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# FEATURE

By DR. VERNARD LEWIS and MICHAEL HAVERTY

## Long-Awaited Nonchemical Alternatives to Drywood Termite Control Study Completed

The much anticipated University of California and USDA Forest Service study on alternatives to fumigation for drywood termite control has been completed. Five years in the making, the study created and built a garage sized building for tests, treated over 86,000 termites, and all at a cost of about \$200,000. The original 90 page report is available through the Structural Pest Control Board and University of California.

Thousands of letters and phone calls have been received from homeowners inquiring about the report. In addition, the results of this report are being used to support a lawsuit by the California Attorney General's Office alleging false and misleading claims against at least one pest control firm that uses one of the treatment methods tested. A referred scientific journal version of the report will appear in the *Journal of Economic Entomology* in August 1996. The information that follows is a more concise version of the state report and journal article.

### Background

For many years, the standard treatment for elimination of drywood termite infestations was fumigation with either methyl bromide or sulfuryl fluoride. The use of fumigants is considered a "whole-structure treatment" (for treating simultaneously all wooden members and extensive or difficult to reach infestations in structures). When properly applied, these toxic gases have been very effective in eliminating infestations of drywood termites throughout the treated structure. However, the public is showing increased interest in nonchemical approaches to insect control.

The list of nonchemical control methods presently marketed in California for control of drywood termites is growing and currently includes excessive heat, excessive cold,



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electrocution, and microwaves. Excessive cold, electrocution, and microwaves are "spot or localized" treatment methods (treatment often restricted to a single spot within a board or small group of boards). Whole-structure heating of homes comes closest to fumigation. Nonchemical methods have been proposed as replacements for fumigation for drywood termite control. However, there has been limited published research,

either in the laboratory or in the field, on any of the alternative control methods. Here we report the efficacy test results of two types of fumigation and four methods currently marketed as alternatives to whole-structure fumigation. We tested each method against two levels of effectiveness: 90 and 99 percent.

### Materials and Methods

**Villa Termiti.** To simulate field conditions, a mock-structure was built specifically for these tests of drywood termite control methods. The *Villa Termiti* is a 20 by 20 ft (400 ft<sup>2</sup>) building constructed of Douglas-fir lumber. This testing facility was designed to be symmetrical with doors and windows on all four sides and also contains an attic, "living space," and a subarea (Fig. 1). The exterior of the *Villa Termiti* consists of stucco walls and a shingle roof. There are no interior walls, insulation, or fire-blocking. However, the building does have electrical wiring and a nonfunctional waste-water plastic (ABS) pipe. The foundation consists of slabs in each corner and raised perimeter walls in the middle of each side.

**Preparation of Test Boards.** In this study, two types of infested materials were used: artificially infested and naturally infested boards. Termites placed in artificially infested boards were extracted from naturally infested wood (lumber, firewood, and grape prunings) containing drywood termites, *Incisitermes minor* (Hagen). For all tests, only healthy termites, primarily workers were used. In preparing artificial boards, kiln-dried, vertical grain, and clear Douglas-fir "1 by 4s," "2 by 4s," and "4 by 6s" were cut into 2-ft lengths. Three gallery spaces were routed into each board (Fig. 2). Since individual treatments may have varying penetration within wood, the exposure of individual galleries to treatment could be impor-

tant. Seventy-five drywood termites were placed within each board, 25 into each of the three routed galleries. With the exception of boards in the untreated group (used to determine robustness of termites prior to testing and handling mortality), no individual board was exposed to more than one treatment or used in more than one test. Naturally infested boards were determined to have active infestations of drywood termites before testing by using a hand-held acoustic emission detector (Wood-destroying Insect Detector®, DowElanco Indianapolis, IN).

**Placement in the Villa Termiti.** Depending on the test, whole-structure or spot-treatment, 48 or 24 artificially infested boards were installed in the test building. When possible, boards were installed throughout the test building, including the attic, living area, and subarea. However, for our tests of liquid nitrogen only the living area was treated. Another exception was made for our tests of microwaves where the subarea was not treated. Individual boards were randomly assigned to a location and position within the attic, walls, or subarea. For the installation of naturally infested boards, nine boards total,

three each were installed in the attic, living space, and subarea. Two drywall screws were used to affix boards (both artificially and naturally infested) to test locations.

