Review of Remedial and Preventative Methods to Protect Timber in Service from Attack by Subterranean Termites in Australia

by

Berhan M. Ahmed[1], John R. French[2] & Peter Vinden[3]

ABSTRACT

With the phasing out of organochlorine compounds as termiticides in Australia in 1995, consumers and the building industry moved to adopt alternative termite control strategies. These include chemical barriers (organophosphates, synthetic pyrethroids, nicotinoids, and phenyl pyrazoles), physical barriers (graded granite stones, stainless steel mesh) use of termite resistant building materials (metal and plastic termite shields and adhesives), and installing a slab construction that conforms with Australian Standard AS 2870-1996. The latter requires vibration of the concrete during slab formation, regular inspections, preventative action such as keeping garden beds, mulch, or stacked firewood away from exterior walls, or, a combination of all of the above methods.

The use of preservative treatment of timber as a second line of defence has gained momentum in Australia in recent years. This has arisen from the decline in availability of wood species with naturally durable heartwood. Shorter rotations for forest crops and higher quantities of non-durable sapwood and heartwood of species used in construction have accelerated this trend.

Increasingly termite control is adopting integrated pest management (IPM) based on ecological knowledge of termites and minimization of environmental impact of treatments. These include adopting a mix of alternative strategies in termite control that include chemical and physical barriers, and combinations of the same, bait and dust toxicants, treated timber and emphasize building practices that are designed to 'build out termites' and ensure 'whole of house' protection of timber in buildings against termites for the reasonable life of the building.

---

[1]The University of Melbourne and CRC Wood Innovations, Parkville, Vic, 3010, AUSTRALIA

[2]Faculty of Science, University of the Sunshine Coast, Maroochydore DC, Qld, 4558, AUSTRALIA

[3]CRC Wood Innovations and The University of Melbourne, Parkville, Vic, 3010 AUSTRALIA

INTRODUCTION

In Australia the protection of building timbers from termites has relied for many years upon the application of persistent organochlorines, as well as the organophosphate compound chlorpyrifos and the pyrethroid bifenthrin as soil chemical barriers (Lenz *et al.* 1988, Lenz *et al.* 1990, Watson 1990, Anon. 1993a,b,c, Australian Standard AS 3660.1-2000). The organochlorine insecticides have been banned since 1987 in the USA and from June 1995 in all Australian states except the Northern Territory.

Around 70% (or 3 million m^3) of the total timber produced in Australia is used for building and construction purposes (Harold Brietinger, Plantation Timber Association Australia pers. comm.). Preservative treatment of timber according to Australian Standard AS 1604-2000 prevents attack and damage of wood and wood products from biodeteriogens (fungi and insects). Above-ground interior timber framing is not liable to decay but is prone to damage by wood-destroying insects (borers and termites). In-ground exterior timbers are liable to damage by termites and wood decay fungi.

Termites cause over $100 million dollars in damage to wooden structures annually throughout Australia. Most of the damage is attributable to subterranean termites (French 1986). The economic loss to timber in service by termites constitutes the greatest problem in both urban and rural environments. At a recent National Termite Workshop sponsored by the Forest and Wood Products Research and Development Corporation (FWPRDC) and the University of Melbourne in April 2002, it was estimated by the Archicentre that the costs of termite activity and damage, and replacement costs are approximately of $780 million annually (Caulfield 2002).

Termites can attack and damage sound and decayed timber of native hardwoods, and native and exotic softwoods. *Mastotermes darwiniensis* is by far the most destructive termite in Australia. It occurs in the region north of the Tropic of Capricorn, with Rockhampton being the southern most area of its natural distribution. *Coptotermes acinaciformis*, however, is responsible for greater economic losses than all the other Australian species of termites combined. This is due to its extensive geographical range, the severe nature of its attack, and its success in adapting to urban areas.

In Australia, the distribution of the major wood feeders, namely, species of *Coptotermes, Nasutitermes, Mastotermes,* and *Schedorhinotermes* occur sympatrically (i.e. overlapping) with each other. Because of similarities in species phenotypic ratio, reproduction, and environmental requirements it is useful to discuss them together when considering new strategies of control against subterranean termites.

IPM Strategies in subterranean termite control in Australia

Integrated pest management (IPM) is a decision making process for determining

- If you need pest suppression treatments,
- When you need them,
- Where you need them, and,
- What strategy and mix of tactics to use.

