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- BIODETERIORATION AND CHEMICAL TREATMENT OF WOOD
- FIBRE AND CHEMICALS FROM WOOD

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SESSION B

Leader: Dr. H. Greaves

Biodeterioration and Chemical Treatment of Wood

(9.00 a.m. - 12.30 p.m. Tuesday 20 November 1984)

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B2. "The Manufacture and Assessment of Preservative Treated Plywood for Above Ground Use"
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B3. "The Effect of Multiple Treatments on the Solution Stability of Commercial CCA Preservative - A Quality Control Problem?"
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B4. "Development of Diffusable Pastes for the Control of Centre Rot Decay"
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B5. "Chemical Modifications of Wood to Improve the Toxicity of CCA Preservatives"
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B6. "The Effect of Copper, Arsenic and Chromium on the Cellulolytic Enzymes of Brown-Rot Fungus, Gloeophyllum trabeum, grown on Pinus radiata Sapwood Shavings"
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B7. "A Laboratory Bioassay of Various Creosotes including PEC"
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B9. "The Peformance in Exposed Situations of Pinus radiata Treated with Organic Solvent Preservatives"
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B12. "Bee-keeping and Wood Preservation in Australia"
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B13. "Soft Rot in Transmission Poles Treated with High Retentions of CCA"
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B28. "Poor Performance of Spotted Gum Sleepers in a Railway Line in South East Queensland"
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PIGMENT EMULSIFIED CREOSOTE
- AN ALTERNATIVE TO HIGH TEMPERATURE CREOSOTE

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**On secondment to CSIRO from Koppers Aust. Pty. Ltd.

ABSTRACT

Collaborative research involving CSIRO, the State Electricity Commission of Victoria (SECV) and Koppers Australia Pty. Ltd. has produced a cleaner alternative to high temperature creosote. This diverse, complex and stable pigment emulsified creosote (PEC) technology is capable of reproduction and modification up to commercial batching and utilization.

Many hardwood pole species have been treated with PEC, from laboratory, through pilot plant to commercial treatment plant scales. Retention and penetration have been verified in commercial pole trial against SECV specifications. Some radiata pine posts were treated with PEC in the pilot plant. Detailed investigative analytical and physical chemistry has affirmed preservative consistency and stability over long periods of varied process conditions. PEC treated samples exposed in the accelerated field simulator together with poles in service have provided good examples of the potential for this preservative.

INTRODUCTION

High Temperature Creosote (HTC) used in the treatment of wooden transmission poles in Australia has been the subject of industrial complaints since its introduction in 1967. The complaints have been due mainly to soiling of clothing and equipment, and mild to severe skin

sensitization from exposure to, or contact with, the creosote. These problems have led to the initiation of a programme of research concerned primarily with investigations into the adverse characteristics of HTC and their elimination or mitigation. The programme is a joint research project being carried out by the Conservation and Biodegradation Section of the CSIRO Division of Chemical and Wood Technology in co-operation with Koppers Aust. Pty. Ltd. and the State Electricity Commission of Victoria.

Several components of creosote exude from treated wood and contribute to the formation of 'crud' on the surface of wood through their oxidation and/or polymerization. The complete removal of these components from creosote is both impractical and undesirable because: (i) the components are evenly distributed throughout the whole distillation range of creosote, and (ii) such 'crud'-forming components as diphenylene oxide, acenaphthene, fluorene and phenanthrene are highly fungitoxic and their removal will result in a reduction in the preservative efficacy of the creosote. It was decided, therefore, to develop a type of creosote in which the components remain permanently in the pole after treatment (i.e. 'crud'-free creosote), and which possesses characteristics of preservative efficacy and adequate penetrability.

The first such creosote, called Pigment Emulsified Coloured Creosote (PECC) (3) was used to treat half-rounds of messmate in the CSIRO pilot scale impregnation plant. The results indicated that the penetration and retention of PECC compared favourably with those of HTC. Early treatments on a semi-commercial scale were equally promising, but, after a number of charges, problems in penetration and distribution became evident and it was considered desirable to reformulate the PECC. Work in this direction led to the development of a 'super-stable' pigment emulsified creosote (PEC) (4). This stabilised formulation has been tested at extremes of temperature, under stress from acids and wood extractives, and in constant use during repeated vacuum-pressure impregnation cycles. The emulsion has been found to be extremely stable under these conditions.

LABORATORY EVALUATION OF PEC

FUNGICIDAL TOXICITY OF PEC VS HTC

PEC and HTC were examined for their ability to prevent decay in *Eucalyptus obliqua* L'Herit. sapwood by three specific fungi using a soil jar bioassay technique (2). It was found that both preservatives provided a similar degree of protection. The fungi toxic components in the PEC appeared to be more resistant to artificial leaching than those in HTC.

Matched samples of hardwood treated with PEC or HTC were artificially weathered for 100 hours in an Atlas Twin Arc weatherometer. These samples were redried and then installed in the Division's Accelerated Field Simlator to test the efficacy of PEC and HTC in ground contact. All the treated samples were sound after three months whereas many of the untreated controls have started to decay.

RETENTION, PENETRATION AND SURFACE APPEARANCE OF TREATED SAMPLES

(a) Hardwood

PEC and HTC were used in the treatment of air-dried 1.4 m long quadrants cut from 11 m poles of non-durable Victorian species. The treatments were carried out at two tempeatures, i.e. 60 and 90°C, using a Lowry schedule (1). The weight retentions obtained in the sapwood of each sample are tabulated in Table 1.

TABLE 1

Weight retentions (kg/m^3) in sapwood of quadrants treated with PEC and HTC

Pole Number	Pigment Emulsified Creosote (PEC)				High Temp. Creosote (HTC)	
	60°C		90°C			
	Emulsion	Creosote*	Emulsion	Creosote*	60°C	90°C
1	279	188	386	264	454	329
2	439	296	482	330	203	365
3	514	348	314	213	296	253
4	766	519	569	386	421	409
5	420	282	299	208	226	191
6	336	226	243	169	300	236
7	318	214	568	396	607	535
8	391	263	400	279	362	362
Mean	433	292	408	281	346	335

* For PEC the retention values are based on actual creosote, i.e. water, pigment, emulsifiers, etc. have been excluded in the calculation.

The results have indicated that: (i) preservative retention and macro-distribution of creosote in the treated sapwood of the PEC and HTC samples are similar. The 30°C increase in treatment temperature does not result in higher retentions for either preservative; (ii) side-matched samples treated with PEC have achieved consistently higher retentions based on total liquid, than those treated with HTC; (iii) the surface of freshly treated PEC quadrants is generally cleaner, less oily and fumes less than HTC treated samples at the same treatment temperature; (iv) after many months of exposure to the weather, 'crudding' is less severe on the surfaces of PEC-treated samples than HTC-treated samples. Many of the PEC samples have no crud on the surface.

