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# IPM for Termites—Termite Baits

*By William Quarles*

Termites are an important part of the ecosystem, as they recycle dead and decaying wood and have other beneficial effects on the world around us. However, destructive termites cost property owners in the U.S. at least $1 billion each year in treatments and repairs (Su and Scheffrahn 1990a; Nutting and Jones 1990). Fortunately, not all termite species cause damage. Economically important termite species in the U.S. can be roughly classified into two general types—drywood or subterranean (see Box A). Drywood termites nest and spend most of their life cycle inside wood. Subterranean termites live and nest in the ground and forage in and aboveground, and cause more damage to homes and other structures than drywood termites (Ebeling 1968).

There are a variety of treatments available for termite infestations. Until recently, homeowners have relied primarily on chemical barriers in soil to prevent subterranean termite damage. Because chemical barriers are not always reliable, are costly, may not give long-term protection and may damage the environment, research on alternatives has escalated over the past few years (Lewis et al. 1996; Gold et al. 1996; Grace et al. 1996).

One alternative is the use of baits. In theory, baits could be used by pest control operators (PCOs) or even homeowners to reduce foraging pressure and destroy subterranean termite colonies around a home. As PCOs become more comfortable with the idea of using bait stations to monitor for termites, baiting technology may act as a bridge between conventional termite treatments and an IPM approach.

*Photo courtesy of the USDA*

**Termite baits can provide effective, long-term protection against termite damage. The bait shown here is being installed underneath pavement to protect historic structures in New Orleans.**

Possible baits range from simple ones that a homeowner can construct, to hi-tech approaches such as the Sentricon® baiting system. As the technology has matured, a variety of baiting techniques have been combined with a broad array of active materials. One approach is to adopt the active ingredients of cockroach baits (see Quarles 1995). Thus, boric acid, hydramethylnon, and sulfluramid have surfaced as toxicants in termite baits. Another approach is to employ precisely targetted biorationals such as insect growth regulators (IGRs) and chitin synthesis inhibitors. Some of these materials have been lab tested, others have progressed through full-scale field trials to EPA registration and commercialization. This article briefly reviews the history of termite baiting and describes attractants, baiting techniques, and toxicants. The following article in this issue discusses field trials and commercially available products.

## In This Issue

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# *Update*

## The Baiting Concept

The termite baiting strategy involves two distinct steps. First, a method is found to attract a large number of termites. One sure way to attract termites is to deploy a food source such as wood, paper, or corrugated cardboard. Alternatively, active galleries in structural infestations can be utilized. Since termites are already feeding there, these termite "dining halls" are natural areas to set baits (French 1994).

After relatively large numbers of termites have accumulated, they are exposed to a slow-acting toxicant or IGR. The slow poison can be added to food, or applied to active galleries, where workers are sure to be exposed by contact and ingestion. A slow-acting, undetected toxicant or IGR is necessary because termites wall off or block tunnels or galleries when they sense a problem with their food supply or environment (Su et al. 1984).

The baiting approach relies heavily on termite biology and the social nature of termite colonies. Through mutual grooming and trophallaxis, the delivery agents of the baiting system are actually the termites themselves. Orally consumed toxicant or IGR in the food is transferred by trophallaxis (see Box A) from foraging workers to the rest of the colony. Topically applied toxicant such as a poisonous dust is transferred by mutual grooming from foraging workers to the rest of the colony. A variant of the baiting process is the trap-treat-release approach. To insure proper exposure to the toxicant, termites are trapped at a food source, then dusted with toxicant and released to destroy their nest (Grace and Abdallay 1990; Grace et al. 1990; Grace 1991; Myles 1996).

## Baiting Galleries

In the 1930s, Randall and Doody (1946) treated subterranean termites by blowing arsenic trioxide into active termite galleries. In laboratory experiments they had found that whole colonies could be eliminated by exposing only 10% of the termites to a slow-acting toxicant. There were a number of problems with this approach, including the need for dry conditions.

Dusting of galleries is still being investigated as a means of termite control. Since arsenic compounds are too dangerous, they have been replaced by materials less toxic to mammals, such as silafluofen (French 1994; Grace et al. 1992), or boric acid salts (Grace et al. 1990; Quarles 1998). Silafluofen is a new pyrethroid that is less acutely toxic to rats than boric acid (see Table 1 for toxicity information). However, a 5% silafluofen dust killed 100% of the Formosan termites tested within 2 hrs in lab tests, and thus may act too quickly to be used in a baiting strategy (Grace et al. 1992).

Not all the experts believe that subterranean colonies can be successfully killed just by dusting termites in galleries or shelter tubes. Grace and Abdallay (1990) think that gallery dusting with a slow toxicant is effective only for drywood termites, not subterranean species. These researchers believe the number of termites exposed by merely dusting a gallery is too few to kill a subterranean colony and recommend a trap-treat-release process.

## Food Baits

Until recently, application of food baits for termite control was not very successful. Failures were probably due to application of an ineffective toxicant or use of a poor baiting matrix. For instance, in the 1930s Randall and Doody (1946) were unable to get termites to eat baits of arsenic trioxide in sucrose solutions. Australians during this time had some success with 5.8% (w/w) sodium arsenite suspended in treacle. The mixture was poured into active termite galleries.

Lack of success until recently was also due to lack of motivation. With the development of apparently successful chemical barrier treatments, baiting technology was largely forgotten until the 1960s and 1970s (French 1994). During this period Esenther and Coppel

(1964) outlined the termite baiting strategy that is currently being commercialized. They believed that a termite food could be combined with a slow-acting toxicant to eliminate ground populations of subterranean termites.

In the first experiments, Esenther and Gray (1968), Ostaff and Gray (1975) and Esenther and Beal (1974; 1978) were able to control *Reticulitermes* spp. with wooden bait blocks soaked in the organochlorine pesticide mirex. Since there was some evidence that foraging termites avoided the baits after initial consumption, Esenther and Beal (1978) suggested that the baiting technique would be more effective if a slower-acting insecticide than mirex could be used. According to Su and Scheffrahn (1991), the concentrations (4,000 to 13,000 ppm) used in these experiments were too high, and the mirex blocks were probably repellent to the foraging workers.

Since Ostaff and Gray (1975) showed that termites on a property could be typically controlled with the application of only 500 mg of mirex, the technology obviously had promise. The method at that time suffered, however, because there was no good way to determine initial and final colony sizes, and thus effectiveness could not be quantitatively assessed (Esenther and Beal 1978; 1979).

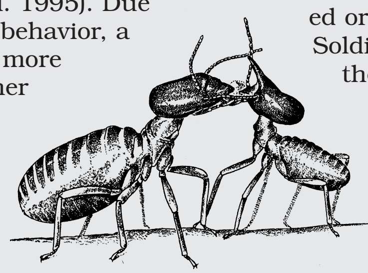
## Perimeter and Interceptive Baiting

There are two general types of food baiting that have been used: perimeter baiting or interceptive

### Box A. Kinds of Termite Damage

There are at least 45 different termite species in the U.S., and 30 of these are pests. Structural damage due to termite attacks has been estimated at $1 billion to $2.5 billion per year (Su and Scheffrahn 1990a; Nutting and Jones 1990). Termites often differ widely in their food and moisture requirements, their appearance and caste structures, and in the amount of economic damage they do (Light 1946). Due to destructiveness and widespread distribution in the U.S., the most economically important subterranean termites are the eastern subterranean termite, *Recticulitermes flavipes,* and the western subterranean termite, *R. hesperus* (Synder 1946; Pickens 1946; Light and Pickens 1946).

The exotic Formosan subterranean termite, *Coptotermes formosanus,* has now become established in Florida and other southern states (Su et al. 1984; Woodson et al. 2001). At least one colony has been found in California (Haagsma et al. 1995). Due to its size and aggressive foraging behavior, a colony of Formosan termites does more damage than single colonies of other U.S. subterranean species, and can cause significant structural damage to a home within 6 months (Su and Scheffrahn 1990a).



Subterranean termites can be distinguished from other termites according to where they live and what they eat. Subterranean termites live in the ground and forage in wood beneath and aboveground. Drywood termites such as *Incisitermes* spp. or *Cryptotermes* spp. spend their entire life cycle inside pieces of dry wood. Dampwood termites such as *Zootermopsis* spp. prefer to eat and dwell in wood with a high moisture content (Castle 1946).

Subterranean colonies are much larger than drywood colonies. *C. formosanus* colonies may contain from 1 to 7 million foragers, with foraging territories extending up to 100 m (109.4 yds). *R.flavipes* colonies range from 200 thousand to 5 million and can range a linear distance of 79 m (86.4 yds) (Su 1994).

#### Termite Society

Termites start life as an egg. Eggs hatch into small larvae, and the larvae proceed to develop through 6 or 7 stages. At each stage, the outer exoskeleton is shed (molting). Time between larval stages typically ranges from 2 weeks to 2 months. Termites are relatively long-lived, with typical lifetimes of 3 to 5 years, but progression to the 4th larval stage takes less than 6 months for *R. hesperus* (Pickens 1946). This dependence on molting and chitin synthesis to form new exoskeletons makes termites vulnerable to chitin synthesis inhibitors.

#### Trophallaxis

Although the situation is complicated, the larger larvae generally become foraging workers. According to the needs of the colony, the workers remain undifferentiated or start specialization as soldiers or reproductives. Soldiers protect the colony, but are unable to forage on their own. They eat regurgitated food supplied by workers. Small larvae feed on the anal secretions of workers. [Social transfer of food in this manner is called trophallaxis]. Reproductives, including termite queens whose specialty is egg laying must also be fed by foraging workers.

Developing reproductives sprout wings, and at the proper moment fly away from the parent colony to start a new one (Hickin 1971). Colonies of subterranean termites such as *R. hesperus* grow in size by consolidation. Isolated colonies merge by tunneling, founding reproductives fight, surviving reproductives lead the enlarged colony (Pickens 1946). As the number of workers and feeders increases, the surviving queen acquires the ability to lay larger numbers of eggs, and colony building begins in earnest.

Termite development and specialization is determined by a complex balance of hormones and pheromones. This "caste chemistry" is vulnerable to manipulation by insect growth regulators and other artificially produced substances introduced into a colony through the baiting technique (Jones 1990; Lebrun 1990).

baiting. If the whereabouts of the termites are unknown, perimeter baiting is used. Wooden stakes, bait blocks, or plastic monitoring stations are set around the perimeter of a structure either on a continuous circle or in a grid pattern. Additional baits can be placed near wooden fence posts, poles, or trees (Ostaff and Gray 1975; Esenther and Beal 1978). Perimeter baiting relies on the certainty that termites foraging at random will eventually discover the bait (Su 1994; Atkinson 2000). Thorne and Traniello (1994) call this initial step diagnostic baiting.

The percentage attack rate on baits tends to be low. Henderson et al. (1997) found about a 7% attack rate in 13 months on pine stakes around structures in New Orleans. However, once baits are found, feeding is persistent. On average 73% of stakes attacked "were found to harbor termites on the next inspection."

Pine stakes set in patterned placement around a perimeter, 10 feet from a building and 20 feet from each other were attacked about half as often by *Reticulitermes* spp. as those set near areas likely to have termite activity. These locations included areas near air conditioners, spigots, downspouts, tree stumps, wood piles, mulch beds and wooden fences (Henderson et al. 1997). Potter et al. (2001), however, had less luck finding areas of preferred placement.

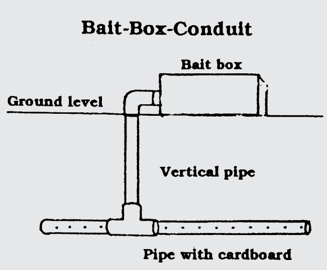
Once termites have been located, either by perimeter baiting or by observation of shelter tubes or active galleries, interceptive baiting

## Box B. Ways to Bait Termites

Hollow wooden stakes capped by a cork can be used to monitor termites and to place toxic baits. Since cork is a favorite termite food, termite attack can be monitored just by removing the cork. If termites are found, corrugated cardboard is inserted into the stake, leaving about an inch of the cardboard exposed above the stake. The stake can then be covered with a capped plastic pipe filled with treated cardboard (see figure below). The cardboard extending from the hollow stake directs the termites into the treated bait (Ewart et al. 1992).