In IPM programs, treatments are not made according to a predetermined calendar schedule; they are made only when and where monitoring has indicated that the pest will cause unacceptable economic, medical or aesthetic damage. Treatments are chosen and timed to be most effective and least disruptive to natural mortality factors. In urban settings, IPM has been used to manage insect pests in parks, gardens, in shade trees and in timber-in-service in and around buildings, both domestic and industrial (Olkowski 1980).

Components of a termite IPM program

A termite IPM program contains the following key components:-

1. Identification of termite species causing damage.

2. A monitoring and record keeping system for regular sampling or inspections of termites.

3. Damage level - A determination of the economic or aesthetic damage level caused by termites sufficient to warrant control actions.

4. Action levels - The amount of termite activity is indicative of the population size, and a determination of other variables, such as season, amount of susceptible timber in the building, and so on, from which it can be predicted that damage levels will be reached within a certain time if no treatments are undertaken.

Main strategies of termite control for timber-in-service

There are five main strategies in subterranean termite control, namely:-

1. Installation of chemical barriers applied as full or partial treatments either directly to soil or by reticulation systems for slab on ground construction (Australian Standard AS 3660.1-2000) to prevent termites from entering a building or attacking timber in contact with the ground. Application of borates in wall cavities to protect timber in service may also be used (Ahmed *et al.* 2000, J. Thorpe, Osmose (Australia) P/L., unpubl. data).

2. Installation of physical barriers such Granitgard® using graded granite stone, (French *et al.* 2003), Termi-Mesh® utilizing stainless steel mesh, (Lenz & Runko 1994), metal and plastic termite caps and shields e.g. Plasmite®. (J.R.J. French, unpubl. data), sintered glass material e.g. Termicide Pest Control, P/L., (J.R.J. French, unpubl. data), concrete slab designed and produced in accordance with Australian Standard AS 2870-1996 and in association with a termite entry seal and/or sealants around service pipes to prevent termites from entering the building or attacking timber in contact with the ground (AS 3660.1-2000).

3. Impregnating termite susceptible timbers with a wood preservative that incorporates a termiticide or termite resistant construction materials such as white mahogany timber (AS 1604-2000) and rammed earth (AS 3660.1-2000).

4. Destruction of the termite nest colony directly using dust toxicants such as arsenic trioxide and triflumuron, and fumigants, or using bait toxicants via baiting methods. The application of dust and/or bait toxicants involves aggregating large numbers of termites with an appropriate baiting system (French *et al.* 1995).

5. Integrated termite control using modern architectural design and advances in construction technology coupled with any of the above termite control measures individually or in combination (of both physical and chemical barriers) to protect timber in buildings from termite attack and damage (Lenz 2002).

Installation of soil chemical barriers

In 2000, Standards Australia released the following Australian Standards:

1. AS 3660.1-2000 (Protection of buildings from subterranean termites. Part 1: – New buildings),

2. AS 3660.2-2000 (Protection of buildings from subterranean termites – Prevention, detection and treatment of infestations. Part 2: Existing buildings), and,

1. AS 3660.3–2000 (Termite management - Assessment criteria for termite management systems. Part 3. New and existing buildings).

These Standards set out methods of implementation during and after construction, for minimizing the risks to new and existing buildings from damage by termites. The Standards include procedures and details for providing both chemical and physical barriers, and offer a range of options. Barriers may be used singly or in combination to provide an integrated system for the protection of timber in buildings.

The chemical soil barriers currently registered for use are the organophosphate, chlorpyrifos (Dursban™), the synthetic pyrethroid, bifenthrin (Biflex®), and the nicotinoid, imidacloprid (Premise®). Barrier treatments may be applied as full, under-slab treatments, and partial or perimeter treatments. Also, reticulation systems are permissible, using chemicals such as chlorpyrifos.

The phenyl pyrazole, fipronil (Termidor® Residual Termiticide), is currently in the "review stage" of the registration process. This chemical, and imidacloprid, are non-repellent liquid termiticides that have the property of acting as bait toxicants. That is, when applied to the exterior of a building, their effects extend inward and well beyond the exterior site of application (Potter & Hillery 2002). The wide application of large volumes of active ingredient (> 600 liters) around building poses environmental, health and safety issue. This was one of the reasons that the use of organochlorines in termite control was curtailed (Anon 1993a,b,c).