**Vendor Cooperation.** The authors did not conduct any of the applications. Licensed commercial vendors were solicited for all applications in the *Villa Termiti*. Cooperation was voluntary. Listed below is a brief summary of methods tested and their application.

**Fumigant gases.** Sulfuryl fluoride, Vikane® fumigant gas (a licensed product of DowElanco), was one of the two fumigants used during the study. The *Villa Termiti* was treated three times with sulfuryl fluoride. The amount of sulfuryl fluoride used for each fumigation was 16, 5.1, and 5.5 pounds. Differences in the amounts of the fumigant used reflected the varying temperature and wind conditions for each day. All treatments were monitored with a fumiscope; readings (ppm) were taken in the attic, drywall, and subarea. The time of exposure for all treatments was 22 hours. Exact placement of test boards was not known to the vendor.

The second fumigant used during the study was CO<sub>2</sub>-synergized methyl bromide, employing the MAKR® Fumigation Process. The active ingredient of this gas is methyl bromide. To enhance the effects of the active ingredient and to minimize aeration time, carbon dioxide is added as a synergist. This synergized mixture allows a two-thirds reduction of the normal application rate: 24 oz per 1,000 ft<sup>3</sup> reduced to 8 oz per 1,000 ft<sup>3</sup>. The amount of carbon dioxide used is approximately 10 percent of the total cubic volume of structure treated. The *Villa Termiti* was fumigated three times with CO<sub>2</sub>-synergized methyl bromide. The amount of methyl bromide used was the same for each treatment (3 lbs) because this fumigant has only one dosage rate irrespective of climatic conditions. The amount of CO<sub>2</sub> used was 69 pounds. The time of exposure for all treatments was 22 hours. Exact placement of test boards was not known to the vendor.

**Heat.** The *Villa Termiti* was treated with heat three times. The tarpaulins used for treatments had several tears to allow air movement through the structure (hot air was continuously circulated through and out of

Table 1. Number of boards with live drywood termites and percent mortality of drywood termites (overall and within building location) in artificially infested boards treated in the Villa Termiti with 1 of 6 control methods<sup>a</sup>.

Treatment	n <sup>b</sup>	Boards w/live termite <sup>c</sup>	Mean% <sup>d</sup>	Location in building <sup>e</sup>		
				Attic	Drywall	Subarea
3-Day/4-wk Mortality						
Sulfuryl fluoride <sup>f</sup>	84	0/0	100/100**	100/100	100/100	100/100
CO <sub>2</sub> -MB <sup>f</sup>	84	0/0	100/100**	100/100	100/100	100/100
Excessive Heat <sup>f</sup>	83	10/10	96/98**	100/100	100/100	86/91
Liquid nitrogen <sup>g</sup>						
30 min@ 3 lbs/min	23	0/0	100/100**	INA	100/100	INA
15 min@ 2 lbs/min	24	3/3	98/99*	INA	98/98	INA
7 min@ 2 lbs/min	24	18/17	84/87	INA	84/84	INA
Electrocution <sup>g</sup>						
Test 1	48	48/40	44/81	26/75	54/85	41/79
Test 2	18	9/3	93/99*	99/100	86/96	95/100
Microwaves <sup>g</sup>	33	9/9	90/92	89/90	90/93	INA

a All percentages rounded up to nearest whole number except 99%. INA, inaccessible to treatment.

b Total number of test boards used during treatment.

c Number of test boards with live termites at 3 days and 4 wks ( / ) after treatment.

d \* = 90% and \*\* = 99% effective after 4 wks.

e Mortality for boards placed in the attic, drywall, and subarea at 3 days and 4 wks ( / ) after treatment.

f Whole-structure treatments.

g Spot- or localized treatments.

the *Villa Termiti*). Thermocouples were placed throughout the structure to record temperature changes. The number of thermocouples used varied with each test: 6 thermocouples were used during the first test, 10 for the second, and 11 for the third. Four convection heaters (each 400,000 BTUs), powered by propane, were positioned outside and hot air blown inside through flexible Mylar® ducts. The objective of heat treatment was to have the temperature of the coolest thermocouple, normally in a large wooden member or mudsill in the subarea, reach at least 120° F (Fahrenheit) and remain at that temperature for 30 min. Two 4.3-amp fans were positioned in the structure (subarea and drywall areas) to help distribute the heat throughout the structure. Exact placement of test boards was not known to the vendor.

