FIELD STUDIES OF EXTERIOR-ONLY APPLICATIONS WITH FIPRONIL (TERMIDOR® SC) FOR THE POST-CONSTRUCTION CONTROL OF INTERIOR POPULATIONS OF SUBTERRANEAN TERMITES (ISOPTERA: RHINOTERMITIDAE)

A Thesis

by

TROY DAVID WAITE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2003

Major Subject: Entomology

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Approved as to style and content by:

Roger E. Gold (Chair of Committee)	Edward D. Harris (Member)
Jimmy K. Olson (Member)	Kevin Heinz (Head of Department)

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ABSTRACT

Field Studies of Exterior-only Applications with Fipronil (Temidor® SC) for the Post-construction Control of Interior Populations of Subterranean Termites (Isoptera: Rhinotermitidae). (December 2003)

Troy David Waite, B.S., Brigham Young University

Chair of Advisory Committee: Dr. Roger Gold

Thirty-two privately owned structures were treated with a 0.06% exterior and interior, 0.06% exterior-only, or 0.125% exterior-only application of fipronil (Termidor SC®) in order to compare their efficacies in the post-construction control of interior populations of *Reticulitermes spp.* (Holmgren). The concentration of fipronil in the soils from the structures was measured pre-treatment and at 1 week, 3, 6, 9, 12, and 18 months post-treatment. Bioassays conducted with fipronil-treated soils from five locations in Texas determined the minimum effective concentration (minimum concentration necessary to stop termites from breeching a 50 mm column of treated soil) was < 1.0 ppm. Lethal concentration (LC_{50}) values ranged from 0.19 to 0.60 ppm for *Reticulitermes flavipes* (Kollar).

All structures receiving a 0.06% fipronil exterior and interior or 0.125% exterior-only application showed full control of interior termite populations within 6 months. In contrast, 36% of the structures that received a 0.06% fipronil exterior-only application still had termites 6 months post-treatment. When taking the point of termite entry into account, it was shown that only structures treated with fipronil at the

point of entry into the structure by termites showed full control within 6 months. This indicated that the placement of the termiticide at the point of subterranean termite entry, and not the rate at which it was applied, was the most important factor that predicted whether a post-construction application of fipronil provided full control of an interior infestation. Results also indicated that Termidor SC® was effective when used according to the current product label, which calls for a thorough application including exterior and interior applications for post-construction termite control.

Soil monitoring data for fipronil indicated that the technical material provided by the manufacturer of Termidor SC® was labeled appropriately in terms of concentration. Tank mix samples, while variable, were between 83 - 96% of the labeled concentrations. Post-treatment soil samples and bioassays with treated soil showed that fipronil concentrations were adequate to effectively control termites through the first 18 months.

DEDICATION

To Ixchelle and the rest of the gang— Brooke, Brielle, and Ammon

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I would like to take a moment to acknowledge in writing those who have been of assistance during this stressful, yet worthwhile, experience we call working towards a Master of Science degree. First of all, I would like to generously thank Dr. Roger E. Gold, my graduate committee chairman. Dr. Gold has allowed me great freedom in taking courses and participating in activities that were in my future's best interest even when it has meant dedicating less of my time to his research interests. He has supported me as I have faced both issues with my health and with my family. He has allowed me to discover for myself how to succeed as a graduate student, yet has always given me sound advice, promptly, when necessary. Financially, I owe a great debt to Dr. Gold for his assistance.

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The staff and all of my fellow students at the Center for Urban and Structural Entomology at Texas A&M University were invaluable in their contributions. Dr. Harry Howell and Dr. Mark Wright were both key to my understanding the intricacies of this project. Dr. Wright and his staff helped prepare and analyze the majority of the field samples on the gas chromatograph. Shannon Gallion deserves special notice for her long hours in the handling of my soil samples. Bryce Bushman performed the soil bioassays for this project. In addition, Laura Nelson, Grady Glenn, Bart Foster, and Mark Fisher all deserve recognition.

I need to thank Brian Springer of Bevis Pest Control and all of his staff for their help in treating the experimental structures, managing the accounts, and spending "off the clock" time to help me become more proficient at inspecting structures and determining where and when termites will infest them. I apologize again for any extra expenses caused to the company as a result of my lack of experience.

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Finally, and most importantly, I express love for my wife, Ixchelle, who has put up with me and my consuming focus on school. She has been a wonderful companion and mother.

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INTRODUCTION

When building repair costs are included, the economic impacts of termites may reach up to $11 billion annually in the United States (Su 2002). Of the 45 termite species found in the U. S., 30 have been mentioned as pests, five of which are considered serious threats to wooden structures and wood products (Su and Scheffrahn 1990a). These 30 termite species have been further divided into three categories based on their biology—dampwood, drywood (powderpost), and subterranean termites. The first two groups inhabit wood with differing moisture contents as suggested by their names; however, they are similar in that they form relatively small colonies and live in wood. In contrast, subterranean termites live in soil, forage on wood, and have much larger colonies.

In the U. S., three genera of subterranean termites have been found including: *Heterotermes* Froggatt , *Coptotermes* Wasmann, and *Reticulitermes* Holmgren. These genera include nine pest species. *Heterotermes* is represented by one species, *H. aureus* (Snyder), which is an extremely destructive structural pest, but is considered less important because of its limited distribution to the desert southwest. Control of the genus *Heterotermes* has been similar to that of *Reticulitermes*.

The genus *Coptotermes* is represented in the U. S. by two species. The most prominent of these two species, *C . formosanus* Shiraki, or the Formosan termite, is

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This thesis follows the style and format of the Journal of Economic Entomology known to have exceptional numbers of individuals per colony and large foraging territories. They tend to form "aerial infestations" with carton nests (a structural infestation with no connection to the ground). Formosan termites have caused unique problems for control as compared to other subterranean termite species (Su and Scheffrahn 1990a). *Coptotermes* has a comparatively limited distribution probably based on high temperatures and humidity. They have been reported from Hawaii, California, and in most southern states from Texas east to Florida. This genus is not native to the U. S., but was imported from the Orient.

The genus *Reticulitermes* contains six species ranging throughout most temperate and humid areas of the U. S. *R. hesperus* Banks & Snyder is the major termite pest in the western U. S. The three species most prevalent in Texas have been the eastern subterranean termite, *R. flavipes* (Kollar), the dark southeastern subterranean termite, *R. virginicus Banks*, and the light southeastern subterranean termite, *R. hageni* Banks. *R. flavipes* has been considered the most economically important termite in the U. S. because it is so widespread (Suiter et al. 2002).

In nature, subterranean termites have been beneficial, breaking down cellulose from dead trees and other wood materials that would otherwise accumulate, recycling the nutrients as humus, and contributing to soil genesis, fertility, stability, and hydrology (Gold et al. 1999, Wagner 2003). However, as urbanization has expanded, termite populations have used sources of wood in human structures, where they cause destruction. The cryptic, soil-dwelling nature of these termites has been such that they are rarely discovered until there is evidence of a reproductive swarm or damage to the structure (Thorne 1999). These insects have the rare ability to metabolize cellulose due to symbionts in their hindguts which express the enzyme cellulase (Moore 1969).

Generally, termites consume the softer spring wood, leaving intact the harder, less digestible (summer) wood along the grain which contains lignin. This gives the wood a layered or channeled appearance, and the thin, outer shell of the wood is typically left intact (Potter 1997). In addition, non-cellulose materials can be damaged as the termites search for food and water. Finally, subterranean termites construct shelter tubes that originate in the soil and are used to protect the termites as they invade structures. These tubes consist of tiny particles of soil, wood, or debris cemented together with salivary secretions and fecal material. The result of structural subterranean termite infestation is a significant reduction in the integrity of wood and the presence of unsightly damage.

Providing consistent control of subterranean termite populations has been a complex, active process requiring knowledge on a variety of topics including; termite biology, the different control tactics available, the assortment of tools required to deliver appropriate treatment options, the landscaping and hydrology surrounding a structure, and building construction (Forschler 1999). The three most important factors allowing subterranean termites to successfully infest a structure consist of locating adequate food sources, securing necessary moisture levels, and encountering suitable soil temperatures in which to forage (Suiter et al. 2002). Control methods for subterranean termite populations have been aimed at disrupting the ability of termites to obtain any one, or a combination of these three elements. Early last century, recommendations for subterranean termite control relied heavily on building construction practices and include: avoiding wood-to-ground contacts; using building materials which are undesirable for termite consumption; managing moisture around the structure; and reducing termite food resources near buildings (Snyder 1927, Brown et al. 1946, USDA 1946). However, for the last 50 years, soil barrier treatments with termiticides have been the standard method of termite control since buildings are rarely constructed with prevention of subterranean termite infestation as a priority (Forschler 1999).

Beginning in 1952, the first termiticides used as barrier treatments were the organochlorine cyclodienes, including chlordane and heptachlor. Chlordane was the most used of the two in the control of termites populations. These insecticides bind gamma amino butyric acid (GABA)-gated chloride channels, blocking the inhibitory currents normally produced by an influx of chloride ions into a neuron as a result of the binding of GABA. This action is manifested physiologically in the insect as hyperactivity, tremors, and seizures (Smith 1991). These insecticides were effective, long-lasting, and economical (Ware 1989). They dominated the market until 1987, when they were no longer registered for use in the U. S. because they posed a possible threat to human health and the environment due to their long residual life, bioaccumulation in food chains, production of detectable air residues in treated areas, and suspected carcinogenic effects in humans. Estimates of longevity have shown that they are present in treated soils for more than 35 years in the continental U. S. (Kard et al. 1989) and between 25 – 30 years in Hawaii (Grace et al. 1993).

Organophosphates and pyrethroid insecticides constituted the next groups of chemicals used as subterranean termite barrier treatments. Organophosphates bind insect acetylcholinesterase, inhibiting the breakdown of acetylcholine in cholinergic synapses. As a result, there is an excess of acetylcholine available to bind the acetylcholine receptor in the synapse. This leads to a continual excitation of, and influx of sodium into, the post-synaptic neuron. Restlessness, hyperexcitability, tremors, convulsions, and paralysis have been common characteristics of organophosphate poisoning in insects (Ware 1989). Although the specific binding site is not known, pyrethroids act at the voltage-gated sodium channels by prolonging their opening in the pre-synaptic neuron. This results in the insect have been hyper-excitability, spontaneous bursts of activity, convulsions, whole body tremors, ataxia, tetany, and paralysis (Ware 1989).

Organophosphate and pyrethroid soil barriers have generally been far more toxic and repellent to termites than was chlordane (Su and Scheffrahn 1990b, Smith and Rust 1990). Today, organophosphates are considered potentially damaging to the environment and to human health. As such, they are being phased out of use for termite control. As of 2002, one organophosphate (chlorpyrifos) and four pyrethroids (permethrin, cypermethrin, bifenthrin and fevalerate) were registered as soil termiticides. Organophosphates and pyrethroids have a shorter residual life in soils than do the organochlorine cyclodienes, lasting for approximately five years in the soil at levels which can kill or repel termites (Gold et al. 1996).

In the past decade, three new chemical classes of insecticides have been registered for use as termiticides. These are considered to be non-repellent, and with a delayed mode of action (Potter 1999b, Osbrink et al. 2001, Kard 2001, Potter and Hillery 2003). The first of these classes, the chloronicotinyls (imidicloprid), was initially used in 1996. These bind the acetylcholine receptor directly as an agonist and cause similar effects in insects as the organophosphates.

Next came the registration of the phenyl pyrazoles in 1999. Fipronil (5-amino-[2,6-dichloro-4-(trifluoromethyl)phenyl]-4-[(1R,S)-(trifluoro=methyl)sulfinyl]-1H-pyrazole-3-carbonitrile) is an example of this chemical class, and is the compound investigated in this study (Fig. 1). The trifluoromethyl sulfinyl moiety is presumably responsible for this agent's outstanding performance against termites (Hainzl and Casida 1996). The pesticidal effects of fipronil were first investigated by Rhone-Poulenc in France in the late 1970s. The product has now been registered in a termiticide formulation as Termidor® by BASF Corporation (Mount Olive, NJ). It has also been registered for the protection of corn, rice, and cotton against orthopteran, lepidopteran, homopteran, and coleopteran pests. Fipronil acts at the same target site as the organochlorine cyclodienes, with similar effects on insects (Cole et al. 1993). As a non-competitive antagonist of the GABA receptor, it leads to the eventual blockage of the chloride channels, which normally allow chloride to enter a nerve cell and to act as part of the nerve's inhibitory system (Narahashi 2001). Fipronil has been shown to have much greater affinity for insect GABA receptors as compared to those in mammals (Hainzl et al. 1998).

Finally, and most recently, the pyrolles (chlorfenapyr), have been labeled for use as

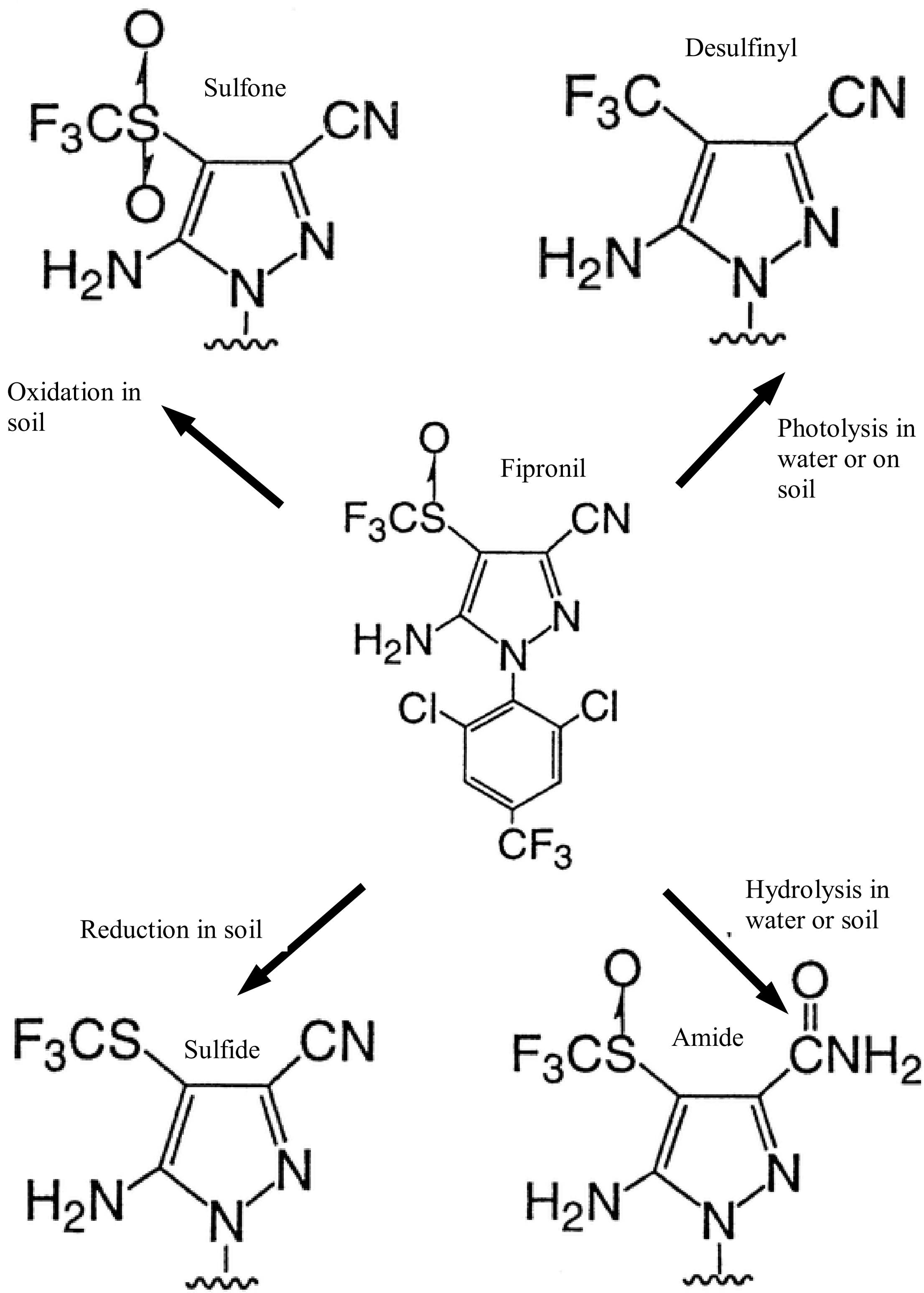

Fig. 1. Degradation pathways of fipronil in soils. (Adapted from Bobe et al. 1998).

termiticides. These are lipophilic weak acids that act as proton shuttles across the mitochondrial inner membrane. They systematically dissipate the proton gradient necessary to produce ATP for energy. The residual life of these chemicals in termiticide barrier treatments has been explored very little to this point, but there is concern that they may not persist long enough in soils to effectively protect structures. Harris (1972) reviewed factors influencing the activity and persistence of soil insecticides. These are summarized in Table 1.

Table 1. Factors influencing the activity of soil insecticides (Harris 1972).

Factors	Example influences
Physicochemical properties of the insecticide	Adsorption of compound to soil particles and organic matter; Solubility of compound in water; Volatilization of compound in soil; Resistance to breakdown of various chemical substituents; Persistence and toxicity of product and degradation products.
Soil type and climate	Organic content/ mineral composition ratios; Moisture; Temperature of soil.
Insect susceptibility and behavior	Tolerance differences among species, stages, and castes; Mode of application and formulation in relation to behavior.

With regards to fipronil, it has been shown that soil temperature, the amount of organic matter, and the soil to water ratio can affect the adsorption of fipronil on soils (Bobe et al. 1997). Generally, the compound binds very tightly to organic matter and other soil particles as reported by the United States Environmental Protection Agency (US EPA) (1995) and Ying and Kookana (2001). Aquatic studies have shown that it is very insoluble in water, and will move rapidly to sediment layers, where it clings and degrades (US EPA 1996). These observations indicate that the loss of fipronil activity in barrier treatments over time is not likely caused by its movement out of the soil by leaching. The volatility of fipronil in soils has never been investigated. Comparative tolerances to fipronil between species of termites, between colonies of the same termite species, and among worker and soldier castes within the same colony of subterranean termites have been explored (Osbrink et al. 2001); however, these were not factors associated with a significant decrease in the toxicity of fipronil over time.

The exploration of the chemical fate of fipronil, and its major metabolites in the environment, together with their toxicity, has proven to be interesting. The only published estimate of the degradation rate of fipronil in soils over time is an anaerobic sediment half-life of 120—130 days, but the values of the derivatives have not been reported (US EPA 1996). A half-life of 36 hours (Bobe et al. 1998) and 44.5—533 hours (Ngim and Crosby 2001) were reported when fipronil was applied to the top of soil. Fipronil is known to degrade in the soil via reduction (to sulfide), oxidation (to sulfone) and hydrolysis (to amide) (Bobe et al. 1998). It can also be converted on the surface of soil in water to a desulfinyl derivative (Fig. 1). Of these four pathways, the sulfide (US EPA 1996), sulfone (Hainzl et al. 1998, Hainzl and Casida 1996), and desulfinyl (Hainzl and Casida 1996) were all toxicologically active against insects. Inside the insect, the major metabolite is the sulfone (Scharf and Siegfried 1999).

There are two times when termiticides are customarily applied to structures: i.e., pre-construction and post-construction. Pre-construction treatments have been the most effective and economical time to apply a barrier treatment (Potter 1997). This is done when soil is treated according to building codes or label specifications after the final grade had been established for the building site, but before the concrete slab is poured. These applications theoretically leave a continual chemical barrier under the foundation and protected against termite entry.

Post-construction treatment has often been necessary because structures have not always been treated for subterranean termites before construction, and because newer termiticides generally have degraded within five years. Establishing a continuous chemical barrier after a structure is built has been difficult, laborious, and expensive. It may have been complicated by the following factors: 1) poor soil absorption; 2) inaccessible areas; 3) hidden construction faults; 4) general inability to see where the chemical is flowing; 5) necessity of more in-depth knowledge of building construction; and, 6) higher risk of puncturing and contaminating ducts, drains, wells, cisterns, plenums, plumbing, and electrical lines (Potter 1997).

After chlordane was removed from the arsenal of termiticides, many pest control operators reported increases in the number of structures needing retreatment. There was a general belief that organophosphates and pyrethroids may not have been as effective as chlordane as post-construction soil barrier treatments. Already mentioned is the fact that these chemical classes are much more toxic (organophosphates) and repellent (pyrethroids) to termites than was chlordane. These properties make it impossible for termites to forage in the treated soil (as was thought to have happened with chlordane) in a manner that can negatively affect populations of termites around a structure. It has been shown that any gaps of untreated soil are generally associated with treatment failure (Craft 1993, Forschler 1994, Kuriachan and Gold 1998), and that neither chemical group appreciably diminishes termite populations in soil away from treated areas (Su et al. 1993, Forschler 1994).

The preceding two characteristics of organophosphates and pyrethroid barrier treatments have made them less “forgiving” than those involving chlordane (Potter and Hillery 2000). Complete coverage underneath a foundation (without gaps) has been a necessity with these newer termiticides, where as such might not have been as critical with chlordane. To ensure adequate coverage, careful, thorough applications, including drilling and treatment to the interior of a structure to any perceivable area of contact with the soil, have been required with the organophosphates and pyrethroid agents regardless of whether the surface treated is wood or not (Potter and Hillery 2002). This has been easier in theory than in practice because, as already alluded to, the trend in modern building construction has had little to do with reducing the threat of termites, and everything to do with making structures energy efficient, cosmetically appealing, and comfortable for humans. These factors have made it all but impossible to deliver conventional termiticides to every termite entry point (Potter 1999a). This is not to say that these chemicals have not functioned as barriers to termite entry, but the chances have been greater that termites might bypass them and infest a structure even with the best efforts of the pest control operator.

As questions arose about the efficacy of organophosphate and pyrethroid barrier treatments, alternative strategies were sought to control termites. The placement of baits around a structure was more fully investigated as a possible replacement for termiticide barrier treatments. Potter (1999a) discusses the advantages and disadvantages of bait systems now on the market. The following references review the development of baits and other products and methods tested for termite control: Myles (1996), Lewis (1997), Su and Sheffrahn (1998), Forschler (1999), Culliney and Grace (2000), Su (2002), and Kard (2003).

Amidst the discovery and testing of alternative control strategies, came the release of imidicloprid, fipronil, and chlorfenapyr. These are all considered to be non-repellent, and to have a delayed mode of action that ultimately kills large numbers of termites (Potter and Hillery 2000). These termiticides have generated interest as soil barrier treatments as they have achieved a level of performance not seen since the days of chlordane (Potter and Hillery 2003). It is believed that these non-repellent termiticides cannot be detected by foraging termites in a treated area (Thorne and Breisch 2001). It, thus, has been hypothesized that populations of termites could be exposed to and killed by the termiticide instead of termites avoiding treated soil much in the same manner as was the case for chlordane (Kard 2003).

New evidence has suggested that there could be an additional advantage associated with using these new products especially due their delayed mode of action. It has been suggested that the toxicant is transferred to nest mates in the field. This is known as the “transfer effect”. When the second termite picks up a lethal dose of chemical in this manner, it is called “secondary mortality”. Laboratory studies have qualitatively shown secondary mortality caused by fipronil in subterranean termites (*Reticulitermes spp*. and *C. Formosanus*) and in the German cockroach, *Blattella germanica* (L.) (Shelton and Grace 2003, Ibrahim et al. 2003, Buczkowski and Schal 2001, Durier and Rivault 2000, Clement 1998). Little information, however, has been available concerning the magnitude and mechanism of the transfer effect (Shelton and Grace 2003).

In the case of carton-forming termites like *C. formosanus,* Su et al. (1982) have proposed that non-repellent and slow-acting termiticides could be introduced into a portion of the colony and distributed to its entire population through social interaction as a control strategy. One hypothesis is that secondary mortality could occur through the social phenomenon of trophallaxis, which Suarez and Thorne (2000) defined as "the direct transfer of alimentary liquids, including suspended particulates and derivatives, from one nest mate to another via regurgitation or anal feeding." Trophallaxis is a mechanism for the transfer of nutrients, symbionts, pheromones, and information within social insect colonies. In *R. flavipes* and *R. virginicus,* >20% of the alimentary fluid in a donor is transferred to a recipient group and it is distributed in a "trophallactic cascade." The donor termite transferred the fluid to a recipient termite and that recipient termite transferred it to another recipient until all had about the same volume (Suarez and Thorne 2000). Both the amount of alimentary fluid passed on from a foraging termite to nest mates and the method in which it is done have made trophallaxis a feasible method for the transfer of fipronil in termite populations. Other possible mechanisms for horizontal transmission have included cannibalism, necrophagy (consumption of dead termites), corprophagy (consumption of termite feces), and social grooming.

Potter and Hillery (2003) noted that even with the advantages associated with the new chemistries, their biggest limitation has been that they have been invasive to property owners because they have been labeled in most states as post-construction treatments to be applied in the traditional manner through drilling and treatment throughout the interior of an infested structure. In a recent survey, 93 percent of householders expressed concern about the application of termite control chemicals inside their homes (Potter and Bessin 2000). This has been a definite problem when a homeowner has had to choose between the use of liquid termiticide barrier treatments and stand-alone baits that are placed only on the exterior of a structure.

Newer research has suggested that subterranean termite infestations can be eliminated by applying fipronil solely around the exterior perimeter of buildings because the "effects of the termiticide extend inward and well beyond the exterior site of application" (Potter and Hillery 2002, Potter and Hillery 2003). This has been a very attractive idea to a pest control operators because it means they could theoretically treat a house without ever going inside, just like with baits. This could save time, labor, and money. This would be especially important, considering that the new termiticides are considered to be less persistent, so structures treated with them may need to be treated more often.

It has been part of an ongoing research project on the part of the manufacturer to assess the effectiveness of fipronil in exterior-only applications in an attempt to persuade the US EPA to change the labeled use of Termidor® in the post-construction control of subterranean termites. Major funding and planning for this project was provided by Aventis (Bridgewater Crossing, NJ), the prior owners of the chemical.

