STERILE INSECT TECHNIQUE (SIT)

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INTRODUCTION

A single wound on a cow was once an open invitation to devastation. The New World screwworm, a parasitic fly, laid its eggs in the exposed tissue of livestock, and within hours, newly hatched larvae would begin burrowing into living flesh.[1] Unlike typical maggots that feed on dead tissue, screwworm larvae consumed healthy tissue, carving deeper into their host and causing intense suffering, infection, and often death.[2] By the mid-twentieth century, this pest was ravaging cattle across the southern United States, inflicting severe economic losses and threatening the livestock industry.[3]

What ultimately stopped the spread of the screwworm was not poison or widespread culling, but a radical new idea: sterilize the pest itself. In a joint effort between the United States and Panama, scientists began irradiating male screwworm pupae, rendering them sterile before releasing them back into the wild. When these males mated, no viable offspring followed, and the population steadily collapsed. This strategy became known as the sterile insect technique (SIT). This Technology Explainer examines the scientific foundations of SIT, its practical implementation, and the regulatory framework that governs its use.

I. THE SCIENCE OF STERILIZATION

A. IONIZING RADIATION AND ATOMIC STABILITY

The atom serves as the foundational building block of all matter. Each atom consists of a dense nucleus surrounded by negatively charged electrons arranged in energy levels.[4] The nucleus contains neutrally charged neutrons and positively charged protons, and its stability depends on the ratio of these particles.[5] An atom is

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[1] *About New World Screwworm*, CTR. FOR DISEASE CONTROL (Feb. 24, 2026), https://www.cdc.gov/new-world-screwworm/about/index.html [https://perma.cc/GZZ3-JHUL].

[2] *Id.*

[3] Linda Qiu & Alexa Robles-Gil, *Gene Editing and Fly Factories: The Fight Against a Flesh-Eating Pest*, N.Y. TIMES (Aug. 9, 2025), https://www.nytimes.com/2025/08/09/us/screwworm-cattle-gene-editing.html?searchResultPosition=9 [https://perma.cc/JVW6-PWNU].

[4] *See* J. KENNETH SHULTIS & RICHARD E. FAW, FUNDAMENTALS OF NUCLEAR SCIENCE AND ENGINEERING 5 (2d ed. 2008).

[5] *See* JOHN R. LAMARSH & ANTHONY J. BARATTA, INTRODUCTION TO NUCLEAR ENGINEERING 18 (Marcia J. Horton et al. eds., 3d ed. 2001) (explaining that only certain proton and neutron combinations yield stable nuclei; that neutrons stabilize the nucleus by

electrically neutral when the number of electrons equals the number of protons.[6] Electrons normally occupy their lowest energy level, called the ground state.[7] When energy is absorbed, an electron may move to a higher energy level in a process called excitation.[8] If enough energy is supplied, an electron can be completely removed from the atom, a process known as ionization.[9]

Ionization can occur through several mechanisms; the relevant mechanism here involves gamma rays. Gamma rays are high energy electromagnetic radiation emitted from the nucleus of an atom.[10] When gamma rays interact with an atom, they can transfer energy to the electrons.[11] If the transferred energy is sufficient to raise the electron to a higher energy level, excitation occurs.[12] If enough energy is imparted to overcome the force holding the electron in its orbit, the electron is ejected from the atom, resulting in ionization.[13]

B. RADIATION - DNA INTERACTIONS

Ionizing radiation may have detrimental effects on living cells. To understand these effects, it is helpful to review some basic biology. Cells are generally divided into two classes: germ cells and somatic cells.[14] Germ cells are involved in reproduction (e.g., sperm and egg cells),[15] while somatic cells make up nearly all other tissues and organs of the body.[16] Although these two classes differ in function, structure, and regulation, they share common internal

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offsetting electrostatic repulsion between protons, acting as nuclear "glue"; and that some elements exist in multiple stable forms, or isotopes, such as oxygen, which, with eight protons, is stable with eight, nine, or ten neutrons but becomes unstable outside those configurations).

[6] *Id.* at 7.

[7] *Id.* at 15.

[8] *Id.*

[9] *Id.*

[10] *Gamma Radiation*, U.S. NUCLEAR REGUL. COMM'N (Mar. 9, 2021), https://www.nrc.gov/reading-rm/basic-ref/glossary/gamma-radiation [https://perma.cc/BT9L-FDZY].