Some quadrants of the 'Royal' pole species were also treated with PEC and HTC using a Bethell schedule. The retentions obtained were geneally lower than those in the 'Victorian' species.

The water content, pigment level, pH, density, surface tension, viscosity and rheology of the emulsion did not vary significantly throughout the twelve treatment charges. Microscopic observations have

indicated that the emulsion improved in appearance with subsequent treatments. The very fine pigment remained evenly dispersed in both phases of the emulsion.

(b) Radiata pine posts

Thirty nine 1 m long air dried *Pinus radiata* D.Don. posts were treated, in five charges, with either PEC at a nominal 60°C using a Rueping schedule, or with HTC at a nominal 95°C using a less severe Rueping schedule. Thirty-six posts were also treated with the PEC using a Lowry schedule at a nominal 60°C. A summary of the retentions obtained is presented in Table 2.

It was observed that the surface of freshly PEC-treated posts, using Rueping schedule, was covered with a thick layer of what appeared to be concentrated emulsion. Compressed air in the samples continued to perforate the layer and the surface was ugly in appearance. However, after 4-5 days the surface became dry and pleasant. The surface of HTC-treated posts was generally dry after a similar period. The surface of posts treated with PEC using the Lowry schedule was dry within 1-2 days.

The weight retentions obtained in the PEC-treated posts were generally lower than those treated with HTC. Increased treatment pressure and time will undoubtedly help towards achieving higher retentions. All treated posts will be assessed for 'crud' after several months of weathering. Selected samples will be cut to examine the macro distribution pattern.

TABLE 2

Weight retentions (kg/m^3) in radiata pine posts treated with PEC and HTC

Treatment schedule	Preservative type	Formulation retentions* (kg/m^3) Average	Range
Rueping	PEC	139	79 - 223
Rueping	HTC	175	60 - 360
Lowry	PEC	142	78 - 248

* Based on total volume of each post

The emulsion remained stable over the fifteen treatment charges. A slight drop in pH of the emulsion was recorded when using Rueping schedules. Very slow build up of pigment in the emulsion was noted. However, this gradual build up of pigment was not significant.

COMMERCIAL TRIAL

A prototype emulsion manufacturing plant has been built by Koppers Aust. Pty. Ltd. at Officer, Victoria. This plant is capable of producing up to 25,000 L of PEC per batch. To date, more than 300,000 L of the emulsion have been manufactured. The treatment plant has treated some 4000 poles of various hardwood species. The operations have involved both Lowry and Bethell schedules. Poles were individually weighed before and after treatment for retention calculations. Each pole was sampled to determine the penetration of the preservative into the sapwood.

It was found that less than 5% of the poles have to be retreated for compliance with the State Electricity Commission Victoria specifications.

The table below presents the summary of retentions obtained in the first 1300 poles treated at Officer.

Table 3

Hardwood pole durability class	Number of poles	PEC retention *(kg/m^3) Average	range	Penetration depth
Class 1	772	250	121 - 694	Full sapwood
Class 2	234	353	136 - 389	Full sapwood
Class 3	297	283	122 - 612	Full sapwood

* Weight retention of emulsion based on sapwood volume.

During the first eight months of operation, a brown-pigmented emulsion was used. Complaints that the colour of the poles treated with brown PEC resemble HTC treated poles led to the development of a white formulation. This is still being rsearched and was used in the treatment of pine posts mentioned above.

Creosote odour from the two coloured emulsions and the emulsion-treated poles is markedly reduced when commpared with HTC. This phenomenon is being examined in a comparative study of vapour-phase emissions from PEC and HTC liquids as well as from treated poles of different ages. This complex study will be carried out at various temperatures.

Many hundreds of PEC-treated poles are now in service. Recently a survey of about 80 brown PEC-treated poles of various species, in the eastern metropolitan region of Melbourne, was conducted. In this study, the surface condition of HTC poles in close proximity to the PEC poles was also assessed and used as a control. Less than 15% of the PEC poles were considered unacceptable in terms of the amount of 'crud' formed on the surface. Almost all of the HTC controls were found to be unacceptable.

Many more PEC poles have to be studied before conclusions such as the effect of species, retentions, charges and pigment colour variation have on surface exudation, can be drawn.

Current research and development is concerned with formulation variations, notably in the use of other pigments, and in the phase specific addition of different biocides aimed at producing a PEC designed for a particular end-use. To date a number of additives variants of PEC has been formulated, including alkyl ammonium compounds, agricuiltural and other organic biocides, and inorganic water-borne chemicals. Treatment has aimed at providing preservation at much reduced levels of total creosote, with the added biocide acting in synergism with the PEC to confer adequate protection by the total treatment. PEC additives are currently under test in the CSIRO Accelerated Field Simulators, and in soil-jar bioassays, while pilot scale treatments of pole stubs are being undertaken.

In the long term, we anticipate the broad application of PEC preservatives of various colours to a wide range of hardwood and softwood commodities, including above-ground timbers such as cladding, joinery, domestic fencing, etc.

REFERENCE

1. Chin, C.W., Watkins, J.B. and Greaves, H. 1983. Clean creosote - its development and comparison with conventional high tempeature creosote. Intern. Res. Group on Wood. Pres. Working Group III - Document No. IRG/WP/3235.

2. Cookson, L.J., Greaves, H. and Pahl, P.J. 1984. A laboratory bioassay of various creosotes including PECC-18. 21st Forest Products Researach Conference Paper B7.

3. Watkins, J.B. 1977. Timber Preservation. Aust. Patent No. 514897.

4. Watkins, J.B., Greaves, H. and Chin, C.W. 1983. Preservative compositon. Aust. Patent Appl. No. PF 9867.

THE MANUFACTURE AND ASSESSMENT OF PRESERVATIVE-TREATED PLYWOOD FOR ABOVE-GROUND USE

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ABSTRACT

A commercial method of preserving plywood using glueline and/or veneer treatments with permethrin and benzalkonium chloride was investigated. The effect of these preservatives on bond quality in plywood treated to a high retention was assessed. Results of bioassays against two species of subterranean termites and a white rot fungus are presented.

INTRODUCTION

As the timber species used in plywood manufacture in Australia are of low natural durability (class 3 or 4), plywood has been excluded from a number of applications or its use limited. However, an effective preservative treatment would allow plywood to be used extensively for external cladding and bracing, fitting out ships, antiskid walkways and industrial containers.