The objectives of the study described herein were five-fold: First, to determine if the post-construction use of Termidor® controls interior populations of subterranean termites when applied to the interior and exterior of a structure according to the current product label;

Second, to determine if an exterior-only, post-construction application of fipronil is as effective at controlling interior populations of *Reticulitermes spp*. as is an application done simultaneously to the exterior and interior of a structure;

Third, to determine how the application rate of Termidor SC® affects the post-construction control of interior populations of subterranean termites when applied only to the exterior of a structure;

Fourth, to examine the availability of Termidor® in soils over the first 18 months post-treatment when used as barriers for the post-construction control of interior subterranean termite populations;

Fifth, to determine the minimum effective concentration (minimum concentration necessary to stop termites from breeching a 50 mm column of treated soil) and 50% lethal concentration (LC_{50}) values for soils treated with fipronil against *Reticulitermes spp.*

MATERIALS AND METHODS

Experimental Design. Thirty-two privately-owned structures were randomly assigned to one of three treatment groups with fipronil (Termidor® SC). These included 10 structures treated at 0.06% fipronil on the exterior and interior according to the product label, 11 structures treated at 0.06% fipronil only on the exterior, and 11 structures treated at 0.125% fipronil only on the exterior.

Structure Selection. The structures were chosen from Galveston and Harris Counties, Texas, based on the following criteria:

1. Slab on grade construction;
2. Clear evidence of an interior infestation of *Reticulitermes spp*. as seen by standing inside the structures. (This criterion was met after confirming the presence of any one of or a combination of exposed structural damage, exit holes, mud foraging tubes, and/or the actual presence of alate remains after the report of swarming.); and
3. The owner and the resident agreed to reasonable access to both the interior and exterior of the structure for the duration of the study.

Treatment of Structures. All structures were treated with Termidor® SC according to the product label. Structures were treated from days to months after confirmation of an active termite infestation on the interior. Each structure was treated with either a 0.06% or 0.125% fipronil solution around the exterior to form a continuous chemical barrier around the perimeter. This was accomplished by using standard trenching and filling techniques in soil to apply solutions of fipronil at a labeled rate of 15 L/3 m (4 gal/10 lin ft) into a 15 x15 cm trench. As necessary, vertical sub-slab applications by drilling through concrete was done at 30 cm intervals.

Only the control structures were treated interiorly. In these structures, any ground-level bath traps were treated with Termidor® SC; detectable cracks in the foundation or internal joints were drilled 30 cm apart and treated; and plumbing penetrations were also drilled and treated where accessible. Treatment was done by technicians from Bevis Pest Control of Texas City, TX, who were all licensed and certified for termite work in Texas. A flat-blade pick and 10 cm (4 in) shovel were used to dig trenches at each structure. A custom made 378.5 L (100 gal) tank equipped with jet bypass agitation and a gear pump (Model 1207) operated at 172 kPa (25 psi) fitted with a 90 m (300 ft) hose (GNC, Houston, TX) ending in a quad-tip rodder (B&G Equipment Company, Jackson, GA) were used to treat the structures. Treatment diagrams for each structure are included as Appendix 1.

Inspection of Structures. Inspections were done on each structure to qualify them for the study. Where possible, termites from the initial and post-treatment inspections were collected and stored in 5 ml of 95% ethanol. Additional inspections were scheduled for each structure at 3, 6, 9, 12, and 18 months post-treatment to record the presence or absence of live termites, check the monitoring stations, and take soil samples as needed. On seven of the structures, these visits were done for only 12 months. In all cases, structures were monitored for at least one year post-treatment to ensure that termite populations had the opportunity to go through one swarming season before inspections ceased. This approach aided in the confirmation of the effects of the treatments. The large number of structures and owners with which this project dealt, along with the required frequent inspections, led to the unavailability of some structures to be inspected at all scheduled periods.

In cases where swarming termites were found on the interior of structures by the resident, the date and location of the infestation was determined via interview. This information was considered valid when the swarmers or live termites were found between regularly scheduled inspection periods. In these instances, Bevis Pest Control was notified by the owner of the structure and its technicians were authorized to inspect the structure and treat it according to the product label at the entry point of the termites.

The 6 month post-treatment inspection of each structure was critical to the study as it was the time at which it was determined if the treatments had been effective. When interior subterranean termite populations were fully controlled within 6 months, no further treatment to the structure was performed. However, structures with the presence of any live worker or soldier termites at the 6 month inspection, or of alates reported to Bevis Pest Control between the 6 month and 9 month scheduled inspections, were considered as ongoing interior infestations. At this point, as already mentioned, the structures were treated at the termite entry points and inspections continued on the regular schedule until full control of the internal termite population was evident.

Chemical Analysis of Technical Material, Tank Mix, and Soil Samples. At the time of treatment of each structure, a 100 ml sample of the Termidor® SC technical material was taken directly from the original container. After mixing, a 100 ml tank sample was also taken from the applicators' equipment in order to determine the actual concentrations of the termiticide being applied to each structure. In both cases, samples were placed into 500 ml polypropylene screw cap containers and transported to the Center for Urban and Structural Entomology, College Station, TX, for analysis.

Soil samples were taken with a 2.5 cm diameter x 15 cm long soil probe. Pre-treatment samples were taken in order to assure that no fipronil was in the soil of the structures prior to the initiation of the study. Sampling was also done at 1 week and at 3, 6, 9, 12, and 18 months post-treatment to determine the concentration of fipronil in the soil. Five structures (numbers 33-37; Appendix 1), in addition to the 32 already included in the perimeter study, were originally treated; however, these five were later found not to have met the criteria established above. In these cases, the structures were still used for soil sampling. One sample was taken from each side of a structure with accessible soil. The resulting soil cores were placed in plastic bags and transferred to the Center for Urban and Structural Entomology, Texas A&M University, College Station, Texas, where they were held at -5º C until analysis on the gas chromatograph. Technical and tank mix samples were frozen.

Analysis of all samples was done with an Agilent 6890N Network Gas Chromatograph (GC) equipped with Agilent 7683 auto-injector (Agilent Technologies, Palo Alto, CA) and an electron capture detector. Technical samples were diluted in acetone at 1:1000, and tank mix samples were diluted at 1:10. One ml of these dilutions was then transferred with a disposable pipette to an injection vial suitable for use on a GC, where 1 ul samples were analyzed.

Preparation of the soil for analysis on the gas chromatograph initiated with the equilibration of the soil to laboratory temperature and relative humidity in weighing dishes. Soil samples were then placed into small, durable bags where they were homogenized by striking clumps of soil with a hammer and stirring the sample. Next, three 5 ± 0.0010 g samples of each sample were extracted into a 22 ml polypropylene screw cap containers. At that point, 15 ml of acetone was added to each container and they were subjected to agitation for no less than 30 minutes in order to solubilize the fipronil out of the soil matrix. One ml of these solutions was then transferred to injection vials, where 1 ul of these solutions was analyzed.

A quartz XTI®-5 capillary column coated interiorly with 5% diphenyl/95% dimethyl polysiloxane (Restek, Bellefonte, PA) was used in the gas chromatograph. The carrier gas was UHP Helium, flowing at a rate of 7 ml/minute, and the makeup gas was P5 (95% Argon: 5% Methane) with a flow rate of 23 ml/minute. This method of measuring concentrations of pesticides has shown 98 ± 0.5% recovery of all pesticides extracted from sandy loam soils. Fipronil analyzed from solution (such as tank mix samples) have shown a recovery coefficient of >98%. The gas chromatograph was calibrated frequently by running pre-measured samples of 0.1, 0.5, 1, 5, 10, 15, 20, 50, 100, 133, and 166 ng fipronil to create a standard curve. A significant part of the preparation of samples and subsequent analysis on the gas chromatograph wascompleted by Dr. Mark Wright and student workers at the Center for Urban and Structural Entomology at Texas A&M University.

Termite Monitoring Stations. As this project was being developed, representatives of Adventis requested that monitoring stations be installed around the perimeter of the structures. As a result, Termatrol® termite monitors (Termatrol™, Kailua, HI) were installed in the soil at 3 m intervals around the perimeter of the treated structures, just outside of treated areas where there was soil. These monitors were opened and inspected on every scheduled visit to determine if there was the presence of termite activity or not.

Termite Bioassays. Soil bioassays (Fig. 2) used were similar to those described by Su et al. (1993) and Gold et al. (1994, 1996). Soil was used from five locations in Texas including; College Station, Corpus Christi, Dallas, Overton, and Lubbock. A 9.9% fipronil solution was supplied by Rhone-Poulenc. Soils to be used in the bioassay were prepared by mixing fipronil into the soil at 0.10, 0.30, 0.70, 1, 2, 3, 5, and 7 ppm. Controls were made by mixing distilled water into the soil. All solutions were added to the soil at 10 ml/100 g. Four replications were done for each of the five soils at each of the concentrations.

After preparation, soils were put into bioassay tubes (Fig. 2). A 2 cm agar plug was placed at 3 cm from one end of a 1.6 cm O.D. x 15 cm glass tube, and was designated the top. Soils were carefully placed in the bottom of the tube and lightly packed to remove air pockets within the soil. After 5 cm of soil was packed into the tube, a second 2 cm agar plug was inserted and pushed into the bottom of the glass tube until it contacted the soil. Once the soil and agar plugs were in place, a 3 cm piece of wooden applicator stick was placed in the bottom of the tube. The end of the tube was then covered with a piece of aluminum foil. To the top of the glass tube, were added 30

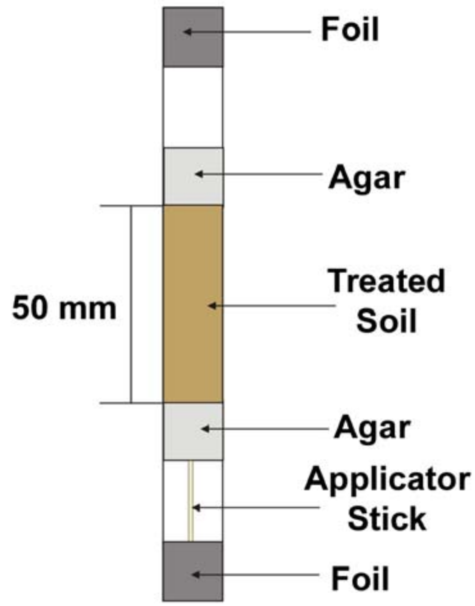

Fig. 2. Bioassay unit set-up to measure vertical tunneling distance of 30 *Reticulitermes spp.* at 1 and 5 days and % percent mortality at 5 days. Termites were placed in the space between the foil and agar at the top of the unit at day 0.

pseudergates (*Reticulitermes flavipes*). It was then sealed with another piece of aluminum foil. Pieces of aluminum foil were held in place by orthodontic rubber bands. After assembly, bioassay tubes were placed in an upright position in a rack and held in an environmental chamber at 25° ± 2 °C with a 12:12 (L:D) photoperiod.

Each bioassay tube was checked for termite tunneling after 24 h. Termite tunneling was recorded from 0.0 mm (soil/agar interface at the top of the bioassay tube) to 50 mm (soil/agar interface at the bottom of the tube). After 5 days, final termite tunneling distance was recorded, and the bioassay tubes were carefully dissembled to determine the number of surviving termites.

Voucher Information. Vouchers termite specimens from this study were placed in the Texas A&M University Insect Collection. The voucher identification number is 638. The Texas A&M University Insect Collection can be found on the second floor of the Minnie Belle Heep Building on the West Campus of Texas A&M University, College Station, TX.

Statistical Analysis. SPSS (2001) was used to run an analysis of variance (ANOVA) to compare the mean concentrations (ppm) of fipronil in the tank mix samples among the treatment groups, to compare the mean concentrations (ppm) of fipronil in the soil of the structures among the sampling periods within each of the three treatment groups, and to compare the mean concentrations (ppm) throughout time in the soil of the structures between the three treatment groups ($\alpha = 0.05$).

RESULTS

Treatment of Structures. The mean perimeter of the treated structures was 72.1 m (Table 2). The product label of Termidor® SC requires that 15 L of tank mix solution be applied per 3 m (5.0 L/m). The application rates of Termidor ® SC to the structures as reported by Bevis Pest Control technicians were consistent with the product label (Table 2). The mean rate applied to the structures was 5.2 L/m. This value, however, is slightly skewed because, in structures receiving a 0.06% fipronil exterior/interior treatment, the amount used in the bath traps or in other sites of interior application was included in the number of liters used.

Concentration of Fipronil in Technical Material and Tank Mix Samples. The mean concentration of fipronil in the technical material was 93% of the expected value (Table 3). The mean concentration of fipronil was 84892.56 ± 7422.16 ppm (8.49%), and the expected value was 91000 ppm (9.10%) listed on the product label.

The mean concentrations of fipronil in the tank mix samples for the 0.06% exterior/ interior, 0.06% exterior-only, and 0.12% exterior-only fipronil applications were 577.78 ± 130.02 (0.058%), 530.21 ± 179.23 (0.053%), and 1042.05 ± 321.20 (0.104%) ppm, respectively (Table 4). The mean values for structures receiving a 0.06% fipronil treatment were 96 and 88% of the expected value of 600 ppm for exterior/interior and exterior-only treatments, respectively. The mean value for structures receiving a 0.125% fipronil exterior-only application was 83% of the expected value of 1200 ppm. There was no significant difference in the mean concentrations of fipronil in the tank

Table 2. Treatment data for structures receiving a post-construction application of fipronil (Termidor® SC) for the control of interior populations of subterranean termites.

Structure #	Treatment date[a]	Treatment group[b]	Linear meters of structure (perimeter)	Liters of Termidor® SC applied[c]	Liters/linear meter[d]
1	06/14/01	0.06 E/I	61.0	303.2	5.0
2	06/15/01	0.06 EO	51.8	284.3	5.5
3	06/15/01	0.06 E/I	39.0	227.4	5.8
4	06/15/01	0.06 E/I	164.6	818.6	5.0
5	06/21/01	0.06 E/I	81.4	405.5	5.0
6	06/22/01	0.06 EO	91.5	454.8	5.0
7	06/29/01	0.06 E/I	67.1	341.1	5.1
8	07/03/01	0.06 E/I	35.6	189.5	5.3
9	07/25/01	0.06 E/I	76.2	379.0	5.0
10	07/31/01	0.06 EO	40.3	208.5	5.2
11	07/31/01	0.06 EO	40.3	208.5	5.2
12	08/09/01	0.06 EO	48.8	246.4	5.1
13	08/09/01	0.06 EO	150.9	833.8	5.5
14	08/16/01	0.06 EO	91.5	454.8	5.0
15	08/16/01	0.06 EO	30.5	151.6	5.0
16	08/22/01	0.125 EO	70.1	348.7	5.0
17	09/14/01	0.125 EO	55.5	284.3	5.1
18	09/17/01	0.125 EO	72.6	379.0	5.2
19	09/17/01	0.125 EO	19.5	98.5	5.1
20	09/18/01	0.125 EO	93.0	473.8	5.1
21	10/01/01	0.125 EO	67.1	333.3	5.0
22	10/02/01	0.125 EO	92.1	458.8	5.0
23	10/05/01	0.06 E/I	66.2	329.7	5.0
24	10/05/01	0.125 EO	20.7	113.7	5.5
25	10/05/01	0.125 EO	54.9	272.9	5.0
26	10/05/01	0.06 EO	65.2	341.1	5.2
27	03/05/02	0.06 EO	85.4	473.8	5.6
28	03/07/02	0.06 E/I	82.0	409.2	5.0
29	04/25/02	0.06 EO	74.1	379.0	5.1
30	06/09/02	0.06 E/I	47.6	303.2	6.4
31	06/10/02	0.125 EO	103.7	553.3	5.3
32	06/10/02	0.125 EO	103.7	553.3	5.3
33	05/30/01	0.06 EO	94.5	473.8	5.0
34	06/21/01	0.06 E/I	61.0	303.2	5.0
35	07/25/01	0.06 E/I	101.5	530.6	5.2
36	08/15/01	0.06 EO	68.6	341.1	5.0
37	09/18/01	0.125 EO	97.6	492.7	5.1
		Mean	72.1	303.2	5.2
		S. D.	31.1	161.0	0.3

[a]Structures treated on the same day are listed in order of treatment for that day. Structures 33-37 were used only for soil sampling in order to determine the concentration of fipronil through time. These structures were treated exactly as the others in their respective treatment group, but did not meet the criteria of having an interior infestation of subterranean termites.

[b]0.06 E/I = 0.06% fipronil exterior/interior treatment; 0.06 EO = 0.06% fipronil exterior-only treatment; and 0.12 E0 = 0.125% fipronil exterior-only treatment.

[c]As reported by Bevis Pest Control.

[d]In the 0.06% fipronil exterior/interior treatments, the amount of chemical used in the bath traps or in interior application may be reflected as a higher application rate.

Table 3. Mean concentration (ppm) of fipronil analyzed from three 1 ul samples of technical material (Termidor® SC) used in the post-construction treatment of structures to control interior infestations of subterranean termites.

Structure #	Expected ppm fipronil[a]	Actual ppm fipronil	S. D.	Structure #	Expected ppm fipronil[a]	Actual ppm fipronil	S. D.
1	9100.00	82928.00	3789.50	21	9100.00	81477.03	5952.31
2	9100.00	86555.80	1351.52	22	9100.00	103356.93	5150.58
3	9100.00	83880.23	4522.25	23	9100.00	81073.33	3621.43
4	9100.00	*	*	24	9100.00	80365.77	2853.60
5	9100.00	86706.37	7216.84	25	9100.00	95666.90	6348.09
6	9100.00	79463.20	2919.59	26	9100.00	87760.93	5901.84
7	9100.00	82186.00	3986.16	27	9100.00	86803.07	4364.50
8	9100.00	87754.47	4126.48	28	9100.00	81744.70	5169.38
9	9100.00	*	*	29	9100.00	94384.27	6359.27
10	9100.00	93287.97	3818.43	30	9100.00	*	*
11	9100.00	93287.97	3818.43	31	9100.00	*	*
12	9100.00	86810.37	4100.25	32	9100.00	*	*
13	9100.00	88373.30	3419.61	33	9100.00	85130.80	5262.25
14	9100.00	78025.30	4175.94	34	9100.00	63857.73	2900.94
15	9100.00	78025.30	4175.94	35	9100.00	74341.70	5926.13
16	9100.00	73500.80	4604.22	36	9100.00	82930.23	5264.07
17	9100.00	88276.90	4478.48	37	9100.00	86300.10	4148.01
18	9100.00	88706.90	3664.45				
19	9100.00	88706.90	3664.45	Mean of means	9100.00	84892.56	N/A
20	9100.00	*	*	S. D.	0.00	7422.16	N/A

[a]Based on Termidor ® SC product label concentration of 9.1%.

* = data not available.

mix samples between the 0.06% fipronil treatments; however, both treatments had mean tank mix sample concentrations that were significantly different from structures receiving a 0.125% treatment (F = 26.57; df = 2; P < .001; Table 4).

Concentration of Fipronil in the Soil Through Time. Fipronil was not found in soils of any of the structures prior to the initiation of this study. The mean concentrations of fipronil in the soil of all structures in the 0.06% exterior/interior, 0.06% exterior-only, and 0.125% exterior-only fipronil applications at one week were 85.23, 99.54, and 93.64 ppm, respectively (Tables 5, 6, and 7). These values were 84, 98, and 44% of the expected values of 101.82 (0.06% fipronil) and 212.13 ppm

Table 4. Mean concentration (ppm) of fipronil analyzed from three 1 ul tank mix samples of Termidor® SC solution used in the post-construction treatment of structures to control interior infestations of subterranean termites.

Treatment group[a]	Structure #	Expected ppm fipronil[b]	Actual ppm fipronil[c]	S. D.	% of expected value
0.06 E/I	1	600.00	417.32	47.68	69.6
	3	600.00	618.43	42.47	103.1
	4	600.00	*	*	*
	5	600.00	540.38	55.48	90.1
	7	600.00	*	*	*
	8	600.00	814.92	253.43	135.8
	9	600.00	*	*	*
	23	600.00	694.27	59.56	115.7
	28	600.00	467.61	51.72	77.9
	30	600.00	658.34	81.88	109.7
	34	600.00	539.62	62.58	89.9
	35	600.00	449.15	41.77	74.9
	Mean of means	600.00	577.78 a	N/A	96.3
	S. D.	0.00	130.02	N/A	N/A
0.06 EO	2	600.00	643.19	61.54	107.2
	6	600.00	*	*	*
	10	600.00	324.35	26.56	54.1
	11	600.00	324.35	26.56	54.1
	12	600.00	498.40	85.22	83.1
	13	600.00	485.37	43.87	80.9
	14	600.00	432.37	52.04	72.1
	15	600.00	432.37	52.04	72.1
	26	600.00	785.87	136.35	131.0
	27	600.00	465.53	85.25	77.6
	29	600.00	504.79	55.28	84.1
	33	600.00	531.38	65.93	88.6
	36	600.00	934.54	67.03	155.8
	Mean of means	600.00	530.21 a	N/A	88.4
	S. D.	0.00	179.23	N/A	N/A
0.125 EO	16	1250.00	*	*	*
	17	1250.00	1040.71	97.57	83.3
	18	1250.00	1148.32	80.82	91.9
	19	1250.00	1148.32	80.82	91.9
	20	1250.00	1104.04	75.55	88.3
	21	1250.00	1027.10	70.73	82.2
	22	1250.00	990.72	73.73	79.3
	24	1250.00	*	*	*
	25	1250.00	764.88	107.58	61.2
	31	1250.00	*	*	*
	32	1250.00	*	*	*
	37	1250.00	1112.28	71.49	89.0
	Mean of means	1250.00	1042.05 b	N/A	83.4
	S. D.	0.00	321.20	N/A	N/A

[a]0.06 E/I = 0.06% fipronil exterior/interior treatment; 0.06 EO = 0.06% fipronil exterior-only treatment; and 0.125 E0 = 0.125% fipronil exterior-only treatment.

[b]Based on labeled tank mixture rates of 0.06% and 0.125%.

[c]Means within a column followed by the same letter are not significantly different ($P < 0.05$; ANOVA [SPSS 2001]).

* = data not available.

Table 5. Concentration (ppm) of fipronil (Termidor® SC) in soil samples collected at 1 week and 3, 6, 9, 12, and 18 months post-treatment at structures receiving a 0.06% exterior/interior post-construction treatment for the control of interior populations of subterranean termites.

Structure #		1 week	3 month	6 month	9 month	12 month	18 month
1	Mean	146.53	63.27	97.35	137.12	132.03	84.72
	S. D.	97.67	24.50	53.11	56.50	40.79	35.90
	n	12	12	12	12	12	12
3	Mean	29.62	27.33	25.80	43.06	43.88	29.36
	S. D.	6.03	14.07	6.48	8.42	1.73	4.26
	n	3	3	3	3	3	3
4	Mean	*	62.68	54.49	62.56	37.26	45.13
	S. D.	*	48.90	12.80	13.23	11.59	3.10
	n	*	6	6	6	6	6
5	Mean	70.77	42.21	66.73	61.69	64.11	*
	S. D.	23.20	30.01	59.26	33.24	40.18	*
	n	12	12	12	12	12	*
7	Mean	40.48	19.78	106.90	51.71	116.06	64.87
	S. D.	31.97	17.01	93.66	16.36	79.55	50.35
	n	12	12	12	12	12	12
8	Mean	36.70	*	84.42	88.13	63.98	103.99
	S. D.	4.50	*	8.50	10.47	7.41	24.92
	n	3	*	3	3	3	3
9	Mean	85.72	85.72	*	46.49	79.87	86.88
	S. D.	16.61	16.61	*	13.36	5.70	7.39
	n	3	3	*	3	3	3
23	Mean	*	95.89	95.57	62.49	83.80	74.92
	S. D.	*	63.54	25.79	27.51	18.78	32.56
	n	*	12	12	12	12	9
28	Mean	113.70	49.38	143.62	80.14	59.66	*
	S. D.	44.02	27.90	76.01	37.42	45.64	*
	n	12	12	12	12	12	*
30	Mean	144.34	195.78	61.38	46.62	*	*
	S. D.	10.04	13.56	1.51	2.87	*	*
	n	3	3	3	3	*	*
34	Mean	169.44	162.69	43.61	79.40	202.84	72.47
	S. D.	16.51	98.00	11.23	83.23	106.19	57.79
	n	6	6	6	6	6	6
35	Mean	38.76	*	120.62	58.00	105.44	*
	S. D.	15.25	*	117.55	51.31	78.67	*
	n	12	*	12	12	12	*
	Mean of means	87.61 a	80.47 a	81.86 a	68.12 a	89.90 a	70.29 a
	S. D.	52.62	57.61	35.19	26.05	47.68	23.85
	N	10	10	11	12	11	8

Means within a row followed by the same letter are not significantly different ($P < 0.05$; ANOVA [SPSS 2001]); * = data not available.; n = number of soil samples analyzed from structures at sampling period (1 sample from each side of the structure analyzed 3 times); N = number of structures sampled from sampling period.

Table 6. Concentration (ppm) of fipronil (Termidor® SC) in soil samples collected at 1 week and 3, 6, 9, 12, and 18 months post-treatment at structures receiving a 0.06% exterior-only post-construction treatment for the control of interior populations of subterranean termites.

Structure #		1 week	3 month	6 month	9 month	12 month	18 month
2	Mean	94.48	41.83	84.57	115.28	91.04	51.97
	S. D.	52.01	24.90	47.01	43.89	60.88	34.89
	n	12	12	12	12	12	12
6	Mean	78.14	*	106.37	107.62	121.31	97.93
	S. D.	61.33	*	104.89	28.92	62.16	54.12
	n	12	*	12	12	12	12
10	Mean	117.28	*	67.29	*	*	*
	S. D.	39.81	*	22.82	*	*	*
	n	9	*	9	*	*	*
11	Mean	58.45	*	62.77	*	*	*
	S. D.	18.73	*	28.72	*	*	*
	n	9	*	9	*	*	*
12	Mean	64.33	*	63.68	66.63	89.11	79.72
	S. D.	35.00	*	50.17	22.97	18.45	10.75
	n	12	*	12	12	12	9
13	Mean	*	*	56.94	11.30	41.13	38.21
	S. D.	*	*	22.75	1.41	20.62	10.73
	n	*	*	6	6	6	6
14	Mean	63.60	*	93.38	96.46	49.10	70.28
	S. D.	54.39	*	76.93	65.04	20.06	40.41
	n	12	*	12	12	9	9
15	Mean	*	*	63.22	51.11	75.17	56.44
	S. D.	*	*	13.96	33.37	61.35	60.89
	n	*	*	9	9	6	6
26	Mean	110.28	79.11	84.82	85.25	98.91	*
	S. D.	34.41	4.73	16.02	55.42	40.72	*
	n	9	9	9	9	9	*
27	Mean	321.20	224.39	98.56	*	65.67	*
	S. D.	200.16	120.83	13.23	*	25.43	*
	n	12	12	12	*	12	*
29	Mean	93.45	56.321	113.42	51.36	28.83	*
	S. D.	63.15	43.90	71.35	5.65	21.33	*
	n	9	9	9	9	9	*
33	Mean	72.49	75.23	55.57	124.15	94.61	19.99
	S. D.	54.33	29.87	44.98	63.28	23.87	10.68
	n	9	9	9	9	9	9
36	Mean	21.23	*	90.53	112.17	64.02	99.46
	S. D.	6.54	*	15.59	103.63	65.04	73.25
	n	6	*	6	6	6	6
	Mean of means	99.54 a	95.38 a	80.09 a	82.13 a	78.81 a	64.25 a
	S. D.	78.2099	73.67	19.63	36.21	27.77	28.03
	N	11	5	13	10	11	8

Means within a row followed by the same letter are not significantly different ($P < 0.05$; ANOVA [SPSS 2001]); * = data not available; n = number of soil samples analyzed from structures at sampling period (1 sample from each side of the structure analyzed 3 times); N = number of structures sampled from sampling period.