### Pipe-Bait Container

Interceptive baiting in or near structures is described by French (1991; 1994). One useful device is the pipe-bait container. According to French, it is constructed in this way: "Cut 300 mm (11.8 in) lengths of 90mm (3.5 in) diameter tubular plastic pipe. Into each length, place two corrugated cardboard inserts (with corrugations inwards) measuring 60 mm (2.4 in) and 240 mm (9.5 in) long respectively. Seal the end with the 240 mm (9.5 in) long insert with a plastic petri dish lid into which is fitted a single filter paper. [The pipe could also be capped, and the cardboard periodically moistened.] Wet the cardboard inserts with water prior to placing the whole container vertically into the soil (to about 50 mm; 2 in) alongside or near active termite shelter tubes on walls, piers or stumps. Also wet the ground around the container. Inspections are made every week for termite activity. and the system re-wet if required." Once termites are found in the bait tubes, treated pieces of cardboard or treated wood blocks are added to the bait tube.

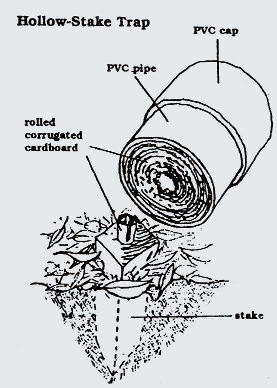



### Bait-Box-Conduit

Another baiting device is the bait-box-conduit. A shallow trench (100 to 150 mm; 4 to 5.9 in deep) is excavated alongside or near sheltertubes, diagonally across the underhouse area, or around the outside of the building. Plastic conduit pipe of 25 mm (1 in) diameter is cut into 2- or 4-m (6.6 to 13.2 ft) lengths and placed in the trench. Small holes of 4 mm (0.16 in) diameter are drilled every 100 to 150 mm (3.9 to 5.9 in) to allow termite access. Corrugated cardboard moistened with water is inserted inside the pipe. Every 2 to 4 meters, a "T" is attached to connect the conduit. To a vertical pipe (200 mm; 7.9 in) extending out of the "T", an elbow fitting is attached. The elbow is secured to a plastic bait box which is 300 x 200 x 95 mm (11.8 x 7.9 x 3.7 in). The bait box is parallel to the ground and is filled with moistened, treated corrugated cardboard or treated bait blocks. Trenches are wet with water before the whole apparatus is buried in the ground.

### Galleries and Shelter Tubes

A less involved baiting technique involves just the addition of treated blocks, cardboard, or treated bait tubes to termite shelter tubes or galleries. According to French (1991; 1994) "break into the galleries or shelter tubes and place several treated blocks, taped onto corrugated cardboard, over the exposed workings. Seal the whole arrangement with masking tape."




Galleries in trees can be baited by drilling holes (25 mm; 1 in) into the tree and inserting plastic pipe. To give access to termites, 8 mm (0.3 in) holes are drilled into the pipe and the pipe is filled with corrugated cardboard. The conduit can be attached to a bait box (300 x 200 x 95 mm; 11.8 x 7.9 x 3.7 in). Inside the bait box treated blocks can be inserted between layers of cardboard, or alternatively, treated cardboard can be used (French 1994).

Another way to bait trees is to drill and insert a plastic pipe with "T" fitting. Pipe-baits can then be attached to each side of the "T". This method has the advantage that two different bait concentrations, or a toxic bait and untreated bait can be directly compared (Henderson 1995).

can be used (see **Box B** for Baiting Techniques). Here, actively foraging termites are intercepted with an active bait. Interceptive baiting of galleries and shelter tubes has the advantage that termites can be baited more quickly, and if successful, colonies are eliminated faster than with perimeter baiting.

### Attractants

Although the baiting concept is rather obvious, the devil is in the details. The trick is to find a food bait that termites can find and accept, and a slow-acting toxicant that is not repellent. One possibility is moistened corrugated cardboard. This material is attractive to termites, and is especially useful when used inside plastic tubes (cut from standard PVC plastic pipe) as part of a trapping program (French and Robinson 1985; Ewart et al. 1992). Cardboard inside plastic pipe can also be turned into a tamper-proof bait station (see Box B).

A number of other wood or cellulose products also have been successfully used to attract termites. In areas with low amounts of rainfall, toilet paper rolls staked to the ground with a wire have been effective (French and Robinson 1980). Toilet paper is also a good trapping medium. A perforated steel drum packed with wetted toilet paper rolls and partially buried in the ground allowed the accumulation of large numbers of *Coptotermes acinaciformis* (French and Robinson 1981).

Further research may lead to better baits. Field experiments have shown that termites have feeding preferences. Pine and eucalyptus bait blocks set next to the toilet rolls were more readily attacked than blocks of white cypress pine, *Callitris columellaris* (French et al. 1981). Mound colonies of *Coptotermes lacteus* will attack and eat cork in preference to sound wood (French et al. 1986). Trees such as *Aesculus hippocastanum* are frequently infested, but *Ailanthus altissima* is rarely infested by *Reticulitermes* sp. (Grace 1997). *R. hesperus* prefers softwoods such as pine, *Pinus ponderosa* and Douglas fir, *Pseudotsuga menziesii*, while hardwood such as *Tabebuia guayacan* is repellent (Grace et al. 1989).

Artificially constructed baits also show promise. A bait matrix of agar and sawdust was used to attract *Mastotermes darwinensis* in Australia (Paton and Miller 1980). Su (1994) used a similar matrix of 80% agar and 20% pine or spruce sawdust. Forschler (1996) used a cellulose powder bait against *Recticulitermes* spp. in Georgia. Thorne and Traniello (1994) developed a bait that *R. flavipes* termites locate significantly faster than pine stakes. At sites showing wide variations in climate and geography, *R. flavipes* found and fed on the baits within 1 to 3 weeks.

Wood that has been partially decomposed by the fungus *Lenzites trabea (=Gloeophyllum trabeum)* is more attactive to foraging termites than sound wood (Esenther et al. 1961). Both *R. flavipes* and *C. formosanus* feed and survive better on wood showing a 5% decay with the brown rot fungus, *Gloeophyllum trabeum. R. flavipes* may even require partially rotted wood, as the number of reproductives increase on this diet (Lenz et al. 1991).

Termite physiology and biochemistry is being studied to find clues to termite attraction. For instance, termites may be attracted toward partially rotted wood because the brown rot fungus produces the termite aggregation pheromone (Z,Z,E)-3,6,8-dodecatrien-1-ol (Lebrun 1990). Hydroquinone and amino acids have been used as attractants (Reinhard et al. 2002). Glycol ethers can act as trail pheromones (Becker 1966). The exciting science of termite physiology and biochemistry is still in its infancy, but profound knowledge of feeding attractants is sure to develop from further research in this area (Lebrun 1990).

### Bait Toxicants

Any non-repellent, slow acting toxicant or IGR is a candidate for use in termite baits. However, commercial success of a bait is more likely if consumers can be assured their pets and their children will

Photo courtesy Dow Agrosciences

**Wood monitoring stakes are being added to a Sentricon bait station.**

not be damaged if a bait is accidentally ingested. Early researchers used sodium arsenite or mirex (Randall and Doody 1946; Esenther and Gray 1968). Arsenic compounds are too dangerous for general use, and mirex has been banned in the U.S. (French 1994). Mirex baits are still being used, however, in Australia (French and Robinson 1985; Paton and Miller 1980). The effective concentration range for *R. flavipes* is 9-15 ppm and for *C. formosanus* is 10-90 ppm. Colonies are completely killed in 4-8 weeks (Su and Scheffrahn 1991).

### Boric Acid and its Salts

The boric acid salt barium metaborate was effective in laboratory tests in concentrations ranging from 1500 to 5000 ppm (Grace 1989; Grace et al. 1990). Jones (1990) field tested a sodium octaborate tetrahydrate (DOT) (Timbor®) bait in Arizona. Concentrations of 2500 to 5000 ppm were not repellent and successfully destroyed a colony of the desert subterranean termite, *Heterotermes aureus.* Forschler (1996) baited *Reticulitermes* spp. with 1000 ppm zinc borate hydrate in cellulose powder, but termites found the bait repellent. Esters of boric acid and ethylene glycol are being tested in baits (French 1994). These compounds are doubly interesting because the ethyl and butyl ethers of diethylene glycol are termite trail pheromones (Becker 1966), and the commercial termiticide Boracare® is a solution of DOT in ethylene glycol (Quarles 1998).

Boric acid itself at 1500 ppm killed 90% of *R. flavipes* in 7 to 12 days in laboratory feeding tests (Su et al. 1994). Boric acid and Boracare can be purchased by the general public. After soaking corrugated cardboard in the toxicants, homeowners could bait their own termites using some of the simpler techniques in Box B. With these techniques and moistened corrugated cardboard as an attractant, monitoring for termites is also in reach of the typical homeowner. Boric acid termite baits are also commercially available (see the next article).

Compared to other substances being tested, however, larger amounts of boric acid must be used to eliminate colonies. For instance, about 2 million Formosan termites can be killed equally well when fed 11.5 g of boric acid or 0.9 g of hydramethylnon (Su et al. 1994).

## Slow Starvation

A number of water-insoluble, slow-acting toxicants or IGRs have been tested in termite baits (See Box C for Active Ingredients). Hydramethylnon and sulfluramid baits are commercially available (see the next article). These compounds block the oxidation of food and cause death by starvation. As we see in Table 1, sulfluramid and hydramethylnon show roughly the same toxicity against *R. flavipes*, however, based on the termite $LD_{50}$, sulfluramid is about 10 times more toxic to Formosan termites than it is to *R. flavipes*. In laboratory feeding tests, according to the amount consumed, about 90% of *C. formosanus* workers are killed in 0.7 to 11.5 days by sulfluramid, and 3.3 to 9.4 days by hydramethylnon. The corresponding times for *R. flavipes* were 3.3 to 14.7 days for sulfluramid and 4.4 to 13.5 days for hydramethylnon.

## Chitin Synthesis Inhibitors

Chitin synthesis inhibitors target the termite's need to grow a new "skin" as part of its normal growth pattern. Larval termites must cover themselves with a new layer of chitin every time molting occurs. The time frame for molting is on the order of 1-2 months. A toxicant that interferes with molting could kill an expanding termite colony over the period of 3 months. The chitin synthesis inhibitors diflubenzuron (Dimilin®), hexaflumuron (Recruit™), and noviflumuron have been tested. Laboratory bait block feeding tests with hexaflumuron and Formosan and eastern subterranean termites showed that it had a wider range of effective concentrations than mirex. Baits containing 2 to 62.5 ppm caused better than 90% mortality to *R. flavipes,* and 15.6 to 125 ppm were effective ranges for *C. formosanus.* Termites were not repelled and 100% mortality was seen in 3-6 weeks (Su and Scheffrahn 1993). Noviflumuron eliminates termite colonies faster than hexaflumuron (Sheets and Karr 2001).

Su (1994) developed the baiting process that led to Sentricon. Wooden stakes were buried around each monitoring station. Stakes that were attacked were replaced with plastic bait tubes containing about 80 g of a matrix composed of 80% agar or Methocel and 20% (w/w) pine or spruce sawdust bait impregnated with hexaflumuron. At one *R. flavipes* colony, the bait toxicant concentration was 150 ppm. At other sites a range of bait toxicant concentrations from 100 to 500 ppm were employed.

Bait stations were inspected monthly and replaced with new tubes if termites had been feeding and with wooden stakes if they had not. To increase bait attractiveness, termites from the wooden stake were shaken into the bait tube. These termites "tunneled through the matrix to enter established foraging tunnels in soil, thus leaving the colony specific semiochemical clues in the matrix." About twice as much bait was consumed when this "self-recruiting procedure was used compared to foraging in tubes that were merely buried without added termites.