CSIRO, in conjunction with Wellcome Australia Pty. Ltd. and the Plywood Association of Australia, has been examining a method of commercially preserving plywood using glueline and/or veneer treatments with permethrin and benzalkonium chloride. The effect of various formulations and combinations of these compounds on bond strength and panel durability to a number of biodeteriogens will be discussed.

MATERIALS AND METHODS

FORMULATIONS

The two compounds used in this study were permethrin (25:75, cis: trans ratio) and benzalkonium chloride (BAC). Permethrin is a pyrethroid insecticide known to be effective against a wide range of wood-destroying insects (1,2,3,4). BAC is an alkylammonium compound with fungicidal properties (5,6). These two compounds were formulated by Wellcome into a miscible oil and used to treat the veneer in one step. A two step process was also explored in which the pyrethroid was added to the glue and the BAC to the veneer.

The first stage in this project was to determine whether the formulations, either as veneer and/or glueline treatments, had any effect on the bond quality of the plywood manufactured. To establish this, panels containing a high loading of each of the eight treatments (see Table 1) were prepared and assessed. In the second stage, specimens from the treatments which passed such tests were then bioassayed to establish the efficacy of each treatment.

MANUFACTURE OF PLYWOOD

The steps taken in the manufacture of the test plywood panels are shown in Figure 1.

All studies were carried out on 2.5 mm thick *Pinus radiata* D.Don veneer obtained from a mill production line. The veneers were passed through a bath of water or preservative and then block stacked for 24 hours. Then they were conveyed through the mill's veneer dryer operated at a maximum temperature of 175^{o}C.

Two panels (900 x 900 x 12 mm) were manufactured for each treatment combination. The adhesive used in the study was a phenol-formaldehyde (Lauxite PP775 with 201 filler). Gluing conditions were within the manufacturer's guidelines. For panels requiring an insecticidal glueline

TABLE 1

Veneer and Glueline treatments[1] of plywood

Veneer treatment	kg/m^3 Permethrin	kg/m^3 BAC	Glueline treatment	kg/m^3
1. Untreated	-	-	Untreated	-
2. Permethrin/BAC (A)	1.2	12.0	Untreated	-
3. Permethrin/BAC (B)	1.2	12.0	Untreated	-
4. BAC	-	12.0	Untreated	-
5. Untreated	-	-	Permethrin (A)	0.5
6. BAC	-	12.0	Permethrin (A)	0.5
7. Untreated	-	-	Permethrin (B)	0.5
8. BAC	-	12.0	Permethrin (B)	0.5

[1] A and B are different formulations

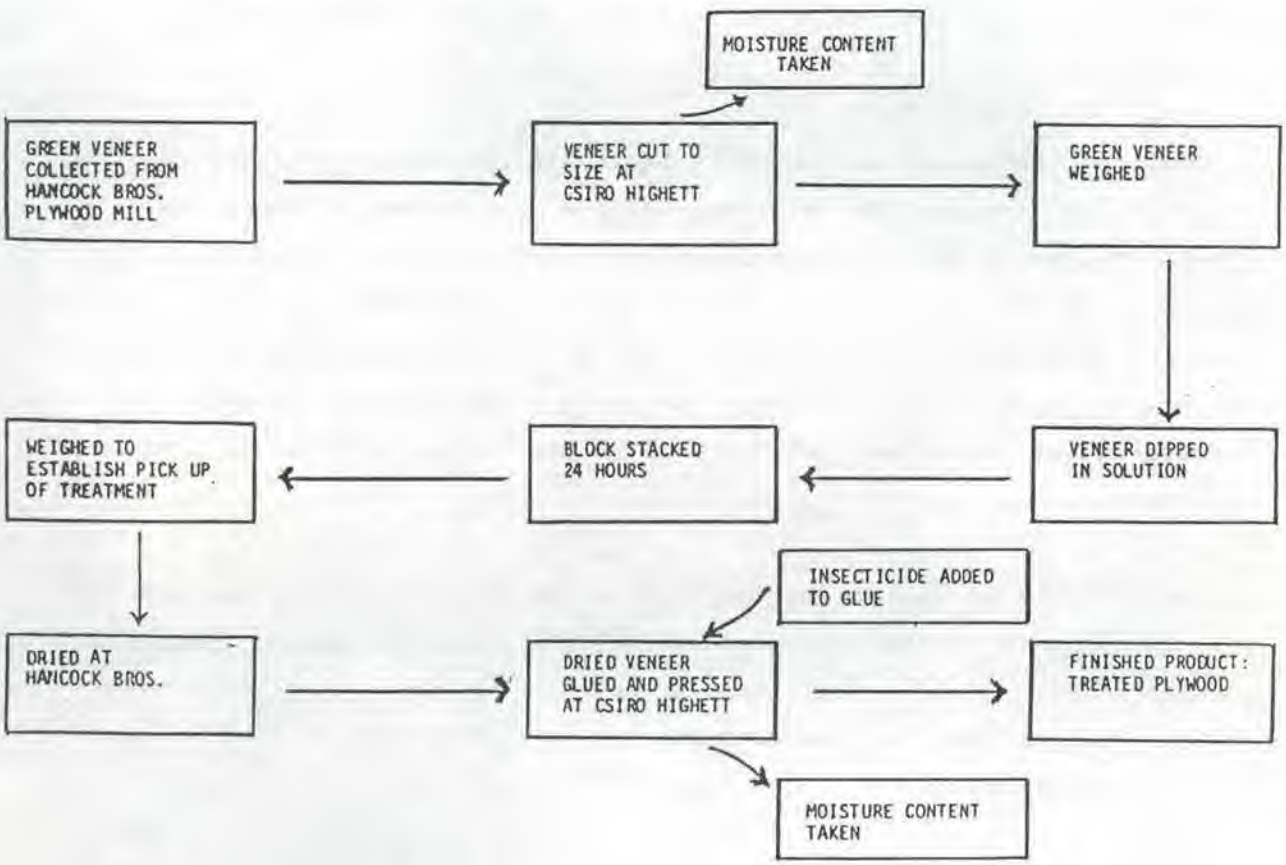

Figure 1. Flow chart for manufacture of treated plywood.

additive, one of two formulations of permethrin was mixed into the glue before spreading. Hot pressing time was 10 minutes at 140°C and 1 mPa. In all cases the gluing procedure adopted was that commonly used in commercial practice.

BOND QUALITY ASSESSMENT

Six samples from each plywood treatment were subjected to bond quality assessment by the dry test method according to AS 2098.2-1977(7). An additional six samples per treatment were exposed to a 72 hour boil test (7).

