to maintain not more than 10°C rise above ambient or minimum 15 air-changes per hour whichever is higher
LV Switchroom	Ventilation rate to maintain not more than 10°C rise above ambient or minimum 6 air-changes per hour whichever is higher
Warehouse	Ventilation only, minimum 10 air changes per hour

Lighting Loads

As per the electrical services general lighting design.

Internal Loads

Equipment: As per the list of equipment to be provided and installed with the facilities. Allow minimum 5 kW for each sterilizing oven.

Occupancy

Production module each — 7–10 workers
Administration — Generally 1 person per 10 m^2.

Supply Air

As required to meet the cooling load and ventilation requirements or to meet the minimum airflow rate specified.

Air Filtration and Air Distribution
Minimum Air Filtration Standard

Production Rooms:

Controlled Environment System serving	Mix Air
Rearing Room, Incubation Room, Blood Store, QA & QC Rooms, Irradiation Rooms, Bio-secured corridors	Class G4 600 mm Deep Bag/Deep Bed Compact Filter
Other Areas of Rearing Facility, Administration Building, Workshop and other Support Facilities	Class G3 600 mm Deep Bag/Deep Bed Compact Filter

Other Areas of Rearing Facility, Administration Building, Workshop and other Support Facilities

Generally, not less than class G3 using 600 mm deep bag filter.

Air Distribution

Rearing room, incubation room, blood store, QA & QC rooms, irradiation rooms, bio-secured corridors:

Using ceiling-mounted diffusers of swirl type (or equal) to achieve uniform desired room temperature distribution.

Noise Levels

Administration building, workshop and other support facilities:

- NR40–45 in general office and laboratory areas,
- NR60 in production areas.

Noise emanating from controlled environment plants at the site boundary shall not exceed the state environmental protection authority's statutory requirements.

Electrical Supply

All equipment electrical characteristics shall match the local electricity authority's supplies.

Over-capacity allowance

10% minimum on cooling and heating units serving rooms for production rearing, Incubation, blood store and colony room.

The complete controlled environment systems shall satisfy the relevant requirements of the local regulatory authorities.

Appendix 3
Glossary

Amplification Colony I

Eggs from the filter colony are seeded onto larval diet and reared to adults (called amplification colony I). These adults are housed in conventional cages.

Amplification Colony II

Eggs from amplification colony I are seeded onto larval diet and reared to adults (called amplification colony II). These adults are housed in conventional cages.

Brown Pupae Recovery (%)

Production of pupae from each of the release colony, amplification colony II and amplification colony I that are able to be used in the production process. For calculation proposes it will be 50% brown (male), 25% white (female).

Cage Unit

A cage unit is comprised of 40 sandwich cages

Conventional Cage

This cage (dimensions 180cm × 30cm × 200cm) is used for flies reared in amplification colony II and amplification colony I.

Egg Incubation Container

Eggs plus water are heated to the target temperature (34°C) to treat 'temperature sensitive lethal' (*tsl*) eggs. Oxygen or air is bubbled or swirled throughout the egg + water (1 : 20) mixture. Eggs are generally treated in the egg incubation container for 48 hours. Usually holds 10L eggs in a total volume of 200 L (eggs + water).

Filter Colony

This is a colony held under very relaxed conditions under conditions (light, %R.H., temperature, etc). This is where aberrant insects (females that emerge from brown pupae or males that emerge from white pupae) are removed so that the genetic integrity of the colony is maintained.

Flying Males Production Level

Not all male (brown) pupae eclose normally and are able to fly. This figure depends on quality control tests on 'Efficiency Brown Pupae to Flying Males'. This value is an independent input into the spreadsheet.

Male Only Production

Eggs from the release colony are heat treated leaving only male eggs which are grown in larval diet to pupation (called male only production), then sterilised and used for male only release.

Male Pupal Production Level

The target number of male only pupae (brown) per week required to be produced by the SIT facility each week.

Mediterranean fruit fly *'tsl' (temperature sensitive lethal)* Genetic Sexing Strain

Males of this strain carry a pseudo-linkage through a chromosome translocation between the 'Y' chromosome and the autosome that carries the tsl^+ gene. This means that males of this strain will be heterozygous for the *tsl* gene while the females will be homozygous. Homozygous *tsl* females are sensitive to high temperature (34°C) and are killed during embryo development when incubated at this temperature for 24h.

Release Colony

Eggs from amplification colony II are seeded onto larval diet and reared to adults (called the release colony). These are housed in cages (40 cages / Cage Unit). Eggs for the male only release are collected from these adults.

Sandwich Cage

This is the cage developed in Guatemala for mass-rearing Mediterranean fruit fly. It is a small cage (dimensions 77cm × 5.5cm × 71cm). This cage is used for flies in the release colony.

White Pupae Recovery (%)

Production of pupae from each of the release colony, amplification colony II and amplification colony I that are able to be used in the production process. For calculation proposes it will be 50% brown (male), 25% white (female).

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The FAO/IAEA Spreadsheet for Designing and Operation of Insect Mass Rearing Facilities

The sterile insect technique has in many countries become an important control tactic for integration in area-wide integrated pest management programmes against fruit flies of economic importance. An important prerequisite of these programmes is the availability of adequate numbers of sterile male flies that are produced in large mass-rearing facilities. This document combines an interactive spread sheet in Excel on a CD Rom and a procedures manual to assist in technical and economic decision making with the design, costing, construction, equipping and operating of such mass-rearing facilities. The model can be used by managers as a support tool for facility design, required investments and financial planning of facilities of different sizes using different scenarios. The software was designed using the Mediterranean fruit fly (Ceratitis capitata) as a model for planning insect mass-rearing facilities, but its default settings can be easily changed to suit any other fruit fly or other pest insect.

The manual includes an appendix on site selection and biological/physical factors that need to be considered when constructing a facility and another appendix on criteria that are relevant for selecting the location and establishment of mass-rearing facilities.

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