[11] LAMARSH & BARATTA, *supra* note 5, at 91.

[12] *Id.*

[13] *Id.*

[14] *See* Belen Hurle, *Somatic Cells*, NAT'L HUMAN GENOME RSCH. INST. (June 10, 2026), https://www.genome.gov/genetics-glossary/Somatic-Cells [https://perma.cc/MA8L-2KKK].

[15] *See Belen Hurle, Germ Line, NAT'L HUMAN GENOME RSCH. INST*. (June 10, 2026), https://www.genome.gov/genetics-glossary/germ-line [https://perma.cc/9X66-A92F].

[16] *Id.*

components known as organelles.[17] Organelles are specialized structures within a cell that perform essential functions.[18] The nucleus is an organelle that contains the cell's genetic material in the form of DNA.[19] When a cell is not dividing, its DNA exists as chromatin: loosely organized strands that allow the cell to access genetic instructions necessary for its specialized functions.[20] During mitosis, the process of cell division, this chromatin condenses into tightly coiled chromosomes so the DNA can be accurately distributed to daughter cells.[21]

DNA is particularly susceptible to radiation damage during mitosis, when it is actively replicating and has limited time for repair before cell division is completed. When gamma rays ionize the atoms that comprise DNA, the damage may be direct or indirect.[22] Direct effects occur when radiation breaks chemical bonds within the DNA molecule itself.[23] Indirect effects occur when ionized atoms or molecules, often produced from surrounding water molecules, react with DNA and alter its structure.[24] In either case, if the damage is properly repaired before the cell divides, no lasting harm occurs.[25] If the damage is too extensive, the cell may die before replication.[26] However, if the DNA is incorrectly repaired or only partially repaired, the cell may still divide and pass the altered genetic material to its daughter cells, potentially resulting in abnormal cellular function.[27] Because different types of cells divide at different rates, their sensitivity to radiation varies accordingly.

C. WHY IRRADIATED INSECTS ARE NOT RADIOACTIVE

Whenever a gamma ray interacts with a cell, it may ionize atoms within that cell and initiate one of the damage mechanisms described above. After the interaction, the gamma ray may continue to produce

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[17] Yukiko M Yamashita, *Subcellular Specialization and Organelle Behavior in Germ Cells*, 208 GENETICS 19, 20 (2018), https://doi.org/10.1534/genetics.117.300184.

[18] *Id.*

[19] *See* LAMARSH & BARATTA, *supra* note 5, at 478.

[20] *Id.* at 476.

[21] *Id.* at 478.

[22] *Id.* at 480.

[23] *Id.* at 480.

[24] *Id.*

[25] *Backgrounder on Biological Effects of Radiation*, U.S. NUCLEAR REGUL. (June 19, 2024), https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/bio-effects-radiation [https://perma.cc/W8H3-JWNF].

[26] *Id.*

[27] *Id.*

additional ionization events in other cells. Importantly, however, irradiated cells do not become radioactive, nor do they emit radiation themselves. Ionization alters molecular structures, particularly DNA, and triggers chemical reactions within the cell. Therefore, the subsequent damage mechanisms from gamma rays are chemical rather than radiological in nature. Accordingly, whether the irradiated cells belong to an insect or a human, exposure to gamma radiation does not make the organism radioactive.

D. BIOLOGICAL BASIS OF POPULATION SUPPRESSION

The SIT relies on carefully controlled doses of gamma radiation to ionize DNA within the germ cells of male insects. The radiation dose must be sufficient to cause irreparable DNA damage, particularly double-strand breaks,[28] while remaining low enough to preserve the sperm motility and ability to fertilize eggs.[29] This balance allows the treated males to survive, compete, and successfully mate. When a female mates with an irradiated male, the damaged sperm fertilizes her eggs, but the genetic damage prevents normal embryonic development. As a result, the female that mates with the altered male produces no viable offspring.