**Liquid Nitrogen.** There was no vendor cooperation for this treatment method. All liquid nitrogen treatments in the *Villa Termiti* were applied by research personnel from the University of California, Berkeley and

Riverside. Since this is a spot-treatment technique, knowledge of the location of test boards in the *Villa Termiti* was made known to personnel applying the treatments. Optimal performance of liquid nitrogen requires an enclosed void space for containment of the liquid and vapor. A 0.5-inch diameter hole was drilled through the drywall near the top plate of the void space being treated. Liquid nitrogen was then injected from 42 gallon dewars into the wall cavity through a 4-foot, flexible, woven, stainless steel hose. The temperature inside the dewar may be lower than -320° F.

In our tests we attempted to have a constant amount of liquid nitrogen delivered to each wall void. We calibrated the time it took to deliver a standard dose. In the first test, we delivered liquid nitrogen for approximately 30 min @ 3 lbs/min into each 0.5 by 1 by 7.3 ft wall void (13 separate wall voids were used during tests). In the second test, we delivered slightly less than one-half and the third test one-fourth the rate applied during the first test (2 lbs/min for either 15 min or 7 min). A scale was used to determine pre- and post-application weights of liquid nitrogen. Twelve thin-wire thermocouples were

also used to monitor temperature changes within studs and test boards in wall voids of the *Villa Termiti*. Temperature readings were taken every minute from 12 different locations in "2 by 6-inch" studs and test boards for each corner of the building undergoing treatment.

**Electrocution.** The equipment used is commercially marketed as the Electrogun®, a device that kills drywood termites by emitting high frequency electricity (100 kHz), high voltage (90,000), but low current (<1 amp). For exposed "2 by 4s" and smaller pieces of wood, the probe end of the device was placed against the wood surface. For larger pieces of wood and wood concealed behind walls, a "drill-and-pin" method was used.

For the "drill-and-pin" method (0.06 inch diameter) holes through the drywall and into the wood. Approximately 6-inch long, straight copper wires were inserted into the holes and into the termite galleries. Several consecutive drillings per hole were used to insure that the electrical current was delivered at various depths within the boards.

An additional and different test in the *Villa Termiti* was requested by the Etex Corpora-

Table 2. Number of boards with live drywood termites and percent mortality of drywood termites (overall and within building location) in naturally  $\Delta\Delta$  infested boards treated in the *Villa Termiti* with 1 of 6 control methods<sup>a</sup>.

Treatment	n <sup>b</sup>	Boards w/live termite <sup>c</sup>	Mean% <sup>d</sup>	Location in building <sup>e</sup>		
				Attic	Drywall	Subarea
3-Day/4-wk Mortality						
Sulfuryl fluoride <sup>f</sup>	15	1	99**	100	99	100
CO <sub>2</sub> -MB <sup>f</sup>	17	1	99**	100	100	99
Excessive Heat <sup>f</sup>	18	0	100**	100	100	100
Liquid nitrogen <sup>g</sup>						
30 min@ 3 lbs/min	8	0	100**	INA	100	INA
15 min@ 2 lbs/min	9	2	88**	INA	99	INA
7 min@ 2 lbs/min	9	5	74	INA	74	INA
Electrocution <sup>g</sup>						
Test 1	9	8	89	93	88	85
Test 2	8	5	95*	99	92	95
Microwaves <sup>g</sup>	9	3	99*	INA	99	INA

<sup>a</sup> All percentages rounded up to nearest whole number except 99%. INA, inaccessible to treatment.

<sup>b</sup> Total number of test boards used during treatment.

<sup>c</sup> Number of test boards with live termites at 3 days and 4 wks ( / ) after treatment.

<sup>d</sup> \* = 90% and \*\* = 99% effective after 4 wks.

<sup>e</sup> Mortality for boards placed in the attic, drywall, and subarea at 3 days and 4 wks ( / ) after treatment.

<sup>f</sup> Whole-structure treatments.