Installation of soil physical barriers

Physical barriers, such as metal and plastic shields (Plasmite®), graded granite stone (Granitgard®) and stainless steel mesh (Termi-Mesh®) that are fitted under slab constructions, around pipes through slab constructions and in cavity wall areas, and around posts and poles supporting buildings, are designed to impede and discourage foraging termites entering into a building (AS 3660.1-2000). Though not so designated in the present Standards, Granitgard® has shown promise as a termite barrier. When retrofitted around test buildings in a field trial established at the Mallee Research Station at Walpeup, Victoria, it successfully prevented termite penetration for over five years (Ahmed & French 1997).

It must be emphasized that termites can bridge and breach barrier systems and that regular inspections of the building are necessary. While termites can build around and over both chemical and physical barriers, they or evidence of their presence can then be detected more readily during regular inspections.

Impregnating termite susceptible timbers with wood preservatives

Australian Standard AS 1604-2000 (Timber-Preservative-Treated-Sawn and Round) specifies the preservative treatment levels required to protect timber from termite infestation in the three major hazard levels of timber performance. These are, interior above ground hazard level 2 (H2), exterior above ground hazard level 3 (H3), and exterior in ground contact hazard level 4 & 5 (H4 and H5). Timbers may also be protected against termites using remedial treatments. Borax and boric acid have been used for many years as active ingredients for wood preservatives because of their broad spectrum activity against a wide range of fungi and effectiveness against a number of wood destroying insects - Bateman *et al.* (1937), Cummins (1938,1939), Carr (1959), Cockroft & Levy (1973), Bunn (1975). Glycol borates, fused borate rods and pastes have also been found to be effective in arresting established decay - Baines & Levy (1979), Edlund *et al.* (1983), Dicker *et al.* (1983), Dietz & Schmidt (1987), Dirol (1988), Henningsson *et al.* 1989, Beauford & Morris (1986), Beauford (1990), Dickinson (1990). In recent years several novel copper boronaphthalene pastes and other diffusible copper-boron preservatives, that can treat both softwoods and hardwood, have been developed. The popularity of boron based preservatives arises from their ability to diffuse into many refractory species considered untreatable by pressure methods, their adaptability to treat a wide range of commodities, their low acute toxicity - LD_{50} values of 3,000-50000 mg/kg (rat), and their provision of an in-depth treatment reservoir of active ingredient which solubilizes and diffuses at moisture contents that can lead to colonization and decay of wood. However, the hazard level classes as proposed are more related to fungal activity than termite hazard levels. This needs to be rectified and termite standards established that tackle the problem of assessing criteria for termite management systems that reflect the termite hazard.

The use of naturally termite-resistant timbers (AS. 3660.1-2000) is mooted. However many of these species are difficult to obtain in any commercial quantity, and the different timber species listed have different levels of resistance to various species of termite. Over time, and with moisture and wood decay organisms present in or on timber, termites will eventually attack and damage nearly all known building construction timbers whether treated with preservative or not.

Destruction of termite nest colony

There are two main approaches in termite nest destruction, depending on whether the nest is located or not.

If the nest colony is located:

Nests may be found outside buildings in above-ground mound colonies, in colonies within trees, in tree stumps, and in colonies in garden beds around buildings. Sometimes, nest and sub-nest colonies, may be found inside buildings, such as in the sub-floor area in buildings with suspended floor construction. In buildings with slab on ground construction, sub-nests may be located within cavity walls and in ceiling cavities. All these types of nests may be eradicated with arsenic trioxide, borates, chlorpyrifos, bifenthrin, imidacloprid, triflumuron (dust), fipronil (liquid or dust), a suitable gas fumigant or bait toxicants.

If the nest colony is not located:

When the nest cannot be located, then a monitoring-baiting system is required. On locating termite activity outside or inside the building, a suitable bait container (e.g., box, pipe, plastic container, wood block, etc.) needs to be placed alongside, or onto active termite galleries or sheltertubes in order to aggregate large numbers of foraging termites.

For example, the CSIRO-type bait box was developed for this purpose (French *et al.* 1995). When using this bait box system, the aggregated termites are removed from the bait box, dusted with an appropriate dust toxicant, and released back into the bait box. Both the untreated and treated termites rapidly move back into the gallery system of the colony network. Then, with trophallactic grooming and coming into contact with each other, the toxicant is spread throughout the colony, leading to its eventual collapse (French & Boschma 2000).