II. FROM LABORATORY TO FIELD: SIT IMPLEMENTATION

A. MASS REARING AND SEX SEPARATION

A principal step in the SIT is producing a sufficient number of male insects for release so that the program achieves its intended environmental impact. Because the target pest species is mass-reared, there is a risk that accidental escape could worsen the very problem the program seeks to address. For this reason, rearing typically occurs in secure, controlled facilities, often located near

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[28] *See* J. Ross Chapman, Martin R.G. Taylor & Simon J. Boulton, *Playing the End Game: DNA Double-Strand Break Repair Pathway Choice*, 47 MOL. CELL 497 (2012), https://doi.org/10.1016/j.molcel.2012.07.029 (explaining that DNA double-strand breaks (DSBs) are severe forms of DNA damage where both strands of the DNA duplex are broken); Wendy J. Cannan & David S. Pederson, *Mechanisms and Consequences of Double-Strand DNA Break Formation in Chromatin*, 231 J. CELL. PHYSIOL. 3 (2016), https://doi.org/10.1002/jcp.25048.

[29] *Radioactive Sources: Applications and Alternative Technologies*, NAT'L ACADS. OF SCIS., ENG'G & MED. (June 14, 2021), https://www.ncbi.nlm.nih.gov/books/NBK573888 [https://perma.cc/5QZZ-AAM6].

the affected area.[30] Accurate sex separation is a critical component of SIT. In species such as mosquitoes, females bite and may transmit disease, so the unintended release of females could exacerbate existing public health or ecological concerns. In many programs, separation is performed manually during the pupal or adult stages based on observable differences between males and females.[31] Although automated systems exist, they may be insufficiently reliable for large-scale operational use due to the computer-based optical recognition system's slow speed and susceptibility to error.[32] Once separated, the male insects are sent to be irradiated prior to release.

B. IRRADIATION AND DOSIMETRY

Irradiation typically occurs at the pupal or late larval stage, when insects are sufficiently developed but not yet emerged as adults.[33] The separated male insects are placed in a gamma irradiator to receive a precisely controlled dose of ionizing radiation. A commonly used device is the Gammacell 220,[34] which utilizes cobalt-60 (Co-60), a radioactive isotope[35] that emits gamma rays of known and consistent energy.[36] Other gamma-emitting sources, such as cesium-137 (Cs-137), may also be used.[37] Radiation dose is determined by the source strength, the distance from the source, and

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[30] V.A. DYCK, J. HENDRICHS & A.S. ROBINSON, STERILE INSECT TECHNIQUE: PRINCIPLES AND PRACTICE IN AREA-WIDE INTEGRATED PEST MANAGEMENT 289 (V.A. Dyck, J. Hendrichs & A.S. Robinson eds., 2d ed. 2021).

[31] *Id.* at 220.

[32] *Id.*

[33] *Id.* at 246.

[34] *Specifications Gammacell 220 Irradiation Unit*, U.S. NUCLEAR REGUL. (Apr. 1, 1974), https://www.nrc.gov/docs/ml0216/ml021630456.pdf [https://perma.cc/M8S8-J9FF].

[35] *What Are Isotopes*, INT'L ATOMIC ENERGY AGENCY (Aug. 19, 2022), https://www.iaea.org/newscenter/news/what-are-isotopes [https://perma.cc/Q96X-AJHT] (explaining that isotopes are atoms of the same element with the same number of protons but different numbers of neutrons).

[36] *Developing Alternatives to Gamma Irradiation for the Sterile Insect Technique*, INT'L ATOMIC ENERGY AGENCY, https://www.iaea.org/sites/default/files/gc/gc56inf-3-att1_en.pdf [https://perma.cc/F75Q-7RU5].

[37] *Id.*

the duration of exposure.[38] In insect irradiation, the source strength and geometry (including distance) are fixed and well characterized.[39] As a result, the primary variable requiring control is the exposure time.[40] By carefully regulating irradiation time, operators can reliably and consistently deliver the intended radiation dose. The selected dose must be high enough to induce sterility while low enough to preserve the insects' fitness, ensuring that they can survive transportation and successfully compete for mates after release.

C. TRANSPORT AND RELEASE

When transporting and releasing sterilized insects, timing is critical. There are practical limits on how far sterile insects can be shipped, as essential traits, such as flight ability and ability to compete with wild males, decline with extended transit times.[41] Because sterile males must compete successfully with wild males, maintaining insect survival, flight ability, and mating competitiveness during transport is essential to program effectiveness. Once the insects reach the release site, they are typically deployed using static, ground, or aerial methods depending on the scale and geography of the target area.