PREPARATION AND BIOASSAY OF TEST SPECIMENS

Test specimens (100 x 25 x 12 mm) were cut from each test panel after the panel was sanded to remove 0.2 mm from each face. The specimens were subjected to a leaching/volatilization schedule (8) before the bioassaying. Those specimens for decay studies were sterilized by irradiation.

Test specimens were subjected to bioassays against two species of subterranean termites. The bioassay against *Coptotermes acinaciformis* (Froggatt), which has an Australia-wide distribution, was conducted according to the techniques described by Gay *et al.* (9), but with customarily adopted modifications (10,11,12,13). The bioassay utilizing *Mastotermes darwiniensis* Froggatt, which is found only in northern Australia, was conducted according to the technique described in Howick and Creffield (13).

The multiple-block test method used in the fungal bioassay was modified from Thornton (14). The test organism was the white rot fungus *Pycnoporus coccineus* (Fr.) Bond. & Sing. that attacks a wide range of timbers used for external woodwork on houses (15). The incubation was carried out at 25°C for twenty weeks.

RESULTS AND DISCUSSION

BOND QUALITY ASSESSMENT

The quality of the bonds observed in the two plywood panels of each treatment combination are given in Table 2. The only treatment which gave an average bond quality (7,16) of less than 5, was treatment 8. Hence this treatment narrowly failed to rate an A bond after the 72 hour boil test. It should be noted that, when dealing with phenolic glues, high wood failure is a good predictor of long-term bond durability in adverse conditions (17).

TERMITE BIOASSAYS

Details of the amount of termite attack on treated and untreated plywood specimens are given in Table 3. Except for the untreated controls, all plywood treatments afforded protection against *C. acinaciformis*. However, for *M. darwiniensis*, in addition to the untreated controls treatments 5 and 7 failed.

TABLE 2

Mean bond quality values of plywood test panels determined according to AS 2098.2 - 1977

Treatment[1] Veneer	Glueline	Panel No.	Dry test $\bar{x}$	Dry test SD[2]	72 hr boil test $\bar{x}$	72 hr boil test SD[2]
1. Untreated	Untreated	1	8.1	0.7	6.0	1.5
		2	6.9	0.9	5.8	1.0
2. Permethrin/BAC (A)	Untreated	1	7.2	0.7	5.7	1.0
		2	6.3	1.2	7.2	1.3
3. Permethrin/BAC (B)	Untreated	1	7.4	1.1	6.3	1.4
		2	8.0	0.6	6.8	1.4
4. BAC	Untreated	1	6.9	1.6	5.8	1.6
		2	7.7	0.7	5.9	1.3
5. Untreated	Permethrin (A)	1	6.7	1.1	5.9	2.1
		2	7.7	1.1	5.8	1.6
6. BAC	Permethrin (A)	1	7.0	1.1	5.6	1.8
		2	6.9	0.9	6.1	0.9
7. Untreated	Permethrin (B)	1	7.4	1.0	5.6	1.6
		2	7.1	1.3	6.1	1.6
8. BAC	Permethrin (B)	1	6.8	1.4	4.8	1.8
		2	7.3	1.0	4.9	1.3

[1] A and B are different formulations
[2] SD = standard deviation

TABLE 3

Amount of termite attack[1] on treated [2] and untreated plywood specimens

Veneer treatment	Glueline treatment	*C. acinaciformis* %	*C. acinaciformis* (SD)[3]	*M. darwiniensis* %	*M. darwiniensis* (SD)[3]
1. Untreated	Untreated	29.8	(2.4)	55.3	(5.3)
2. Permethrin/BAC (A)	Untreated	0.3	(0.4)	0.7	(0.4)
3. Permethrin/BAC (B)	Untreated	2.4	(0.2)	2.1	(0.5)
4. BAC	Untreated	0	(0)	1.1	(0.9)
5. Untreated	Permethrin (A)	0.7	(0.8)	17.0	(5.1)
6. BAC	Permethrin (A)	1.6	(0.3)	2.4	(0.5)
7. Untreated	Permethrin (B)	1.0	(0.4)	9.3	(6.3)
8. BAC	Permethrin (B)	1.0	(0.1)	1.3	(0.7)

[1] Expressed as percentage mass loss (mean of six replicates)
[2] A and B are different formulations
[3] Standard deviation

DECAY BIOASSAY

The percentage mass loss sustained by treated and untreated specimens is shown in Table 4. Those plywood treatments incorporating BAC (2,3,4,6,8) were significantly (1% probability level) more resistant to attack by *P. coccineus* than those which did not contain BAC (1,5,7). Furthermore, as there was no significant difference between the untreated specimens and those containing permethrin in the glue (5,7), it is apparent that permethrin was neither fungicidal nor fungistatic to *P. coccineus*.

TABLE 4

Mass loss and moisture content of treated and untreated plywood specimens after 20 weeks incubation with *Pycnoporus coccineus*

Treatment No.	Treatment[4] Veneer	Glue	% Mass loss[1] Adj. $\bar{x}$[2]	SE[3]	% Moisture content Adj $\bar{x}$[2]	SE[3]
1	-	-	31.0	2.7	41.8	5.7
2	P/BAC (A)	-	4.4	0.7	29.1	1.6
3	P/BAC (B)	-	2.3	0.7	28.4	1.6
4	BAC	-	1.8	0.7	29.6	1.6
5	-	P (A)	29.8	2.7	45.1	5.4
6	BAC	P (A)	4.5	0.7	30.1	1.6
7	-	P (B)	35.1	2.9	51.9	5.5
8	BAC	P (B)	1.8	0.7	30.5	1.6

[1] Mean of 8 replicates
[2] Mean adjusted for tray-to-tray variation
[3] Standard error of estimate
[4] A and B are different formulations

FURTHER STUDIES

In addition to the previously described studies, plywood panels treated with the following concentrations and combinations of preservatives have been manufactured:

Veneer treatment[1]	Glueline treatment[1]
1. Untreated	Untreated
2. Permethrin/BAC (A) (1,4,8,12 kg/m^3)	Untreated
3. Permethrin/BAC (B) (1,4,8,12 kg/m^3)	Untreated
4. BAC (1,4,8,12 kg/m^3)	Untreated
5. Untreated	Permethrin (A, 0.5 kg/m^3)
6. BAC (1,4,8,12 kg/m^3)	Permethrin (A, 0.5 kg/m^3)

[1] A and B are different formulations

Test specimens from the above are being bioassayed now against the following organisms:

Termites	Fungi
C. acinaciformis	*Gloeophyllum abietinum*
C. lacteus (Froggatt)	*P. coccineus*
M. darwiniensis	*Serpula lacrymans*

ACKNOWLEDGEMENT

We gratefully acknowledge the assistance of Dr A.J. Miller, CSIRO Division of Mathematics and Statistics, for the statistical analysis of the decay bioassay.