Table 7. Concentration (ppm) of fipronil (Termidor® SC) in soil samples collected at 1 week and 3, 6, 9, 12, and 18 months post-treatment at structures receiving a 0.125% exterior-only post-construction treatment for the control of interior populations of subterranean termites.

Structure #		1 week	3 month	6 month	9 month	12 month	18 month
16	Mean	*	59.62	193.95	121.02	110.19	130.37
	S. D.	*	34.13	61.17	168.19	61.74	77.63
	n	*	12	12	12	12	8
17	Mean	170.48	119.39	248.83	292.44	142.51	238.17
	S. D.	55.11	64.95	88.44	134.65	79.32	168.06
	n	12	12	12	12	12	12
18	Mean	82.88	112.25	248.62	257.73	191.40	191.40
	S. D.	63.43	69.58	83.23	122.22	89.09	45.66
	n	12	12	12	12	12	12
19	Mean	48.98	44.46	110.18	74.33	136.18	117.43
	S. D.	15.86	17.43	16.82	38.59	34.66	21.43
	n	12	12	12	12	12	12
20	Mean	80.08	82.25	248.60	238.54	256.88	189.55
	S. D.	37.59	29.51	41.27	121.03	75.31	121.45
	n	12	12	12	12	12	12
21	Mean	*	277.72	341.43	219.06	251.35	164.14
	S. D.	*	96.06	124.65	49.55	98.41	110.12
	n	*	12	12	9	12	12
22	Mean	*	103.03	174.77	60.39	113.61	130.80
	S. D.	*	86.76	65.26	17.82	37.65	41.89
	n	*	9	9	6	9	9
24	Mean	*	217.74	198.27	219.58	116.39	169.70
	S. D.	*	58.34	61.17	104.70	41.28	61.91
	n	*	9	9	9	9	9
25	Mean	*	129.10	178.31	89.03	111.18	99.90
	S. D.	*	48.42	51.86	54.76	41.45	59.67
	n	*	12	12	12	12	12
31	Mean	67.00	29.27	51.73	51.71	89.18	*
	S. D.	51.08	16.79	27.56	11.23	46.76	*
	n	6	6	6	6	6	*
32	Mean	112.41	138.23	61.37	58.29	80.56	*
	S. D.	27.08	76.95	38.00	8.57	46.73	*
	n	6	3	6	6	6	*
37	Mean	*	113.12	113.08	131.40	205.82	154.66
	S. D.	*	76.44	65.59	122.79	48.49	30.69
	n	*	9	9	9	9	9
	Mean of means	93.64 a	118.85 a	180.76 a	151.13 a	150.44 a	158.61 a
	S. D.	43.04	70.22	85.62	88.45	60.93	41.16
	N	6	12	12	12	12	10

Means within a row followed by the same letter are not significantly different ($P < 0.05$; ANOVA [SPSS 2001]); * = data not available; n = number of soil samples analyzed from structures at sampling period (1 sample from each side of the structure analyzed 3 times); N = number of structures sampled from sampling period.

(0.125% fipronil). The expected values were calculated by estimating the trench size as 15 cm deep and 15 cm wide in the soil, similar to those used in termite control in Texas. Then, using the specific gravity of soil (1.3 g/cm^3), the mass of the volume of the soil was calculated. Finally, at labeled application rate of 15 L/3 m (4 gal/10 lin ft), the mass of the fipronil added to the trench was determined and compared to the mass of the soil to calculate the expected ppm of fipronil in the soil.

There was a significant difference ($F = 19.097$; $df = 2$; $P < .001$) in the mean concentrations of fipronil in soils between structures receiving a 0.06% and 0.125% fipronil application as was expected (Tables 5, 6, and 7). In all cases, fipronil was stable in the soil for the first 18 months post-treatment. There was no significant difference in the mean concentrations of fipronil within any of the treatment groups over the 6 sampling periods [0.06% fipronil exterior/interior ($F = 0.495$; $df = 5$; $P < 0.05$); 0.06% fipronil exterior-only ($F = 0.593$; $df = 5$; $P < 0.05$); 0.125% fipronil exterior-only ($F = 0.149$; $df = 5$; $P < 0.05$); Tables 5, 6, and 7]. It is certain that at some point, fipronil will degrade over time similar to findings reported by Gold et al. (1994, 1996) with pyrethroids and organophosphates, and unpublished data on fipronil from work done at the Texas A&M University Center for Urban and Structural Entomology from at least 4 years of sampling. The current data shows that the he half-life of fipronil in treated soils exceeds 18 months.

Termite Monitoring Stations. The monitoring stations were not effective as indicators of the presence or absence of subterranean termites on the interior of a structure when placed around the perimeter in conjunction with a post-construction barrier treatment. This was indicated by the fact that neither active termites nor termite damage were ever found in any of the monitoring stations within the first year of inspections, even though several structures had active termites on the interior during the 3 and/or 6 month inspection periods. In addition to being ineffective indicators of interior populations of subterranean termites, these monitors were often covered by soil or grasses between inspections making them very time-consuming to relocate even with diagrams.

A number of organisms besides termites were collected in the monitors that were similar to those reported by Sharf et al. (2002). Termite monitoring stations were occupied by several invertebrates including collembolans, earwigs, ants, mites, spiders, isopods, centipedes, millipedes, slugs, snails, and earthworms. In some cases, fungus and slime molds covered the wooden stakes in the monitors. Water rot was also a common occurrence on the wooden stakes in the monitors and less frequently the wood desiccated.

Comparison of Treatments. Four (36%) out of 11 structures treated with a 0.06% fipronil exterior-only application were infested with interior populations of termites at or after the 6 month inspection. All structures treated with either a 0.06% fipronil exterior/interior treatment or a 0.125% fipronil exterior-only treatment were found to have their interior termite populations controlled within 6 months of treatment (Fig. 3).

Twenty-one out of the 28 (75%) structures that showed full control of termites within 6 months did so by the 3 month inspection. The other 7 structures exhibited full control

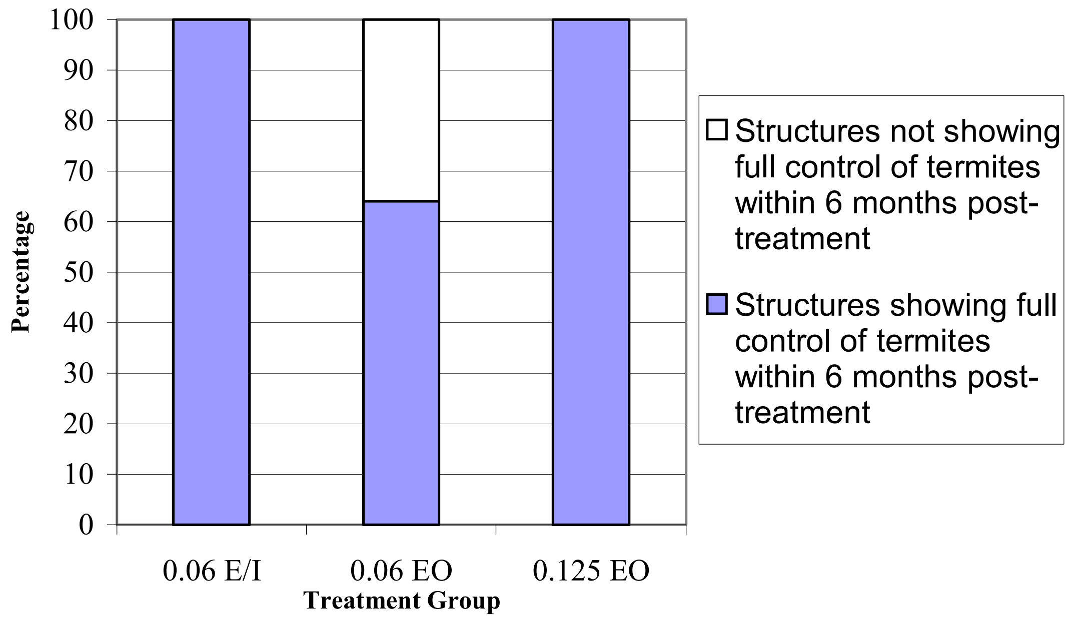

Fig. 3. Percentages of structures showing full control of interior populations of subterranean termites within 6 months after a post-construction application of fipronil (Termidor® SC) for three treatment groups including: 0.06 E/I = 0.06% fipronil exterior/interior treatment; 0.06 EO = 0.06% fipronil exterior-only treatment; and 0.12 E0 = 0.125% fipronil exterior-only treatment.

at the 6 month inspection (Table 8).

In the four structures not showing full control within 6 months, live termites were found in central bath traps or on the interior of wood pilings (Table 9). The distance from the exterior fipronil treatment to the point of infestation ranged from < 0.03 to 4.57 m.

Provided in Table 10 is a list of the points of entry for the interior infestations of termites for each structure. In all structures where the only point of entry was associated with the exterior perimeter wall, the structure exhibited full control of the interior population of subterranean termites within 6 months. In all structures where

Table 8. Best estimate of time (months) necessary to achieve full control of interior infestations of subterranean termites in those structures showing full control within 6 months of a post-construction treatment with fipronil (Termidor® SC).

Structure #	Treatment Group[b]	Estimated time to full control (months) of termites[c]	Structure #	Treatment Group[a]	Estimated time to full control (months) of termites[c]
1	0.06 E/I	3	19	0.125 EO	3
2	0.06 EO	6	20	0.125 EO	6*
3	0.06 E/I	3	21	0.125 EO	6*
4	0.06 E/I	3	22	0.125 EO	3
5	0.06 E/I	3	23	0.06 E/I	3
7	0.06 E/I	3	24	0.125 EO	3
8	0.06 E/I	6*	25	0.125 EO	3
9	0.06 E/I	6*	26	0.06 EO	3
13	0.06 EO	6*	27	0.06 EO	3
14	0.06 EO	6*	28	0.06 E/I	3
15	0.06 EO	6*	29	0.06 EO	3
16	0.125 EO	3	30	0.06 E/I	3
17	0.125 EO	3	31	0.125 EO	3
18	0.125 EO	3	32	0.125 EO	3

Structures 6, 10, 11, 12 are not represented in this table due to the fact that they did not demonstrate full control of interior populations of termites within 6 months.

[b]0.06 E/I = 0.06% fipronil exterior/interior treatment; 0.06 EO = 0.06% fipronil exterior-only treatment; and 0.125 EO = 0.125% fipronil exterior-only treatment.

[c]For estimated times with "*" 3 month inspection data was not available for the structure.

Table 9. Summary of structures in which interior populations of termites were not fully controlled within 6 months with a post-construction application of fipronil (Termidor® SC).

Structure #	Treatment group[a]	Retreatment date	Entry point of termite population	Distance of entry point from nearest fipronil application (m)
6	0.06 EO	02/25/03	Interior bath trap	4.57
10	0.06 EO	06/14/02	Interior bath trap	2.44
11	0.06 EO	08/23/02	Interior bath trap	2.44
12	0.06 EO	08/23/02	Interior side of wood piling in wall and wood base of cabinet	< 0.30

[a]06 E/I = 0.06% fipronil exterior/interior treatment.

Table 10. Relationship between the application of fipronil (Termidor ® SC) at the entry point of a subterranean termite population into structures and the achievement of full control of those populations at those points within 6 months after a post-construction treatment.

Treatment group[a]	Structure #	Entry point	Entry point treated	Full control of interior population of termites at entry point within 6 months
0.06 E/I	1	Perimeter wall	Yes	Yes
		Bath traps	Yes	Yes
	3	Perimeter wall	Yes	Yes
		Internal joint	Yes	Yes
	4	Wood post	Yes	Yes
	5	Perimeter wall	Yes	Yes
		Bath trap	Yes	Yes
		Internal joint	Yes	Yes
	7	Perimeter wall	Yes	Yes
	8	Perimeter wall	Yes	Yes
	9	Perimeter wall	Yes	Yes
		Internal joint	Yes	Yes
	23	Perimeter joint	Yes	Yes
		Internal joint	Yes	Yes
		Bath trap	Yes	Yes
	28	Perimeter wall	Yes	Yes
	30	Perimeter joint	Yes	Yes
		Internal joint	Yes	Yes
		Wood post	Yes	Yes
0.06 EO	2	Perimeter wall	Yes	Yes
	6	Wood piling near perimeter wall	No	No
	10	Bath trap	No	No
		Perimeter wall	Yes	Yes
	11	Bath trap	No	No
		Perimeter wall	Yes	Yes
	12	Bath trap	No	No
	13	Perimeter wall	Yes	Yes
	14	Perimeter wall	Yes	Yes
	15	Perimeter wall	Yes	Yes
	26	Perimeter wall	Yes	Yes
	27	Perimeter wall	Yes	Yes
	29	Perimeter wall	Yes	Yes
0.125 EO	16	Perimeter wall	Yes	Yes
	17	Perimeter wall	Yes	Yes
	18	Perimeter joint	Yes	Yes
	19	Perimeter wall	Yes	Yes
	20	Perimeter wall	Yes	Yes
		Perimeter joint	Yes	Yes
	21	Perimeter wall	Yes	Yes
		Perimeter joint	Yes	Yes
	22	Perimeter wall	Yes	Yes
		Perimeter joint	Yes	Yes
	24	Perimeter wall	Yes	Yes
	25	Perimeter wall	Yes	Yes
	31	Perimeter wall	Yes	Yes
	32	Perimeter wall	Yes	Yes

[a]0.06 E/I = 0.06% fipronil exterior/interior treatment; 0.06 EO = 0.06% fipronil exterior-only treatment; and 0.125 EO = 0.125% fipronil exterior-only treatment.

the point of entry was an interior site, and that site was treated (0.06% exterior/interior treatments), full control was also seen within 6 months. Finally, in contrast to all structures where the point of entry was an interior site and that site was not treated, full control was not exhibited within 6 months. Even with random assignment of structures to the three treatment groups, all of the structures receiving a 0.125% fipronil exterior-only application had entry points either at an exterior perimeter wall or an exterior perimeter joint.

Bioassay Data. Fipronil was effective at killing subterranean termites in bioassay tests. The lowest concentrations of fipronil in any of the five soils at which there was no surviving termites ranged from 1 to 3 ppm (Table 11). The LC_{50} of the soils was 0.26, 0.19, 0.60, 0.23, 0.23 ppm for soil in College Station, Corpus Christi, Dallas, Lubbock, and Overton, respectively as determined by the methods of Hamilton et al. (1977).

Fipronil was also effective at minimizing the tunneling distance of subterranean termites in treated soils. The tunneling distances of the termites was inversely proportional to the concentration of fipronil in the soils after 1 day, and changed little over the next 4 days (Table 11), supporting the fact that the termiticide was active in preventing tunneling within 2 days. The minimum effective concentration (MEC) refers to the minimum concentration at which the termites were unable to tunnel through all 50 mm of soil. This value was 0.1, 0.1, 0.1, 0.1, 1.0, and 1.0 ppm for soil in College Station, Corpus Christi, Dallas, Lubbock, and Overton, respectively.

Table 11. Laboratory bioassay results showing mean (over 4 replicates) percent mortality at 5 days and vertical tunneling distances (mm) at 1 and 5 days after the introduction of 30 *Reticulitermes flavipes* (Kolar) pseudergates placed into vertical glass tubes containing 50 mm of one of 5 different soils from Texas treated at various concentrations (ppm) of fipronil.

Soil Locale	Fipronil (ppm)	Mortality (%)	S. D.	LC_{50} (ppm)[a]	Day 1 tunneling (mm)[b]	S. D.	Day 5 tunneling (mm)[b]	S.D
College Station	0.0	0.8	1.7	0.26	46.3	7.5	47.3	5.5
	0.1	5.0	1.9		37.5	14.6	39.0	13.3
	0.3	68.3	13.7	.	32.5	12.3	34.3	11.1
	0.7	81.7	26.7		29.8	10.0	32.3	13.9
	1.0	99.2	1.7		34.8	2.8	35.0	4.2
	2.0	97.5	5.0		19.3	5.0	19.5	4.8
	3.0	100.0	0.0		16.0	10.7	16.0	10.7
	5.0	100.0	0.0		12.0	4.8	12.8	4.3
	7.0	100.0	0.0		4.3	2.2	4.3	2.2
Corpus Christi	0.0	9.2	1.7	0.19	43.0	14.0	43.3	13.5
	0.1	27.5	13.2		34.5	18.2	34.8	17.8
	0.3	67.5	19.1		35.3	16.8	35.5	16.8
	0.7	87.5	11.7		19.5	7.1	19.5	7.1
	1.0	100.0	0.0		16.0	9.0	16.3	9.3
	2.0	100.0	0.0		13.8	4.9	14.3	4.6
	3.0	100.0	0.0		11.3	7.6	11.3	7.6
	5.0	100.0	0.0		3.3	3.9	3.3	3.9
	7.0	100.0	0.0		9.5	3.5	9.8	3.2
Dallas	0.0	8.3	4.3	0.60	50.0	0.0	50.0	0.0
	0.1	11.7	15.0		38.8	8.8	50.0	10.0
	0.3	3.3	4.7		40.3	19.5	41.5	17.0
	0.7	62.5	8.3		35.3	12.4	39.3	14.2
	1.0	82.5	19.9		22.5	19.4	22.5	19.4
	2.0	95.8	8.3		22.8	3.0	22.8	3.0
	3.0	100.0	0.0		37.5	12.1	37.5	11.7
	5.0	100.0	0.0		15.0	11.6	15.3	11.4
	7.0	100.0	0.0		10.8	8.0	11.5	7.9
Lubbock	0.0	5.0	3.3	0.23	50.0	0.0	50.0	0.0
	0.1	2.5	3.2		50.0	0.0	50.0	0.0
	0.3	65.0	15.5		50.0	0.0	50.0	0.0
	0.7	99.2	1.7		50.0	0.0	50.0	0.0
	1.0	100.0	0.0		46.3	4.4	48.3	3.5
	2.0	100.0	0.0		29.5	6.2	30.8	6.9
	3.0	100.0	0.0		25.3	2.4	25.5	2.7
	5.0	100.0	0.0		16.3	2.5	16.8	2.6
	7.0	100.0	0.0		14.3	1.5	14.3	1.5
Overton	0.0	3.3	4.7	0.23	50.0	0.0	50.0	0.0
	0.1	1.7	3.3		50.0	0.0	50.0	0.0
	0.3	73.3	11.2		50.0	0.0	50.0	0.0
	0.7	97.5	5.0		50.0	0.0	50.0	0.0
	1.0	98.3	3.3		48.3	3.5	48.5	3.5
	2.0	100.0	0.0		36.3	18.0	36.3	18.0
	5.0	100.0	0.0		20.0	4.2	25.0	4.0

[a]Values calculated using methods described in Hamilton et al. (1977).

[b]Tunneling distances calculated from top of 50 mm of soil.

DISCUSSION AND CONCLUSIONS

The strengths of this study were, first, that it mirrored what actually occurs in the termite control industry when treating termite infestations with a liquid termiticide, and second, that the number of structures treated allowed for scientific analysis. The study was conducted in cooperation with property owners whose structures were infested with subterranean termites. Although overseen by researchers, all structures were treated by licensed pest control technicians without interference.

At times, the very strengths of this study created difficulties. Maintaining consistent communication between the owners of treated structures, the pest control technicians, the manufacturers of Termidor® SC, and members the graduate committee was difficult. While every effort was made to conduct the study according to good research standards, there were occasions when scheduled sampling periods were missed, or the customers were not available to allow access to the properties. Some customers moved to new locations, and contracts had to be reestablished with new owners. Termite monitoring stations occasionally had to be reinstalled because they were physically removed or covered by mulch in areas of treated soil. Regardless of these difficulties, the study and conclusions drawn have relevancy to those interested in using fipronil at the labeled rates in post-construction exterior/interior or exterior-only treatments for the control of interior populations of subterranean termites.

Bioassays with soils treated at various concentrations of fipronil showed that it effectively controlled termites within 5 days at 1 ppm or less depending on the soil type

(Table 11). Fipronil was non-repellent to the termites at the concentrations tested. It was fast-acting and halted termite tunneling in treated soils within 2 days.

A total of 37 structures were treated with fipronil (Termidor® SC) for this study; however, five of these were used only for soil sampling because of construction modifications in the structures or the inability of the researches to confirm the presence of interior subterranean termite populations upon inspection (Table 2). The thirty-two structures used in the comparison of post-construction treatments all had visible signs of an interior infestation with subterranean termites in the genus *Reticulitermes*. No fipronil was found in the soil samples taken the day of treatment from any structure as determined by chemical analysis.

The technical material used to treat structures came in the original containers provided by the manufacturers, or was purchased from local suppliers. Each container originally held 2.3 L (78 oz) of fipronil at 9.1% active ingredient by weight. Technical material sampling was done at the time of application by licensed pest control operators. The concentration of fipronil in the technical material samples was consistent with the product label, showing a mean concentration of 93% of the label level (91000 ppm; Table 3). Any variation from the labeled concentration was due to storage or handling of the product after leaving the manufacturing plant, natural degradation (Fig. 1), and sampling or analytical errors. The recovery coefficient for fipronil from solutions was >98% in chemical analysis done in the laboratory at the Center for Urban and Structural Entomology at Texas A&M University. Soluble concentrate (SC) formulations require agitation of technical material in the container to ensure that the active ingredient was adequately mixed prior to sampling. It is possible that inadequate mixing of the product occurred. Regardless of these possible sources of error, the concentration of active ingredient in the technical material samples was more than adequate to be mixed in a tank and then applied to soil for termite control.

Two application concentrations were used in the study. Fipronil was applied at either 0.06% or 0.125% active ingredient. Tank mix sampling was done by the licensed pest control operators after they had added technical fipronil to water and the tank mix had been agitated via a "jet by-pass system". If followed, the mixing instructions on the label for Termidor® SC would yield a 0.06% or 0.125% active ingredient finished solution depending on the amount of active ingredient added to the mix. There was no significant difference between the mean concentrations of fipronil in tank mix samples from the two 0.06% fipronil treatments, even though both means were significantly different than the mean concentration of fipronil in structures receiving a 0.125% fipronil treatment (Table 4).

Chemical analysis of tank mix samples showed considerable variation; however, the mean concentration of fipronil in the 0.06% fipronil treatments was 92% of the expected value. The mean concentration of the 0.125% fipronil tank mix samples was 83% of the expected value (Table 4).

Variance in tank mix concentrations can be explained in part by the difficulty of adding the correct volume of technical material necessary to the proper volume of water. The total volume of finished solution necessary to treat a structure was determined prior to treatment based on the length of the perimeter of each structure.

Water was added first, followed by the appropriate amount of technical material. The label of Termidor® SC requires 2.3 L of technical material (the volume in the commercial container) be added to 376 L of water (78 oz fipronil to 99.25 gal of water) to make 378.5 L (100 gal size of the tank) of a 0.06% tank solution. The 0.125% fipronil solution requires 4.6 L of fipronil added to 371.4 L of water (156 oz fipronil to 98 gal of water) to make the same 378.5 L (100 gal). The fipronil containers were constructed to measure only three volumes including 0.023 L to make 3.7 L (1 gal) of tank mix, 1.15 L to make 189.3 L (50 gal), or 2.3 L to make 378.5 L (100 gal).

Also, the sizes of the structures used in this study varied (Table 2). As the volume of finished tank mix solution necessary to treat a structure deviated from the 378.5 L label recommendation, which coincided with both the volume of the technical material in the commercial container and size of the tank used by the applicator, more calculations were required.

Variation in tank mix samples is also explained by the mixing procedures. Agitation of the tank mix must be thoroughly done to dissolve and disperse the fipronil in water. It is possible that inadequate mixing of the tank occurred. Finally, sampling and analytical errors may have occurred, but the recovery coefficient for fipronil in solution is > 98%. The 0.125% tank mix samples were lower than expected (Table 4). This particular concentration required more mathematical skills, and proportionally more agitation to ensure dispersion of the active ingredient. In all cases, there was sufficient chemical in the tank mixes to control termite populations when applied to the soil.

Soil sampling was done at 1 week post-treatment at each structure in order to determine the concentration of fipronil applied to the soils. Samples were subsequently taken at 3, 6, 9, 12, and 18 months post-treatment. The expected values for the initial soil concentrations of fipronil were calculated as 101.82 (0.06% fipronil) and 212.13 ppm (0.125% fipronil) using calculations based on a standard 15 x 15 cm trench size around the entire structure. A specific gravity value of $1.3 g/cm^3$ for soil, and an application rate of 15 L fipronil/3 m from the product label were also used in the calculations of the expected values.

Concentrations of fipronil in soil samples showed great variation similar to unpublished data on 14 homes treated with fipronil in a previous study by scientists from the Center for Urban and Structural Entomology at Texas A&M University. The mean concentrations of fipronil in soil samples from the structures in the current study that received 0.06% active ingredient treatments had a mean that was 91% of the expected value (Table 5, 6), while the mean concentration of the 0.125% active ingredient treatments was 44% of the expected value (Table 7). The fact that structures receiving a 0.125% active ingredient treatment had a mean initial concentration of fipronil that was less than 50% of the expected value was due in part to missing data from this sampling period (Table 7) . The mean concentration over the next five sampling periods was 151.96 ± 19.86 ppm or 72% of the expected value. This value is still lower than expected, but more closely represents the concentrations in the 0.06% fipronil treatment groups.