Static release involves placing containers of sterilized insects, typically in the pupal stage, throughout the target area.[42] As environmental conditions such as temperature and daylight regulate development, the insects emerge naturally from the containers.[43] This method is generally limited to smaller, accessible areas. Ground release involves distributing insects from slow-moving trucks or all-terrain vehicles, often along areas of dense vegetation, with insects released either mechanically or by hand.[44] Aerial release entails dispersing insects from aircraft over large areas.[45] In this method, insects are usually released as chilled adults to facilitate handling and uniform distribution.[46] Aerial release is particularly effective for expansive or inaccessible terrain, and unmanned aerial

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[38] *Ionizing Radiation Equations*, U.S. DEP'T OF LABOR, https://www.osha.gov/ionizing-radiation/introduction/ionizing-radiation-equations [https://perma.cc/H96L-R4TL].

[39] DYCK ET AL., *supra* note 30, at 360.

[40] *Id.*

[41] *Id.* at 302.

[42] *Id.* at 314.

[43] *Id.*

[44] *Id.* at 315.

[45] *Id.*

[46] *Id.* at 316.

vehicles (drones) are increasingly used in place of traditional rotary- or fixed-wing aircraft.[47]

III. ECOLOGICAL AND ENVIRONMENTAL IMPLICATIONS

A. INTENDED ECOLOGICAL EFFECTS

The primary ecological goal of the SIT is species-specific population suppression. By targeting only the pest species, SIT avoids broad mortality typical of chemical insecticides. This selectivity can preserve beneficial insects, pollinators, and natural predators. In agricultural systems, reduced pesticide reliance may improve soil health, water quality, and biodiversity.[48] In certain public health contexts, suppressing disease spreading insects can decrease transmission without introducing toxic chemicals into the ecosystem.

B. POTENTIAL RISKS

Despite the species-specific targeting of the SIT, it is not risk free. Ecological systems are complex, and suppressing a single species may disrupt existing food webs. Predators reliant on the targeted insect may have diminished food sources available, potentially altering local ecological dynamics. In some cases, ecological niches vacated by the suppressed species may be filled by other insects, which could alleviate predator-prey imbalances but create new pest problems.

Operational risks also exist. Incomplete sterility or unintended escape of fertile, mass-reared specimens may undermine the effectiveness of the program. Furthermore, inefficiency in any part of the implementation process, from rearing and sex separation to irradiation and release, may reduce the overall performance of the program, increasing cost to taxpayers and diminishing environmental benefits. Finally, in cases where sterilization efforts result in complete eradication of a species, additional ecological and ethical concerns arise, particularly where the species' ecological role is not fully understood.

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[47] *Id.* at 467.

[48] Wei Zhou, Mengmeng Li & Varenyam Achal, *A Comprehensive Review on Environmental and Human Health Impacts of Chemical Pesticide Usage*, 11 EMERGING CONTAMINANTS 1, 3 (2025), https://doi.org/10.1016/j.emcon.2024.100410.

C. COMPARISON TO ALTERNATIVES

For all its potential risks, the SIT offers significant advantages over alternative pest control methods. Unlike chemical insecticides, which directly kill insects and may harm non-target species, contaminate soil and water, and promote insecticide resistance,[49] the SIT leaves no toxic residues and minimizes ecological disruption. SIT also does not compromise the human food supply. Compared to biological control using predators or parasitoids,[50] SIT avoids introducing new species into the ecosystem, reducing the risk of unintended ecological consequences. SIT provides flexible strategies for managing target species, including suppression, eradication, containment, and prevention, options that are difficult to achieve with other methods. Overall, SIT offers an environmentally cautious alternative within integrated pest management strategies. It has been used successfully in the U.S. for nearly sixty years and is currently implemented on six continents.[51]

IV. LEGAL AND GOVERNANCE FRAMEWORKS

A. FRAGMENTATION OF REGULATORY OVERSIGHTS

The SIT occupies a unique regulatory space in the United States, reflecting its hybrid nature as both a biological and radiological intervention. The irradiation sources used to sterilize insects are regulated by the Nuclear Regulatory Commission (NRC), which ensures the safe handling of gamma-emitting isotopes, including cobalt-60.[52] When SIT is applied for agricultural pest control, coordination with the U.S. Department of Agriculture (USDA) is additionally required, as it oversees crop protection and integrated

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[49] *Insecticide Resistance: Causes and Action*, U.S. DEP'T OF AGRIC., https://www.nifa.usda.gov/sites/default/files/resources/Insecticide%20resistance.pdf [https://perma.cc/75A7-YGUT] (defining insecticide resistance as reduced sensitivity of an insect population to an insecticide, evidenced by repeated failure to achieve expected control despite proper application and normal environmental conditions).