The insertion of bait toxicants, via application into or on suitable cellulosic substrates into the bait container is generally known as the "bait-block method of termite control" (Beard 1974). The bait toxicants act as delayed action stomach poisons with usually, minimum contact action. While bait toxicants have been used with success in Australia (French 1991, 1994), it is in North America that commercial bait products and programs have been developed most successfully. These systems are being offered by a growing number of chemical and professional pest control companies who offer both above- and below-ground stations (Quarles 1995a,b, Potter 1999, Su & Scheffrahn 2000, Su 2002a,b). Compounds used include sulfluramid, and the insect growth regulators, diflubenzuron, hexaflumuron and **novaflumuron**, which are the active ingredients of Sentricon® *Termite Colony Elimination System* and Exterra baiting systems respectively. Each of these active ingredients are chitin synthesis inhibitors and kill by disrupting the molting process in termites (Potter 1999, Su & Scheffrahn 2000). The organochlorine, mirex (Paton & Miller 1980, French 1988), is still used under a special licence in Australia (Western Australia and the Northern Territory) against the Giant Northern Termite, *Mastotermes darwiniensis* that can attack horticultural crops such as mangoes and avocados.

Current termite control measures in Australia

In Australia the termiticides presently registered for use in termite control by the National Registration Authority (NRA) are arsenic

This is now Recruit III™

trioxide, bifenthrin (Biflex®), chlorpyrifos (Dursban® and clones); deltamethrin impregnated into a polymer barrier (Kordon®), imidacloprid (Premise®), and triflumuron (Intrigue¢â Termite Dust). The phenyl pyrazole, fipronil (Termidor® Residual Termiticide) is currently being processed for registration as a soil termiticide and bait toxicant (Phil Morrow, pers. com.).

The term pre-treatment refers to complete or partial soil chemical barrier and physical barrier treatments for buildings under construction, while the term post-treatment refers to complete or partial treatments of existing buildings using a termite eradication method, either chemical or non-chemical. Both these terms refer in turn to Australian Standards AS 3660.1-2000 and AS 3660.2-2000.

The strategies available for termite control in Australia are in Table

Table 1: Current subterranean termite control practices used in Australia.

Strategy	Chemical/physical/ non chemical	Application	New Building		Existing building	
			full	partial	full	partial
Barriers	Bifenthrin	sprayed	+	+	+	+
	Chlorpyrifos	sprayed	+	+	+	+
	Chlorpyrifos	reticulated	+	+	+	+
	Premise®	sprayed	+	+	+	+
	Deltamethrin	Installed	+	+	+	+
	Granitgard®	Installed	+	+	NA	+
	Termi-Mesh®	Installed	+	+	NA	+
	Sintered glass	Installed	+	+	NA	+
	Plastic flange	Installed	NA	+	NA	+
	Plasmite®	Installed	NA	+	NA	+
	Metal shields	Installed	NA	+	NA	+
Wood preservatives	CCA	Timber	NA	NA	NA	NA
	Borates	Timber	NA	+	NA	+
	LOSP	Timber	+	+	NA	+
	PEC	Timber	NA	NA	NA	NA
	PROCCA	Timber	NA	NA	NA	NA
Nest colony destruction	As_2O_3	dust	NA	NA	NA	+
	Borates	bait	NA	NA	+	+
	IGR's	bait	NA	NA	NA	+
	Mirex	bait	NA	NA	NA	+
	Triflumuron	dust	NA	NA	NA	+
	Fumigant	gas	NA	NA	NA	+
	OP or SP	spray	NA	NA	NA	+

Key: As_2O_3 = Arsenic trioxide; CCA = Copper chromium and arsenic; IGR = Insect growth regulators (e.g., chlorfluazuron, diflubenzuron, hexaflumuron; hydramethylnon; imidacloprid,); LOSP = Light organic solvent preservative; NA = Not applicable; + = applicable; OP = organophosphate (chlorpyrifos); PEC = Pigmented emulsified creosote; Premise® = Imidacloprid; PROCCA = Oil based copper chromium arsenic.

1.