## IPM Bait Stations

Su's successful field trials and other work encouraged Dow Agrosciences to register hexaflumuron as the toxicant in their Sentricon baiting system (see following article). Termite control with Sentricon is a 3-step process involving detection, elimination, and continued monitoring. Central to the technology is the Sentricon

**Table 1. Toxicants for Termite Baits***

| Toxicant | Termite LD50 µg/g | Effective Bait Concentration in ppm | Oral Acute Toxicity. LD50 in mg/kg (Species) | Reference |
|---|---|---|---|---|
| Boric Acid | *C. formosanus (722)* | —— | 2660 (rat) | Pestline 1991; Su et al. 1994 |
| Boric Acid | *R. flavipes* (264) | 1500 | 2660 (rat) | Pestline 1991; Su et al. 1994 |
| Di-iodo-ptolylsulfone | *C. formosanus* | 600 | —— | Su et al. 1991 |
| Diflubenzuron | *R. flavipes* | 7.8-31.3 | 4640 (rat) | Su and Scheffrahn 1993; Tomlin 1997 |
| Diflubenzuron | *C. formosanus* | repellent above 2 ppm | 4640 (rat) | Su and Scheffrahn 1993; Tomlin 1997 |
| Fenoxycarb | *R. flavipes* | 1120 | 10000 (rat) | Jones 1984; Tomlin 1997 |
| Hexaflumuron | *R. flavipes* | 2-62.6 | 5000 (rat) | Su and Scheffrahn 1993; Tomlin 1997 |
| Hexaflumuron | *C. formosanus* | 15.6-125 | 5000 (rat) | Su and Scheffrahn 1993; Tomlin 1997 |
| Hydramethylnon | *C. formosanus* (56) | —— | 1131 (rat) | Tomlin 1997; Su et al. 1994 |
| Hydramethylnon | *R. flavipes* (31) | —— | 1131 (rat) | Tomlin 1997; Su et al. 1994 |
| Mirex | *C. formosanus* (31.4) | 10-90 | 236 (rat) | Su et al. 1994; Su and Scheffrahn 1991; Pestline 1991 |
| Mirex | *R. flavipes* (4.2) | 9-15 | 236 (rat) | Su et al. 1994; Su and Scheffrahn 1991; Pestline 1991 |
| Silafluofen | *C. formosanus* | 10-100 | 5000 (rat) | Tomlin 1997; Grace et al. 1992 |
| Sulfluramid | *C. formosanus* (4.3) | 4-10 | 543 (rat) | Tomlin 1997; Su et al. 1994; Su and Scheffrahn 1991 |
| Sulfluramid | *R. flavipes* (41.3) | 18-30 | 543 (rat) | Tomlin 1997; Su et al. 1994; Su and Scheffrahn 1991 |

*The greater the LD50, the less toxic the material. Acute toxicity data above shows that mirex is the most toxic, and fenoxycarb is the least-toxic. Sulfluramid, mirex, and hydramethylnon are more acutely toxic than boric acid. Silafluofen, hexaflumuron, diflubenzuron, and fenoxycarb are less acutely toxic than boric acid. Long-term chronic toxicity studies may reveal problems with some of these new materials, but as long as small amounts are contained in tamper-proof bait stations, they should have low environmental impact.

plastic bait station. The station itself is a cylindrical plastic tube with side ports for termite access. It is designed to be placed in soil. It has a tamper-resistant cap that requires a special key to open. The station has a flat round soil cover that lies flush with the soil surface.

To use the Sentricon system, stations are buried in the ground every 10 to 20 ft (3 m to 6.1 m) or so around the perimeter of the structure. Stations first contain wooden monitoring blocks, which are monitored until termites are found. Monitoring blocks are then replaced by bait tubes. Alternatively, if enough information on the infestation is available, a computer program indicates how many bait stations should be used and where they should be placed.

### Limitations of Baits

Termite activity is seasonal, and thus baiting is less effective at certain times of the year. Most intense feeding occurs while reproductives are being produced and in the period of a few weeks before swarms occur. The best time to bait *R. flavipes* is thus in the late spring and early summer. During the winter, activity is reduced. Foraging also drops back during hot weather or periods of intense rain. The western subterranean termite, *R. hesperus,* can probably be baited year-round but best results would probably be obtained in June, July and August-right before the fall swarm after the first seasonal rains (Pickens 1946).

Baits work slowly to eliminate a colony. It can take 2 to 3 months or more. For homeowners needing termite treatments in order to sell their house, baits may not do the job fast enough.

### Advantages of Baits

Baiting has a number of advantages over soil applications of pesticides. For instance, smaller

## Box C. Bait Active Ingredients

If one is searching for a perfect toxicant, the best approach is to find a substance that targets only the pest species. By studing termite biology, researchers felt that insect growth regulators (IGRs) that interfered with the hormones and pheromones regulating the termite caste system were possible selective termite toxicants. Because the entire colony must be fed by workers, hormonal shifts toward fewer workers and more soldiers could cause a colony to die.

In lab tests, Jones (1984) fed bait blocks containing 1000 ppm fenoxycarb or a derivative, RO16-1295, to *R. virginicus* and *C. formosanus*. The compounds were not repellent at this concentration. Fenoxycarb and Ro16-1295 converted more than half the *R. virginicus* population to a dependent caste within 4 weeks and killed about 65% of the population in 6 weeks. Subsequent field tests with *Reticulitermes* showed a reduction in foraging activities after exposure to fenoxycarb baits at 1000 ppm (Jones 1988; 1989).

Formosan termites are more difficult to kill with 1000 ppm fenoxycarb than *Reticulitermes.* Jones (1984) found that although about half of the population was converted to soldiers or intercastes within 4 weeks, the Formosan termites tested showed little mortality in 6 weeks. Since Formosan colonies can absorb excess soldiers for long periods, significant mortality might have been seen if the lab test had been continued for 12 weeks. In fact, Haverty et al. (1989) found that 500 ppm of the IGR methoprene was not repellent to *C. formosanus* and resulted in 73.7% mortality and 47.3% dependent castes in 12 weeks.

A followup study by Jones and Lenz (1996) using a range of concentrations from 10 to 3,162 ppm fenoxycarb on two different Formosan colonies showed about a 50% reduction in workers at the most effective concentration within 28 days. In one colony the most effective concentration was 100 ppm, and workers were reduced through increased production of intercastes. In the other, the most effective concentration was 3,162 ppm, and worker reduction was due to death of undifferentiated indviduals.

### Other IGRs

Su and Scheffrahn (1989) found that the novel IGR pyridine derivative S-31183 at 300 ppm had no significant effect on Formosan termites after 12 weeks. However, concentrations of 30-150 ppm were not repellent to *R. flavipes* and led to about 80% worker mortality after 12 weeks.

The experiments above and earlier work shows that IGRs are effective in termite baits, but termite species with soldiers as a small fraction (1-2%) of the population are more vulnerable than species committing a large fraction of the population to the soldier caste. Thus, IGRs are more effective against *Reticulitermes* spp. than *Coptotermes formosanus*. Although hormonal IGRs are definitely worth further study, none of the compounds tested so far demonstrates the stability and wide range of effectiveness seen for other toxicants now being tested (Su and Scheffrahn 1990b; Su and Scheffrahn 1993).

### Novel Compounds

The novel compound diiodomethyl para-tolyl sulfone (A-9248) at 600 ppm was not repellent and reduced baited Formosan colonies by 65-98% over a 1-year period in Florida. Although colony suppression may be slower than with the use of other substances, further tests with this compound would seem profitable (Su and Scheffrhan 1988; Su et al. 1991).

Abamectin at 80-200 ppm caused 100% mortality in 1-4 days, and 20 ppm caused 50% mortality in 14 days to *Recticulitermes* sp. (Su et al. 1987). Nutting (1983) found that abamectin was repellent in *Reticulitermes* sp. field tests. Forschler (1996) was able to remove an infestation from a structure with 1 ppm abamectin bait in cellulose powder. However, termites were still feeding near the structure and probably found the bait repellent.

amounts of active materials are used. Rather than kilograms of toxic chemicals applied to soil, only milligrams of bait are applied. Not only are the amounts applied a thousand to a million times less, but the toxicant or IGR is fully contained in bait stations that are inaccessible to animals and children. From an environmental point of view, bait stations are a vast improvement over toxic pesticide barriers.

Another advantage that baits have over current pesticide barriers is the ability to provide long-term protection. Once termite colonies are eliminated, monitoring stations can be left in place. If another colony invades the yard, baiting can be resumed. Baiting and monitoring can give protection against subterranean termites for the lifetime of a structure.

## Safety

Since most of the toxicants or IGRs used in the new baiting technology have low acute toxicity and concentrations generally used are low, termite baits are relatively safe. For instance, if an entire 80 g (0.18 lb) bait tube of 500 ppm hexaflumuron is eaten, only 40 mg of IGR is consumed. The acutely toxic dose for a child would be about 1250 times this amount. Manufacturers have safety in mind and are designing bait stations that are tamper-proof. Such an approach should protect children and animals from accidental exposure. For baits deployed in the soil, since most of the toxicants are insoluble in water, very little should leach out into the soil. [Note: Boric acid baits would leach into the soil under wet conditions. However, since the amounts involved are so small, there should be no noticeable damage.]

## Conclusion

Baiting can provide a safe, effective method of subterranean termite control. Until PCOs become familiar with it, the technique will probably be used to moderate foraging pressure on structures that have been treated with physical or chemical barriers. Baits could also be used to replace aging chemical barriers. When the effective lifetime of a chemical barrier is reached, rather than retreating with large amounts of toxic chemicals, baits could be installed instead. Conversion to least-toxic technology under these circumstances would be very convenient and inexpensive.

Termite baits also may act as a bridge between dedicated chemical treatment methods and an IPM approach. PCOs can offer baiting as part of a general program of monitoring, moisture and food reduction, structural borate treatments, and when absolutely necessary, use of termiticides. In many cases, conventional subterranean termite treatment methods might be eliminated altogether. According to the termite experts Thorne and Traniello (1994), "at least in some circumstances baits will be an effective stand-alone remedial treatment. It is in that sphere that they will have the advantage in minimizing pesticide exposure to applicators and to the environment."

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## References

Atkinson, T.H. 2000. Use of dyed matrix in bait stations for determining foraging territories of subterranean termites (Isoptera: Rhinotermitidae: *Reticulitermes* spp. and Termitidae: *Amitermes wheeleri. Sociobiology* 36(1):149-167.

Becker, G. 1966. Spurfolge-Reaktion vonTermiten auf Glykol-Verbindungen. *Z. Angew. Zool.* 53:495-498.

Castle, G.B. 1946. The dampwood termites of the Western United States, genus *Zootermopsis.* In: Kofoid et al., pp. 273-291.

Ebeling, W. 1968. *Termites: Identification. Biology, and Control of Termites Attacking Buildings.* Univ. Calif. Agri. Exp. Sta. Manual No. 38. 73 pp.

Esenther, G.R., T.C. Allen, J.E. Casida and R.D. Shenefelt. 1961. Termite attractant from fungus-infected wood. *Science* 134:50.

Esenther, G.R. and H.C. Coppel. 1964. Current research on termite attractants. *Pest Control* 32:34-38.

Esenther, G.R. and D.E. Gray. 1968. Subterranean termites in southern Ontario. *Can. Ent.* 100:827-834.

Esenther, G.R. and R.H. Beal. 1974. Attractant-mirex bait suppresses activity of *Reticulitermes* spp. *J. Econ. Entomol.* 67:85-88.

Esenther, G.R. and R.H. Beal. 1978. Insecticidal baits on field plot perimeters suppress *Reticulitermes. J. Econ. Entomol.* 71:604-607.

Esenther, G.R. and R.H. Beal. 1979. Termite control: decayed wood bait. *Sociobiology* 4(2):215-222.

Ewart, D. McG., J.K. Grace, R.T. Yamamoto and M.Tamashiro. 1992. Hollow stakes for detecting subterranean termites (Isoptera: Rhinotermitidae). *Sociobiology* 20(1):17-22.

Forschler, B.T. 1996. Baiting *Reticulitermes* (Isoptera: Rhinotermitidae) field colonies with abamectin and zinc borate treated cellulose in Georgia. *Sociobiology* 28(3):459-484.

French, J.R.J. and P.J. Robinson. 1980. Field baiting of some Australian subterranean termites. *Z. Ang. Ent.* 90:444-449.

French, J.R.J. and P.J. Robinson. 1981. Baits for aggregating large numbers of subterranean termites. *J. Aus. Ent. Soc.* 20:75-76.

French, J.R.J., P.J. Robinson and N.R. Bartlett. 1981. A rapid and selective field assessment of termite wood feeding preferences of the subterranean termite *Heterotermes ferox* (Froggatt) using toilet roll and small wood-block baits. *Sociobiology* 6(2):135-151.