The variations in concentration of fipronil in the soils reinforced the concept that it is difficult to apply pesticides in the field in a consistent and uniform manner. Even though the application equipment had been calibrated to deliver the tank mixes at the labeled application rate, it was difficult to meet these requirements for a number of reasons including: differences in soil types, landscaping design, building construction, obstructions, soil conditions related to weather, and personnel issues for each site. Variations are also due to sampling and analytical error; however, the recovery coefficient of fipronil from soil samples was 98%.

There was no significant degradation of fipronil throughout the 18 months of this study (Tables 5, 6, and 7). The presence of termites after 6 months observed in 4 of the 11 structures receiving a 0.06% fipronil exterior-only application (Table 9) was not due to incomplete applications of fipronil. The interior areas of the structures where termites were found were not treated, and the exterior applications were ineffective in controlling interior infestations. Again, there was sufficient concentrations of fipronil in soil treated with fipronil to control termites based on the bioassay studies (Table 11).

In was difficult to locate and to open the termite monitoring stations, and they did not provide accurate indications of termites on the interior of structures in these tests. This may have been due to a flaw in the design of the monitoring stations or in the design of the experiment. Monitors may have been placed in soil too close to the treated perimeter trench where the termites populations might have been controlled. It is recommended, that if monitors are to be used in future work, researchers wait until there is termite activity before termiticide treatments are made. However, this may be impractical as it is difficult to find structures with active interior infestations and monitoring stations with termites.

Despite its non-repellency, delayed mode of action, and possible "transfer effect" from exposed to unexposed nest mates, fipronil must be applied thoroughly in post-construction barrier treatments to be effective. Treatment should start with a careful inspection of the structure to be treated based upon knowledge of building construction. The potential points of termite entry on the exterior and interior of a structure must be identified and treated.

Based on the data resulting from this study, treatment should include an application to the exterior of a structure to form a barrier around the perimeter of the structure. When termites are found on the interior of structures, treatments should be made with appropriate application equipment including drilling and rodding, in an attempt to place the product at all potential entry points. Even after the best efforts of a pest control operator to treat a structure in this manner, there is still the possibility that an interior population of termites will not be controlled due to inaccessible entry points that were not treated. It is inevitable that some structures will have callbacks; but thorough application with fipronil could minimize these problems.

Fipronil (Termidor® SC) was effective in post-construction barrier treatments when applied to the exterior and interior of a structure according to the product label (Fig. 2). All structures treated in this manner showed full control of interior populations of termites within 6 months. This study also showed that placement of the termiticide directly in the vicinity of an entry point of foraging termites was the most important determinant for full control of termites.

Two other types of applications with fipronil have been proposed including an exterior-only (Potter and Hillery 2002) and an exterior-mostly (Potter and Hillery 2003) treatment. These treatments reportedly reduced or even eliminated the need for entering and treating the interior of a structure; thus they reduced treatment time and labor. These alternative treatments are also less intrusive and require less total volume of chemical for treatment.

To explain the effectiveness of exterior-only treatments with fipronil, Potter and Hillery (2003) commented that, although subterranean termites may appear in the center of buildings, most infestations are associated with perimeter walls and adjoining areas. A representative of a major pest control company was quoted as having reported that up to 90% of their accounts fit this description. In the present study, less than 67% (20 of 32) of structures had infestations limited to perimeter walls (Table 10). In two structures (numbers 10 and 1l, Appendix 1), evidence of an active termite infestation was associated only with a perimeter wall at the time of the initial treatment, yet swarming occurred in central bath traps after 6 months. This study showed that exterior-only applications of fipronil will not consistently control interior infestations of termites. This method is not recommended, as 33% of the structures in this study would not have shown full control of subterranean termite infestations.

Potter and Hillery (2003) suggested that if perimeter liquid treatments are used commercially, it still may be prudent to selectively spot-treat infested or high-risk interior areas. Although this method would decrease callbacks as compared to an exterior-only treatment, it would not fully control subterranean termite infestations as effectively as treatment to all potential termite entry points. Those promoting exterior-only treatments have missed the point that every callback is upsetting to the property owner, and costly to the pest control company. Any potential point of entry is a high-risk area because foraging termites have been shown to be persistent and locate any untreated areas over time.

Foraging termites explore, occupy, and consume cellulose products in a “home range” that can span a linear distance of at least 79 m (Grace et al. 1989). Each colony usually contains a “colony headquarters”, where the king and queen live (Thorne 1999). In addition, there are also smaller central units, satellite locations, where other reproductives live. Reproductives are dependent upon foraging termites to bring them food, as are the soldiers and nymphs. Foragers bring food to the center of the colony and it subunits, which are interconnected with each other through a series of galleries. Thus, it is possible for trophallaxis to move termiticides like fipronil through the colony . The results of this study indicated that the trophallaxis of fipronil in the colony did not follow this model.

Fipronil killed subterranean termites and halted their tunneling activity in treated areas within days at concentrations as low as one ppm based on bioassay studies (Table 11). It fully controlled termites within 3 months in structures when applied according to the label. The results of this study did not support the proposed alteration of the label of Termidor® SC to allow exterior-only or exterior-mostly applications. The goal of pest control technicians is to protect the structure, not just to kill termites or apply chemicals. The best protection of the structure would be provided at the maximum label rate in a complete exterior and interior application of the termiticide in conjunction with eliminating conditions condusive to subterranean termites entering and surviving within a structure.

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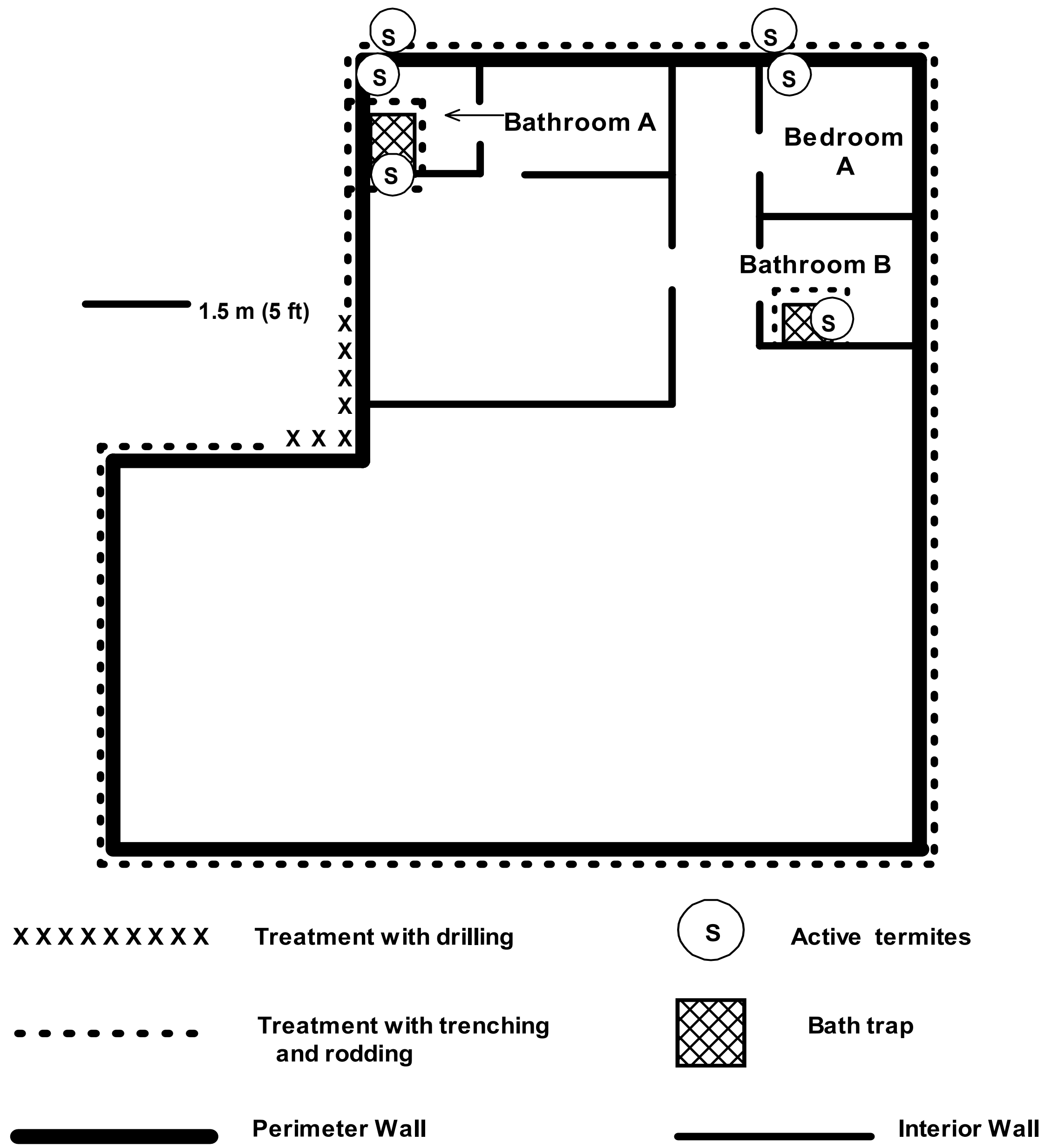
APPENDIX 1

TREATMENT DIAGRAMS OF STRUCTURES 1-32

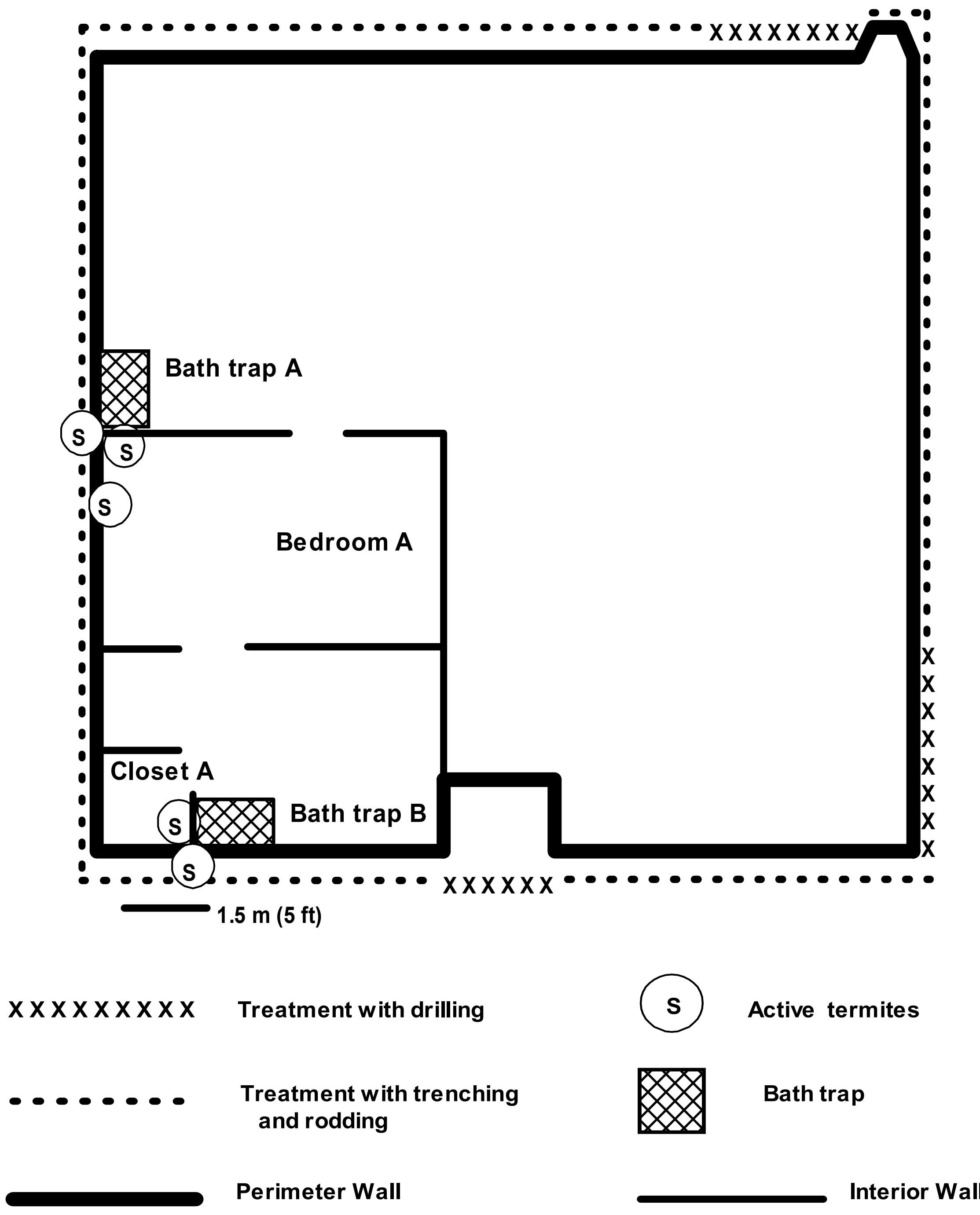
Treatment (0.06% fipronil exterior/interior) diagram for structure 1.

Interior areas of termite infestation included exit holes on wall/ceiling joint above bathtub in bathroom A, foraging tubes and wood damage in bath traps of bathrooms A and B, and exit holes in closet of bedroom A.



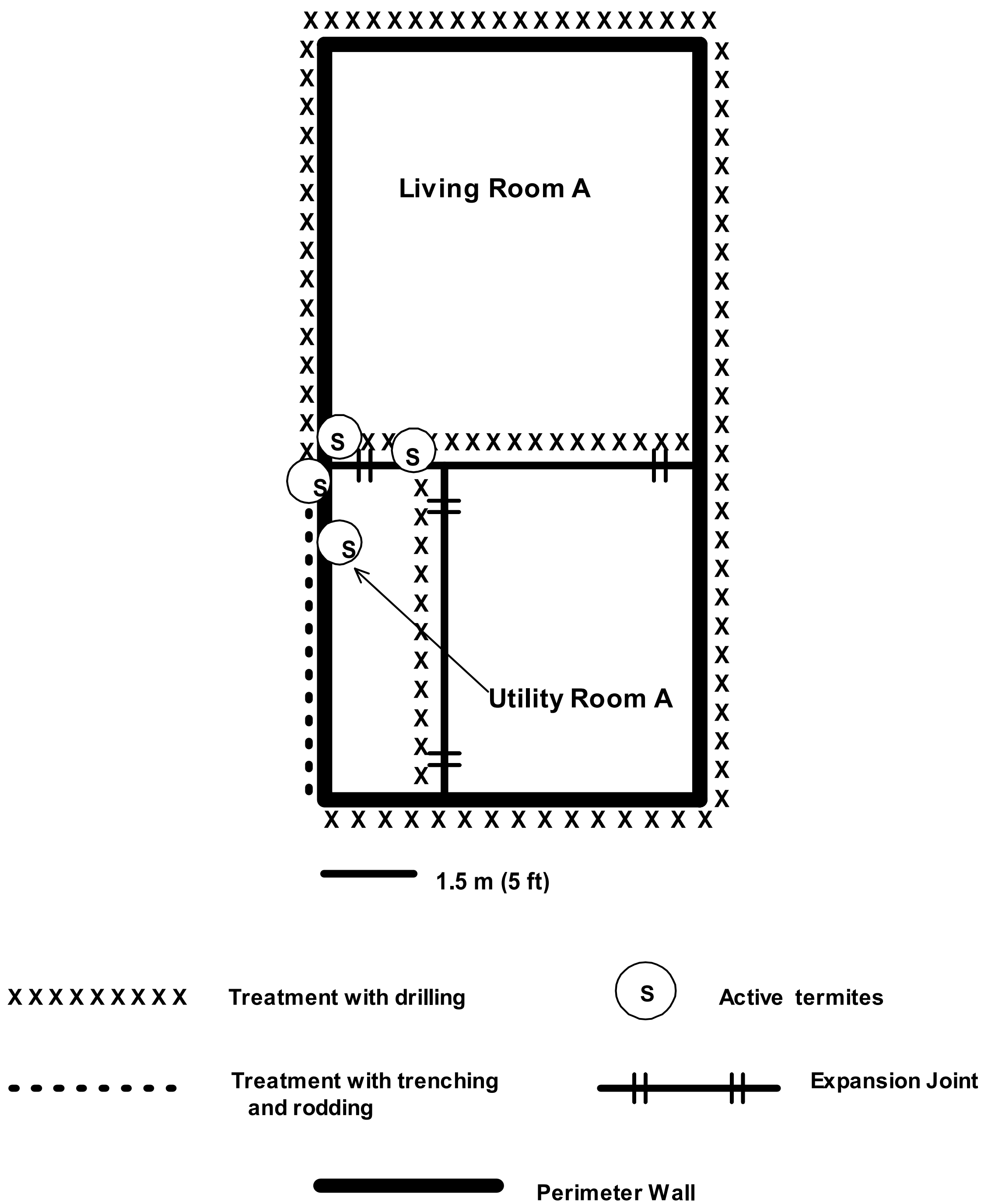
Treatment (0.06% fipronil exterior-only) diagram for structure 2.

Interior areas of termite infestation included foraging tubes and wood damage in bath traps A and B holes in closet A, and exit holes and exposed tunneling damage in wall of bedroom A.



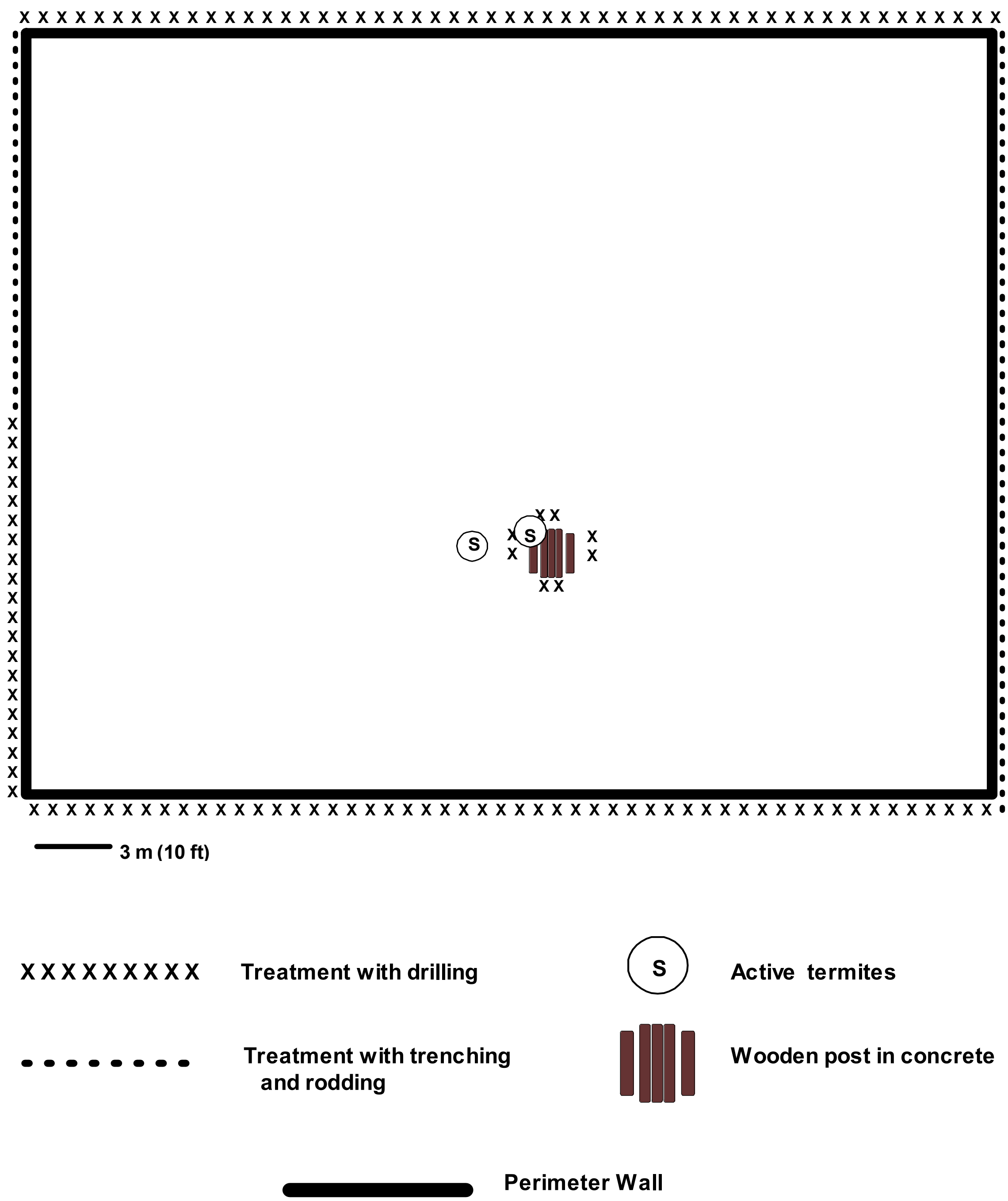
Treatment (0.06% fipronil exterior/interior) diagram for structure 3.

Interior areas of termite infestation included foraging tubes in closet corner of utility room A and exposed tunneling and visible damage on interior of perimeter wall of living room A and on wall above the expansion joint.



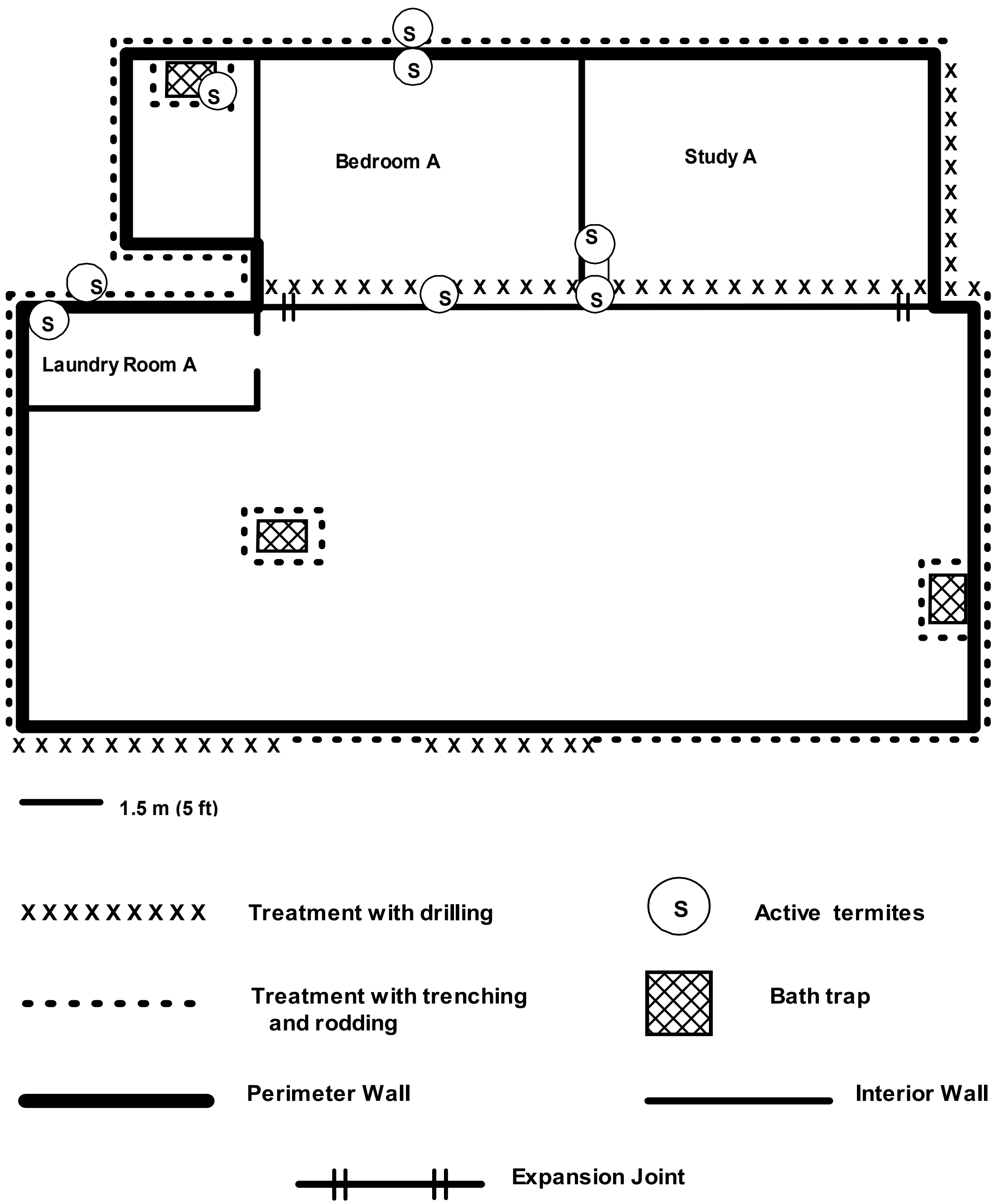
Treatment (0.06% fipronil exterior/interior) diagram for structure 4.

Interior areas of termite infestation included foraging tubes leading from the ground up a wooden post and across an exposed wooden rafter with exit holes in both pieces of wood.