<sup>g</sup> Spot- or localized treatments.

tion because they felt the conditions of the first test produced results biased against the Electrogun®. They were concerned about proximity of test boards to metal (wire-mesh in stucco and metal support bars in detachable walls) and to concrete in the foundation of the subarea. They felt the performance of the Electrogun® would be improved if tested against infested boards in locations without interfering metal or concrete. For the second electrocution test, 18 artificially

infested boards and 9 naturally infested boards were installed in locations away from sources of metal and concrete. For both tests in the *Villa Termiti*, the location of test boards behind drywall was revealed to the vendor.

**Microwaves.** Treatment procedures included treating infested wood with a 700-watt device (more powerful devices are available from other vendors). The 2.4 GHz frequency oscillation causes vibration of water molecules within termites, which produces lethal temperatures above 120° F. This spot-application method treats a section of wood

approximately 4 by 12 inches at a time. For safety, the device is operated remotely, and all persons are kept a minimum of 30 ft from the apparatus while it is operating. For tests in the *Villa Termiti*, the location of test boards was known by the vendor. Treatment time was approximately 8 min per spot.

**Assessment of Treatment Efficacy.** The day following treatment, all treated test boards were removed from the *Villa Termiti* and stored in the laboratory until they were opened for assessment of mortality. Live and dead termites were counted and removed from each gallery in every board. For artificially infested boards, 3 days after treatment live termites from each gallery were placed in separate wooden holding chambers and stored in a glass greenhouse. The mortality of these remaining termites was determined 4 weeks after treatment. Percent mortality was calculated by combining the counts of live and dead termites for all three galleries. Since we had little control over the number of termites in a naturally infested board, we calculated percent mortality using all of the live and dead termites removed from the board 4 weeks after treatment. All test boards were visually inspected after treatment for any signs of damage such as drilled holes or burn marks.

## Results and Discussion

### Fumigant Gases

**Sulfuryl fluoride.** Termite mortality for all artificially infested boards in the sulfuryl fluoride treatments was 100% (Table 1) see page 21. For naturally infested boards, only one soldier survived among thousands treated (Table 2) see page 22. Since soldiers can't reproduce, this survivor is insignificant and would pose no threat to homes. No visual signs of damage were noted for test boards treated with sulfuryl fluoride.

**CO<sub>2</sub>-synergized methyl bromide.** Termite mortality for all artificially infested boards was 100 percent (Table 1). Mortality for naturally infested boards was slightly lower (99 percent), due to 30 survivors found in one "2 by 4" in the subarea (Table 2). None of the survivors were reproductives. Results from this study suggest that care must be taken in calculating fumigant dosage, as well as placement and number of fans when using reduced methyl bromide methods, especially in subareas. There were no visual signs of damage to test boards.