French, J.R.J. and P.J. Robinson. 1985. A technique used on mounds of *Coptotermes lacteus* to screen potential bait substrates. *J. Aust. Ent. Soc.* 24:111-112.

French, J.R.J., P.J. Robinson and D.M. Ewart. 1986. Mound colonies of *Coptotermes lacteus* (Isoptera) eat cork in preference to sound wood. *Sociobiology* 11(3):303-309.

French, J.R.J. 1991. Baits and foraging behavior of Australian species of *Coptotermes. Sociobiology* 19(1):171-186.

French, J.R.J. 1994. Combining physical barriers, bait and dust toxicants in future strategies for subterranean termite control (Isoptera). *Sociobiology* 24(1):77-91.

Gold, R.E., H.N. Howell, Jr., B.M. Pawson, M.S. Wright and J.C. Lutz. 1996. Persistence and bioavailability of termiticides to subterranean termites (Isoptera: Rhinotermitidae) from five soil types and locations in Texas. *Sociobiology* 28(3):337-353.

Grace, J.K., D.L. Wood and G.W. Frankie. 1989. Behavior and survival of *Reticulitermes hesperus* Banks (Isoptera: Rhinotermitidae) on selected sawdust and wood extracts. *J. Chem. Ecol.* 15(1):129-139.

Grace, J.K. 1989. Oral toxicity of barium metaborate to the eastern subterranean termite (Isoptera: Rhinotermitidae). *J. Econ. Entomol.* 25(1):112-116.

Grace, J.K. and A. Abdallay. 1990. Termiticidal activity of boron dusts (Isoptera: Rhinotermitidae). *J. Appl. Entomol.* 109:283-288.

Grace, J.K., A. Abdallay and J.M. Sisson. 1990. Preliminary evaluation of borate baits and dusts for eastern subterranean termite control. Pub. No. IRG/WP/1433, Intl. Res. Group on Wood Preservation. 7 pp.

Grace, J.K. 1991. Response of eastern and Formosan subterranean termites (Isoptera: Rhinotermitldae) to borate dust and soil treat-

ments. *J. Econ. Entomol.* 84(6): 1753-1757.
Grace, J.K., R.T. Yamamoto and R.H. Ebesu. 1992. Laboratory evaluation of the novel soil insecticide silafluofen against *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae). *J. Appl. Ent.* 113:466-471.
Grace, J.K., J.R. Yates III, C.H.M. Tome and R.J. Oshiro. 1996. Termite resistant construction: use of stainless steel mesh to exclude *Coptotermes formosanus* (Isoptera: Rhinotermitidae). *Sociobiology* 28(3):365-372.
Grace, J.K. 1997. Influence of tree extractives on foraging preferences of *Reticulitermes flavipes* (Isoptera: Rhinotermitidae). *Sociobiology* 30(1):35-42.
Grossman, J. 2002. ESA Conference Notes. *IPM Practitioner* 24(7):16.
Haagsma, K., M. K. Rust, D.A. Reierson, T.H. Atkinson and D. Kellum. 1995. Formosan subterranean termite established in California. *Calif Agric.* 49(1):30-33.
Hamel, M., ed. 1990. *Proceedings of the 1st Intl. Conf. on Wood Protection with Diffusible Preservatives,* Nov. 28-30, 1990. Nashville, TN. USDA/ARS/Forest Service Southern Forest Experiment Sta., New Orleans, LA.
Haverty, M.I., N-Y. Su, M. Tamashiro and R. Yamamoto. 1989. Concentration-dependent presoldier induction and feeding deterrency: potential of two insect growth regulators for remedial control of the Formosan subterranean termite (Isoptera: Rhinotermitidae). *J. Econ. Entomol.* 82(5):1370-1374.
Henderson, G. 1995. Dr. Gregg Henderson, Dept. of Entomology, 402 Life Sciences Bdlg., LSU Agricultural Center, Baton Rouge, LA 70803. Pers. comm.
Henderson, G., K. Sharpe-McCollum and C. Dunaway. 1997. Tracking termites. *Pest Control Technology* February: 56,61.
Hickin, N.E. 1971. *Termites World problem.* Rentokil/Hutchinson, London. 232 pp.
Jones, S.C. 1984. Evaluation of two insect growth regulators for the bait-block method of subterranean termite control. *J. Econ. Entomol.* 77:1086-1091.
Jones, S.C. 1988. Field evaluation of several bait toxicants for subterranean termite control: a preliminary report. Intl. Res. Group Wood Pres. No. IRG/WP /1376. 11 pp.
Jones, S.C. 1989. Field evaluation of fenoxycarb as a bait toxicant for subterranean termite control. *Sociobiology* 15(1):33-41.
Jones, S.C. 1990. Borate baiting systems for subterranean termite (Isoptera: Rhinotermitidae) control. In: Hamel, p. 128.
Jones, S.C. and M. Lenz. 1996. Fenoxycarb-induced caste differentiation and mortality in *Coptotermes formosanus* (Isoptera: Rhinotermitidae). *J. Econ. Entomol.* 89(4):906-914.
Kofoid, C.A., S.F. Light, A.C. Homer, M. Randall, W.B. Herms and E.E. Bowe. 1946. *Termites and Termite Control,* 2nd ed., rev. University of California Press, Berkeley, CA. 795 pp.
Lebrun, D. 1990. Termite control: biological basis. *Sociobiology* 17(1):115-127.
Lenz, M., T.L. Amburgey, Z-R. Dai, J.K. Mauldin, A.F. Preston, D. Rudolph and E.R Williams. 1991. Interlaboratory studies on termite-wood decay associations: II. Response of termites to *Gloephyllum trabeum* grown on different species of wood (Isoptera: Mastotermitidae, Termopsidae, Rhinotermitidae, Termitidae). *Sociobiology* 18(2) :203-254.
Lewis, V.R., M.I. Haverty, D.S. Carver and C. Fouche. 1996. Field comparisons of sand or insecticide barriers for control of *Reticulitermes* spp. (Isoptera: Rhinotermitidae) infestations in homes in Northern California. *Sociobiology* 28(3):327-335.
Light, S.F. 1946. Habitat and habit types of termites and their economic significance. In: Kofoid et al., pp. 136-149.
Light, S.F. and A.L. Pickens. 1946. American subterranean termites, their classification and distribution. In: Kofoid et al., pp. 150-156.
Myles, T. 1996. Development and evaluation of a transmissible coating for control of subterranean termites. *Sociobiology* 28(3):373-401.
Nutting, W.L. 1983. Results of a field test of avermectin on *Heterotermes aureus* in a southern Arizona desert grassland. Proc. 38th Ann. North Central Branch ESA. [cited in Jones 1989]
Nutting, W.L. and S.C. Jones. 1990. Methods for studying the ecology of subterranean termites.*Sociobiology* 17(1):167-189.
Ostaff, D. and D.E. Gray. 1975. Termite (Isoptera) suppression with toxic baits. *Can. Ent.* 107:1321-1325.
Paton, R. and L.R Miller. 1980. Control of *Mastotermes darwiniensis* Froggatt (Isoptera: Mastotermitidae) with mirex baits. *Aust. For. Res.* 10:249-258.
Pestline. 1991. *Pestline: Material Data Sheets for Pesticides and Related Chemicals.* Van Nostrand/Reinhold, New York. 2097 pp.
Pickens, A.L. 1946. The biology and economic significance of the western subterranean termite, *Reticulitermes hesperus.* In: Kofoid et ai., pp. 157-185.
Potter, M.F., E.A. Eliason, K. Davis and R.T. Bessin. 2001. Managing subterranean termites (Isoptera: Rhinotermitidae) in the Midwest with a hexaflumuron bait and placement considerations around structures. *Sociobiology* 38(3B):565-584.
Quarles, W. 1995. Least-toxic cockroach baits. *Common Sense Pest Control Quarterly* 11(1):5-13.
Quarles, W. 1997. New subterranean termite treatments. *Common Sense Pest Control Quarterly* 13(2):13-19.
Quarles, W. 1998. Borates for wood protection. *IPM Practitioner* 20(3): 1-12.
Randall, M. and T.C. Doody. 1946. Poison dusts. In: Kofoid et al., pp. 463-476.
Reinhard, J., M.J. Lacey and M. Lenz. 2002. Application of the natural phagostimulant hydroquinone in bait systems for termite management (Isoptera). *Sociobiology* 39(2):213-229.
Sheets, J.J., and L. Karr. 2001. Kinetics of uptake, clearance, transfer and metabolism of noviflumuron in termites (*Reticulitermes flavipes*). Entomological Society of America Conference, Atlanta, GA, 2001. [see Grossman 2002]
Su, N-Y., M. Tamashiro, J.R. Yates and M.I. Haverty. 1984. Foraging behavior of the Formosan subterranean termite (Isoptera: Rhinotermitidae). *Environ. Entomol.* 13:1466-1470.
Su, N.-Y., M. Tamashiro and M.I. Haverty. 1987. Characterization of slow-acting insecticides for remedial control of the Formosan subterranean termite (Isoptera: Rhinotermitidae). *J. Econ. Entomol.* 80:1-4.
Su, N.-Y. and R.H. Scheffrahn. 1988. Toxicity and feeding deterrency of a dihaloalkyl arylsulfone biocide, A-9248, against the Formosan subterranean termite (Isoptera: Rhinotermitidae). *J. Econ. Entomol.* 81(3):850-854.
Su, N-Y. and R.H. Scheffrahn. 1989. Comparative effects of an insect growth regulator, S-31183, against the Formosan subterranean termite and eastern subterranean termite (Isoptera: Rhinotermitidae). *J. Econ. Entomol.* 82(4):1125-1129.
Su, N-Y. and R.H. Scheffrahn. 1990a. Economically important termites in the United States and their control. *Sociobiology* 17(1):77-94.
Su, N-Y. and R.H. Scheffrahn. 1990b. Potential of insect growth regulators as termiticides: a review. *Sociobiology* 17(2):313-328.
Su, N-Y. and R.H. Scheffrahn. 1991. Laboratory evaluation of two slow-actingtoxicants against Formosan and eastern subterranean termites (Isoptera: Rhinotermitidae). *J. Econ. Entomol.* 84(1):170-175.
Su, N-Y., P.M. Ban and R.H. Scheffrahn. 1991. Suppression of foraging populations of the Formosan subterranean termite (Isoptera: Rhinotermitidae) by field applications of a slow-acting toxicant bait. *J. Econ. Entomol.* 84(5):1525-1531.
Su, N-Y. and R.H. Scheffrahn. 1993. Laboratory evaluation of two chitin synthesis inhibitors, hexaflumuron and diflubenzuron, as bait toxicants against Formosan and eastern subterranean termites (Isoptera: Rhinotermitidae). *J. Econ. Entomol.* 86(5):1453-1457.
Su, N-Y., M.Tokoro and R.H. Scheffrahn. 1994. Estimating oral toxicity of slow-acting toxicants against subterranean termites (Isoptera: Rhinotermitidae). *J. Econ. Entomol.* 87(2):398-401.
Su, N-Y. 1994. Field evaluation of a hexaflumuron bait for population suppression of subterranean termites (Isoptera: Rhinotermitidae). *J. Econ. Entomol.* 87(2):389-397.
Synder, T.E. 1946. American subterranean termites other than Pacific Coast. In: Kofoid et al., pp. 187-195.
Thorne, B.L. and J.F.A. Traniello. 1994. Detection and control through baiting termites. *Pest Management* 13(9):1-13,16-18.
Tomlin, C., ed. 1997. *The Pesticide Manual,* 11th ed. British Crop Protection Council, Farnham, Surrey, UK. 1606 pp.
Woodson, W.D., B.A. Wiltz and A.R. Lax. 2001. Current distribution of the Formosan subterranean termite (Isoptera: Rhinotermitidae) in the United States. *Sociobiology* 37(3B):661-671.

# Termite Bait Update

*By William Quarles*

Since Dow introduced the Sentricon™ System in 1995, termite baits have been widely accepted by pest control operators (PCOs), homeowners, and even environmental groups. Baits have less of an environmental impact than the alternative, which is application of a chemical ground barrier. To form a ground barrier, more than a hundred gallons of a pesticide formulation must be added to the soil underneath or around a structure. In contrast, baits are targeted to termites, are contained in bait stations, and deploy very small quantities of active ingredients.