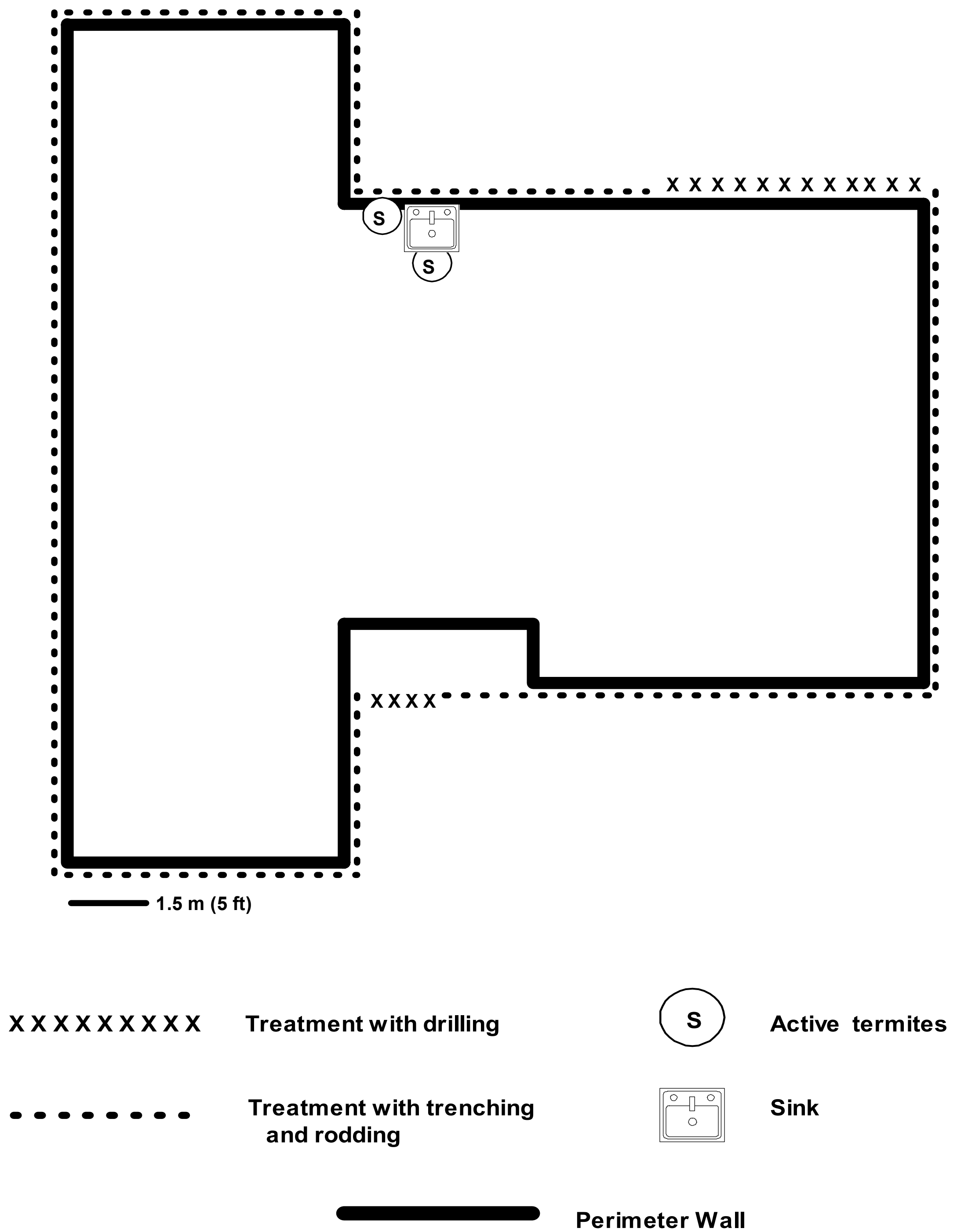
Treatment (0.06% fipronil exterior/interior) diagram for structure 5.

Interior areas of termite infestation included exit holes in two walls of bedroom A and wall of study A, exposed tunneling damage in laundry room A sheetrock, foraging tubes coming up expansion joint in bottom, left corner of study A, and termite foraging tubes on bath trap of bathroom adjacent to bedroom A.



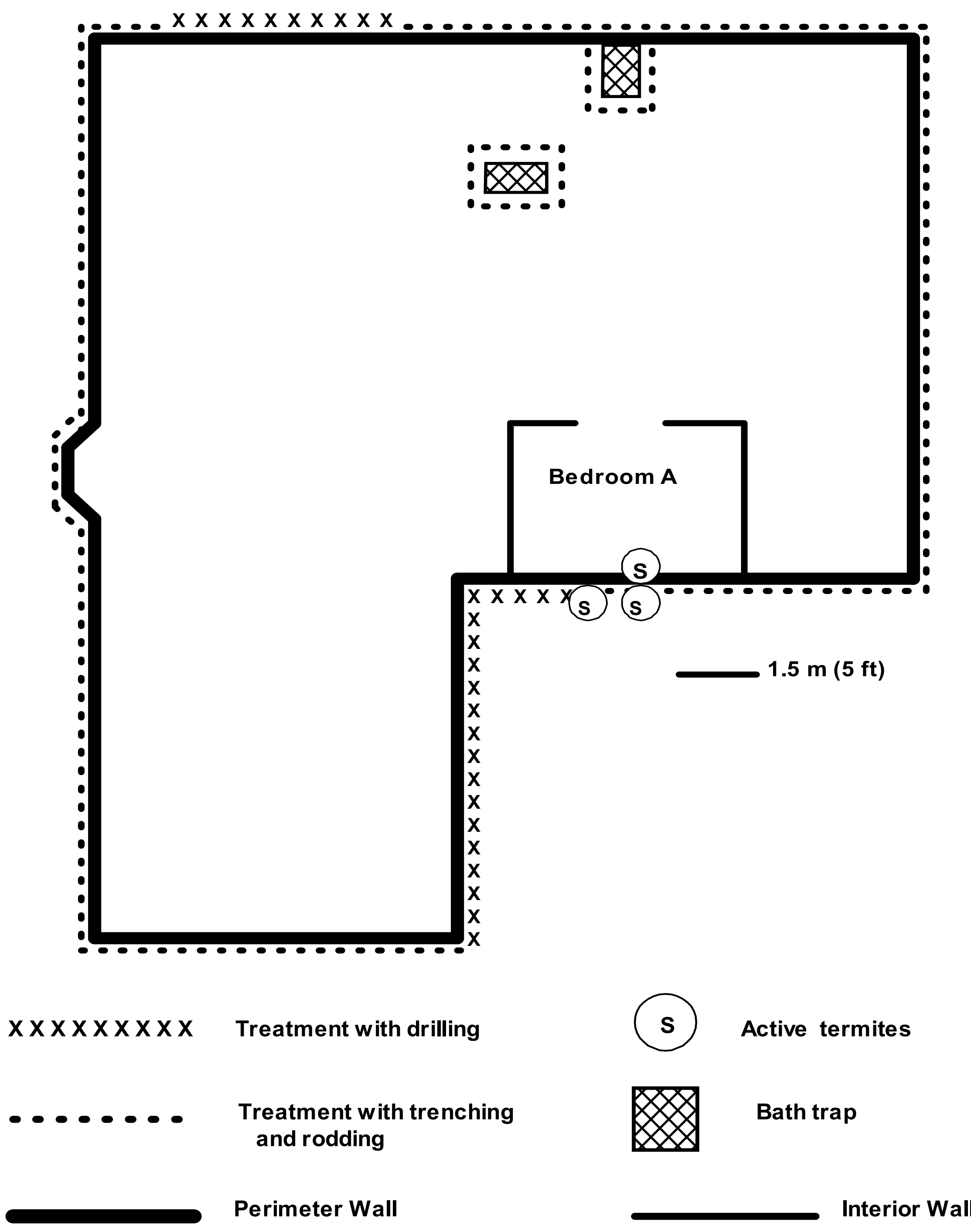
Treatment (0.06% fipronil exterior-only) diagram for structure 6.

Interior areas of termite infestation included extensive termite damage in the wood at the base of the cabinet under the sink and termite damage on a wooden post that is exposed in the wall in another lower cabinet directly to the right of the sink.



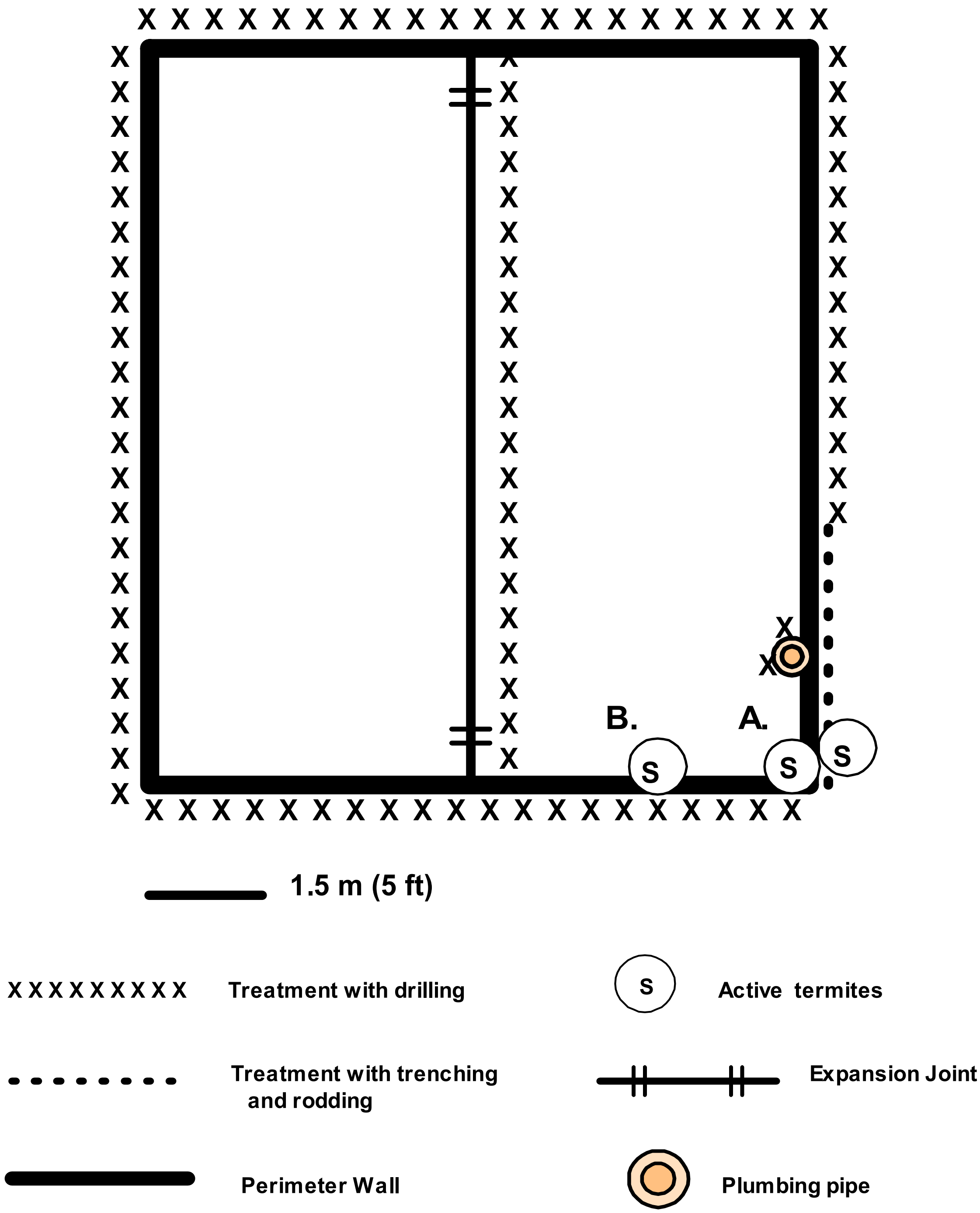
Treatment (0.06% fipronil exterior/interior) diagram for structure 7.

Interior area of termite infestation included exit holes and foraging tubes in window sill of bedroom A.



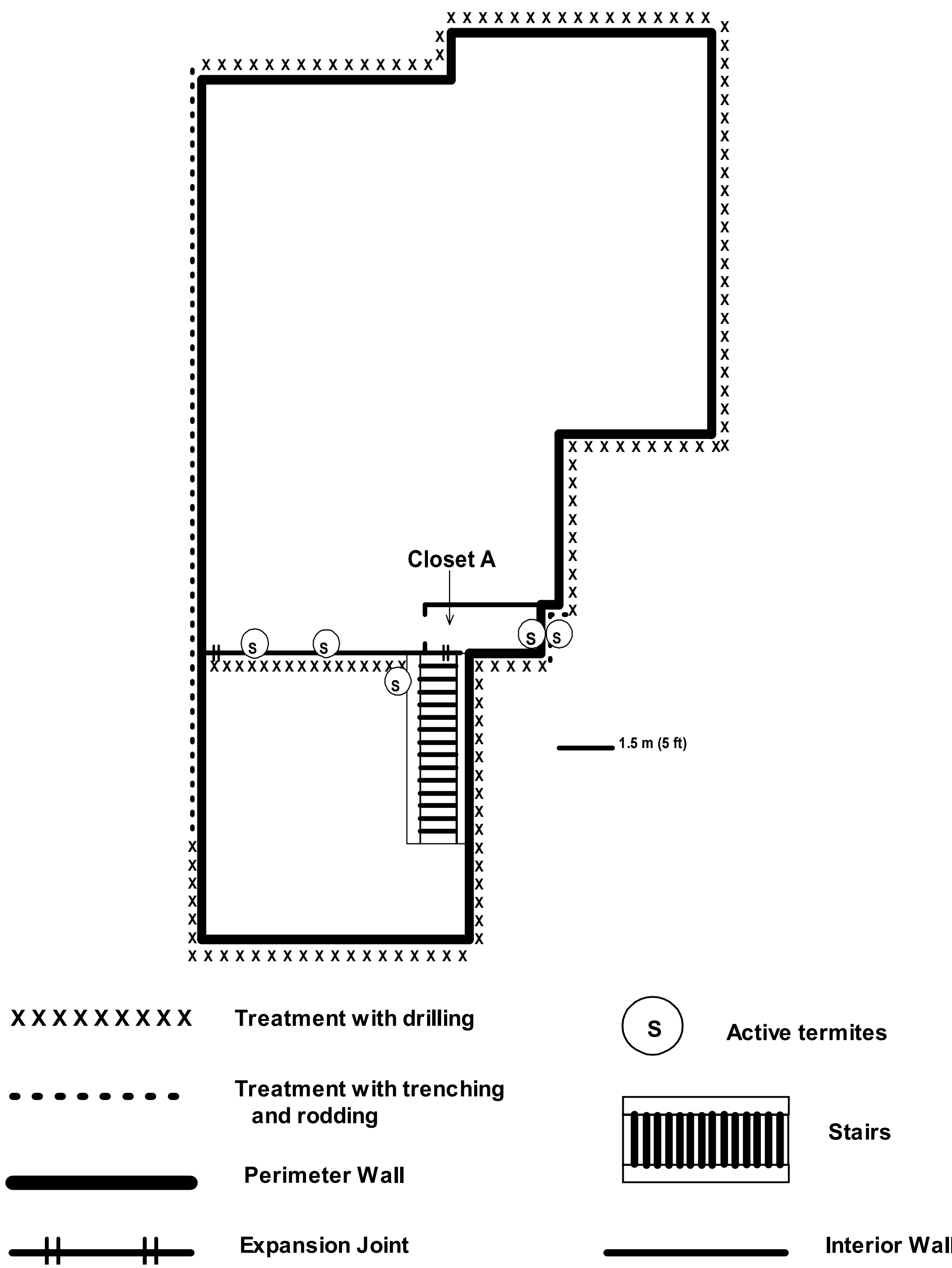
Treatment (0.06% fipronil exterior/interior) diagram for structure 8.

Interior areas of termite infestation included extensive tubing on the wall and ceiling originating from point A and exit holes in bedroom wall on second level above point B.



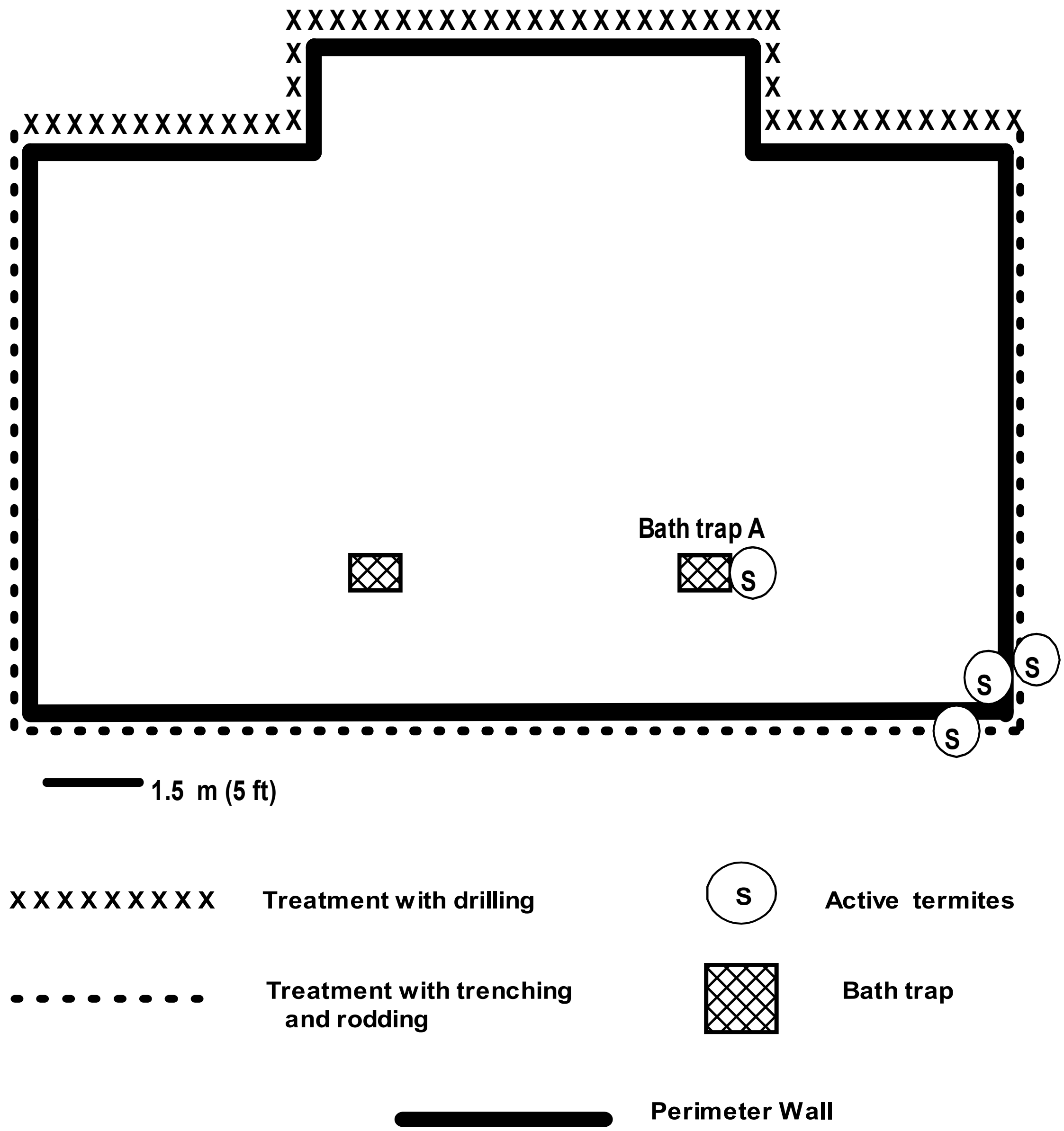
Treatment (0.06% fipronil exterior/interior) diagram for structure 9.

Interior areas of termite infestation included foraging tubes in closet A and extensive damage in the tile-covered wood floors in front of and under the stairs.



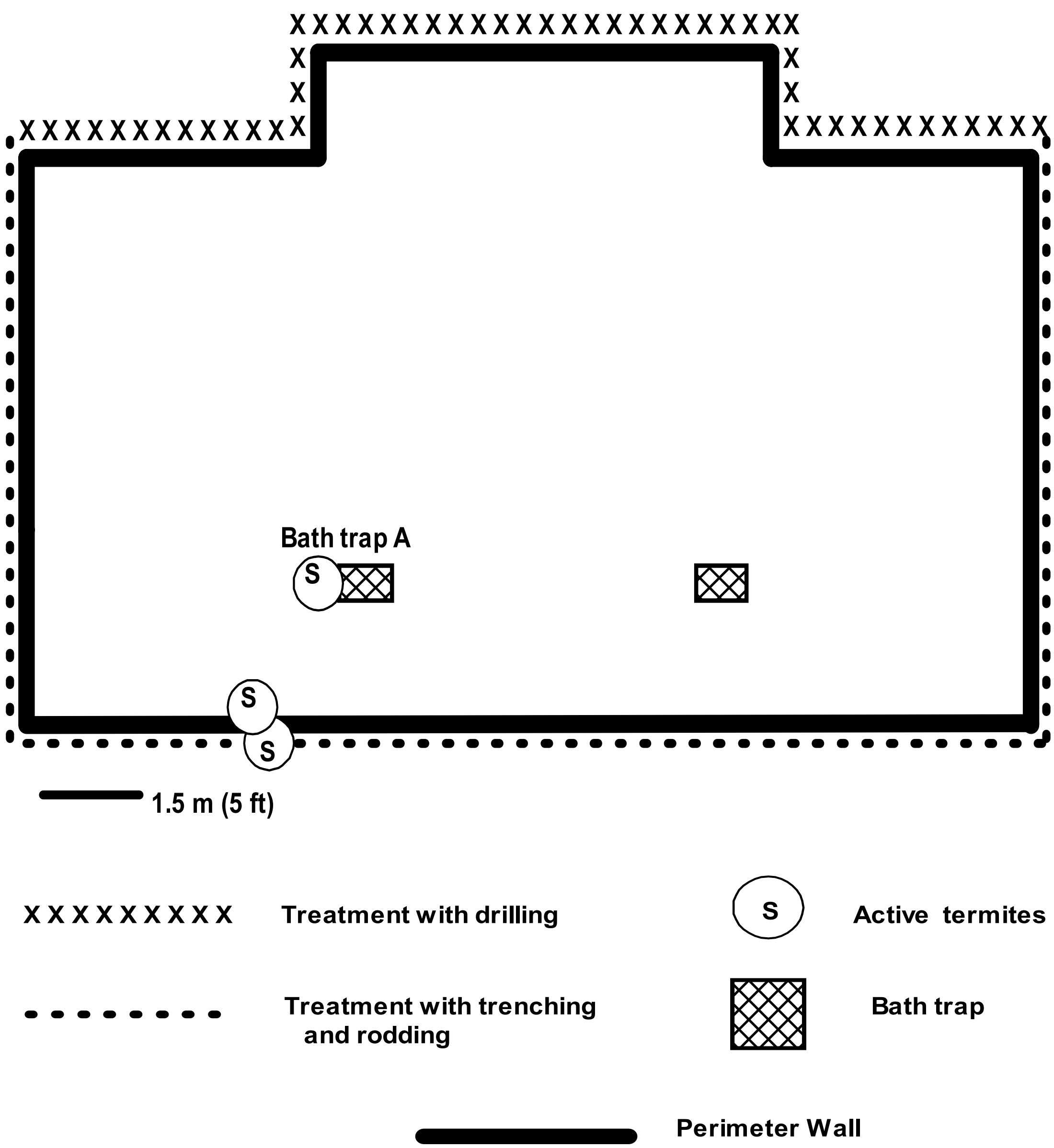
Treatment (0.06% fipronil exterior-only) diagram for structure 10.

Interior areas of termite infestation included exit holes and impressions in the wall under which termite tunneling had occurred. Later, swarmers were discovered coming from bath trap A.



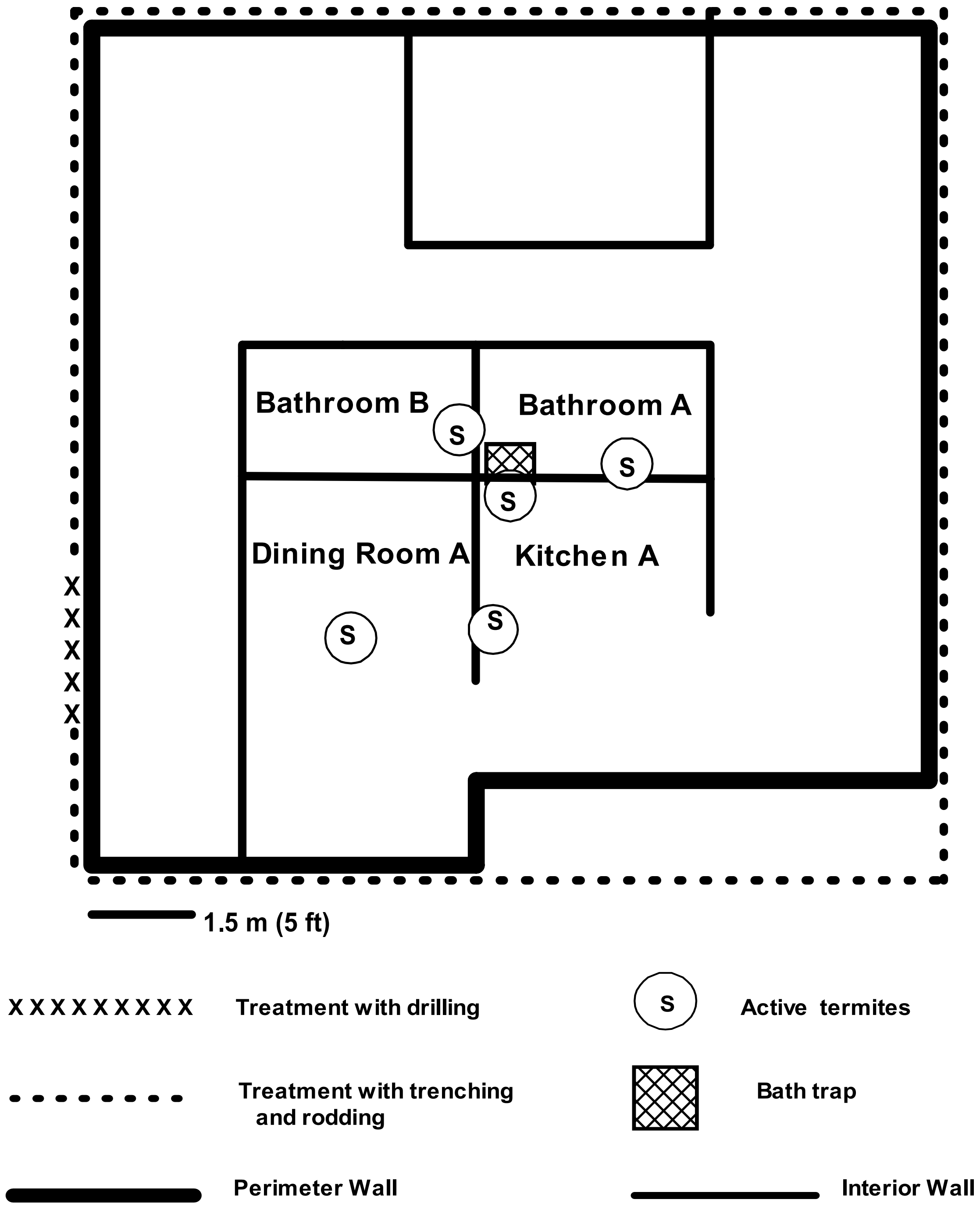
Treatment (0.06% fipronil exterior-only) diagram for structure 11.