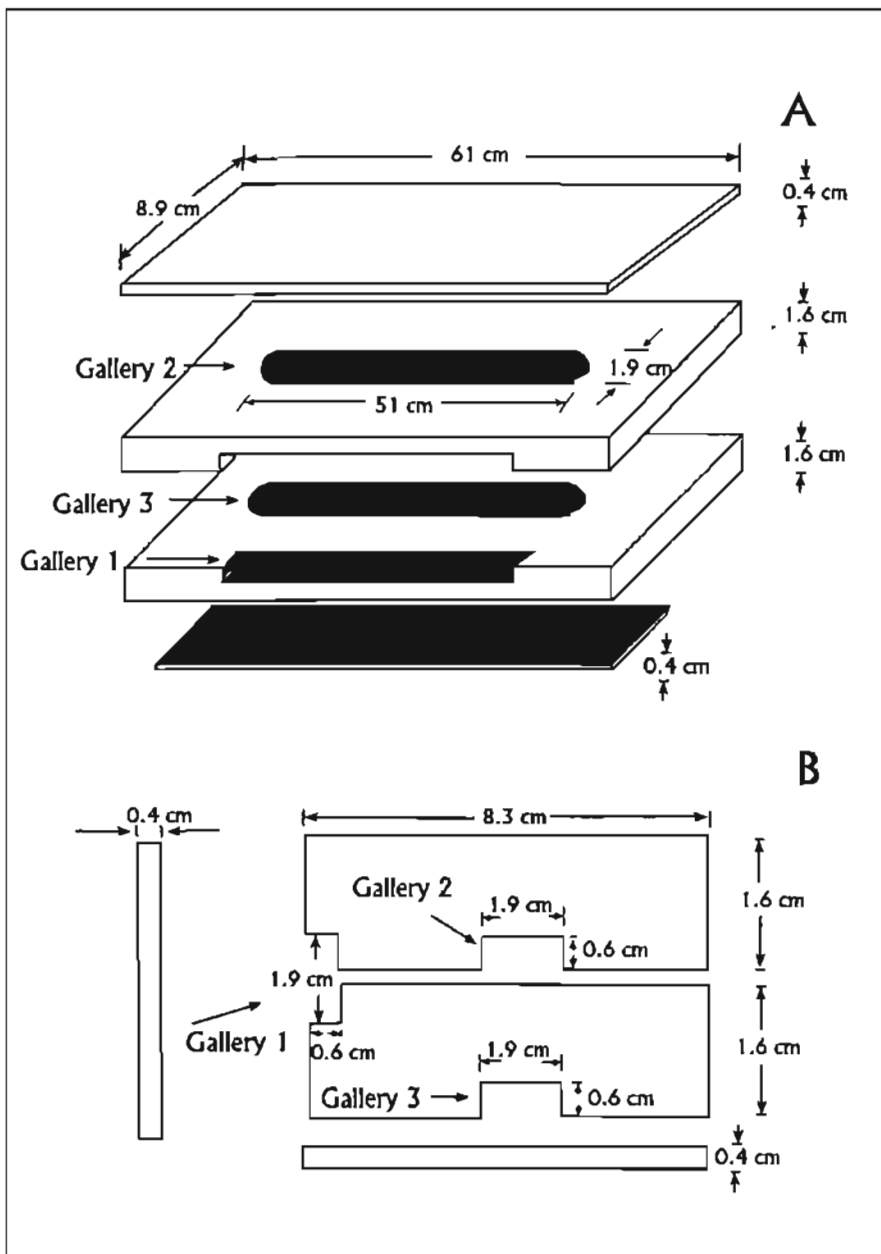


Figure 2. Disassembled (a) and cross-sectional (b) views of a 2 by 4 Douglas-fir test board showing routed gallery locations. Drawings not to scale.



Figure 1. *Villa Termiti* used to test fumigation techniques and alternatives to fumigation for control of drywood termites. The *Villa Termiti* is symmetrical with all four sides structurally identical.

### Alternative Methods

**Excessive heat.** The subarea was the only location that artificially infested board mortality levels did not reach 100 percent (Table 1). Mortality for the subarea at 3-days and 4-weeks after treatment were 85.8 and 91.1

percent. Analysis of data from the subarea revealed an uneven distribution of mortality for artificially infested test boards. The size of the artificially infested boards did not have a significant impact on mortality levels achieved. However, the data for individual galleries within boards revealed that sur-

vivorship occurred only in Gallery 2 when this gallery was positioned against the foundation wall. Concrete is cold to the touch and test boards on concrete are difficult to heat due to the phenomenon called "heat sink." Drywood termites can also infest areas in homes on or near "heat sinks."

All thermocouple probes reached the 122° F lethal temperature for at least 1 hour; however there were still survivors. It is not known how much more time would have been required to achieve 100 percent mortality for test boards contacting concrete in the subarea.

In naturally infested boards mortality was 100 percent across all test locations in the *Villa Termiti* (Table 2). From these results, with both artificially and naturally infested boards, we conclude that excessive heat, applied as described, can achieve mortality levels that exceeds 90 percent and sometimes as high as 99 percent.

During heat treatments there were a few visual signs of damage, including sticking of doors in the *Villa Termiti* (reversible damage), fluorescent lights going-out (reversible damage) and warping of a non-functional ABS plastic waste-water pipe (non-reversible damage). Minor structural damage from heat treatment, as well as pre-treatment preparations to minimize damage to household items, have been previously reported.