DISCUSSION AND CONCLUSION

An overview of termite control measures in Australia and future research and control methods was presented by French and Ahmed (2002) at the National Termite Workshop held in April 2002 and sponsored by FWPRDC and University of Melbourne. Information presented at this workshop indicated that in Australia, the cost of termite attack and damage to timber in service has risen from an estimated $100 million annually in 1985 (French 1986) to an estimated $780 million (Caulfield 2002). Also, over this period we have seen an increase in the growth of human populations, which has given rise to an increase in the production and use of structural timbers that are susceptible to termite attack and damage. Thus, termite damage will be expected to increase, as will the need to protect timber in service from these insects. Any future developments in new termite control technologies will need to combine physical and chemical strategies (French 1994).

Remedial treatments

Detection systems

Professional pest control operators are taught a variety of skills by which to detect the presence of termite activity and damage within and around buildings. These range from visual inspections in accessible parts of buildings, using tapping and probing instruments, to moisture meters (e.g., Tramex®) and acoustical emission devices (e.g., Termitrac®). However, there is a need to research cost effective, hand-held devices that will detect termite presence through a combination of properties such as heat, moisture, movement and sound characteristic of the alarm noises used by the major economic termite pest species.

Dust toxicants

The direct injection of dust toxicants into active termite workings exploits the habit of grooming, trophallactic behavior, and the process of direct contact by members of a colony. Arsenic trioxide has been used in Australia for several decades and is the only dust toxicant mentioned by name in the Australian Standard AS 3660.2-2000. However, permethrin dust has been recommended for termite nest colonies in trees and above-ground mounds (Gerozisis & Hadlington 1995), and more recently, triflumuron (Intrigue¢â Termite dust) has been registered as a termite dust toxicant.

While not registered as a dust toxicant, fipronil (Termidor® Residual Termiticide) has proved an excellent dust termiticide, even at concentrations of 0.5% w/w (J.R.J. French, unpubl. data).

Bait systems

In recent times, a rapid introduction into the pest control industry of bait monitoring stations has occurred (e.g., Sentricon Colony Elimination system, Dow AgroSciences LLC; and Exterra, Ensystex Inc.; Su *et al.* 2001), partly in response to the loss of the use of organochlorines in termite control, and partly from the need to have more 'environmentally friendly' control measures. In the United States of America, a case has been made for the use of termite monitoring-baiting systems for long-term structural protection (Grace & Su 2001). However, to date, this approach has not been critically examined by termite researchers in Australia. Our experience suggests that such baiting systems are more practical as remedial treatments rather than preventative treatments.

Biological control

There has been limited research on biological control in termite strategies compared with research into bait, dust and liquid termiticides. The reasons may be as much political as they are scientific. Suffice it to say that the variation in virulence of the pathogens used including nematodes (e.g. *Heterorhabditis* sp.) and entomophagus fungi (e.g. *Metarhizium anisopliae* and *Beauveria bassiana*) is a main impediment. It seems that the pest control industry requires treatments that have a longer shelf-life than these biological agents. Environmental factors, such as temperature, moisture, seasonality and handling techniques seem to contribute to a reduction in virulence.

The "Trojan Termite" technique was proposed to capitalise on behavior such as colony aggression and grooming in order to distribute a toxin in a suitable form throughout an active termite colony (French 1991). Large numbers of *Coptotermes lacteus* were collected from above-ground mounds in the Boola Boola State Forest, central Gippsland, and transported to Melbourne (125 km). On locating active infestations of *C. acinaciformis* in Melbourne, the field collected *C. lacteus* individuals were coated with a fine dust of arsenic trioxide, and then released into the active workings of *C. acinaciformis*. The ensuing aggressive behavior when these two species were mixed spread the toxin throughout the colony, leading to its eventual demise. Again, this technique is probably too complex and costly for it's adoption on a national scale. But there are localized situations in which such a technique can be effective.

Preventative treatments methods

Chemical barriers

Notwithstanding the banning of the organochlorine insecticides for use in termite control as of June 1995 in most states of Australia, soil termiticide applications will continue because of their mandatory use in new and existing buildings as promulgated in the Australian Standard AS 3660.1-2000 and 3660.2-2000. Liquid termiticides will also continue to play a vital role in remedial treatments in and around new and existing buildings.

The new generation of termiticides (e.g. Termidor® Residual Termiticide, and Premise®, Potter & Hillery 2002) will have properties and characteristics vastly different from the chemicals previously used as termiticides in the 'organochlorine-era'. Thus, innovative, flexible and performance based evaluative methods are required to screen potential termiticides that may act as soil barrier, bait, dust, contact toxicants or repellent (Ahmed *et al.* 1997b). Already in the market place are various liquid products (e.g., biflex, chlorpyrifos, Kordon®) for application as horizontal and vertical soil barriers and the active ingredients may be used in reticulation systems installed under and in slab on ground constructions.