Interior areas of termite infestation included exit holes in window sill. Later, swarmers were discovered coming from bath trap A.



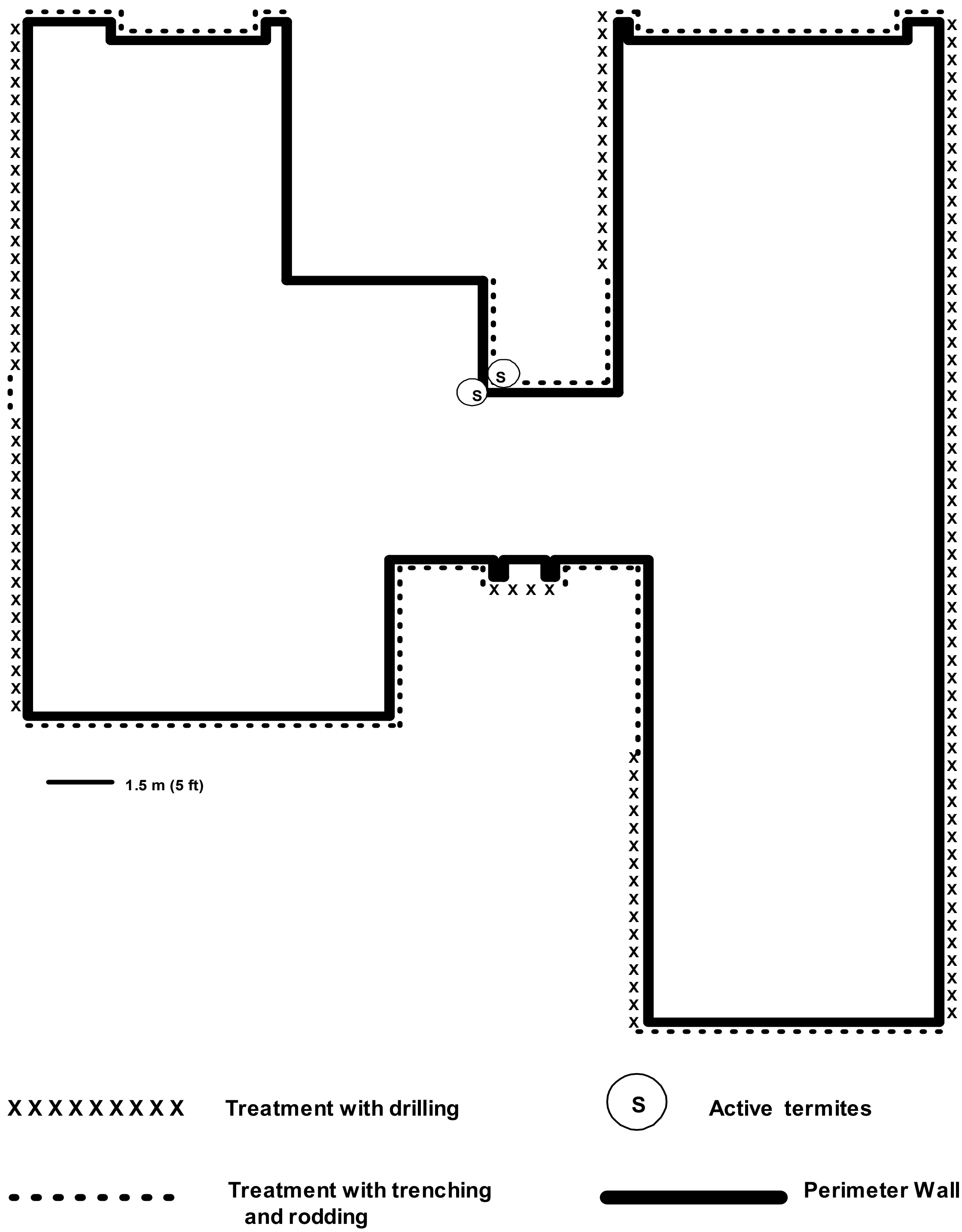
Treatment (0.06% fipronil exterior-only) diagram for structure 12.

Interior areas of termite infestation included large foraging tubes in the bath trap and exit holes on the wall in bathroom B, in a small towel closet in the wall of bathroom A, in the wall of kitchen A, and in the ceiling near a light fixture in dining room A.



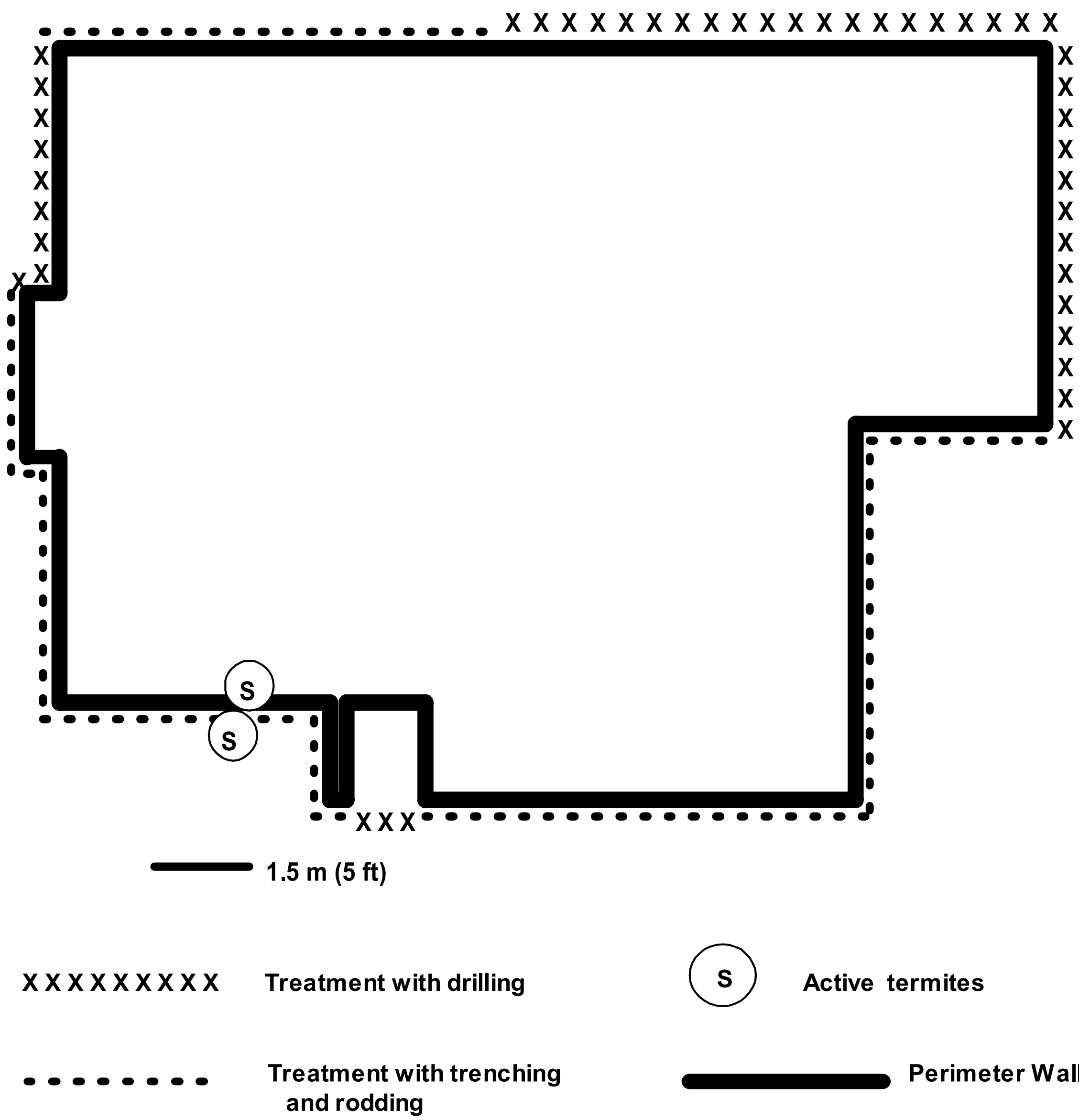
Treatment (0.06% fipronil exterior-only) diagram for structure 13.

Interior area of termite infestation included a foraging tube near the base of the wall and one forming from the ceiling down.



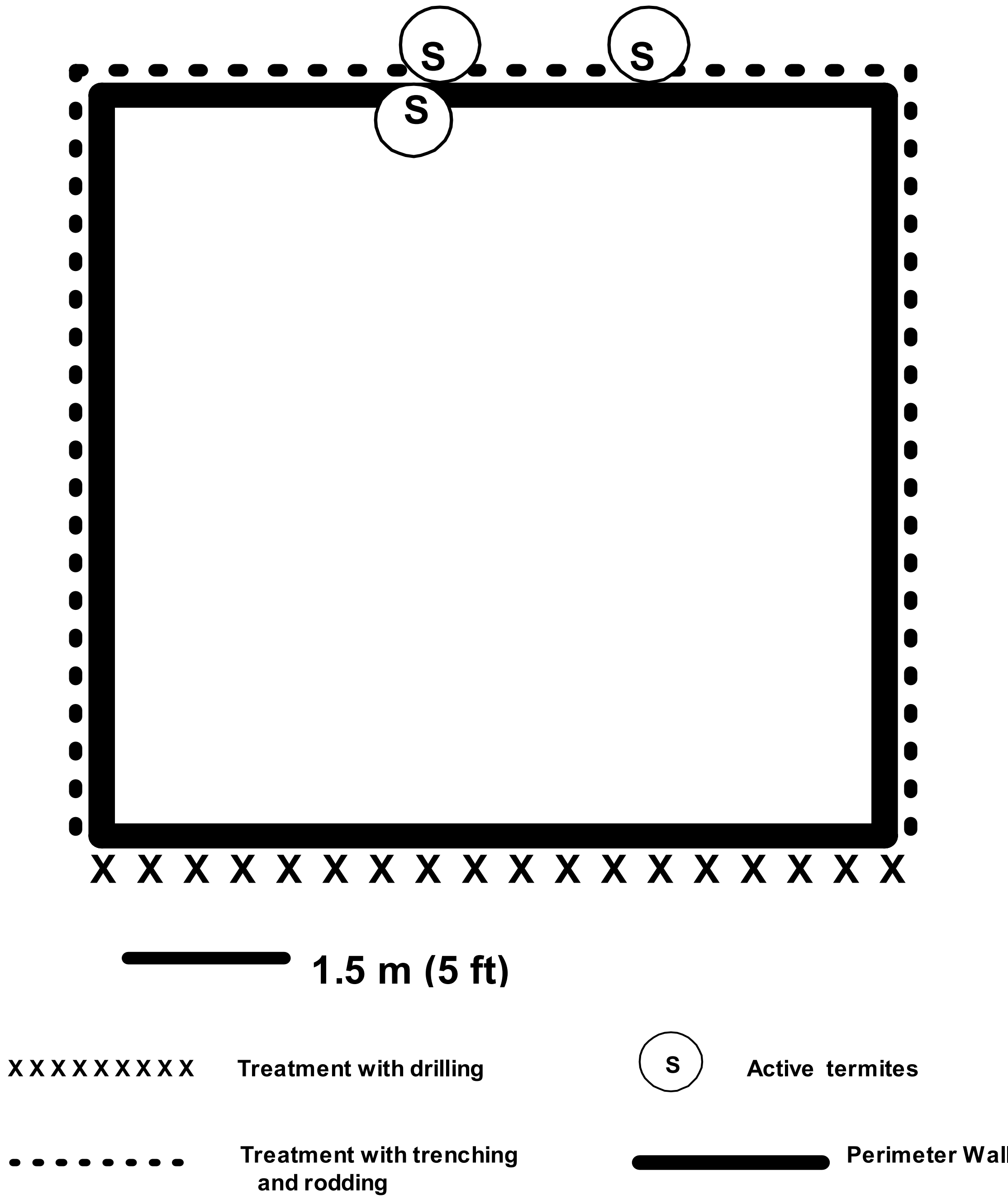
Treatment (0.06% fipronil exterior-only) diagram for figure 14.

Interior areas of termite infestation included visible damaged wood in window sill and base of wall.



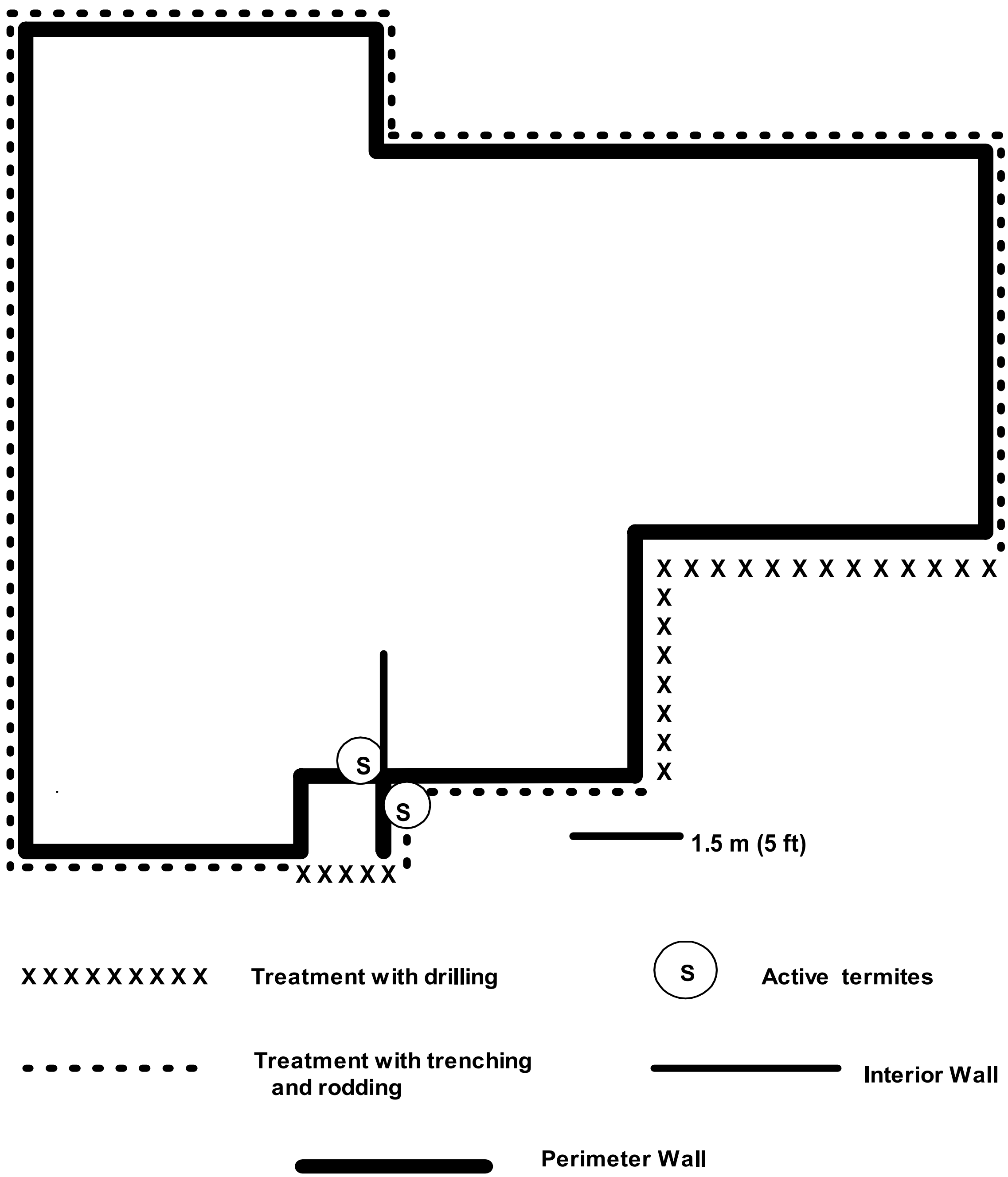
Treatment (0.06% fipronil exterior-only) diagram for structure 15.

Interior area of termite infestation included exit holes and foraging tubes at the base of the wall.



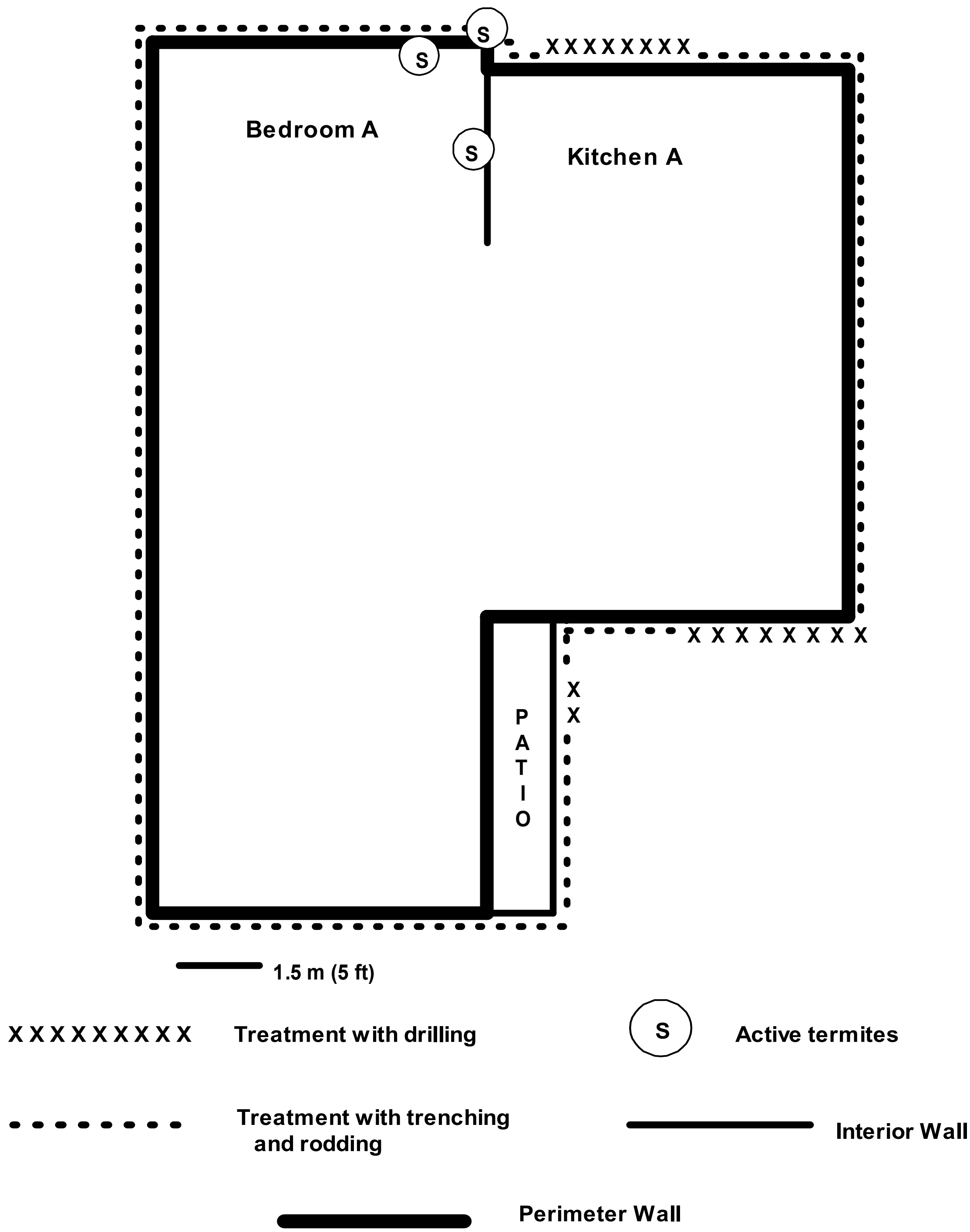
Treatment (0.125% fipronil exterior-only) diagram for structure 16.

Interior area of termite infestation included damaged wood in the doorframe and baseboards of the wall.



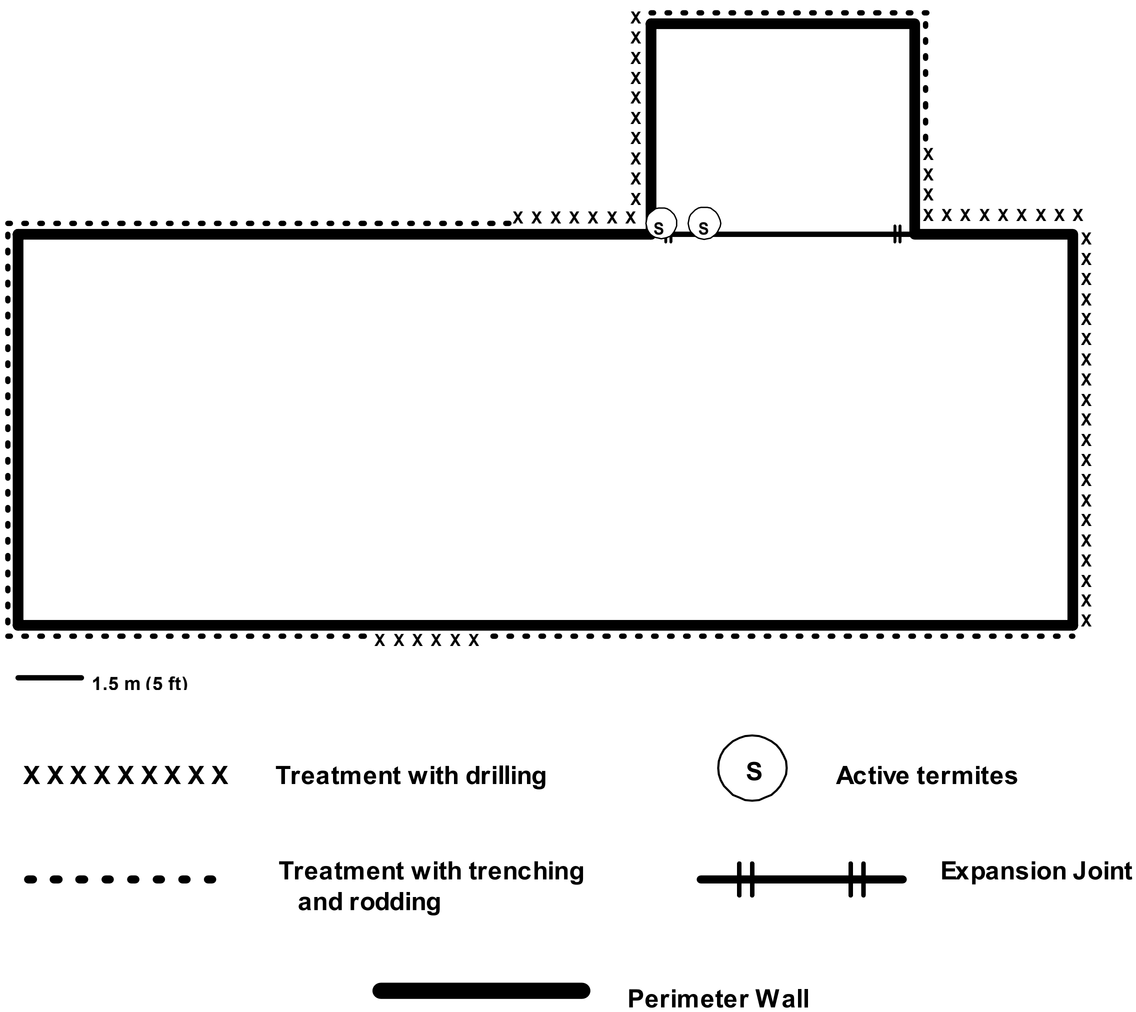
Treatment (0.125% fipronil exterior-only) diagram for structure 17.

Interior areas of termite infestation included exit holes at both locations with some exposed foraging trails in the wall between bedroom A and kitchen A.



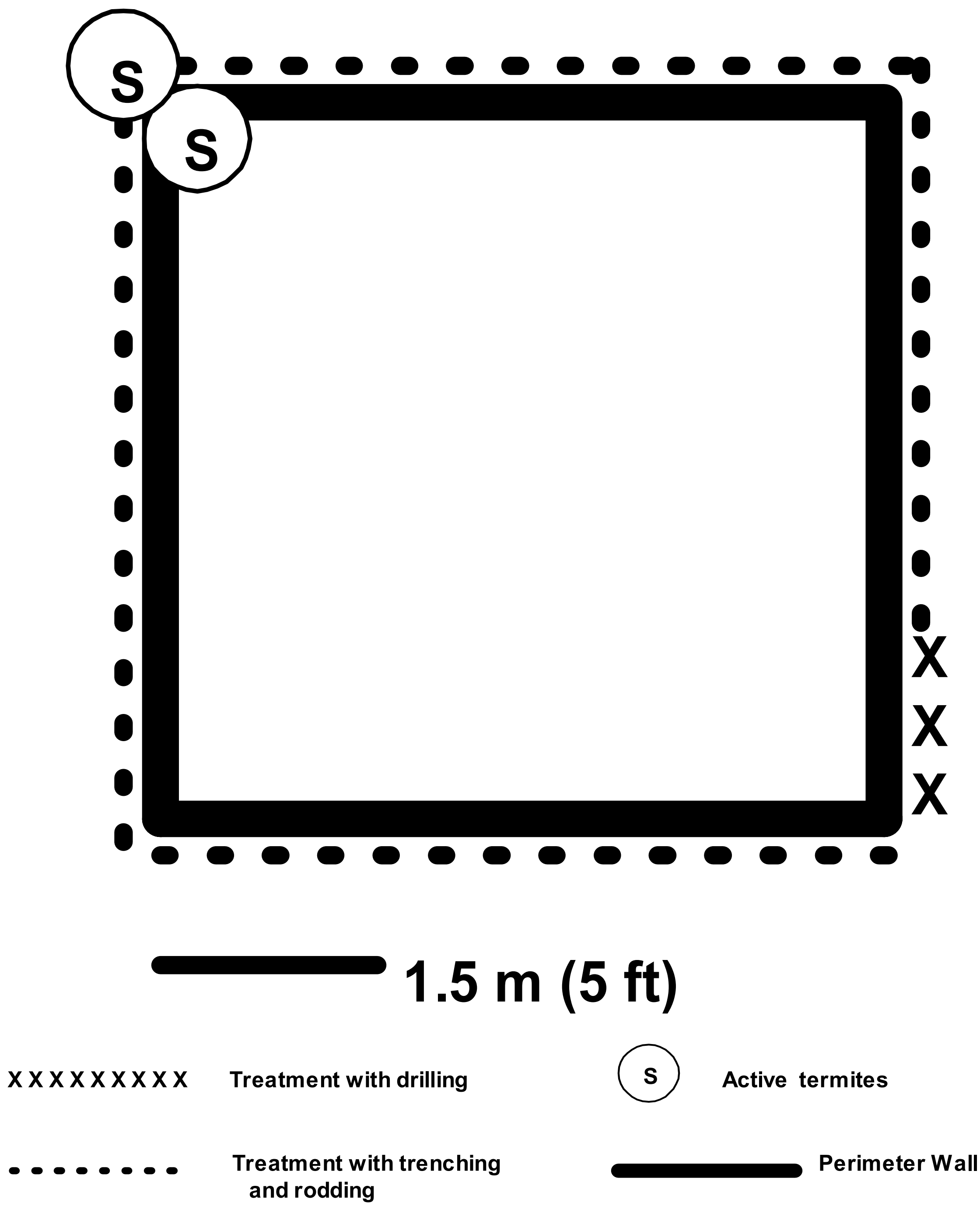
Treatment (0.125% fipronil exterior-only) diagram for structure 18.