The Sentricon System has now been installed in more than a million locations worldwide (Dow 2002b). The expanding market for termite baits has also stimulated competition. Customers now have a choice among six different competing products, (Dow)Sentricon™, (Ensystex) Exterra™, (Bayer) Outpost™, (FMC) Firstline™, (Spectrum) Terminate™, (BASF) Subterfuge™ and TermiRid™ (Bayer 2000, BASF 2001, Dow 2002a, Ensystex 2003, Potter 1997; Cabrera et al. 2002). (see Resources)

## Different Active Ingredients

Commercial baiting systems have different active ingredients, and also different baiting and marketing strategies. Active ingredients are either chitin synthesis inhibitors (CSI's) such as hexaflumuron and diflubenzuron, metabolic inhibitors such as sulfluramid or hydramethylnon or a salt of boric acid (disodium octaborate tetrahydrate).

Sentricon uses the CSI hexaflumuron. Chitin synthesis inhibitors make it impossible for termites to produce effective amounts of chitin. If growing termites are unable to molt, they die. Because termites normally molt every 2 weeks to 6 months, according to larval stage, hexaflumuron works slowly. Even with active feeding, colony elimination can take three months or more (see Quarles 1995ab; Quarles and Bucks 1995; Su 1993ab; 1994).

The current Sentricon bait formulation, Recruit II, contains 0.5% (5000 ppm) hexaflumuron soaked into paper towels or sawdust (Potter 1997). Dow has developed a new CSI called noviflumuron that will probably replace hexaflumuron. Noviflumuron is 5-6 times more potent than hexaflumuron and is eliminated more slowly by termites. Both hexaflumuron and noviflumuron are eliminated unchanged, but the half-life for hexaflumuron is 8-9 days and for noviflumuron is 1-6 months. Increased potency and slower excretion leads to quicker buildup of effective doses in all the termites and faster colony elimination. Both hexaflumuron and noviflumuron have low acute toxicity to mammals with LD50s for oral doses in rats of about 5000 mg/kg (Sheets and Karr 2001; Sheets et al. 2000; Grossman 2002).

Exterra and Outpost use the CSI diflubenzuron as the active ingredient. About 0.25% diflubenzuron is added to a baiting matrix of paper, in the case of Exterra, or powdered cellulose, in the case of Outpost. Diflubenzuron was the first registered CSI and is by far the most widely used around the world. It has been registered in the U.S. since 1976 for forestry, food crops, and horticulture applications (Tomlin 1997; Farm Chemicals 1999).

The active ingredient of Firstline and Terminate is 0.01% (100 ppm) sulfluramid. The active ingredient of Subterfuge is 0.3% (3000 ppm) hydramethylnon (Quarles 1998a, FMC 1995; BASF 2001). Sulfluramid and hydramethylnon have both been used extensively and effectively in ant and roach bait stations. They are metabolic inhibitors that block the oxidation of ingested food. Since food cannot be utilized, termites slowly starve to death (Tomlin 1997). The active ingredient of TermiRid is sodium borate. Boric acid and borates kill termite intestinal microbes and inhibit digestive enzymes, making it impossible for termites to metabolize cellulose (Quarles 1998b). All these materials are effective in termite baits because they are not repellent at label rates and work very slowly (Su et al. 1994; Su et al. 1987; Logan and Abood 1990).

## Different Baiting Techniques

Sentricon uses a perimeter prebaiting technique. Stations are buried in the ground at intervals of about 10 ft (3 m) around a structure, and more than 2 ft away from foundations to avoid conflicts with repellent chemical barriers. These ground stations are prebaited with pine stakes and used as monitoring traps. Monitoring traps are inspected regularly until termites are found. When termites are found, hexaflumuron bait tubes replace the pine stakes in the bait station (Potter 1997).

Exterra and Outpost use a similar perimeter baiting strategy. Walls of each station are lined with a thin layer of wood. The active bait formulation is added to the center of the station when termites begin feeding on the wood. This strategy minimizes disturbance of feeding termites. However, in areas of known termite activity, wooden prebaits and the active baits are both added when the station is installed. The Outpost label also recommends installation of baits in crawl spaces if termites are seen there (Bayer 2000).

Subterfuge does not use prebaiting. Perimeter bait stations are installed, and the active bait is added immediately. To install the baits, holes are drilled into the soil around the perimeter of the building. The outer plastic casing is inserted into the holes. Then, an inner plastic bait tube is inserted, and the powdered bait is poured into the bait tube. The active bait is supposedly more attractive to termites than other items on their foraging menu, and they are diverted from feeding on houses to feeding on bait stations. Finally, the bait station is capped to prevent tampering by non-target organisms (BASF 2001).

The Firstline bait station uses either "interceptive" or "directed baiting" or a perimeter baiting technique. With interceptive baiting, holes are drilled into the ground, and stations are dropped into place in areas where termites are known to be foraging. Active bait is added immediately. Alternately, perimeter monitoring stations are installed that contain just wood attractants, and active bait is added when termites appear. In another variant, a large bait station (Home Defender™) contains simultaneously wood attractants and active baits. According to the label, up to 14 bait stations can be used on any one property. Visibly infested wood, wood mulches, areas near fence posts, and visible termite tubes are baited (see Quarles 1995b; FMC 1996ab).

Terminate baits are normally installed without a prebaiting cycle. Active baits are applied to the perimeter or near where termites have been seen. Terminate is available as a "Do it Yourself" bait, but the manufacturer recommends that the structure is first inspected by a pest control operator (PCO) (see Resources).

Another option for the "Do it Yourselfer" is to buy HomeChoice monitoring stations to operate a perimeter prebaiting cycle. When termites appear, then active Terminate or TermiRid baits can be dropped into the stations (see Resources).

## Different Marketing Strategies

Sentricon differs from the other termite baits in that the manufacturer insists that all PCOs using the system be directly trained by the company. In contrast, for states where the materials are registered, PCOs can purchase Firstline and Outpost just by calling a distributor or ordering from the Internet. Exterra can be obtained if the PCO signs an agreement with the manufacturer Ensystex to use it properly. Subterfuge is also sold only to PCOs (Potter 1997, Bayer 2000, BASF 2001).

In most states, property owners can do their own termite baiting without hiring a PCO. Terminate and TermiRid can be purchased at hardware stores, home supply outlets, or through online suppliers on the Internet. If prebaiting is desired, HomeChoice bait stations are available online. The do-it-yourself baits are less expensive than Sentricon or other baits applied by PCOs.

On the negative side, it is possible that the stations may not be installed and inspected properly by someone new to the termite control business. Best results come from proper placement of the stations and introduction of the active bait without disturbing foraging termites. Homeowners who try the do it yourself bait may fail to control their termites, and then think that termite baiting does not work. Thus, the Terminate approach could possibly cause an unfair backlash against the new baiting strategies.

Terminate baits are sold with a money-back guarantee. No money is lost if someone wants to try to bait their own termites. However, if the attempt fails, the homeowner must accept the extra three months or so of termite damage, and turn to another approach.

## Termite Foraging and Bait Discovery

The key to success with termite baits is bait discovery and acceptance. Most likely, termites forage randomly, and baits are discovered by accident as part of the constant search for food (see below). One study measured bait discovery and acceptance over a 16-month period. One group of 24 homes was monitored with 475 pine wooden stakes. Over this period, 13.7% of the stakes were attacked. Another 22 termite-infested homes were monitored with Sentricon stations, and 20.2% of these stations were attacked. At 2 of 22 locations, monitoring stations were never discovered by termites, and termite control was not possible. At the other 20 locations, termites were eliminated from structures. An average of 2.7 wooden stakes and 4.1 monitoring stations per structure were discovered by the termites (Potter et al. 2001ab).

In another study, when a large housing complex of 28 buildings with 205 units was baited with Sentricon, 9.2% of the 2,041 monitoring stations had been discovered by termites within a 9-month period. Some of the foraging was focused, as 25 of 34 stations around one building were attacked (Dow 2002a). Although few stations are attacked, feeding by the colony is usually persistent, and this persistence leads to colony suppression (Henderson et al. 1997; Thorne and Forschler 2000).

Foraging patterns are hard to predict. However, Potter et al. (2001b) found that Sentricon stations were more likely to be attacked in bare ground than in grass or mulch. Proximity to termite damage or moisture sources did not increase termite attacks on the stations. A higher percentage of the wooden stakes were attacked in mulched areas than in bare ground or grass. Attacks on stakes or stations were more likely in shaded areas than in direct sunlight.

## Field Trials of Termite Baits

These competing bait technologies have all been tested in field trials, some of which have only recently been published. Are these techniques successful, and is one approach better than another? These questions can only be answered if the goals and criteria necessary for success are clearly defined. For a homeowner, success might simply mean that termites are not feeding on or in a structure. This is the bottom-line result needed for any control method, including chemical barriers. Additional goals possible only with baits are suppression and/or elimination of subterranean colonies that are threatening a structure. Different termite monitoring strategies are necessary according to established goals (**see Box A**).

## Choice of Active Ingredient

If the goal is colony suppression or removal of termites from structures or baited areas, either toxicants (Firstline, Terminate, Subterfuge, TermRid) or CSI's (Sentricon, Exterra, Outpost) would be appropriate. If the goal is colony elimination, then CSI's may be a better choice. In fact, up to 1996, the only published cases demonstrating colony elimination involved Sentricon (Su and Scheffrahn (1996b).

The reason that a CSI might be a more suitable choice for colony elimination is due to the termite foraging process. Baits are taken from bait stations by foragers, then transferred to the rest of the colony by trophallaxis (social food exchange). Though termites feeding at an active station usually move on to another food source within 30 days (Atkinson 2000), workers in the immediate area of an active bait initially tend to accumulate higher concentrations of active materials than those foraging elsewhere. Lethal time is dose-dependent for toxicants such as sulfluramid. For example, 90% of *C. formosanous* workers are killed within 16 hours after ingestion of sulfluramid at 24 ppm, but 11.5 days are required at 9 ppm (Su et al. 1994). Repetitive foragers at treated stations accumulate high concentrations and may eventually die near the bait station. Even though the toxicant is slow acting, some termites can die within a few days. Others are exposed to sublethal doses. Those exposed to sublethal doses avoid the baits, thus the colony is only suppressed, not eliminated (Su et al. 1995).

Sublethally poisoned termites also tend to avoid a baited area, and the area can become repellent. Sulfluramid and hydramethylnon baits, which are toxicants, should be effective in removing termites from structures if baits are installed in mud tubes and active galleries. Toxic baits installed on the perimeter should ultimately repel termites from the structural foundations. But as the poisoned colony begins to die, there are also fewer foragers to deliver the bait to the remaining colony. The result is colony suppression instead of elimination. Sulfluramid has totally eliminated colonies only when applied in the trap-treat-release method with a groomable coating (Myles 1996).

Su et al. (1984) concluded that field populations of *Coptotermes formosanus* foraged randomly. Workers cycle through diffuse galleries, and move from food source to food source. Though early experiments suggested that *Reticulitermes* did not forage randomly, (Oi et al. 1996; Thorne et al. 1996), later research supports random foraging of each worker throughout the whole colony foraging range (Atkinson 2000). This dispersal and trophallaxis insures that the whole colony is exposed to an active bait (Su et al. 1995; Grace and Su 2001).

Chitin synthesis inhibitors such as hexaflumuron (Sentricon) are not dose dependent. Any non-repellent concentration builds throughout the colony. Whether concentrations are high or low in an individual termite, results are the same. Death occurs only when the termite tries to molt. By the time the first termites start dying, the CSI is already present throughout the colony. As termites are dying uniformly throughout the foraging area, active feeding stations do not become repellent. In fact, for Sentricon to be successful in removing a structural infestation, severe colony suppression and perhaps elimination is necessary (Su and Scheffrhan 1996ab; Su et al. 1995).

## Diflubenzuron Repellent?

Early experiments seemed to show that diflubenzuron was repellent in concentrations greater than 2 ppm (Su and Schefferan 1993). The bait matrix may be a factor, however. According to Ensystex company literature, the diflubenzuron bait used in Exterra is not repellent in concentrations up to 1%. Ensystex choice tests showed termites preferred 1% diflubenzuron to the 0.5% hexaflumuron bait used by Sentricon (Quarles 1998a). Presumably, choice tests with Outpost bait would produce similar results.