**Excessive Cold.** Our assessment of the effectiveness of spot-treatments with liquid nitrogen was mixed and highly influenced by dosage and thermocouple placement. At the highest dosage tested, 30 min @ 3 lbs/min, both 3-day and 4-week mortality of drywood termites in artificially infested boards was 100 percent (Table 1). However, the mortality levels for the 15-min @ 2 lbs/min and 7-min @ 2 lbs/min dosages were lower (Table 1). The 7-min @ 2 lbs/min dosage was below the 90 percent efficacy level. Laboratory studies from the University of California, Riverside report that the minimum dosage rate required to achieve 100 percent control with liquid nitrogen was at least 21 min @ 2 lbs/min in an un-insulated 8-ft by 6.6-ft artificial wall used in their tests. Their results are similar to ours. Lower dosage rates are not likely to achieve the minimal lethal temperature because wood is a poor thermal conductor

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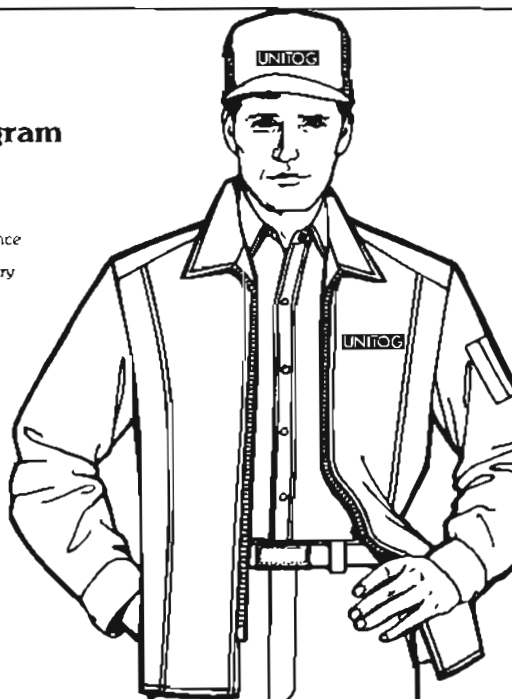
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and may provide termites with insulation from cold.

Considerable variation in temperature was recorded in wall voids for all liquid nitrogen dosages tested. Treated boards containing live termites after the 15-min and 7-min @ 2 lbs/min dosages appeared to be associated with boards failing to achieve lethal temperatures. These results suggest that higher dosage rates with thermocouple placement for verification are critical for achieving high levels of efficacy.

Naturally infested boards revealed a similar pattern to that of artificial boards, i.e. decreasing levels of mortality with decreasing dosage rates (Table 2). Similar to the results with artificially infested boards, termite survivors were associated with failure to achieve minimum lethal temperatures.

Because we were not able to obtain information on application rates from vendors who apply liquid nitrogen, we assessed different dosage rates to determine a minimum application rate that was efficacious. Each individual wall void volume in the *Villa Termiti* is approximately 3.1 ft<sup>3</sup> (0.5 by 1 by 7.3 ft). For successful control (>90 percent), at least 10 lbs/ft<sup>3</sup> of liquid nitrogen will be needed. Application rates exceeding this level are more likely to provide mortality levels in excess of 99 percent. However, frost formation during high dosage treatments can be considerable and may cause damage to some wall coverings. With this treatment, repair of drilled insertion holes is required.

**Electrocution.** Drywood termite mortality levels at 3-days after treatment in artificially infested boards were well below 50 percent in the attic and subarea (Table 1). Four weeks after treatment, mortality levels increased to 81.2 percent. However, this efficacy value was still significantly below the minimum 90 percent level of acceptance. Mortality results in the naturally infested boards used in the first test showed a pattern of low mortality similar to that observed in the artificially infested boards (Table 2). Eight of 9 boards contained surviving termites while 2 of these 8 boards had several hundred survivors. The overall mortality level, 88.6 percent at 4-weeks after treatment, did not exceed the 90 percent level of efficacy. The penetration of electric current into wood is limited and may explain the poor performance of electrocu-

tion during the first test. Delayed mortality from the effects of electrocution were not significantly different from natural mortality seen in untreated boards.

The results from the second test of electrocution in locations away from metal and concrete were improved. Three-day assessment of artificially infested boards showed mortality levels still did not statistically exceed the 90 percent level of efficacy (Table 1). However, mortality levels at 4-weeks after treatment (98.5 percent) did exceed the 90 percent efficacy level.

Mortality in naturally infested boards was also higher than in the first test (Table 2). Only 5 boards contained survivors, as compared to 8 in the first test. However, one board contained over 100 survivors. The mean mortality level in naturally infested boards for the entire structure was 95.1 percent, and exceeded the 90 percent efficacy level (Table 2).