Interior area of termite infestation included a doorframe lying directly over the expansion joint with visible tunneling damage behind wood paneling on both sides.



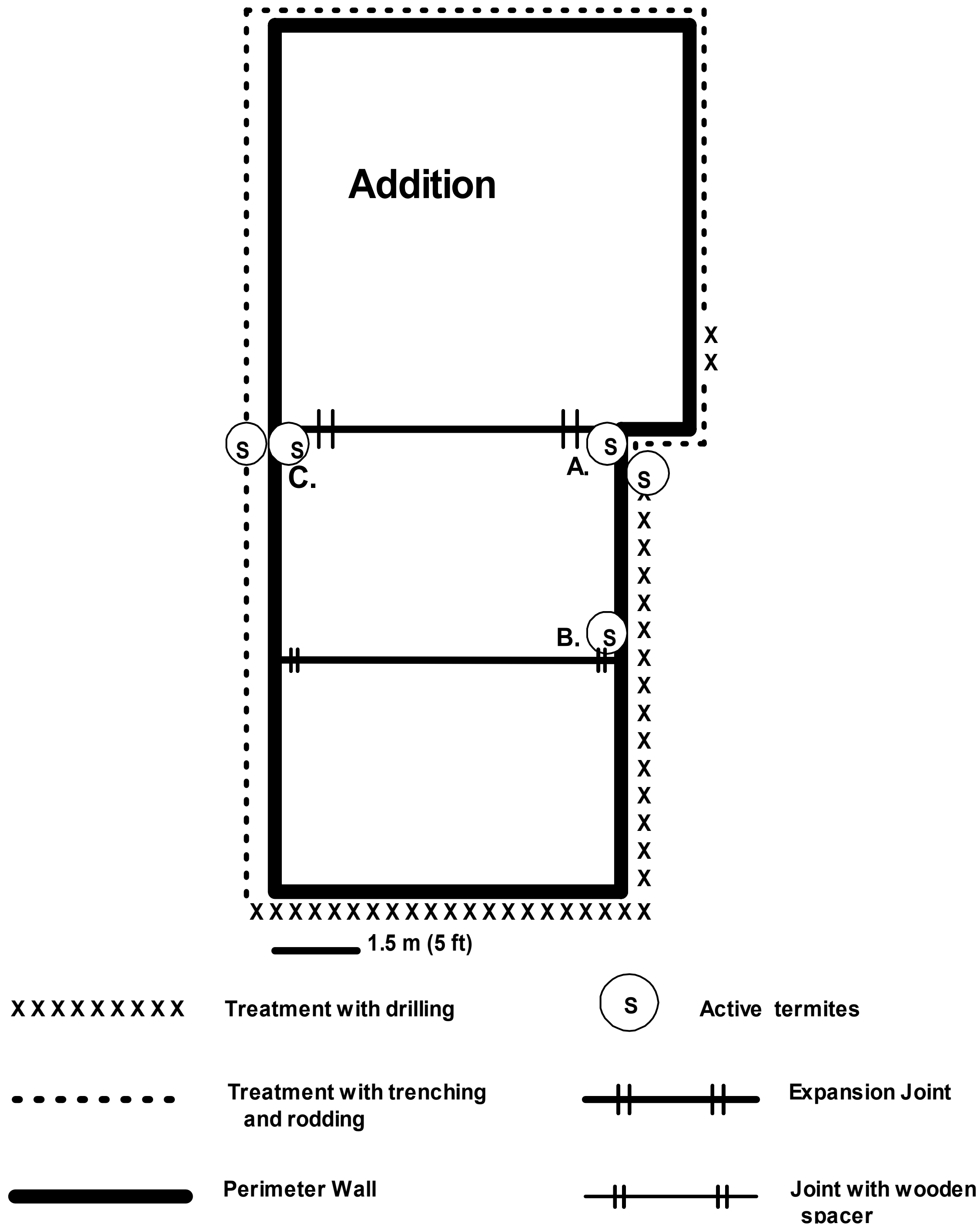
Treatment (0.125% fipronil exterior-only) diagram for structure 19.

Interior area of termite infestation included foraging tubes starting from the ground up to eye-level where about a square foot area had been hollowed out between the wall and a piece of soft wood put over it to organize tools.



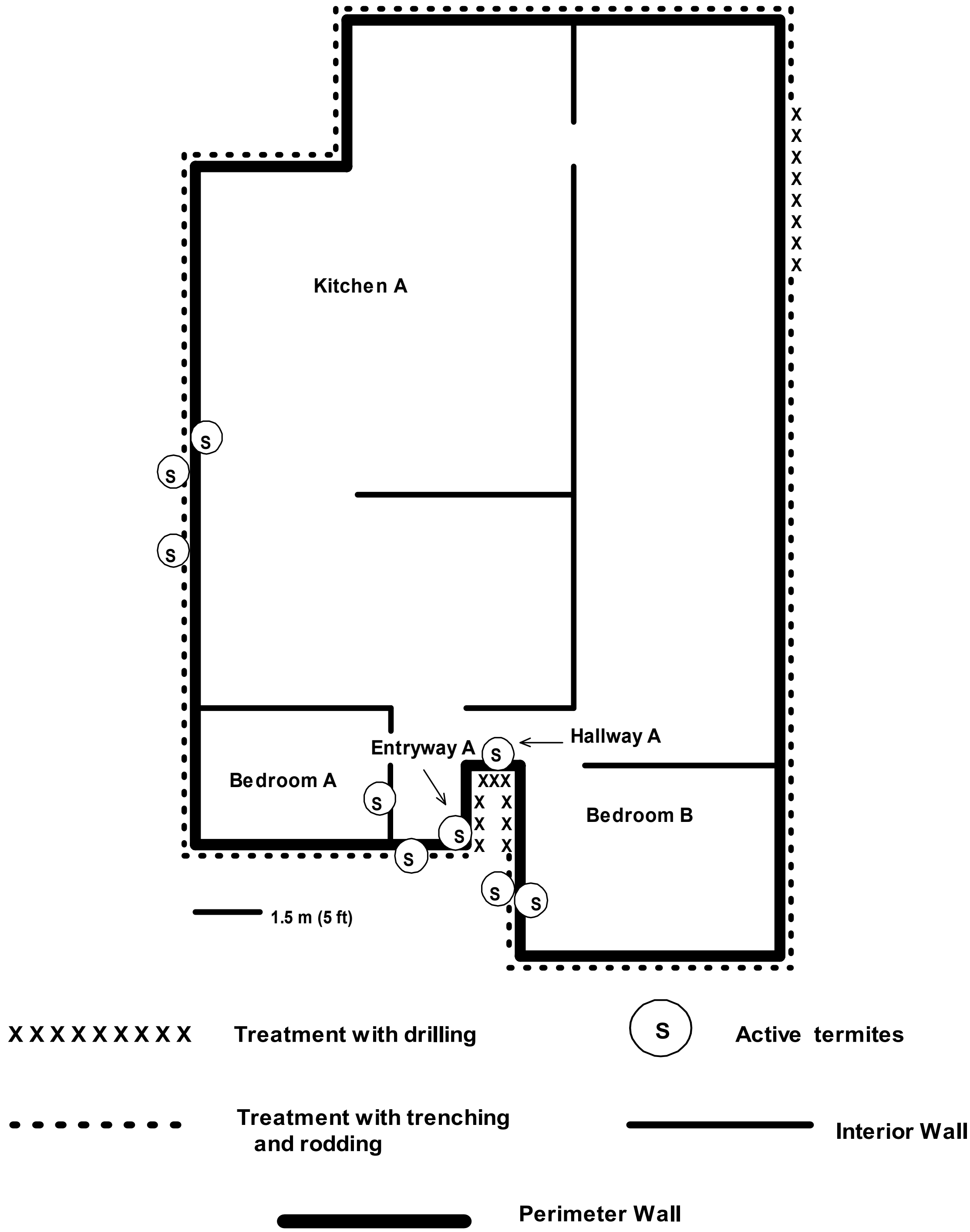
Treatment (0.125% fipronil exterior-only) diagram for structure 20.

Interior areas of termite infestation included foraging tubes on door at point A and foraging tubes and exposed damage on the wall at point B and C with damaged wood in the space between the joint stemming from point B.



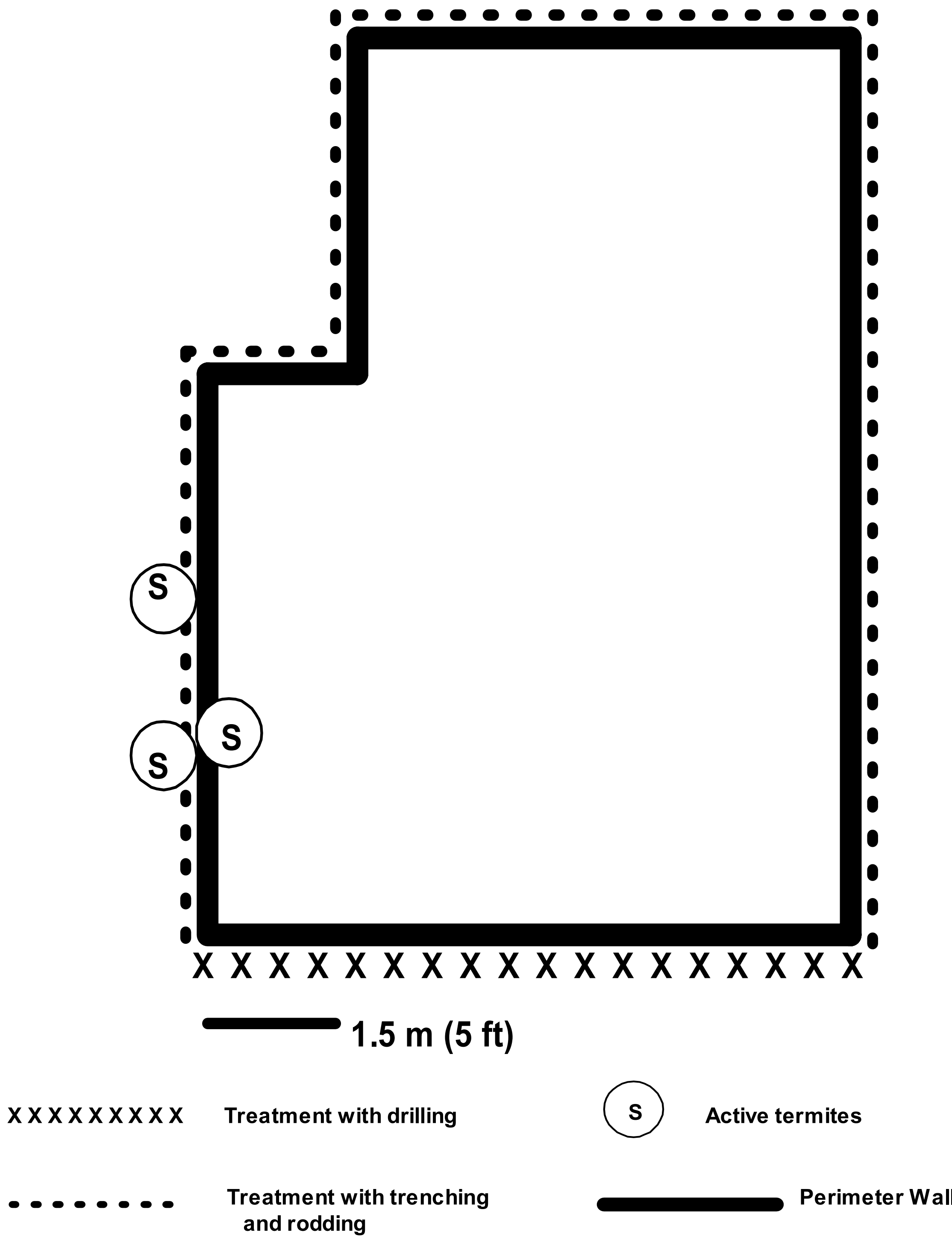
Treatment (0.125% exterior-only) diagram for structure 21.

Interior areas of termite infestation included exposed damage in baseboards in entryway A; exit holes on the wall in bedroom A, above the window sill in hallway A, and in the closet of bedroom B; and exposed holes in hardwood paneling of window sill in kitchen A.



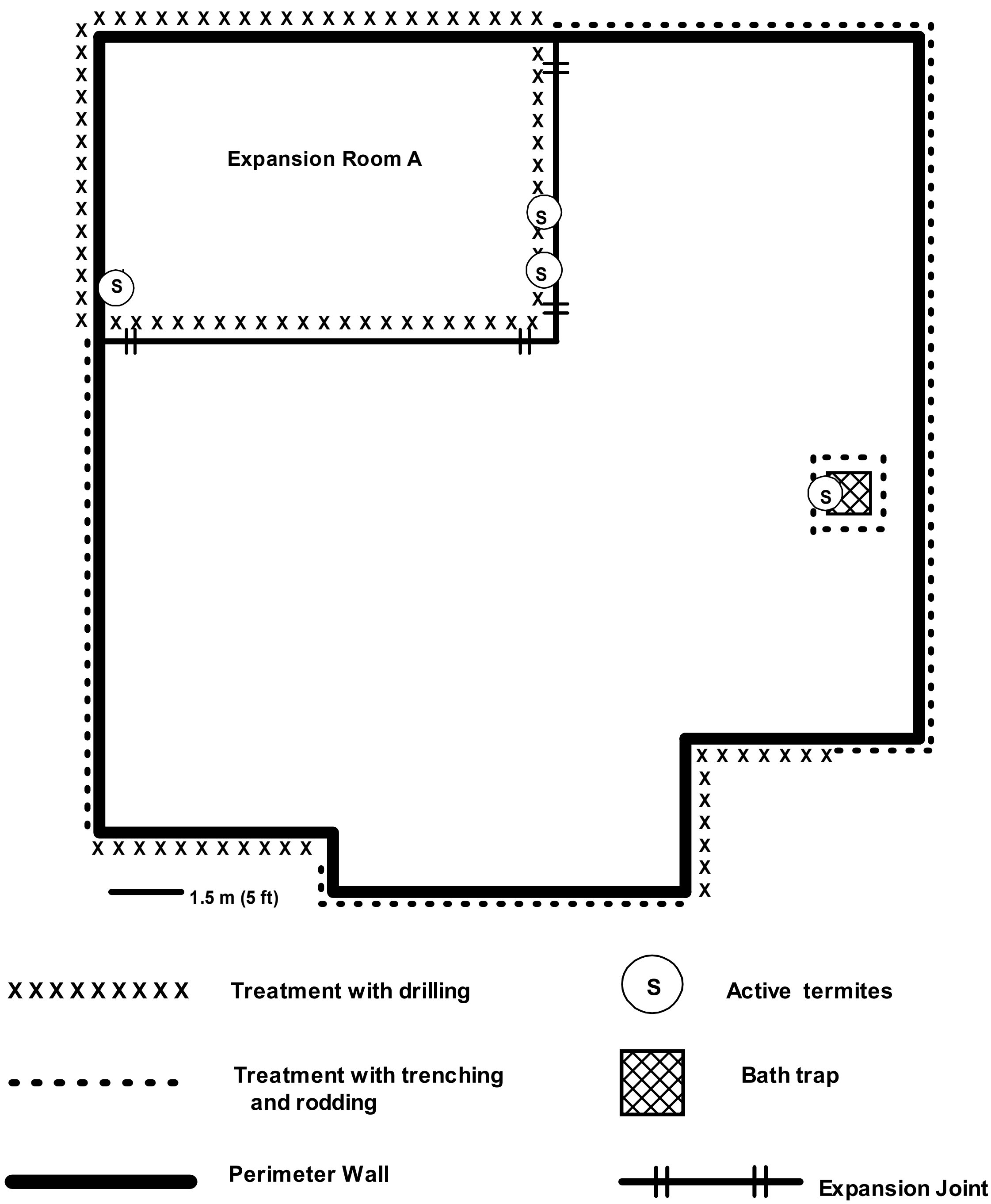
Treatment (0.125% exterior-only) diagram for structure 22.

Interior area of termite infestation included foraging tubes on wall.



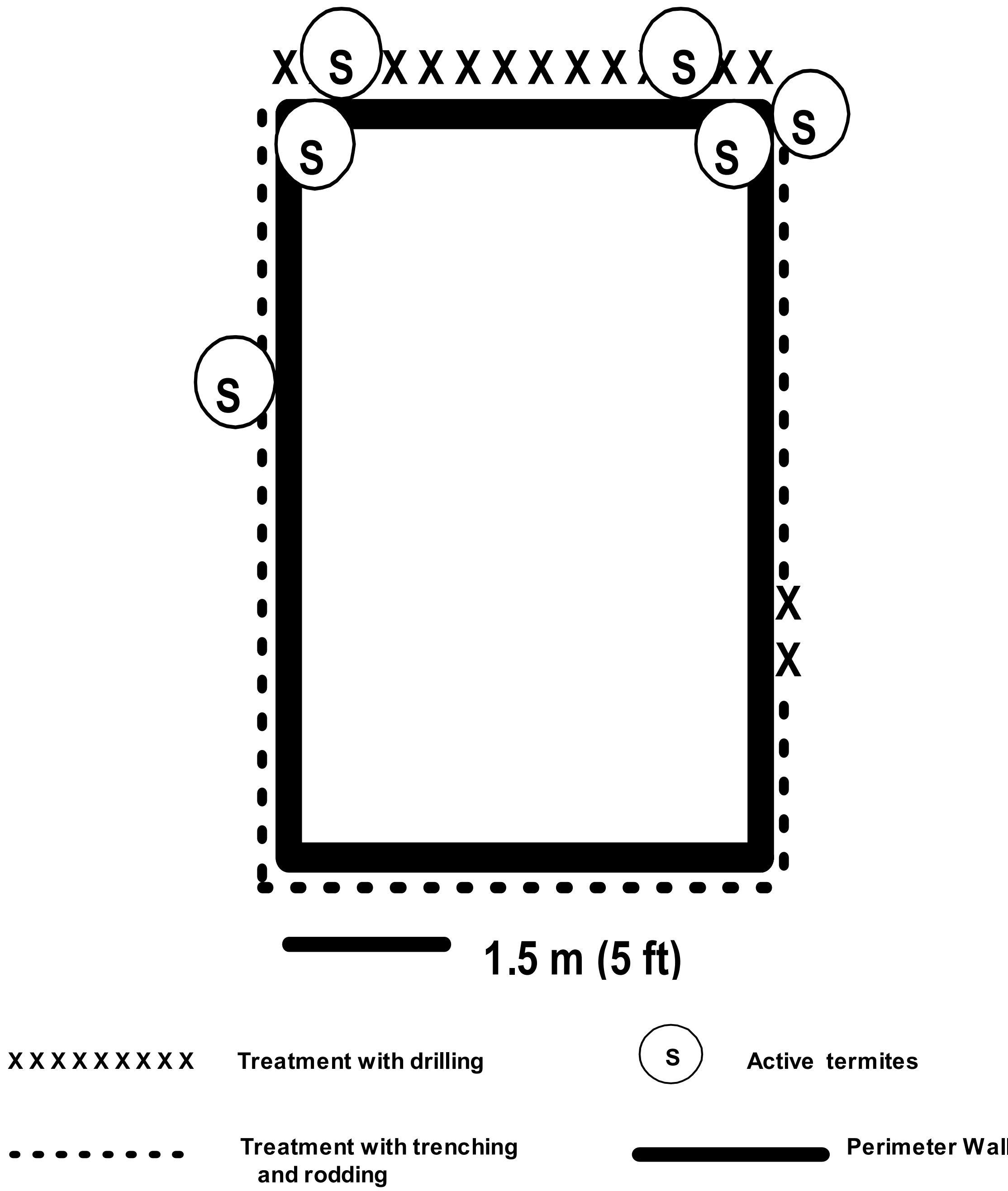
Treatment (0.06% fipronil exterior/interior) diagram for structure 23.

Interior areas of termite infestation include foraging tubes in bath trap and coming out of expansion joint on right side of expansion room A and exit holes near air conditioning unit on left side of expansion room A with exposed termite damage along about 3.66m of the baseboard.



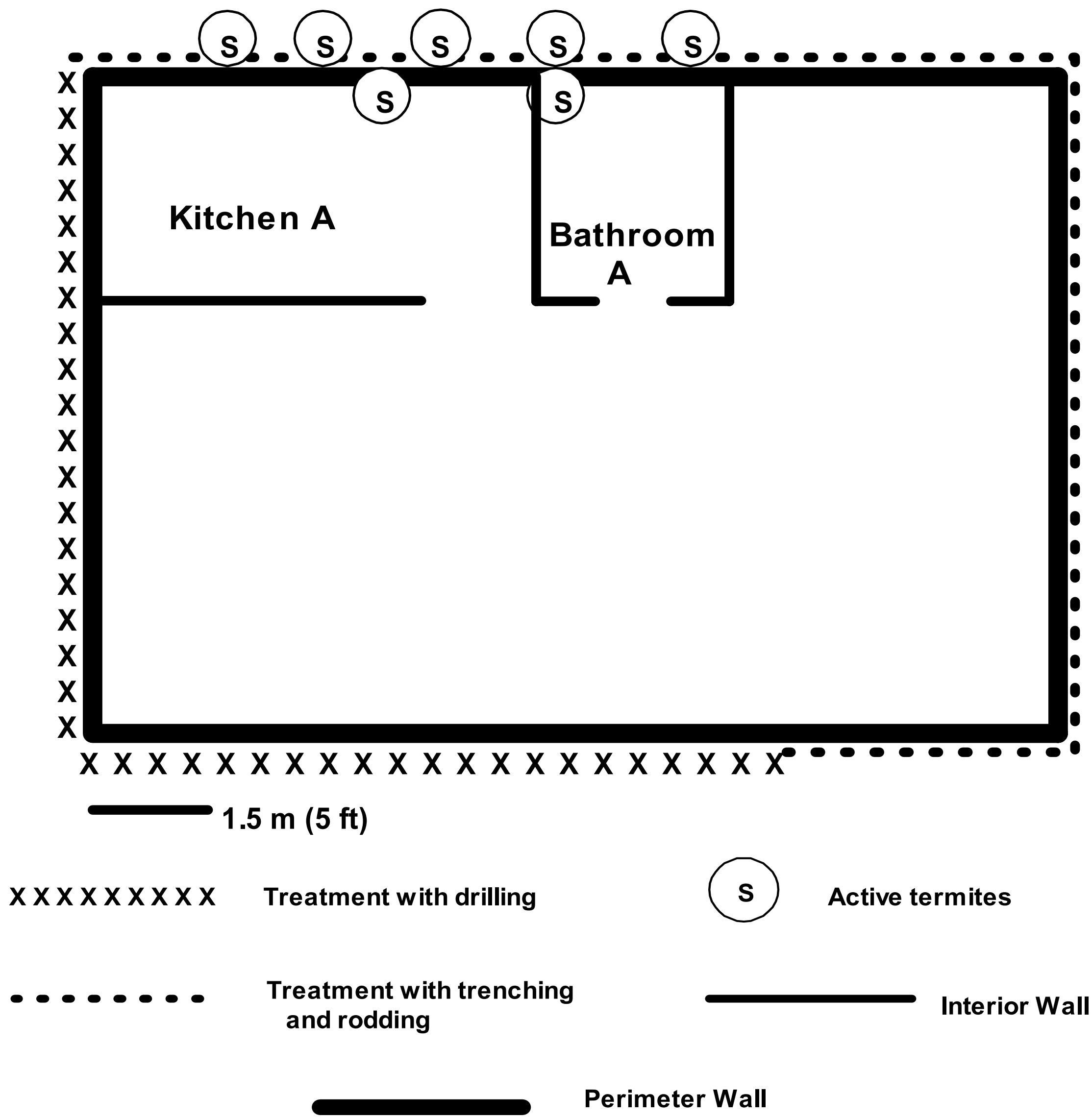
Treatment (0.125% fipronil exterior-only) diagram for structure 24.

Interior areas of termite infestation included foraging tubes in both directions from infested corners and exposed foraging trails in wall and ceiling with sheetrock lining damaged.