## Results with Sulfluramid

The final test of a termite bait is effectiveness in the field. Most of the products probably work effectively to suppress or eliminate termite populations. Su et al. (1995) conducted field tests with sulfluramid at three structures. Formosan termites fed at first on boards with 8 ppm sulfluramid, but later avoided them. However, population size was reduced from 2.7 million to 764,000. A test at a second colony led to reduction from 4.1 million to 574,000. Foraging territory was not affected by the baiting. At a third colony foragers were reduced from 1.8 million to 867,000. Foraging activity or territory was not reduced (Su et al. 1995).

Dr. James Ballard of FMC directed the Firstline field trials for his company. Ballard assists bait installations and helps to train PCOs who must replenish, and sometimes move, bait stations. In trials leading up to registration of Firstline, he baited 54 structures. At 45 of these sites, conditions were such that control with baiting seemed likely. At 15 sites, successful control of active infestations was achieved within 70 days. Successful control is defined as disappearance of termites from bait stations and structures. *Heterotermes*, *Coptotermes*, and *Reticulitermes* species have all been successfully baited.

Ballard believes that complete elimination of a termite colony is

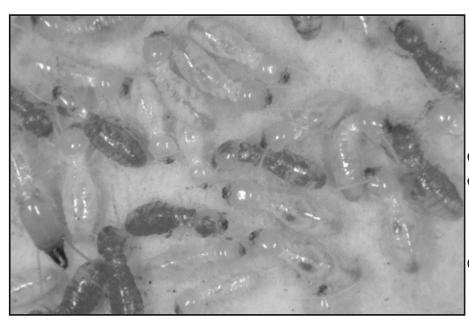

*Photo courtesy of Tim Myles*

**Termites marked with dye can be used to estimate populations.**

# Update

## Box A. Termite Monitoring Strategies

According to Forschler (1996), the primary result of a baiting strategy should be prevention or removal of termite infestations in structures, not necessarily colony suppression or elimination. If this approach is taken, termite activity can be monitored near the baiting sites. Success occurs when foragers are no longer present in structures or near structures.

Another possible goal of termite baiting is colony suppression or elimination. According to Su and Scheffrahn (1996ab), there are three parameters that can be used to measure colony suppression or elimination: reduced foraging activity, reduced foraging territory, and reduced foraging population size. One possible way of assessing foraging activity is by counting the number of termites and amount of bait consumed in treated bait stations. Presence of termites means a colony is present and feeding, but absence of termites could mean that termites have been repelled either by the bait or dead termites in the area and are foraging elsewhere.

Feeding at a number of untreated monitoring stations followed by no activity is good necessary evidence for colony elimination. Reduced activity at untreated monitoring stations is one measure of success in colony suppression. If the idea is colony suppression or elimination, then termite activity should be monitored at sites away from active bait stations (Forschler and Ryder 1996).

To insure that monitoring stations are observing the colony that is feeding on the bait, marked termites should be used to establish foraging ranges. Termites are captured, marked, then released. As they show up in other monitoring stations, a map of the foraging territory can be constructed (Su et al. 1984; Grace 1990; Grace et al. 1989).

Termite activity at monitoring stations can be misleading if the observation is over a short time interval. The amount of feeding is subject to weather conditions and seasonal activity, and the number of termites collected provides only a limited view of activity. Unless a colony is observed for a long period to establish some kind of baseline for normal variation, effects of a bait are difficult to assess.

Termite populations have been estimated with mark-release-recapture techniques (see below). Current mark-release-recapture techniques assume that the colony is not merging with another colony, breaking into satellite colonies, or another colony is not involved with a takeover of feeding sites (Forschler and Ryder 1996).

### Mark-Recapture Technique

"Field populations can be estimated into small, medium, large, or mega- colonies using mark-release-recapture studies or simply by the number of stations attacked, time to attack and the number of termites attacking each station" (Pawson and Gold 1996). However, to successfully conduct field trials with hexaflumuron and other bait toxicants, techniques had to be devised to unambiguously prove efficacy. Earlier baiting trials with mirex had used wooden stakes to monitor for foraging termites amidst bait blocks soaked in mirex. Foraging termites in the area diminished, but researchers could not determine whether the colony had been killed or had just moved to another location (Esenther and Beal 1978).

When Su (1994) field tested hexaflumuron, he used a mark-recapture methodology to estimate the number of foraging workers present before and after deploying baits. Wooden stakes were set up to find foragers. At stakes where foragers were found feeding, monitoring stations were established that consisted of plastic cylinders filled with wooden blocks and buried in the soil. At one station with high activity (5000 foragers) termites were captured and marked with Nile Blue A dye, then released. One week after release at the monitoring station, termites were again captured at the same station and the number of dyed termites were counted. Forschler (1994) has used fluorescent paint to mark termites for mark-recapture population estimates.

### Counting Jellybeans

Counting termites with mark-recapture is like counting a mixture of white and blue jellybeans in a jar. A known number of blue beans is added to an unknown number of white beans, and the jar is shaken. A handful is then scooped out. If the handful contains very few blue beans, there are very many white beans. Similarly, if very few marked termites are recaptured, the colony is very large. If most of the termites recaptured are marked, the colony is small. A statistical formula allows computation of the number of foragers in the colony. Mark-recapture can estimate a population because "each colony is a closed unit with no individuals moving between colonies, and populations do not increase or decrease rapidly" (Su 1993a). *C. formosanus* workers also forage at random, a condition that is required for valid mark-recapture work (Su et al. 1984). Thorne et al. (1996) believe that random foraging has not been established for *Recticulitermes* spp. Errors due to non-random foraging can be minimized by using a large number of traps (Grace 1990).

Successful use of mark-recapture also requires that the dye does not kill termites, that the dye is not transferred by trophallaxis, that marked termites are not attacked and killed by their nestmates, that the dye is not lost due to feeding, and that termite fitness is not reduced by dye marking under a wide range of field conditions. Any process that systematically eliminates marked termites gives an overestimation of colony size. Preliminary laboratory studies and the triple mark-recapture method minimize errors of this sort (French 1994; Thorne et al. 1996).

A major problem with mark-capture-release is low recapture ratios. This problem, and the fact that many assumptions about termite foraging are necessary in order to fit the model, should lead to cautious interpretations of the foraging numbers (Thorne et al. 1996; Forschler and Townsend 1996). Mark-recapture colony size estimates are about 10-fold higher than direct counts based on excavated nests (Su and Scheffrhan 1988).

impractical and unnecessary. What is important is continued monitoring, and prevention of termite damage. If colonies are knocked back to the point that no termites are seen in structures, and no PCO call backs are necessary, Ballard believes that adequate control has been achieved.

To bait infestations inside structures, Ballard breaks into the leading edge of a mud shelter tube and attaches a bait station with tamper-resistant screws. Termites then rebuild the shelter tube around the bait station. At locations outside, Ballard pursues an approach called directed baiting. Baits are placed near fenceposts, in wooden mulches, and in other areas where termite infestation is likely.

Ballard sees baiting as part of an IPM program involving inspection, moisture and food reduction, termiticide application, use of foam and sand barriers. Which elements predominate in the treatment depends on the site. For instance, in areas where a well is supplying drinking water, baits would be used instead of chemical barrier treatments. Where treatment is mandated by a real estate sale, however, baits might act too slowly and another method might have to be employed (Ballard 1995).

## Trials in New Orleans

Dr. Gregg Henderson of Louisiana State University Agricultural Center in Baton Rouge, LA has baited Formosan termites with prototype Firstline stations in New Orleans. He started by baiting colonies in cypress trees. Because the cypress trees are surrounded by swamp water, colonies are isolated from the ground and results from baiting can be more easily determined. Placement of cardboard baits containing 100-1000 ppm sulfluramid inside trees completely eliminated these colonies (Henderson 1995).

## Baiting Structures

Where the primary purpose of baiting was removal of termites from structures and other areas, Henderson also had success. For instance, underground telephone cables in New Orleans are often attacked by Formosan termites. Toxic sprays cannot be used in this situation because toxic vapors in closed spaces can be very hazardous to personnel involved in repairs. Also, cables are close to the water table and groundwater could be easily contaminated. Since there is no real termite food in these areas, baits are quickly eaten and colonies are eliminated (Henderson 1995).

At 14 manhole sites baited initially with 10 ppm and then with 100 ppm sulfluramid over a two-year period, suppression was complete at 36% of the sites, excellent at 21%, high at 36%, and low at 7% of the sites. "Excellent" meant the total absence of termites for 3 consecutive months, and "high" meant a large reduction (Felix and Henderson 1995).

Henderson has also successfully baited active infestations in structures. For some of these infestations, PCOs have called Henderson as a last resort when other methods of elimination fail. Henderson drills into infested galleries and adds moistened cardboard soaked in 100 ppm sulfluramid. He has found that Formosan infestations centered in attics are more easily eliminated than those in basements. Formosan colonies in attics are more desperate for water, and thus find the moistened baits more palatable.

Henderson was able to completely eliminate Formosan infestations in the Ursiline Convent, which is the oldest building in the Mississippi Valley. Termite infestations also vanished from St. Patrick’s Cathedral after structural baiting with sulfluramid. At a Lutheran Church in the New Orleans area, however, the infestation was apparently too large for elimination by baiting within a reasonable 4-month time frame.

To test repellency, Henderson fed cardboard soaked in 10 to 100 ppm sulfluramid to laboratory colonies. Feeding termites were not initially repelled even by the highest concentration. However, the amount of feeding was less than on lower concentrations. High concentrations and low concentrations produced similar mortality rates, however. Even though termites ate less of the higher concentration, the more concentrated toxin had extra potency. In fact, Formosan termites are so sensitive to sulfluramid that very little needs to be ingested for mortality (Grace et al. 2000).

Henderson believes that once PCOs have become accustomed to the process of monitoring and baiting termites, they will readily accept the technique. Even if colonies are not totally eliminated, both PCO and client should be better able to make treatment decisions if there is good information on the type and extent of the infestation (Henderson 1995).

## Early Results with Subterfuge

Like other metabolic inhibitors, results with hydramethylnon (Subterfuge) are dose-dependent. For example, 24 hr exposure to 2000 ppm kills 90% within 12 days, but 18000 ppm kills this percentage within 1 day. Concentration of hydramethylnon in the Subterfuge bait is 3000 ppm. Logan and Abood (1990) estimated that an effective baiting concentration for *R. santonensis* should lie between 1250 and 5000 ppm. Hydramethylnon is not initially repellent to *C. formosanus* in laboratory tests at concentrations up to 1000 ppm (Su et al. 1987). However, after termites start dying, others start avoiding the treated area (Su et al. 1982ab).

Results with hydramethylnon have been inconsistent. Early field tests showed that hydramethylnon was not repellent and was suppressive to subterranean termites over a two-year period (Anon 1995; Thorne and Traniello 1994), but termite colonies were not eliminated (Su and Scheffrahn 1996ab; Su et al. 1982ab).

But Pawson and Gold (1996) had less success. They did preliminary trials with the Subterfuge formulation of hydramethylnon (3000 ppm and 30 g bait tubes) at four structures. At one structure, about 1 tube (1.09) of placebo and 1 tube of active material were consumed and *Reticulitermes* termites were not controlled over the period of a year. At a second structure, 1.70 cartridges of placebo and 1.26 cartridges of active bait were consumed. Apparently, *Reticulitermes* sp. found hydramethylnon repellent and were not controlled.

At a third structure of pier-and-beam construction, 13 of 37 stations were attacked, 5.79 tubes of placebo, and 2.02 cartridges of active bait were consumed, and there was partial suppression. At a 4th structure of slab-on construction, 45 bait stations were installed. The mixed infestation of *Coptotermes formosanus* and *Reticulitermes* sp. consumed 3.78 active bait tubes from 33 locations. Hydramethylnon baits did not control the infestation, and may have been repellent. Since this early work, the formulation has been changed to make it less repellent (BASF 2001).

## Hexaflumuron Field Trials

Su (1994) had success with hexaflumuron (Sentricon) in Florida. Three colonies of *R. flavipes* and three of *C. formosanus* were baited in these initial trials. Three bait tubes from which 3.9 mg of hexaflumuron were consumed killed one colony of 400,000 *R. flavipes* within three months. Another colony of 730,000 was killed with 11 tubes and 20.3 mg of hexaflumuron. The third colony of *R. flavipes* contained nearly 3 million foragers ranging over 2,361 $m^2$ (0.58 acre). The colony was killed after 4 months with 69 bait tubes and about 1500 mg (1.5 g) of hexaflumuron.