REFERENCES

1. Berry, R.W. 1976. The toxicity of the synthetic pyrethroid NRDC 143 to some wood boring insects. Int. Biodetrior. Bull. 12: 42-43.

2. Berry, R.W. 1977. The evaluation of permethrin for wood preservation. Pestic. Sci. 8: 284-90.

3. Howick, C.D. and Creffield, J.W. 1979. Synthetic pyrethroids and wood preservation. Proc. 19th Forest Prod. Res. Conf., Topic 3/12: 1-5.

4. Howick, C.D. and Creffield, J.W. 1981. Further information on the efficacy of some synthetic pyrethroids in wood preservation. Proc. 20th Forest Prod. Res. Conf., Topic WP2: 1-8.

5. Butcher, J.A., Preston, A.F. and Drysdale, J. 1977. Initial screening trials of some quaternary ammonium compounds and amine salts as wood preservatives. For. Prod. J. 27: 19-22.

6. Hedley, M.E., Preston, A.F., Cross, D.J. and Butcher, J.A. 1979. Screening of selected agricultural and industrial chemicals as wood preservatives. Int. Biodeterior. Bull. 15: 9-18.

7. Standards Assoc. of Australia. 1977. Bond quality of plywood (chisel test) AS 2098.2 - 1977.

8. Greaves, H., Tighe, M.A. and McCarthy, D.F. 1982. Laboratory tests on light organic solvent preservatives for use in Australia. 1. Evaluation of candidate fungicide, including some commercial formulations. Int. J. Wood Preserv. 2(1): 21-27.

9. Gay, F.J., Greaves, T., Holdaway, F.G. and Wetherly, A.H. 1955. Standard laboratory colonies of termites for evaluating the resistance of timber, timber preservatives, and other materials to termite attack. Bull. Commonw. Scient. Ind. Res. Org. No. 277, 60 pp.

10. Howick, C.D., Creffield, J.W., Butcher, J.A. and Greaves, H. 1982. The termiticidal efficacy of a quaternary ammonium compound and a tertiary amine salt in wood protection. Mater. Org. 17(2): 81-92.

11. Creffield, J.W. and Tam, M.K. 1979. Laboratory assessments of the efficacy of CCA and PCP-treated *Dyera costulata* (Jelutong) against two species of Australian termites. Malay. Forester 42(3): 230-239.

12. Howick, C.D. 1975. Influences of specimen size, test period and matrix on the amounts of wood eaten by similar groups of laboratory termites. Proc. Br. Wood Preserv. Assoc. Annual Conv. 51-63.

13. Howick, C.D. and Creffield, J.W. 1975. The development of a standard laboratory bioassay technique with *Mastotermes darwiniensis* Froggatt (Isoptera: Mastotermitidae). Z. Angew. Entomol. 78: 126:138.

14. Thornton, J.D. 1979. Evaluation of a new laboratory decay technique using *Serpula lacrymans*. Int. Biodeter. Bull. 15(2): 45-48.

15. Walters, N.E.M. 1973. Australian house fungi. For. Prod. Techn. Notes No. 13. CSIRO Division of Building Research.

16. Standards Association of Australia. 1979. Structural plywood. AS 2269-1979.

17. Perkins, N.S. 1950. Predicting exterior plywood performances. For. Prod. Res. Soc. Proc. No. 4: 352-364.

THE EFFECT OF MULTIPLE TREATMENTS ON THE SOLUTION STABILITY OF COMMERCIAL CCA PRESERVATIVE - A QUALITY CONTROL PROBLEM?

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ABSTRACT

The treatment of twelve messmate (*Eucalyptus oblique* L'Herit.) posts using Tanalith C solution is described. The change in pH, specific gravity, concentration and elemental composition of copper, chromium and arsenic of the treatment solution over six charges are tabulated and discussed. The elemental distribution of copper, chromium and arsenic in the redried treated messmate posts is deliberated. Results indicated a gradual decrease in the concentration of arsenic in the solution took place during the six charges. After charge 3 sludge appeared on the wood. Analysis showed that the sludge contained mainly arsenic. Disproportionation of copper, chromium and arsenic in the wood occurred over the full sapwood depth.

INTRODUCTION

In the research and development of a wood preservative, its toxicity is based initially on laboratory bioassay tests and consequently the performance of the treated specimens in field tests. In both cases the exact composition and concentration of each active component in the preservative are known. Fresh solution is inevitably used in the treatment of test samples. In commercial treatment plants, huge quantities of preservative solutions are stored in work tanks and are used repeatedly. The topping up of the tank with 'virgin' preservative is carried out when the quantity left is insufficient to fill treatment cylinder and/or the concentration is lower than specified value. The concentration of copper-chromium-arsenic (CCA) solution used in commercial treatment plants is

normally determined from tables provided by the preservative manufacturer in conjunction with actual measured values of solution specific gravity and temperature. The tables are constructed based on fresh formulations in which all the active components are in balance. No consideration is given to possible changes in the ratios of the elemental components or contamination of the preservative, e.g. water soluble extractive from timber and dirt.

It is well known that the formation of solid sludge in treatment plants is a serious problem in terms of choking of pumps, loss of usable preservative, etc. However, sludging will also undoubtedly alter the composition and therefore the ratios on the three active elements in the solution.

This paper presents analytical results of changes in the elemental concentratons and ratios of copper (Cu), chromium (Cr) and arsenic (As) in a commercial Tanalith C solution which was used successively over six treatment charges. The specific gravity and pH of each pretreatment solution as well as composition of the sludge collected from treated samples are tabulated. The elemental ratios of Cu, Cr and As in the treated messmate (*Eucalyptus obliqua*) stubs are discussed.

MATERIAL AND METHODS

Twelve air-dried half meter long regrowth messmate (*E. obliqua*) stubs of 40-70 mm diameter were used in the study. Twenty kilograms of 8% m/m Tanalith C (Tan C) solution was prepared from commercial Tan C paste of 85.7% concentration. This solution was used to treat the twelve stubs in six charges without top up of fresh Tan C. For each treatment charge, two messmate stubs were placed in a stainless steel trough which was then filled with all the 8% Tan C solution. The trough was placed into a pressure cylinder. A Bethell treatment schedule was used with an initial vacuum (min. - 85 kPa) for half hour followed by an air pressure of 1400 kPa for one hour. The solution was emptied in a plastic bin and the treated stubs were individually weighed. The specific gravity, solution temperature and pH were measured prior to each treatment. A 100 ml sample of the solution was taken for atomic absorption spectrophotometer (AAS)

elemental analysis of Cu, Cr and As.

