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EVALUATION OF MACHINE-BASED SOURCES FOR STERILE INSECT TECHNIQUE

A Landscape Study

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Abstract

The Sterile insect technique (SIT) is a well-proven and environmentally positive method for controlling and reducing the impact of pest populations including disease vectors, and crop and livestock antagonists. The study investigates the current state of SIT and compares the three principal irradiation modalities gamma –x-ray, and electron beam. These technologies are assessed as part of the Office of Radiological Security's Alternative Technologies pillar in an attempt to address the discontinuation of the cobalt-60 based Gammacell 220 irradiator. Assessing these technologies will inform ORS on how they address SIT security concerns by suggesting non-source irradiators where applicable and improving security for facilities with source-based irradiators. The study also reviews existing programs and identifies unmet demand for international SIT programs using a combination of literature review, manufacturer interviews, SIT expert interviews, and facility walkdowns. The paper provides economic and strategic guidance on the decision-making process involved in establishing a new SIT facility. Finally, existing SIT facilities' areas of influence are assessed and compared with insect prevalence to show where unmet demand of SIT might lie, along with the need for new facilities. While the biological effectiveness of the three technologies is generally the same, the guidance on selecting the best irradiator for a facility depends on a myriad of considerations including cost, ease of use, throughput, safety and security, and insect type. Gamma irradiators exceed in their throughput efficiency, long-term cost, and ease of use but raise questions for safety and security, thus recommendations for future action are given in this study based on these and other relevant factors.

1. INTRODUCTION

The sterile insect technique is a process that is used to supress and sometimes eradicate certain insect types due to their problematic effects on biological factors, including their role as disease transfer vectors and food pests. The process involves the mass rearing of an insect type, the sterilization of the insect, and the subsequent mass release of large numbers of males to compete with other fertile males to mate wild females which will produce eggs which will not hatch [1]. This technique was developed in the mid-1900s using multiple methods including, hybrid sterility on the tsetse fly populations in Moscow and ionizing x-ray radiation to eradicate the New World screwworm fly (*Cochliomyia hominivorax*). While the research of hybrid sterility was not effectively investigated further during this period, the use of ionizing radiation was shown to effectively sterilize large populations of the screwworm fly. By 1979 the use of mutagenic chemicals was considered another effective method of inducing sterility in insects. These chemicals would be applied to the eggs, pupae, or diet of the insect to produce sterility. However, the use of these chemical sterilant is waning due to fears of environmental contamination after research concluded they are cariogenic to humans. Programs have begun developing to combat new pests across the world including a number of fruit fly species, pink bollworm (*Pectinophora gossypiella*), the coddling moth (*Cydia Pomonella*), the false coddling moth (*Thaumatotibia leucotreta*), and many others. The preferred method of SIT uses ionizing radiation, mostly in the form of ^{137}Cs or ^{60}Co, due to its environmental friendliness and its ability to efficiently provide the necessary dose to a high throughput of insects. These sources, however, pose a certain level of threat to global safety and security due to their possibilities of being stolen for malicious intent. This combined with the discontinued production of the GC-220, a widely used ^{60}Co irradiator, has created renewed interest in developing alternatives to these isotopic devices that can compete in efficiency and effectiveness without any threat of malicious use.

The intent of the paper is to capture the landscape of SIT as it exists now. The study objective is to provide a better understanding of the methodologies involved in SIT, and the use of non-isotopic methods and their viability in comparison to gamma irradiators. The paper also examines current isotopic sources and the economic demand, or lack thereof, for current technologies or viable alternatives.

2. LITERATURE REVIEW

2.1. Mass Rearing and Release Methodologies

For the sterile insects to outcompete the fertile population, it is most often necessary to produce vast quantities of juvenile insects for release. The screwworm SIT facility in Tuxtla Gutierrez, for example, has a capacity of 500,000,000 specimens produced each week [2]. Some species are produced only seasonally, due to either biological or environmental factors. The facilities that rear these species most often shut down temporarily as the costs associated with altering the equipment to accommodate a different species are rarely worth the versatility. This initial larval rearing step in the SIT process is the most sensitive and resource intensive at most SIT facilities due partially to larva diet since the larvae must reach a certain weight before irradiation. The lifecycles of many pests are governed by physical growth and quickly growing larvae allows for a greater number of sterile insects to be produced for a specific larva capacity. Additionally, as most SIT programs require the insects to be sorted and separated by sex, it is beneficial for the specimens to reach the point in their development at which sexual dimorphism makes insect gender possible to distinguish.

Transportation of sterilized insects is not strictly regulated as they are not considered active pests since they are unable to reproduce. Therefore, the operations of these large-scale SIT facilities are not dependent on local demand and are likely to continue even when local populations have been eradicated or adequately supressed. Transportation over long distances requires the insects to be cooled down to a state of inactivity or otherwise immobilized to keep them alive, and some insects have a limit of distance they can be transported due to their lifespan. Upon arrival at the destination, the irradiated pupae or adults need to be cleared by the national phytosanitary and customs authorities. Sterile insects need to conform to international accepted quality control standards and operation procedures [3].