The improved performance of electrocution in the second test warrants some discussion. Several editorials in pest control magazines and pest management newsletters have reported that the first electrocution test was inappropriate. It is the authors belief that the results of both tests need to be weighed when considering electrocution for treatment. Results from both tests show that large extremes in effectiveness can occur when using electrocution, ranging from 50 to 100 percent. Results are further confounded by proximity to metal (sometimes it helps; other times its an impediment). The length of treatment time and number of holes drilled for treatment are also confounded between the two tests. More time was spent treating test boards in the second test (27 min/board) as opposed to the first (6.9 min/board) and more holes were drilled per board during the second test (13.1 versus 6.5 holes/board). It is also noteworthy that since most of the test boards were treated with the drill-and-pin technique (59 of 66 for artificially infested boards and 14 of 18 naturally infested boards), statements cannot be made about the normal treatment operations in homes of passing of the probe end emitting electricity over boards.

We conclude that the efficacy of this treatment appears to be technique-driven and there are no clear standards for successfully treating homes with minimal damage. Clearly, electrocution causes mortality in termites. However, to achieve reasonable levels of mortality the operator should use the drill-

and-pin technique and spend as much time as possible treating an infested area. This control method, more than any of the other tests in this study, requires precise information as to the extent and location of the drywood termite infestation. Without accurately delimiting the infestation, efficacy will likely drop to unacceptable levels.

Damage to test boards using electrocution was considerable. Eighty percent (53 of 66) of artificially infested boards and seventy-eight percent (14 of 18) of naturally infested boards, showed visible signs of damage. Drill holes from administration of the drill-and-pin technique comprised most of the damage. Twenty-nine test boards had minor burn marks.

**Microwaves.** Considerable variability in mortality was observed in artificially infested boards treated with microwaves. Mortality at 3-days and 4-weeks after treatment did not exceed the 90 percent efficacy (Table 1). However, the mortality level for naturally infested boards was 97.4 percent (Table 2). Forty-five survivors (no reproductives) were found among three naturally infested boards. The results of the microwave study were mixed. Without a doubt, sufficient microwave energy applied to infested wood will kill termites. Termite mortality in artificially infested boards approached 90 percent, but did not exceed 90 percent with statistical certainty. Mortality of termites in naturally infested boards was good, statistically exceeding the 90 percent level of control. As with electrocution, definition of the extent of an infestation, location of the infested wood, and access to the infested wood are all critical to achievement of the desired level of mortality with microwave treatments.

Visible signs of damage were noted for some artificial boards. In total, six artificially infested boards were burned, two severely. No naturally infested boards were burned.

**Conclusions.** Three of the 6 methods tested for control of drywood termite infestations (both fumigants and whole-structural heat) achieved or exceeded the 90 percent efficacy level for both artificially and naturally infested boards for all dosages tested. This study was a test of treatment efficacy under "best case conditions" (boards contained healthy robust termites and, if requested, vendors were told the exact location of test boards). Under normal field conditions, treatments may not always be done so carefully and with such advance knowl-

edge regarding the location and intensity of infestation. Test results from whole-structure treatments for test boards reveal that only the fumigant gases demonstrated near 100 percent elimination. Whole-structure treatment with heat was very similar.

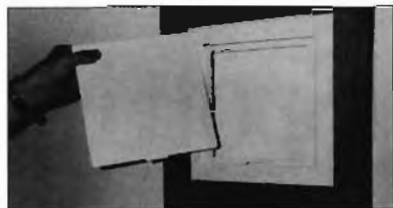
For localized treatments, 30-min@ 3 lbs/min and 15-min@ 2 lbs/min dosages of liquid nitrogen and long application times using drill-and-pin techniques with electrocution were efficacious at the 90 percent level. Microwave treatments (700 W) were deemed efficacious at the 90 percent level, but only when treating naturally infested boards. Not efficacious, even at the 90 percent level, were electrocution without drill-and-pin technique and 7-min@ 2 lbs/min treatments of liquid nitrogen.

In general, treatments that used monitoring instruments fared better than non-monitored treatments. Although damage may occur from fumigation, heat, or microwaves, it is a certainty for liquid nitrogen (repairs to drilled holes in wall voids) and electrocution (drill-and-pin applications). The development of improved devices to monitor termite populations termite under field conditions could improve the performance of all spot-

treatment techniques. Field efficacy rates for all available drywood termite control methods, mode of action of these techniques, safety to technicians, and potential damage to structures are important areas for future research.

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