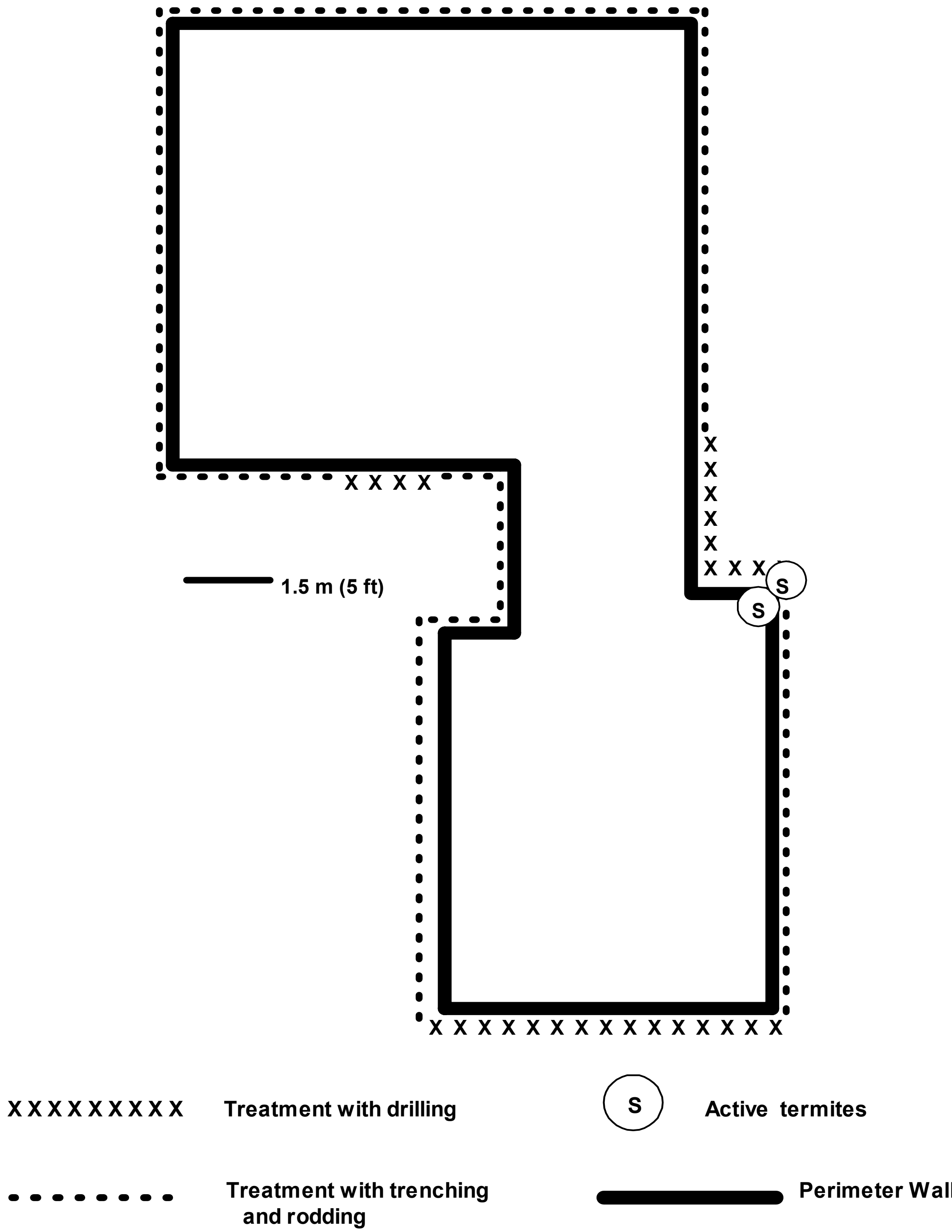
Treatment (0.125% fipronil exterior-only) diagram for structure 25.

Interior areas of termite infestation included foraging tube in doorframe of kitchen A and exposed termite damage above bathtub in bathroom A.



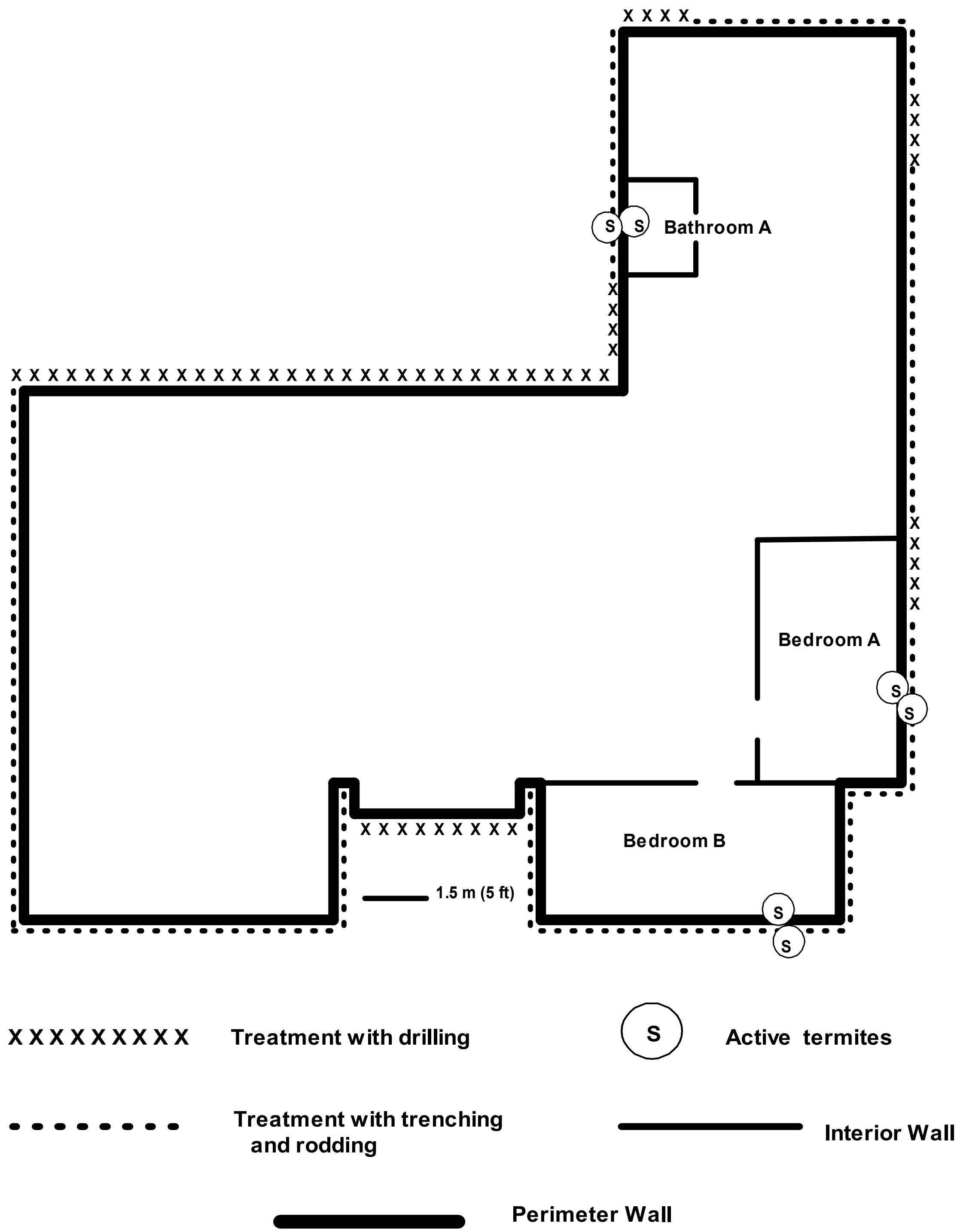
Treatment (0.06% fipronil exterior-only) diagram for structure 26.

Interior area of infestation included exit holes above kitchen sink.



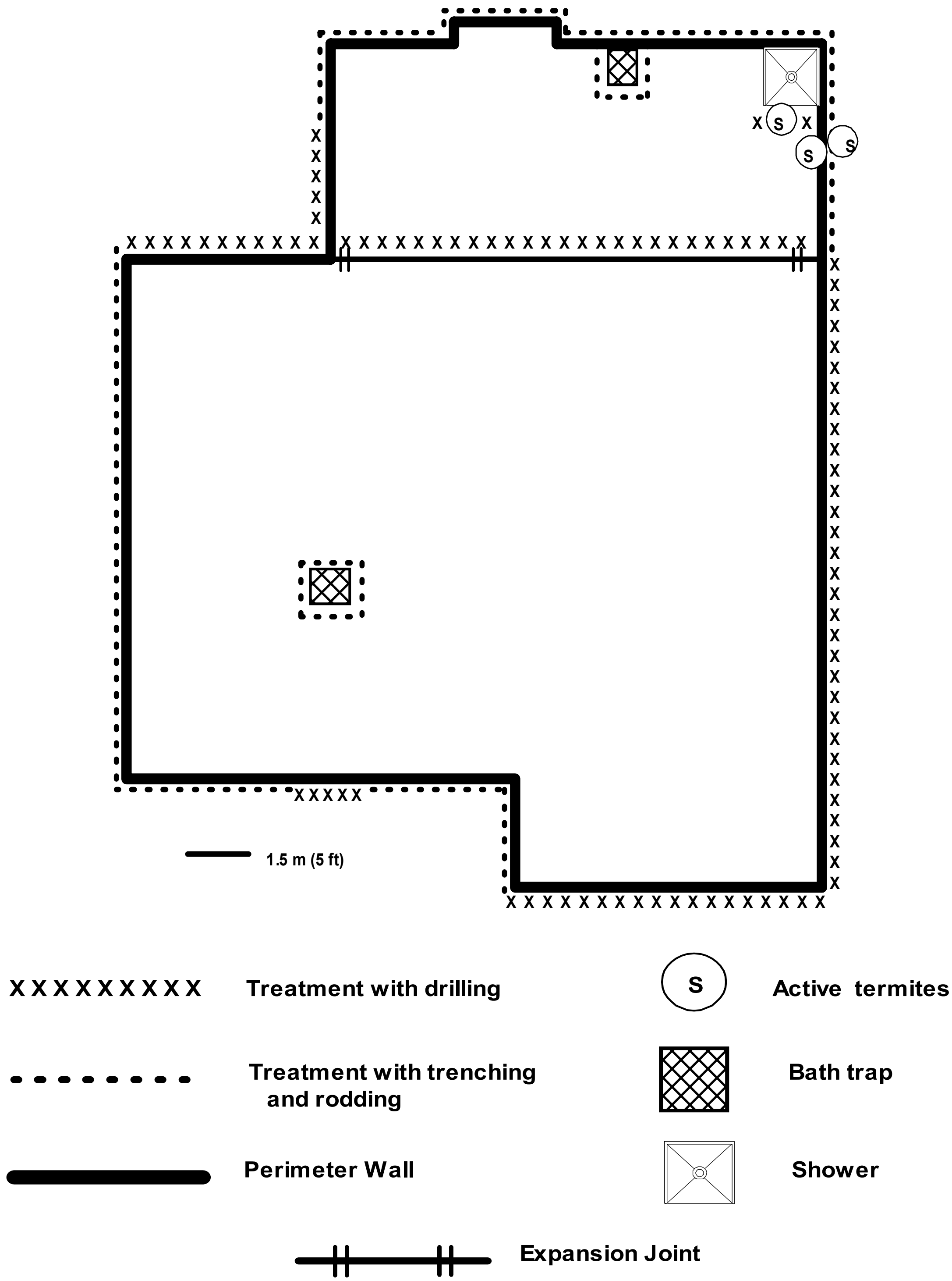
Treatment (0.06% fipronil exterior-only) diagram for structure 27.

Interior areas of termite infestation included exposed tunneling and exit holes in bathroom A above shower, and in wall of bedroom A and exit holes in window sill of bedroom B.



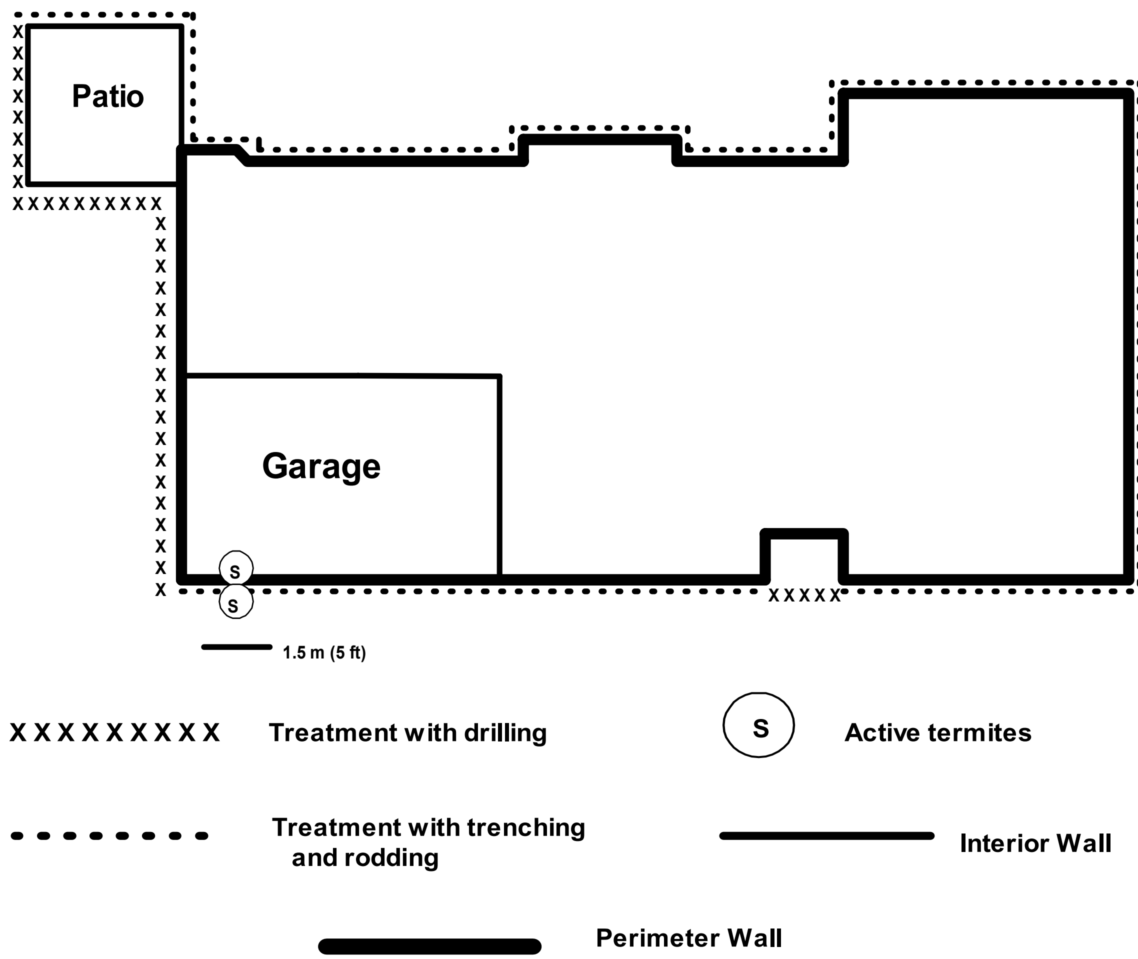
<u>Treatment (0.06% fipronil exterior/interior) diagram for structure 28.</u>

Interior areas of termite infestation included foraging tube on shower doorframe and exposed damage in baseboards along the wall.



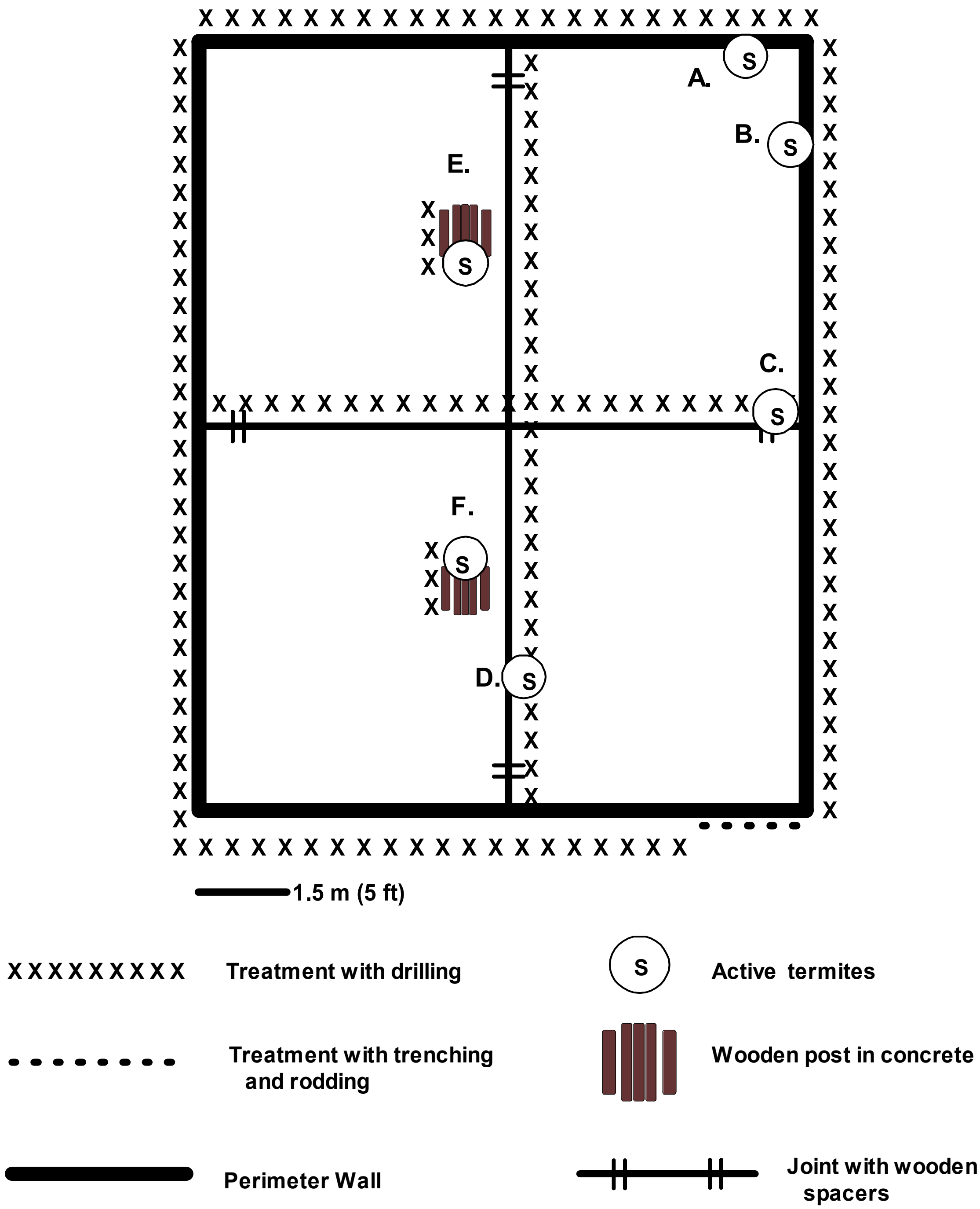
Treatment (.06% fipronil exterior-only) diagram for structure 29.

Interior areas of termite infestation included foraging tubes along base of wall and exposed tunneling galleries in wall and ceiling with damaged sheetrock lining.



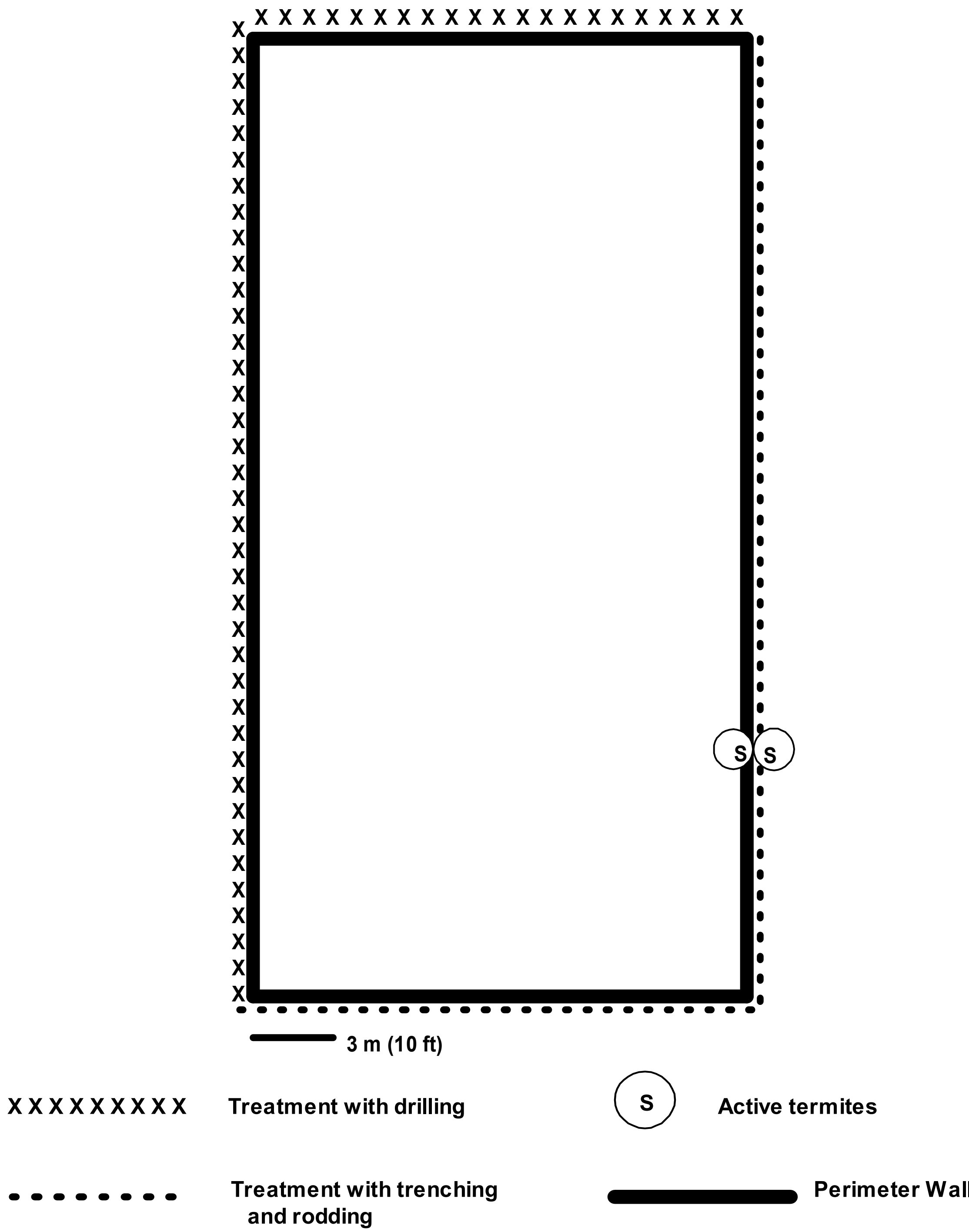
Treatment (0.06% fipronil exterior/interior) diagram for structure 30.

Interior areas of termite infestation included extensive, exposed damage to wood at points A, B, and C; foraging tubes and damage in the wood in joints at points C and D; and foraging tubes on outside of the posts at points E and F.



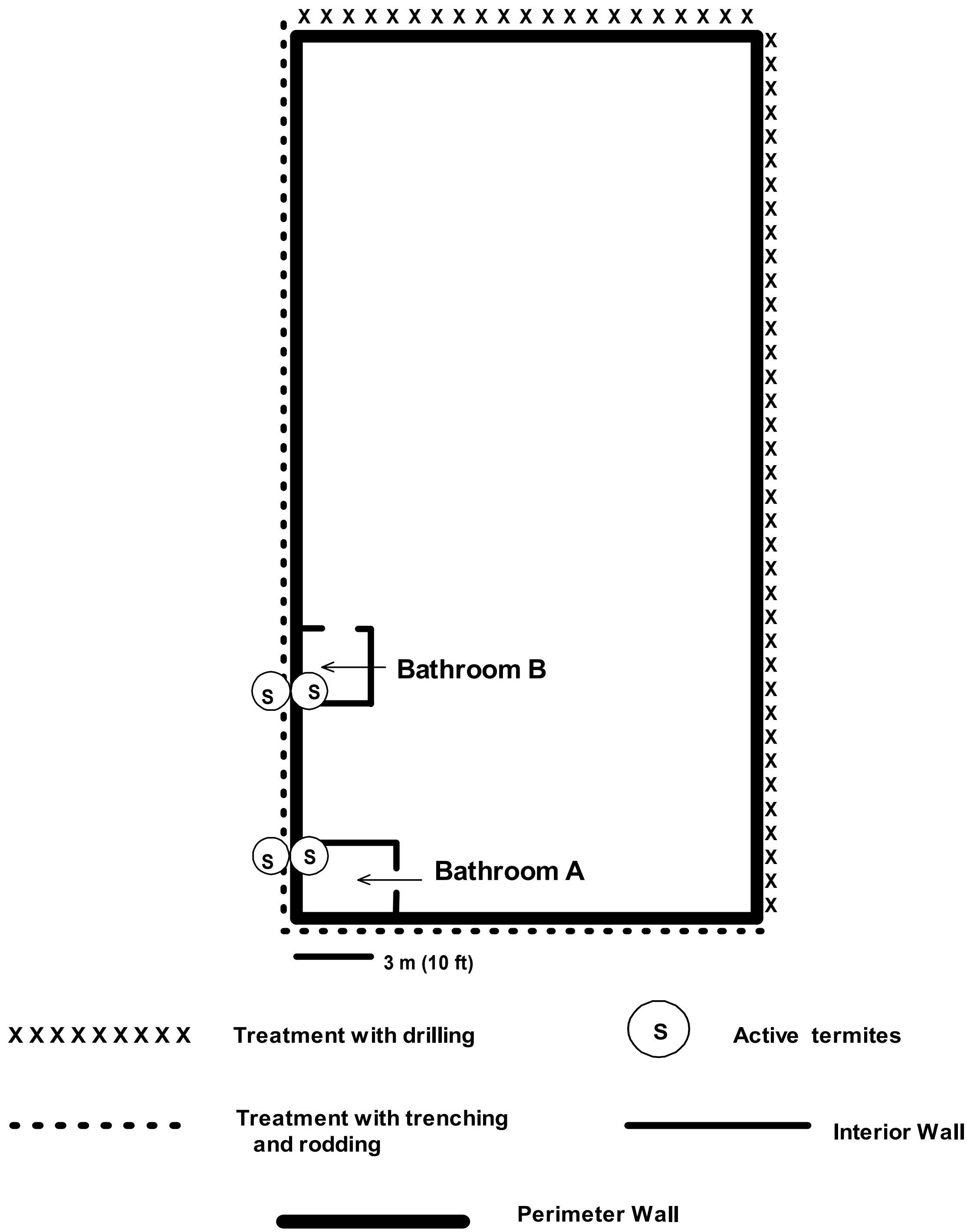
Treatment (0.125% fipronil exterior-only) diagram for structure 31.

Interior areas of infestation included foraging tubes on concrete leading to cardboard boxes and exit holes in wall.



Treatment (0.125% fipronil exterior-only) diagram for figure 32.

Interior areas of infestation include foraging tubes in window sill of bathroom A and visible damage at base of wall in bathroom B.



VITA

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