The above termite control technologies depend on a sound understanding of termite biology, foraging and feeding behavior, nutritional physiology, ecology and environmental factors. Research has been lacking, in the past, on termite nesting, reproduction, distribution and success as pests as well as foraging and feeding behavior. Recently in Australia and USA, research has focussed on termite baiting and mark-recapture release technique for estimating termite population size (Evans *et al.* 1999). This research would bring about understanding of termite colony population and distribution territory. Also, this study has indicated that relatively little is understood about many aspects of termite life. There are specific areas that need special focus in the near future. The division of labor and adaptability to a wide range of climatic zones in *Coptotermes* species needs to be better defined and understood. Termite nesting site choices need further research. Influences on foraging and feeding patterns are an area of study because of the direct effect on timber-in-service. Research is also continuing on termite attractants, and resistant and repellents properties of wood extracts promise to allow some control of termite foraging patterns in the future.

Physical barriers

Research into better physical barriers and building design is essential in the process of "building-out termites". These new areas of research will become stronger and produce more varied approaches to termite control. At present, there are several physical barriers in the market place, such as Granitgard®, Plasmite®, Termi-Mesh® and sintered glass material.

Furthermore, physical barrier methods will need to be coupled with chemical systems. Combining physical barriers, bait and dust toxicants will offer the community options, other than the continued sole-reliance on a chemical approach to termite control (French 1994).

But whatever the type of physical barrier, bait or dust toxicant used in future, there is always the need to keep the "consumer" informed about environmentally sound integrated termite pest management. That may mean both industry and the public paying more for the costs of termite management information and services that have been offered in the past free, or relatively so, by government organizations. Judging from the current trend in Federal and State Government funding for termite research, one could not be blamed for assuming a pessimistic attitude with respect to continuity of funding and research in that area.

IPM approach

Suggestions are offered for the pest control industry, government and people to pursue and engage in an integrated pest management (IPM) approach to termite control based on sound ecological parameters and social priorities (French 1991, Su 2002). These include adopting a mix of alternative strategies as mentioned above, plus planning to ensure continuous funding for R&D and training and education programs necessary to supply 'termite expertise' in the future.

Combined studies such as the "whole-of-house termite protection" approach accelerate progress, as questions raised by results from one methodology lead to further experiments by a different methodology. Thus, the greater use of multiple methodologies in an integrated research strategy can prove valuable in termite research. Currently, it would be prudent to undertake further studies on an integrated termite management approach which incorporates building design techniques, non-destructive detection methods for locating termites in inaccessible areas of buildings, physical and chemical termite barriers in conjunction with environmentally approved wood preservatives, preservative carriers and registered soil chemical barriers.

ACKNOWLEDGMENTS

The authors are indebted to the Forest and Wood Products Research and Development Corporation (Australia), and Cart Holt Harvey for their collaboration and generous funding for the work report in this paper.

REFERENCES

Ahmed, B. & J.R.J. French 1997. Termite physical barriers: update on retrofitting Granitgard around 'mock-up' buildings after five years. 28th IRG Meeting, Whistler, B.C., Canada. Doc. IRG/WP/97-10226. pp. 6.

Ahmed, B., J.R.J. French, P. Kwint, & G. Webb 1997. Laboratory evaluation of fipronil (a phenyl pyrazole) as a candidate termiticide in the protection of wood against the subterranean termite, *Coptotermes acinaciformis* (Froggatt) Rhinotermitidae. 28th IRG Meeting, Whistler, B.C., Canada, Doc. IRG/ WP/97-10225, pp.7.

Ahmed, B., French, J.R.J. & P. Vinden 2000. Protection of simulated wooden houses against *Coptotermes acinaciformis* (Froggatt) (Isoptera: Rhinotermitidae) in an accelerated field simulator. Mat. und Organismen 33: 289-318.

Anonymous 1993a. Cyclodiene insecticide use in Australia. Report prepared by the National Health and Medical Research Council's working party on cyclodiene insecticides. Common. Govt. Printer, Canberra, pp. 255.