The treated stubs were redried under cover until constant weight was achieved. A 10 mm disc was cut from the mid-length of each treated stub. A 10 mm wide x full length section of the treated sapwood was cut from each disc. The outer surface (about 0.5 mm) of each section was removed and discarded. Using a chisel each section was split into four zones (0 to 2, 3 to 7, 8 to 12 mm and the remainder of the treated sapwood). The volume of each zone was determined by displacement method before being chipped for extraction and AAS elemental analysis using the method discussed by Johanson (1).

RESULTS AND DISCUSSION

A. GENERAL OBSERVATION

For the first two charges, the Tan C solution was clear with no apparent suspended particles. The surface and ends of each treated stub were clean. After the third charge, thin layers of greenish sludge were deposited on the posts with more on the end grains. An increase in the amount of sludge on the ends of each stub, particularly at the latewood rings, was observed as treatment progressed from charge 4 to charge 6. Slight sludge deposition on the stub surface was apparent. Ease of penetration of the preservative through the hardwood end grain may account for the greater build up of sludge at the ends as compared with the radial surface. All stubs removed after treatment, with the exception of those in the first two charges, were observed to have sludge bubbling from the end grains as a result of pressure build up in the wood during treatment. The sludge formation may be the result of the reaction of treatment solution with the chemical components within the wood (e.g. reducing sugars, extractives) (2,3). This investigation has demonstrated that sludging on timber occurs without obvious external contamination. Sludge samples were collected from the ends of posts treated in the 4th, 5th and 6th charges for AAS analysis. A slow build up of insoluble sludge, possibly from treated posts, was observed in the solution as treatments progressed.

B. VARIATION IN pH, SPECIFIC GRAVITY AND CONCENTRATION OF TREATMENT SOLUTIONS

Table 1 presents the pH and specific gravity of the treatment solutions before each charge. The strength of each solution was then determined from tables supplied by the manufacturer (see Table 1). It can be seen that the concentration of Tan C solution dropped from 0.085 to 0.083 kg/L after the first charge. The value varied by only 0.001 kg/L over the next five charges.

TABLE 1
The pH, specific gravity and concentration of treatment solutions

Treatment charge	pH	Specific gravity at °C		Concentration* (kg/L)
Fresh Tan C solution i.e. Pre 1	1.86	1.056	(16.3)	0.085
Pre 2†	1.92	1.055	(15.0)	0.083
Pre 3	1.95	1.055	(15.3)	0.083
Pre 4	2.01	1.055	(16.0)	0.084
Pre 5	2.07	1.054	(17.0)	0.083
Pre 6	2.10	1.055	(17.2)	0.084
Post 6	2.13	1.054	(18.0)	0.083

* Values are from tables used by commercial plants and expresssed as kg of Tan C salt per L of solution

† Pre 2 is as Post 1

The elemental concentration of Cu, Cr and As in each pretreatment solution was measured by AAS analysis. The detailed results are shown in Table 2. The concentrations of all three elements decreased noticeably after the first charge. This was indicated from the hydrometer reading, i.e. bulk solution concentration. After this charge, the Cu concentration appeared to stay relatively constant whereas Cr and more so As gradually

TABLE 2

AAS analysis results of treatment solutions

Treatment charge	Copper (mg/mL)	Chromium (mg/mL)	Arsenic mg/mL)	Ratio of Copper:Chromium :Arsenic
Tan C Formulation	7.128	12.728	9.016	1 : 1.79 : 1.27
Fresh Tan C solution i.e. Pre 1	7.259	12.238	9.153	1 : 1.69 : 1.26
Pre 2	6.928	11.916	8.816	1 : 1.72 : 1.27
Pre 3	7.009	11.778	8.615	1 : 1.68 : 1.23
Pre 4	6.906	11.789	8.228	1 : 1.71 : 1.19
Pre 5	7.017	11.296	7.740	1 : 1.62 : 1.10
Pre 6	7.069	11.032	7.434	1 : 1.56 : 1.05
Post 6	7.004	10.895	6.969	1 : 1.56 : 0.99

* Basing on 8% m/m of Tan C formulation as stated in AS 1604-1980.

decreased in successive charges. This must account for the increase in pH values of the solutions. Overall the change in Cu concentration was 3.5% as compared with 11.0% of Cr and a massive 23.9% of As at the end of the sixth charge. It is obvious that hydrometer readings did not show the charge in concentration of all the three elements in solution.

The disproportionation of elemental Cu, Cr and As in the solution appeared to take place from the beginning of treatment. Greater changes in the ratios of Cu, Cr and As took place as treatment continued (see Table 2). It may be said that even if the total concentration of the treatment solution can be kept constant by the addition of fresh CCA solution after several treatment charges, the ratios of Cu, Cr and As must differ from the intended Tan C formulation. This may affect the fixation of the three elements and ultimately the service performance of the treated products.

C. COMPOSITION OF SLUDGE FROM TREATED POSTS

The percentage elemental compositon of sludge collected from the ends of treated stubs is presented in Table 3. Elemental As is the main component (52.5% m/m) in the sludge. This must account for the sharp drop in the concentration of As in the treatment solutions, however, Cu and Cr elements are present in almost equal amount in the sludge. The insolubles from the sludge consist mainly of iron, sulphur and silicon which possibly are contaminants from tap water, extractives from the wood and the steel container used to package Tan C paste. Recent publication by Pizzi *et al.* (3) indicates that Tan C solution, with or without prior contact with timber, on standing will also form precipitates or sludge-like deposits.

TABLE 3

AAS analysis results of sludge from treated messmate posts

	% m/m
Elemental copper	17.7
Elemental chromium	17.2
Elemental arsenic	52.5
Insolubles*	12.6

* Insolubles, as determined by X-Ray microanalysis, contained mainly silicon, iron and sulphur

D. ELEMENTAL DISTRIBUTION IN TREATED POSTS

The first 2 mm of all sections cut from disc of CCA treated posts contained higher concentration of Cu, Cr and As when compared with the remaining three zones in each corresponding section. In the first 2 mm the ratios of Cu:Cr were always higher whereas the ratios of Cu:As were lower than that in the pre and post solutions of each charge. The elemental retentions in this zone for the twelve samples tested were Cu: 3.6-6.6 kg/m^3; Cr: 8.9-15.2 kg/m^3 and As 3.6-6.6 kg/m^3.