SIT program success metrics are often ascertained by recapture of the target species at key infestation locations. Recapture techniques can vary widely by species but accomplishes the same measurement—the ratio of wild insects to sterilized insects captured. This ratio, indicative of the proportion of fertile to sterile insects attempting to reproduce, is valuable in determining the effectiveness of an SIT program. Recapture efforts are often performed at a variety of distances and time periods from the initial release to provide additional data on specimen fitness, longevity, and distribution range. These factors can affect release schedule and location as well as dosages.

2.2. Current SIT Methods

A vast majority of the SIT facilities in existence employ the use of 24k Ci ^{60}Co or 12kCi ^{137}Cs sources. As of 2019 there were 24 self-contained ^{60}Co, 18 panoramic ^{60}Co, and 10 ^{137}Cs SIT units in use worldwide [3]. These sources requireenhanced security protection to prevent their loss to a malicious entity. They also require “reloading” when they decay beyond a certain point and can no longer provide a sufficient dose in a timely manner to the insect. This security concern has made shipment of these sources across international borders and reloading more difficult. The discontinuation of the production of the Gammacell-220, an irradiator well-suited for SIT, has also sparked a need to pursue alternatives, though there has been an effort to replace this device with the JL 109-68 from JL Shepard and the Gammacell 220F from Fosstherapy.

Insects are generally sterilized as pupae due to their lowered resistance to sterilization, easier transportability, and more lenient regulatory aspects. This is not always the case, however, as some species of moth are sterilized as adults and are thus more difficult to transport.

2.2.1. Dose Rates and Time of Irradiation

To achieve adequate results, a large quantity of insects must be irradiated with a sufficient dose to induce sterility without negatively affecting the insects’ mating competitiveness. This requires irradiators which can achieve a high throughput of sterilized insects and low Dose uniformity ratio (DUR), the difference between the maximum and minimum dose for a single sterilization, across a batch of insects for an SIT technology and its facility to be effective [4]. There are two general types of gamma irradiators: Self-contained dry-storage irradiators which pass a small (1 to 4 Liter) canister of insects into an irradiation position and rotate the canisters; and large-scale panoramic irradiators which use ^{60}Co rods arranged in a plane and are surrounded by several canisters which are irradiated simultaneously. Self-contained irradiators have good DURs but suffer from low throughputs. Panoramic irradiator performs better regarding throughput but typically produces a DUR of about 2. Most insects require about 50-150 Gy of dose which can take about 5-10 minutes. The study did encounter data that stated certain irradiators required an hour for irradiation, though these times could be due to the use of older sources requiring a reload. A significant amount of shielding is required for the safety of workers for these irradiators.

2.2.2. X-ray

X-rays with an energy range of 150-250keV can suitably replace gamma irradiators for smaller SIT facilities (<100 million insects per week) [5]. X-rays generate a spectrum of energies with the average energy at about one third the maximum energy [3]. These units can be turned on or off which benefits their facilities from a safety and security standpoint but requires a large amount of power. Their throughputs tend to be much lower than gamma irradiators due to the lower dose and penetration of the x-rays. The DUR can be acceptable for these machines but this requires further reducing the dose rate or changing the orientation or rotation of the insect canisters. Calibration of these units can be difficult as well. Currently there are nine x-ray SIT units with five more units planned or under construction.

2.2.3. E-beam

E-beams produce high energy focused beams which can be pulsed or continuous depending on dose requirements. The high energy (1-10MeV) electrons produced make most of these units unsuitable for SIT due to the high dose rates they produce. This can be somewhat mitigated by pulsing the e-beam and using a high conveyer speed to move insect canisters through, which contributes to a very high throughput. Currently only one e-beam facility exists in Spain irradiating the fruit fly *C. capitata* [3]. Like the x-ray, the e-beam unit can be turned off and has few security concerns. Shielding may still be required for these devices, and DUR is difficult to control like most irradiation methods. This technology is very costly still and requires a high energy power source and large facility to operate. More technological advancements are expected to come with these devices due to prototypes being produced by the IAEA, Mevex, and Nuctech [5].

2.2.4. Genetic, chemical and alternative methods

Chemical sterilants, hybrid sterility, inherited sterility, and the use of Wolbachia bacteria are all alternative methods for sterilization. While these methods show promise each of them has many drawbacks in comparison to irradiation-based methods. While they were necessary to investigate for the landscape view of SIT methods, they were not analyzed further in the study due to these disadvantages.