A *C. formosanus* colony containing about 1 million foragers covering about 1,600 $m^2$ (0.40 acre) was killed with 40 bait stations and about 233 mg hexaflumuron over a 9-month period. Another *C. formosanus* colony of about 2.5 million infesting a high rise was eliminated in 7 months with 89 tubes and 742.3 mg of hexaflumuron. This colony had resisted soil termiticides and one chemical fumigation. Another *C. formosanus* high rise colony was reduced from 1.2 million to 104,000 in a 4-month period with 42 bait tubes and about 260 mg of hexaflumuron (Su 1993ab; 1994).

## Sentricon in Hawaii

Grace et al. (1996) used Sentricon baits at three Formosan termite sites in Hawaii. Stations were installed at least 30 cm (11.8 in) away from foundations at invervals of 4 to 5 m (13 to 16 ft). At one site, a colony of 0.33 million attacked 4 of 25 bait stations, consuming 3.25 bait tubes containing 113 mg of hexaflumuron. The colony was eliminated. At another site, a colony of 5.35 million attacked 5 of 45 bait stations, consuming 17 bait tubes containing 595 mg of hexaflumuron. The colony was eliminated. At the third site, a colony of 0.94 million attacked 4 of 27 stations, consuming 12 bait tubes containing 420 mg of hexaflumuron. The intial colony was eliminated, but the area was reinvaded within 8 months by a colony from next door. Baiting was continued, and no activity was observed 18 months later.

## Sentricon in Texas

Pawson and Gold (1996) baited 8 structures with Sentricon using standard techniques over a 2-year period. Bait stations were installed every 3 to 5 m around each perimeter. Stations were inspected every month for presence of termites and amount of bait consumed. Termites were able to locate stations at 6 of 8 locations within a month. Altogether, termites attacked 18.7% of the monitoring stations, but they probably did not continuously forage there. At some bait stations, termites had been present, but were not foraging at the time of the inspection. Control was achieved at one of 8 structures. Increasing the number of stations in Texas did not increase the number of termite encounters (Pawson and Gold 1996).

## Sentricon in Georgia

Forschler and Ryder (1996) baited four well-characterized *Reticulitermes* spp. colonies averaging 43,000 termites per colony with Sentricon. After taking bait, three colonies were eliminated after 3 months, the 4th showed activity for 8 months. A further 12 small colonies were studied, without characterizing colony size or foraging range. Six of these removed bait and showed no activity at monitoring stations after 5 months, two colonies removed bait but were still active after 9 months, 3 colonies were only briefly monitored and were not baited, 1 colony remained active in a monitoring station, but did not take the bait. In 93% of the colonies where baiting was attempted, termite activity was eliminated within a year. In 100% of colonies where bait was taken, the colony was eliminated within a year.

Studies in California, Iowa and other locations have also shown Sentricon baiting can control structural termites (Kistner and Sbragia 2001; Prabhakaran 2001).

## Feedback from PCOs

Though field trials conducted by entomologists associated with Universities may be necessary to establish a product's effectiveness, the final approval must come from PCOs and their customers. For instance, Robert Davis of ABC Pest and Lawn Service in Austin, TX reported success with Sentricon at the 1999 Entomological Society of America meeting in Atlanta, GA. From 1996 to 1999, Davis baited 1,276 properties with 35,006 Sentricon stations. Over the 3-year period, 945 of 1,276 colonies were eliminated (74%). Of 335 sites treated in 1997, only 20 (6%), still had termites in 1998. At the time of his presentation, 331 clients (26%) had bought preventive contracts after their termites had been eliminated (Grossman 2000).

## When are Termites Eliminated?

When baits were first being developed, researchers had to establish efficacy by setting up separate monitoring and baiting stations. Termites were marked and released to measure effects of baits on populations (see Box A). Pains were also taken to identify colonies of termites by dye marking and cuticular hydrocarbons. In this way, researchers knew whether termites being monitored were part of the original colony, or represented a reinvasion of a new colony (Getty et al. 2000).

As a practical matter, PCOs and their clients must be able to tell when termites are no longer a problem. Thorne and Forschler (2000) suggest the problem is over when winged termites disappear, when termites disappear from pre-baiting and post-baiting monitoring stations, and when feeding is vigorous on an active bait, followed by termite inactivity. The manufacturer of Exterra is using the following criterion of success: “if all termite feeding and activity in an area has been absent from the area for six consecutive months and termites fed on the bait for three months prior to the cessation of feeding and activity, we presume that colony elimination has occurred” (Quarles 1998a). Again, as a practical matter, termites should no longer be foraging inside the structure or constructing mud tubes.

Even if a colony is eliminated, and signs of an infestation disappear, the baiting process should continue in order to maintain protection. When colonies are no longer feeding on active baits, active materials should be removed, and the monitoring process continued with wood or other attractant (Bayer 2000; Exterra 2003).

## Recovery of Suppressed Populations

What happens after colonies have been suppressed or eliminated by baits? The possibilities are rebound of the colony, invasion by another colony, or total lack of activity. In any event, monitoring must be continued to find out. Su and Scheffrhan (1996a) studied colony recovery after suppression, but not elimination, with baits. A colony of *R. flavipes* was baited for four months with Sentricon, was suppressed from 2.8 million to 260,000, then was intentionally allowed to recover. However, recovery did not occur and the colony was completely dead within four years. A colony of Formosans reduced from 3.6 million to 68,000 by the metabolic inhibitor A-9248, had rebounded to 743,000 within four years. Three colonies suppressed with sulfluramid from ranges of 1.9-4.1 million to 575,000 to 847,000 remained low for two years. Populations then resurged to levels greater than 1 million and were treated either with Sentricon or soil termiticides.

Elimination of colonies, on the other hand "created zones of termite-free soil" that lasted from nine months to more than four years. Sometimes the territory of the eliminated colony was reinvaded by neighboring colonies, but usually was not (Su and Scheffrhan 1996a).

## Aboveground Termite Baits

Though commercial baiting systems were all originally installed in subterranean systems, baits can also be installed aboveground. Aboveground termite baits were pioneered by the APG Specialty Products Group of FMC Corporation (see Resources). The aboveground bait, called Firstline™ consists of cardboard impregnated with 100 ppm of sulfluramid. The cardboard is protected by a bait station that is inserted into the leading edge of an active mud tube to control subterranean termite infestations at their source (FMC 1995; 1996c).

Dow distributes an aboveground bait called Recruit AG. The active ingredient is the same hexaflumuron used in the Sentricon underground bait station. The combination of underground and aboveground baits introduces the active ingredient into underground colonies faster than underground baits alone. Recruit AG is used wherever the aboveground infestation is visible and evident. This baiting approach is especially useful for aboveground infestations of Formosan termites (Potter 1997; Josof 1997; Yates and Grace 2000).

Studies have also shown that aboveground stations alone can lead to elimination of termites (DeMark and Thomas 2000; Yates and Grace 2000; Su et al. 2001). The diflubenzuron bait (Labyrinth™) used in the Exterra system is also labeled for use in aboveground stations (Ensystex 2003).

## Acute Safety

All the termite baits contain low concentrations of active ingredients, which insures their acute safety. The small amount of toxicant used makes them potentially less toxic than chemical ground treatments, which use several pounds of formulated product. For sulfluramid, the acute oral LD50 for a rat is about 543 mg/kg. Since each ground station contains 3.54 grams of cardboard at 100 ppm (0.01%), only 0.35 mg of sulfluramid is present in each station. Thus, a 1 kg rat could eat 1550 bait stations before reaching the LD50 dose. Since no more than 14 stations are ever installed on one property, the stations have more than adequate acute safety (Tomlin 1997; FMC 1996a).

Aboveground Firstline stations contain 0.43 oz (12.7 g) of treated cardboard, containing about 1.3 mg of sulfluramid. Thus, about 418 aboveground stations, if ingested, would equal the LD50 for a 1 kg rat. Since no more than four aboveground stations are ever installed in one unit, the sulfluramid aboveground stations should be acutely safe (Tomlin 1997; FMC 1996d).

The Recruit bait used in Sentricon should cause no problems. If an entire 80 g bait tube containing 0.1% hexaflumuron were eaten, only 80 mg of active ingredient would be ingested. [For comparison, the active ingredient in one aspirin is about 300 mg.] A 1 kg rat would have to eat about 62 bait stations to reach the LD50. Recruit II, which is currently used, contains 0.5% hexaflumuron, and about 12 stations would have to be eaten to reach the mammalian LD50 (Su 1993ab, Su 1994; Tomlin 1997).

In the case of Outpost, 200 g of bait contains 500 mg of diflubenzuron. About 100 of the 200g bait units would have to be consumed to equal the mammalian LD50 of about 5000 mg/kg (Bayer 2000).

# Update

Subterfuge bait stations contain an average 30 g of bait containing 0.3% hydramethylnon. Each bait station, then contains 90 mg of hydramethylnon. Since the LD50 in rats in 1150 mg/kg, consumption of about 13 bait stations would equal the LD50 for a l kg rat (Tomlin 1997; BASF 2001).

## Water Solubility

Sulfluramid, hydramethylnon, and hexaflumuron are nearly insoluble in water, and thus should not leach out of the bait stations into the environment. The little that does leach out should be strongly bound to the soil (Tomlin 1997).

However, because low solubility is not insolubility, none of these baits should be used in direct contact with water (FMC 1996b). The MSDS's of hexaflumuron and diflubenzuron warn that the material is toxic to aquatic invertebrates (Dow 2002a; Bayer 2000).

## Conclusion

All of these baits can suppress or eliminate subterranean termite colonies if termites find the active bait and eat enough of it. Choice of bait depends on goals of homeowners and PCOs. Firstline should quickly eliminate a structural infestation and tends to repel termites from the area of bait installation. Sentricon or other systems containing CSI's should be the choice if the goal is colony elimination. No matter which baiting technology is used, termite baits require a long-term committment to termite monitoring in order to prevent structural damage. The necessary installation of monitoring stations are the first step toward implementation of a structural IPM program for termites.

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### Resources

Firstline Bait (sulfluramid)—FMC Corporation, PO Box 8, Princeton, NJ 08543; 800/321-1362; 609/951-3000

HomeChoice (monitoring stations)—www.epestsupply.com; 877/500-0011

Labyrinth Bait (diflubenzuron, Exterra)—Ensystex, 2709 Breezewood Avenue, PO Box 2587, Fayetteville, NC 28303; 1888-Exterra; Fax 888/368-4789

Outpost (diflubenzuron)—Bayer Environmental Sciences, 95 Chestnut Ridge Rd., Montvale, NJ 07645; 800/438-5837, 214/484-6326, Fax 201/307-9700

Recruit Bait (hexaflumuron, Sentricon)—DowAgrosciences, 9330 Zionsville Rd., Indianapolis, IN 46268; 317/337-4379; 800/678-2388

Subterfuge Bait—BASF Corporation, 26 Davis Drive, Research Triangle Park, NC 27709; 800/669-2273, 973/426-2610

Terminate (sulfluramid)—Spectrum Industries, St. Louis, MO; 800/242-1166; www.epestsupply.com; 877/500-0011

TermiRid (borate bait)—www.epestsupply.com; 877/500-0011

## References


Anonymous. 1995. Shots heard round the world: a revolutionary termite treatment. *Pest Control Technology* August:54-55, 58,91,92.

Atkinson, T.H. 2000. Use of dyed matrix in bait stations for determining foraging territories of subterranean termites (Isoptera: Rhinotermitidae: *Reticulitermes* spp. and Termitidae: *Amitermes wheeleri*). *Sociobiology* 36(1):149-167.

Ballard, J. 1995. Pers. comm. Dr. James Ballard, FMC Corporation, PO Box 8, Princeton, NJ 08543; 800/321-1362; 609/951-3000.

BASF. 2001. Subterfuge termite bait. Subterfuge label. BASF Corporation, 26 Davis Drive, Research Triangle Park, NC 27709. EPA Reg. No. 241-371.

Bayer. 2000. Outpost™ Termite Bait Response. Outpost label, Bayer Environmental Sciences, 95 Chestnut Ridge Rd., Montvale, NJ 07645, 800/438-5837. EPA Reg. No. 499-488-3125.