For the remaining three zones in each section, the concentrations of all three elements were much lower than the first 2 mm and generally decreased slightly towards the inner sapwood. The ratio of Cu, Cr and As in each zone was different to that in the pre and post treatment

solutions. The ratio of Cu:Cr in each zone was consistently higher than the treating solution whereas Cu:As ratios were much lower.

The average concentration in each section, i.e. the four zones combined, was Cu: 3.0-4.0 kg/m^3; Cr: 5.3-7.9 kg/m^3 and As: 1.6-4.9 kg/m^3. The ratio of the average concentration of the three elements in each section again differed from the treatment solutions with Cr generally higher and As lower. Tangential penetration of the treatment solution which is limited to the outer 2 mm possibily contributes to the high concentration of the three elements in this zone.

The consistently high Cu:Cr ratios in each zone could be due to the highly reactive nature of Cr with the wood substrate. This may account for the decrease in concentration of Cr in the treatment solutions. The variation in the ratios of Cu:Cr:As and the elemental loadings between each zone in a section as well as between sections, must affect the fixation of the elements in the wood. This must eventually result in different service performances of the treated product.

1. Johanson, R. 1973. Determination of Cu-Cr-As in preserved wood by atomic absorption spectroscopy. Holzforschung 27(4): 126-132.

2. Pizzi, A. 1982. The chemistry and kinetic behaviour of Cu-Cr-As/B wood preservatives, Part IV: fixation of CCA to wood. To Polym: Sci., Chem. Ed., 20: 739.

3. Pizzi, A., Conradie, W.E. and Jansen, A. 1984. Sludge formation in timber treatment with CCA preservatives origin and elimination. Holzforschung und Holzverwertung 3: 54-59.

DEVELOPMENT OF DIFFUSIBLE PASTES FOR CONTROL OF CENTRE ROT DECAY

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ABSTRACT

Short rounds of *Eucalyptus obliqua* were bored in their centres with 200 mm long holes, 22 mm in diameter. Mixtures of fungitoxic chemicals in the form of pastes or gels were introduced into the drilled holes. The holes were tightly sealed and the treated specimens stored horizontally under cover.

After a specific time period replicate stubs treated with each formulation were split longitudinally. The extent of radial and longitudinal penetration of each fungitoxic component in the chemical mixture was determined using elemental indicators and bioassay techniques.

Results indicate that pastes containing Busan 30/Busperse 47 and various combinations of Arsenic, Boron and Fluoride diffuse adequate throughout most of the heartwood. It is believed these concentrations will be sufficient to inhibit heart-rot decay. The type of gelling agent used appears to be important to obtain maximum diffusion. Very poor copper diffusion was apparent in Blue 7 and Basilit BFB pastes.

INTRODUCTION

Due to current economic factors wood-pole inspection and maintenance is becoming increasingly important. Minimizing the rate of pole replacement has become the prime objective of all electricity supply authorities.

Internal fungal attack is the principal cause of pole deterioration, however, it occurs without warning or visible external signs. A number of inspection methods each with certain limitations are commonly used to detect internal decay. It is important that inspection methods accurately detect deterioration and, equally significant, detect decay in very early stages so that preventative measures can be taken to inhibit serious strength losses.

In Australia centre rot is found in the heartwood of preservative treated hardwood poles, particularly of class 3 species (1) while in America it occurs in the non-durable heartwood of Douglas fir poles (2). The State Electricity Commission of Victoria (SECV) currently uses an ammoniacal copper-fluorine-boron preservative, Blue 7, for *in situ* treatment of poles to protect them against the fungi responsible for centre rots. It is applied through side-bored holes which extend from just above grouindline to 150 mm below groundline (3).

Another approach to the problem of eliminating internal decay in poles is the use of fumigants which have been used with varying success overseas (4). Under Australian conditions, however, eucalypt poles tend to develop collapse checks on drying as well as normal checking in service, which will provide ready avenues for the loss of fumigant.

The objective of the current investigation was to evaluate preservative pastes prepared from chemicals known to be toxic to wood-destroying organisms, as diffusible formulations for the treatment of wooden transmission poles against centre rot organisms before, or at, installation, and for the remedial treatment of poles in service.

EXPERIMENTAL

1. COMMERCIAL FORMULATIONS

The four commercial formulations chosen consist of three copper fluoroborates (Blue-7, Basilit BFB, acid copper fluoroborate) and one organic fungicide (Busan 30). Blue-7 was included in the trial as a 'yardstick' since the SECV currently use it for the *in situ* treatment of

poles to protect them from centre rot decay (3).

Laboratory diffusion trials indicate Blue-7, Basilit BFB and Busan-30 have the ability to diffuse through the sapwood of *Eucalyptus regnans* (5). All three were included as toxicants in a bandage trial designed to control soft rot decay, and have been shown to diffuse through the sapwood of CCA-treated spotted gum (*Eucalyptus maculata*) poles (6).

The acid copper fluoroborate, which has not previously been used as a fungitoxicant, was included because laboratory studies have indicated it to be extremely toxic to a wide range of microfungi. Busan-30 which is an emulsifiable microbiocide containing 2 thiocyanomethylthio benzothiazole (TCMTB) as its active ingredient has been found to be very toxic to a wide range of microfungi (7) and is extremely diffusible.

The Division of Chemical and Wood Technology have been in the researach and development of a TCMBT pole gel (Busan 1022) which is now available commercially as an *in situ* treatment for the control of wood decay.

2. EXPERIMENTAL FORMULATIONS

Six experimental preservatives were formulated as potential diffusible pastes for control of centre rot decay. The pastes contained various concentrations and combinations of fluorine, boron and arsenic. Boron and fluoride were chosen for their well known diffusibility and toxicity to most common basidiomycetes that cause centre rot decay (7,8). In addition, when present in high concentrations within the wood they both have some termiticidal properties (9). Arsenic was included in some formulations in an attempt to enhance the termiticidal properties of these gels.

3. MATERIALS AND METHODS

Stubs of messmate (*Eucalyptus obliqua* L'Herit) each 500 m long and varying from 200 to 300 mm in diameter were cut from poles felled in the Wombat State Forest, Victoria. The stubs were debarked and each stub butt-bored to a depth of 200 mm, the diameter of each hole being 22 mm.

Each hole in each stub was filled with one of the ten test formulations. These were prepared in the form of a paste using either cab-o-sil (fumed silica) or carbapol (water soluble resin) as a coagulant and, after application, the holes were tightly closed using a rubber stopper. Six specimens per treatment were used and they were taken from not less than three different trees. Treated stubs were close-stacked under cover for a number of days to allow diffusion to take place.