Some methods such as inherited sterility or the use of the Wolbachia bacteria can be used in concert with irradiation methods. Inherited sterility can be used when certain insects are resistant to radiation-based sterilization such as moths and butterflies. They might require near lethal dose for sterility which reduces their mating competitiveness. However, a male can still be irradiated with a lower dose and produce less offspring of which the males will show near sterility and often the females will be completely sterile. This method will continue to affect reproduction through several generations [3]. The Wolbachia bacteria is a type of bacteria that is found in most insects and is known for its ability to manipulate its host's reproduction. Specifically, the Wolbachia bacteria induces cytoplasmic incompatibility in the paternal nuclear material which causes a failure of development in an insect's offspring [6]. This method is effective only if the male contains the Wolbachia and the female does not. When used in concert with irradiation-based SIT methods a population of both male and female insects can be irradiated with a low dose, which will completely sterilize the more radio-sensitive female insects, and infected with Wolbachia.

3. ANALYSIS FRAMEWORK

The analysis of the paper attempts to answer a few different questions concerning the present and potential future of SIT concerning the unmet demand and opportunity for SIT, the comparison of costs for different facility types, and the direct comparison of technology pros and cons.

3.1 Current Market, Unmet Demand, and Opportunity for SIT

In an effort to assess the existing market for SIT, both source and non-source based, databases were used to collect a series of information: each existing facility and its location; the machine type used; type of irradiation method; activity of the source (if one was used); whether the facility cooperates with ORS; and the type of insect being irradiated at each facility. A meta-analysis showed the majority of SIT facilities focus on the irradiation of the Tsetse fly and the fruit fly. A majority of the facilities also employ the use of a GC220 however, as previously stated, this irradiator model is no longer being produced.

The study is focused on determining the unmet demand and opportunities for SIT worldwide. While some pest-dense locations where SIT has not been implemented, have expressed the desire for its use, other geographic locations have great opportunities for SIT without any determinable desire for it. Cross-referencing facility geographic locations with insect population map data allows the study to attempt to preliminarily determine where both the demand and potential opportunity for SIT lie. Of course, it should be considered that a facility's "sphere of influence" might reach far beyond its surrounding area due to the transport of insects. This transport distance is limited but can reach beyond international and continental borders. Interviews and more data analysis were performed to determine how insect problem areas, remote from SIT facilities, were being dealt with. In concert with this analysis, data was collected to determine what area size a facility could service based on the number of sterilized insects it produced. Some data was found concerning mosquitoes, however other data proved to be sparse. Indeed, determining the precise method for each problem area proved to be difficult to determine. In some cases these were questions that could be answered from interviews with government entities or facilities, however performing individual interviews for each facility and pest-dense location would require a much larger effort than is appropriate for the scope of the report. In some areas it is likely that demand might be already met through non-sterilizing methods such as pesticides. In other cases, there might be no demand or opportunity for SIT due to cost of technology, political issues, infrastructure or a lack of industries who would invest. In cases where desire for SIT has been expressed, interviews were conducted to determine how entities fund new facilities or those replacing gamma sources, how other organizations such as might be involved and provide guidance.

Technology and Cost Comparison

Information was collected online and through various interviews with technology providers and facility sites to determine the various costs and technology performances of a facility employing each technology type. The study attempted to look at each device that is presently in use. It was determined that it would be problematic to compare existing facilities costs due to their variance in size, throughput, insect type, energy requirements, mass rearing methodology, etc. In an effort to mitigate this, only the costs and capabilities related to irradiation were considered and were standardized to a single insect type. An attempt to collect information on the various funding types was performed however this data, along with many of the ancillary costs related to the different technology types, was difficult to find and in some cases was proprietary information. A cost analysis was performed between the three technology types using the available information. The technologies were also assessed using data from comparative technology assessment studies. The result of these technology and cost comparisons do not definitively declare a "winner" between gamma, x-ray and e-beam irradiators, but instead can provide a decision guideline based on the resources, needs, and wants for specific facilities interested in SIT.

4. RESULTS AND DISCUSSION

Overall, it appears that each technology used has various drawbacks in one of the areas of Safety/security, cost effectiveness, throughput, and dose uniformity. As stated in the previous section if safety and security are major concerns for a facility x-ray appears to be the best alternative technology to employ so long as the facility isn't required to have a relatively high throughput of insects. E-beam technology is employed in one facility in Europe and has some positives however it is very costly and might require more technological advancements before it becomes a widespread SIT technology.

It was very difficult to determine the current market of SIT as each facility is its own entity. There are many different insect types, different governments and commercial organizations implementing a variety of methods to deal with their own pest problems. There is some international communication but databases containing much information are limited and interviewing each existing facility and potential new facility might be necessary to gain a complete understanding of the SIT landscape. The same can be said for the intricacies of the costs for each technology type along with the market opportunities for further expansion of SIT. If there is to be a complete understanding of the SIT effort much more information needs to be collected through individual interviews.

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