Cabrera, B.J., N.-Y. Su, R.H. Scheffrahn and P.G. Koehler. 2002. Termite baits. University of Florida Cooperative Extension.

DeMark, J.J. and J.D. Thomas. 2000. Seasonal activity, wood consumption rates, and response to aboveground delivery of hexaflumuron-treated bait to *Reticulitermes flavipes* (Isoptera:Rhinotermitidae) in Pennsylvania and Wisconsin. *Sociobiology* 36(1):181-200.

Dow. 2002a. MSDS Recruit II termite bait. DowAgrosciences, Indianapolis, IN 46268.

Dow. 2002b. A cradle-to-grave review of the Sentricon termite colony elimination system with ESP™ technology. *Pest Control Technology* March: 2002.

Ensystex. 2003. Labyrinth™ Termite Bait. Labryrinth label, Ensystex Corporation, 2709 Breezewood Avenue, PO Box 2587, Fayetteville, NC 28303; 888/exterra. EPA Reg. No. 68850-2.

Esenther, G.R. and R.H. Beal. 1978. Insecticidal baits on field plot perimeters suppress *Reticulitermes. J. Econ. Entomol.* 71:604-607.

Farm Chemicals. 1999. *Farm Chemicals.* Meister Publishing Co., Willoughby, OH.

Felix, J. and G. Henderson. 1995. Debugging New Orleans' phone lines. *Pest Control Technology* 23(10):76,78,151.

FMC. 1995. FirstLine™ termite bait. MSDS No. 4151-50-2-4. FMC Corporation, Agricultural Products Group, Philadelphia, PA. 4pp.

FMC. 1996a. FirstLine™ termite bait station. Label, Code 1629, FMC Corporation, Agricultural Products Group, Philadelphia, PA. 1 p.

FMC. 1996b. FirstLine™ GT termite bait station. Label, Code 1743, FMC Corporation, Agricultural Products Group, Philadelphia, PA. 1 p.

FMC. 1996c. FirstLine™ GT termite bait station. MSDS No. 4151-50-2-6. FMC Corporation, Agricultural Products Group, Philadelphia, PA. 4 pp.

Forschler, B.T. 1994. Fluorescent spray paint as a topical marker on subterranean termites (Isoptera: Rhinotermitidae). *Sociobiology* 24(1):27-38.

Forschler, B.T. 1996. Baiting *Reticulitermes* (Isoptera: Rhinotermitidae) field colonies with abamectin and zinc borate treated cellulose in Georgia. *Sociobiology* 28(3):459-484.

Forschler, B.T. and J.C. Ryder, Jr. 1996. Subterranean termite, *Reticulitermes* spp. (Isoptera: Rhinotermitidae), colony response to baiting with hexaflumuron using a prototype commercial termite baiting system. *J. Entomol. Sci.* 31(1):143-151.

Forschler, B.T. and M.L. Townsend. 1996. Mark-release-recapture estimates of *Reticulitermes* spp. (Isoptera: Rhinotermitidae) colony foraging populations form Georgia, U.S.A. *Environ. Entomol.* 25(5):952-962.

French, J.R.J. 1994. Combining physical barriers, bait and dust toxicants in future strategies for subterranean termite control (Isoptera). *Sociobiology* 24(1):77-91.

Getty, G.M., M.I. Haverty, K.A. Copren and V.R. Lewis. 2000. Response of *Reticulitermes* spp. (Isoptera: Rhinotermitidae) in Northern California to baiting with hexaflumuron with Sentricon termite colony elimination system. *J. Econ. Entomol.* 93(5):1498-1507.

Grace, J.K., A. Abdallay and K.R. Farr. 1989. Eastern subterranean termite (Isoptera: Rhinotermitidae) foraging territories and populations in Toronto. *Can. Ent.* 121:551-556.

Grace, J.K. 1990. Mark-recapture studies with *Reticulitermes flavipes* (Isoptera: Rhinotermitidae). *Sociobiology* 16(3):297-303.

Grace, J.K, C.H.M. Tome, T.G. Shelton and R.J. Oshiro. 1996. Baiting studies and considerations with *Coptotermes formosanus* (Isoptera:

Rhinotermitdae) in Hawaii. *Sociobiology* 28(3):511-520.

Grace, J.K., R.T. Yamamoto and C.H.M. Tome. 2000. Toxicity of sulfluramid to *Coptotermes formosanus* (Isoptera: Rhinotermitidae). *Sociobiology* 35(3):457-466.

Grace, J.K. and N.-Y. Su. 2001. Evidence supporting the use of termite baiting systems for long-term structural protection (Isoptera). *Sociobiology* 37(2):301-310.

Grossman, J. 2000. ESA Conference Notes. *IPM Practitioner* 22(5/6):15.

Grossman, J. 2002. ESA Conference Notes. *IPM Practitioner* 24(7):16.

Henderson, G. 1995. Pers. comm. Dr. Gregg Henderson, Dept. of Entomol., 402 Life Sciences Bdlg., LSU Agric. Cntr., Baton Rouge, LA 70803.

Henderson, G., K. Sharpe-McCollum and C. Dunaway. 1997. Tracking termites. *Pest Control Technology* February:56-61.

Josof, L. 1997. Food fight: termite baiting in the Crescent City. *Pest Control Technology* June: 75,76,80,82,83.

Kistner, D.H. and R.J. Sbragia. 2001. The use of the Sentricon™ termite colony elimination system for controlling termites in difficult control sites in Northern California. *Sociobiology* 37(2):265-280.

Logan, J.W.M. and F. Abood. 1990. Laboratory trials on the toxicity of hydramethylnon (Amdro: AC 217,300) to *Reticulitermes santonensis* Feytaud (Isoptera: Rhinotermitidae) and *Microtermes lepidus* Sjöstedt (Isoptera: Termitidae). *Bull. Ento. Res.* 80:19-26.

Oi, F.M., N-Y. Su, P.G. Koehler and F. Slansky. 1996. Laboratory evaluation of food placement and food types on the feeding preference of *Reticulitermes virginicus* (Isoptera: Rhinotermitidae). *J. Econ. Entomol.* 89(4):915-921.

Myles, T. 1996. Development and evaluation of a transmissible coating for control of subterranean termites. *Sociobiology* 28(3):373-401.

Pawson, B.M. and R.E. Gold. 1996. Evaluation of baits for termites (Isoptera: Rhinotermitidae) in Texas. *Sociobiology* 28(3):485-510.

Potter, M.F. 1997. Termite baits: status report. *Pest Control Technology* 25(2):24-26,28,30,35-37, 97, 105, 106, 110.

Potter, M.F., E.A. Eliason and K. Davis. 2001a. Targeting termites. *Pest Control Technology* 29(7):58-63.

Potter, M.F., E.A. Eliason, K. Davis and R.T. Bessin. 2001b. Managing subterranean termites (Isoptera:Rhinotermitidae) in the Midwest with a hexaflumuron bait and placement considerations around structures. *Sociobiology* 38(3B):565-584.

Prabhkaran, S.K. 2001. Eastern subterranean termite management using baits containing hexaflumuron in affected University of Iowa structures (Isoptera: Rhinothermitidae). *Sociobiology* 37(1):221-233.

Quarles, W. 1995a. Least-toxic termite baits. *Common Sense Pest Control Quarterly* 11(2):5-17.

Quarles, W. 1995b. New technologies for termite control. *IPM Practitioner* 17(5/6):1-9.

Quarles, W. and C. Bucks. 1995. Non-toxic termite control. *Organic Gardening* 42(9):44-50.

Quarles, W. 1998a. New competition in termite bait markets. *IPM Practitioner* 20(10):6-9.

Quarles, W. 1998b. Borates for wood protection. *IPM Practitioner* 20(3):1-12.

Sheets, J.J., L.L. Karr and J.E. Dripps. 2000. Kinetics of uptake, clearance, transfer and metabolism of hexaflumuron by eastern subterranean termites (Isoptera: Rhinotermitidae). *J. Econ. Entomol.* 93(3):871-877.

Sheets, J. and L. Karr. 2001. Kinetics of uptake, clearance, transfer and metabolism of noviflumuron in termites (*Reticulitermes flavipes*). Entomological Society of America Conference 2001, Atlanta, Georgia (see Grossman 2002).

Su, N.-Y. M. Tamashiro and J.R. Yates. 1982a. Trials on the field control of the Formosan subterranean termite with Amdro bait. Doc. No. IRGWP/1163. The International Research Group on Wood Preservation, Stockholm, Sweden.[cited in Su et al. 1996a]

Su, N.-Y., M. Tamashiro, J.R. Yates and M.I. Haverty. 1982b. Effect of behavior on the evaluation of insecticides for prevention of or remedial control of the Formosan subterranean termite. *J. Econ. Entomol.* 75:188-193.

Su, N.-Y., M. Tamashiro, J.R. Yates and M.I. Haverty. 1984. Foraging behavior of the Formosan subterranean termite (Isoptera: Rhinotermitidae). *Environ. Entomol.* 13:1466-1470.

Su, N.-Y., M. Tamashiro and M.I. Haverty. 1987. Characterization of slow-acting insecticides for the remedial control of the Formosan subterranean termite (Isoptera: Rhinotermitidae). *J. Econ. Entomol.* 80:1-4.

Su, N.-Y. and R.H. Scheffrahn. 1988. Foraging population and territory of the Formosan subterranean termite (Isoptera: Rhinotermitidae) in an urban environment. *Sociobiology* 14(2):353-359.

Su, N.-Y. 1993a. Development of a new termite control bait. *Pest Control* June:39,42,44,48.s

Su, N.-Y. 1993b. Baits. *Pest Control Technology* July: 72,73,76,78,80,114.

Su, N.-Y. and R.H. Schefferan. 1993. Laboratory evaluation of two chitin synthesis inhibitors, hexaflumuron and diflubenzuron, as bait toxicants against Formosan and eastern subterranean termites (Isoptera: Rhinotermitidae). *J. Econ. Entomol.* 86(5):1453-1457.

Su, N.-Y., M. Tokoro and R.H. Scheffrahn. 1994. Estimating oral toxicity of slow-acting toxicants against subterranean termites (Isoptera: Rhinotermitidae). *J. Econ. Entomol.* 87(2):398-401.

Su, N.-Y. 1994. Field evaluation of a hexaflumuron bait for population suppression of subterranean termites (Isoptera:Rhinotermitidae). *J. Econ. Entomol.* 87(2):389-397.

Su, N.-Y., R.H. Scheffrahn and P.M. Ban. 1995. Effects of sulfluramid-treated bait blocks on field colonies of the Formosan subterranean termite (Isoptera: Rhinotermitidae). *J. Econ. Entomol.* 88(5):1343-1358.

Su, N.-Y. and R.H. Scheffrahn. 1996a. Fate of subterranean termite colonies (Isoptera) after bait applications—an update and review. *Sociobiology* 27(3):253-275.

Su, N.-Y. and R.H. Scheffrahn. 1996b. A review of the evaluation criteria for bait toxicant efficacy against field colonies of subterranean termites (Isoptera). *Sociobiology* 28(3):521-534.

Su, N.-Y., P.M. Ban and R.H. Scheffrahn. 2001. Control of subterranean termites (Isoptera:Rhinotermitidae) using commercial prototype aboveground stations and hexaflumuron baits. *Sociobiology* 37(1):111-120.

Thorne, B.L. and J.F.A. Traniello. 1994. Detection and control through baiting termites. *Pest Management* 13(9):1-13, 16-18.

Thorne, B.L., E. Russek-Cohen, B.T. Forschler, N.L. Breisch and J.F.A. Traniello. 1996. Evaluation of mark-release-recapture methods for estimating forager population size of subterranean termite (Isoptera:Rhinotermitidae) colonies. *Environ. Entomol.* 25(5):938-951.

Thorne, B.L. and B.T. Forschler. 2000. Criteria for assessing efficacy of stand-alone termite bait treatments at structures. *Sociobiology* 36(1):245-255.

Tomlin, C., ed. 1997. *The Pesticide Manual*, 11th ed. British Crop Protection Council, Farnham, Surrey, UK. 1606 pp.

Yates, J.R., III and J.K. Grace. 2000. Effective use of aboveground hexaflumuron bait stations for Formosan subterranean termite control (Isoptera: Rhinotermitidae). *Sociobiology* 35(3):333-356.

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