[50] CHARLES GODFRAY, PARASITOIDS: BEHAVIORAL AND EVOLUTIONARY ECOLOGY 6 (John R. Krebs & Tim Clutton-Brock eds., 1st ed. 1994) (defining parasitoids as a group of insects whose larvae develop on or in the bodies off other insects, which they eventually kill).

[51] *Sterile Insect Technique*, INT'L ATOMIC ENERGY AGENCY, https://www.iaea.org/topics/sterile-insect-technique [https://perma.cc/9C5L-CB67].

[52] Atomic Energy Act of 1954, 42 U.S.C. §§ 2011, 2014, 2201; 10 C.F.R. § 20.1301 (2002).

pest management programs.[53] For disease vector control, the Environmental Protection Agency (EPA) may provide guidance, when releases affect public health.[54] In rare cases involving treated insects or insect products associated with food crops, the Food and Drug Administration (FDA) may also have jurisdiction.[55] As a result, the SIT is simultaneously treated as a biological control method, a radiation-based activity, and, in some contexts, a pesticide alternative. This overlapping jurisdiction creates fragmented oversight across multiple agencies, which can complicate permitting, reporting, and program coordination. Effective implementation therefore requires careful navigation of interagency regulations, bureaucracy, and cooperation.

B. PUBLIC PERCEPTION AND RADIATION STIGMA

Public perception plays a significant role in shaping the future deployment of the SIT. Radiation is often associated with major nuclear accidents, such as Chernobyl, Fukushima, and Three-mile Island,[56] or nuclear weapons, leading to stigma and misunderstanding. These associations differ markedly from the controlled, low-dose irradiation used to sterilize insects. The disconnect between perceived and actual risk presents a major risk communication challenge. Bridging this gap requires that the scientific principles underlying SIT, and other safe applications of nuclear technology, must be explained in clear, accessible language. Failure to address these concerns may erode public trust and delay implementation. Thus, SIT is not only a biological and technical intervention but also a sociotechnical one, where success depends as much on transparent communication and community engagement as on scientific principal.

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[53] Animal Health Protection Act, 7 U.S.C. §§ 8301–8317 (authorizing USDA to prevent, detect, control, and eradicate livestock diseases and pests); Plant Protection Act, 7 U.S.C. §§ 7701–7772, 7781–7786, (regulating the importation, exportation, and interstate movement of plants, plant products, certain biological control organisms, plant pests, and noxious weeds).

[54] Federal Insecticide, Fungicide, and Rodenticide Act, 7 U.S.C. § 136.

[55] Federal Food, Drug, and Cosmetic Act, 21 U.S.C. §§ 201(g)(1)(C), 201(v), 321(g)(1)(C), 321(v).

[56] *Safety of Nuclear Power Reactors*, WORLD NUCLEAR ASSOC. (Feb. 11, 2025), https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/safety-of-nuclear-power-reactors [https://perma.cc/3ZCD-QE8P].

CONCLUSION

The sterile insect technique began as an audacious response to a devastating pest but has since grown into a striking example of how nuclear science can be harnessed for innovation rather than destruction. By sterilizing rather than exterminating, SIT transforms radiation from a symbol of catastrophe into a tool of targeted utility. Its success in controlling the New World screwworm and other pests demonstrates the effectiveness of focused biological intervention compared with broad chemical methods. Yet SIT's future depends on more than physics alone. Its deployment requires clear regulatory frameworks, institutional coordination, and public confidence in the safe use of radiation. As global agriculture faces challenges associated with invasive species, pesticide resistance, and vector-borne disease, SIT offers a model of sustainable innovation, one that integrates scientific rigor with governance and communication. Its continued success will hinge not only on technical refinement but on aligning scientific capability with societal trust.