Anonymous 1993b. Submission to the NRA Inquiry into the continued use of the organochlorine insecticides for termite control. Prepared by the CSIRO Institute of Plant Production and Processing, pp. 14.

Anonymous 1993c. Transcript of proceedings. National Registration Authority for Agricultural and Veterinary chemicals. Inquiry into the continued use of the organochlorine insecticides for termite control. Wednesday, 8 September, 1993. pp. 258.

Australian Standard AS 1604 2000. Australian Standard: Preservative treated - Sawn and round. Standards Association of Australia, Homebush, NSW.

Australian Standard AS 2870 1996. Residential slabs and footings – construction. Standards Association of Australia, Homebush, NSW.

Australian Standard AS 3660.1 2000. Protection of buildings from subterranean termites. Part 1: New buildings. Australian Standard AS 3660.1. Standards Association of Australia, Homebush, NSW.

Australian Standard AS 3660.2 2000. Protection of buildings from subterranean termites - Prevention, detection and treatment of infestations. Part 2: Existing buildings. Australian Standard AS 3660.2. Standards Association of Australia, Homebush, NSW.

Australian Standard AS 3660.3 2000. Termite management - Assessment criteria for termite management systems. Part 3: New and existing buildings. Australian Standard AS 3660.3. Standards Association of Australia, Homebush, NSW.

Baines, E.F. & J.F. Levy 1979. "Movement of Water through Wood" Journal of the Institute of Wood-Science, 8(3), 109-113.

Bateman, E & R.H. Baechler 1937. Some toxicity data and their practical significance. Proc. Ann. Meeting, AWPA, 33: 91-104.

Beard, R.L. 1974. Termite biology and bait-block method of control. Conn. Agric. Exp. Stn. Bull. 748. pp. 19.

Beauford, W. 1990. "In situ and Supplementary Treatments using Solid Water Diffusible Preservatives" in The Chemistry of Wood Preservation. Proc. Royal Chem. Soc.

Beauford, W. & P.I. Morris 1986. "A new approach to the maintenance of wooden railway sleepers", The Inter. Res. Group on Wood Preserv. Doc. No. IRG / WP / 3392.

Bunn, R. 1974. Boron compounds in timber preservation. New Zealand Forest Service. Technical Paper No. 60: 112.

Carr, D.R. 1959. Boron as wood preservative. Record of the Annual Convention of the British Wood Preserving Association.

Caulfield, R. 2002. Termite problem from an architectural perspective. In Asumadu, K. (Ed). Smarter design and construction of buildings. Proc. National Termite Workshop. Melbourne, 17 April 2002.

Cockcroft, R. & J.F. Levy, 1973. Bibliography on the use of born compounds in the preservation of wood. Journal Institute of Wood-Science, 6(33): 28-37.

Cummins, J.E., 1938. Recommendations for the commercial treatment of green veneer to render it immune from the attack of powder post borer (*Lyctus brunneus* Stephens) by impregnation with boric acid. Aust. Timber Journal, 4: 661-667.

Cummins, J.E., 1939. The preservation of timber against the attacks of the powder Post borer (*Lyctus brunneus* Stephens) by impregnation with boric acid. Journal Coun. Scient. Ind. Res. Aust. 12: 30-49.

Dickinson, D.J. (1990). Remedial Treatment: in-situ treatments and treatments of historical structures, pp. 87-90. *In:* Proceedings 47355, First International Research Group on Wood Preservation, Stockholm, Sweden.

Dicker, P.E., M-L. Edlund, Henningsson, B., & A. Kaarik (1983) "A chemical and mycological evaluation of fused borate rods and a borate / glycol solution for remedial treatment of window joinery". The International Research Group on Wood Preservation Doc. No. IRG / WP / 3225

Dietz, M.G., & E.L. Schmidt 1987. Borate rods as an on-site remedial treatment for control of decay in wood decks. Journal of the Minnesota Academy of Science, Vol 53(2), pp. 26.

Dirol, D. 1988. Borate diffusion in wood from rods and liquid product application to laminated beams. In The 19th Annual Meeting of the International Research Group on Wood Preservation. Spain - Madrid. 11 pp.

Edlund, M.L., B. Henningsson, A. Kaarik, & E. Dicker 1983. A chemical and mycological evaluation of fused borate rods and borate/glycol solution for remedial treatment of window joinery. Doc. No. IRG/WP/3225. Intl. Res. Group on Wood Pres., Australia 36 pp.

Evans, T.A., M. Lenz, & P.V. Gleeson 1999. Estimating population size and forager movement in a tropical subterranean termite (Isoptera: Rhinotermitidae). Environmental Entomology 28: 823-830.

French, J.R.J. 1986. Termites and their economic importance in Australia. *In*: Vinson, S.B., Ed. Economic impact and control of social insects. New York: Praeger; 103-129.

French, J.R.J. 1988. Justification for use of mirex in termite control. 19th International Research Group on Wood Preservation annual meeting, Madrid, Spain, Doc. IRG/WP/1346.

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

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

French, J.R.J. & B. Ahmed 2002. Overview of subterranean termite control measures in Australia: Discussion of future research and control methods. Prepared for proceedings of national termite workshop, Hilton Melbourne Airport, 17 April, 2002. A report for the Forest Wood Products Research and Development Corporation, Melbourne.

French, J.R.J., A. Ahmed, & D. Ewart 1995. Bait box technique for remedial subterranean termite control. 26th International Research Group on Wood Preservation annual meeting, Helsingor, Denmark, Doc. No. IRG/WP/95-10115, pp. 14.

French, J.R.J., B. Ahmed & A. Trajstman 2003. Laboratory and field evaluation of granite aggregate as a physical barrier against subterranean termites of the genus *Coptotermes*. Sociobiology 42 (1): 129-149.

French, J.R.J. & T. Boschma 2000. Controlling *Coptotermes* (Isoptera: Rhinotermitidae) infestations in buildings with bait boxes. 31st IRG Meeting, Kona, Hawaii, USA, Doc. IRG/WP/00-10372, pp.11.

Gerozisis, J. & P. Hadlington 1995. Urban pest control in Australia. UNSW Press, Sydney, pp. 294.

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

Henningsson, B., H. Friis-Hansen, A. Kaarik, & M. L. Edlund 1989. Remedial ground-line treatment of CCA poles in service. A final report after 60 months' testing. Doc. No. IRG/WP/3554. Intl. Res. Group on Wood Pres. Stockholm, Sweden.

Lenz, M. 2002. Termite problem species and management of termite problems in Australia. Sociobiology: 40: 11-12.

Lenz, M. & S. Runko 1994. Protection of buildings, other structures and materials in ground contact from attack by subterranean termites (Isoptera) with a physical barrier – a fine mesh of high grade stainless steel. Sociobiology 24: 1 - 16.

Lenz, M., J.A.L. Watson, & R.A. Barrett 1988. Australian efficacy data for chemicals used in soil barriers against subterranean termites. Canberra, Australia: CSIRO, Division of Entomology, Tech. Paper No. 27.

Lenz, M., J.A.L. Watson, R.A. Barrett, & S. Runko 1990. The effectiveness of insecticidal soil barriers against subterranean termites in Australia. Sociobiology. 17: 9 – 36.

Olkowski, H. 1980. What is IPM? Urban ecosystem management. IPM Practitioner 2: 2 - 4.

Paton, R. & L. Miller 1980. Control of *Mastotermes darwiniensis* Froggatt (Isoptera: Mastotermitidae) with mirex baits. Aus. For. Res.10: 249-258.

Potter, M.F. 1999. The changing face of termite control. Pest Control Tech. Feb. pp. 6.

Potter, M.F. & A.E. Hillery 2002. Exterior-targeted liquid termiticides: An alternative approach to managing subterranean termites (Isoptera: Rhinotermitidae) in buildings. Sociobiology 39: 373 - 405.

Quarles, W. 1995a. Least-toxic termite baits. Common Sense Pest Control: XI: 5 -17.

Quarles, W. 1995b. New technologies for termite control. IPM Practitioner: XVII: 1 - 9.

Su, N-Y. 2002a. Novel technologies for subterranean termite control. Sociobiology 40: 95 - 101.

Su, N-Y. 2002b. Current and future trends of termite management. Sociobiology. 40: 1-2.

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

Su, N-Y. & R. H. Scheffrahn 2000. Termites as pests of buildings. *In*: Takuya A, David, B. & Masahiko, H. (Eds). Termites: Evolution, Sociality, Symbioses, Ecology. Kluwer Academic Publishers, Dordrecht, pp.437-453.

Watson, J.A.L. 1990. Alternative termiticides and alternative to termiticides. Pestalk 10: 2 – 10.