At the end of defined periods of diffusion (i.e. either 30, 60, 150, 180 or 240 days) one or two specimens from each treatment group were sawn longitudinally. The sawn halves were split open (to avoid smearing) and colorimetric tests carried out as described in Australian Standard AS1605-1974 (Methods for the sampling and analysis of wood preservatives and preservative-treated wood) on the split surfaces to determine the extent of radial and longitudinal penetration of each toxic component from each preservative formulation. The extent of penetration of Busan-30 was determined using slab bioassay techniques (10) against two known decay fungi *Coniophora olivaceae* and *Gloeophyllum trabeum*.

RESULTS AND DISCUSSION

The heartwood diffusion results of the ten pastes used in the trial are presented in Tables 1 and 2. Rapid diffusion of toxicant from most of the formulations took place in the first thirty days with a gradual increase during the following months. This could be caused by both the wood drying and a decrease in diffusion gradients. Most of the pastes had dried to a powder by the end of the trial and were no longer diffusible. In some cases a decrease in the radial diffusion depth of toxicant with increasing time was observed. This possibily resulted from the preservative reservoir being depleted due to continuing diffusion through an increasing volume of heartwood. This would cause a decrease in the overall concentration of toxicant per unit volume of wood which may be below the detection limits of the indicators used.

TABLE 1

Diffusion depths of components using commercial formulations

Chemical components of pastes	Coagulant	Period of diffusion (days)	Depth of diffusion (mm) Copper R*	Copper L*	Fluoride R	Fluoride L	Boron R	Boron L
Basilit BFB (copper fluoroborate)	2% Carbopol	60	0-2	nil	7-13	90	20-23	180
		150	nil	nil	15-18	110	12-14	240
		180	nil	nil	19-28	290	12-16	170
		240	1-2	10	16-20	220	10-12	200
Blue-7 (ammoniacal copper fluoroborate	2% Carbopol	60	nil	nil	3-8	40	nil	nil
		150	nil	nil	9-12	140	3-4	30-40
		180	1-2	10	20-24	230	4-6	70
		240	1-2	20	18-20	170	5-8	60
Acid copper fluoroborate (elemental copper + 2.5% free fluoroboric acid)	5% Cab-o-sil	60	5-15	20-30	10	90	20	100-120
		150	5-8	20-30	5-9	100	12-15	120-130
		180	5-10	100-120	15-18	180	8-15	150
		240	2-3	160-180	8-10	260	20-22	290

			Depth of diffusion of effective fungicide using slab bioassay technique R	L
Busan 30 and Busperse 47 in a 1:1 mixture	5% Cab-o-sil	60	20-23	60
		150	10-16	150
		180	14-20	190
		240	12-16	210

* R - radial diffusion depth
* L - longitudinal diffusion depth

TABLE 2

Diffusion depths of components using non-commercial formulations

Chemical components of pastes	Coagulant	Period of diffusion (days)	Depth of diffusion (mm) Fluoide R*	Fluoide L*	Boron R	Boron L	Arsenic R	Arsenic L
1. 40% Timbor + 55% water	5% Cab-o-sil	30			13-17	80		
		60			12-15	120		
		150			6-8	80		
		180			4-6	110		
2. 30% Timbor 10% NaF 55% water	5% Cab-o-sil	30	15-20	80	20-25	100		
		60	12	70	20-24	70		
		150	7-8	110	10-12	120		
		180	6-9	130	14-17	180		
3. 25% fluoro-boric acid 25% arsenic acid 45% water	5% Cab-o-sil	30	9-12	180	8-10	120	9-12	70
		60	15-18	170	12-17	150	7-9	100
		150	30-34	210	28-32	220	12-15	120
		180	25-30	300+	20-23	300+	25-30	90
4. 10% arsenic acid 30% Timbor 55% water	5% Cab-o-sil	30			10-12	90	6-12	100
		60			24-29	180	22-25	240
		150			20-23	180	15-18	170
		180			17-20	210	12-16	150
5. 40% NaF 30% ethanol 25% arsenic acid	5% Cab-o-sil	30	20-28	180			17-21	100
		60	12-15	120			10-13	70
		150	14-18	130			10-12	130
		180	12-17	210			9-11	150
6. 50% arsenic acid 25% NaF 20% Timbor	5% Cab-o-sil	30	15	70	6-8	150	5	130
		60	8-10	110	3-6	70	5-7	80
		150	20-22	110	11-14	110	3-5	120
		180	12-16	180	12-18	120	4-7	110

* R - radial diffusion depth
L - longitudinal diffusion depth
\+ - remaining length of stub

Formulations which initially contained high elemental concentrations of toxicant generally diffused furthest, and over a longer period of time. As expected all formulations diffused more readily longitudinally than radially, facilitated by the large vessels which allow both diffusion and capillarity to assist preservative movement in this direction.

The diffusion results of the four commercially produced formulations are listed in Table 1. Of these formulations Busan-30, Blue-7 and Basilit BFB have been previously used as *in situ* diffusion treatments against decay. The copper present in the acid copper fluoroborate treatment achieved good radial diffusion, however, no copper diffusion was apparent in stubs treated with either Basilit BFB or Blue-7. Boron diffused well in all formulations, while fluoride diffused poorly as evidenced by the Blue-7 treated stubs. The better diffusion of components in stubs treated with acid copper fluoroborate is probably a result of the acid formulation being more compatable with the pH of the wood.

Bioassay results of stubs treated with Busan-30 paste indicated that diffusion of fungitoxicant was sufficient to inhibit two common heart-rot fungi to a radial depth of 23 mm.

Results presented in Table 2 show diffusion depths of toxicants from the six experimental pastes developed by CSIRO. With the possible exception of treatment 6 all formulations achieved good radial diffusion of fungitoxicant. In most formulations the diffusibility of boron appeared superior with radial depths of up to 30 mm achieved. Formulations which achieve good diffusion of two or more different fungitoxic components should provide adequate protection against a wider range of heart-rot fungi. Formulations which did not contain arsenic, but did achieve good penetration of boron and fluoride would require these elements in high concentration to protect the heartwood from termite attack. Although arsenic diffusion was less than boron or fluoride, it would still provide a significant proportion of the heartwood with protection from termite attack. Formultions 2,3,4 and 5 have the most potential for the use of diffusible pastes for the *in situ* control of centre rot in eucalypt poles.

CONCLUSIONS

The results of this investigation indicate that:

1. Pastes containing the fungitoxic compounds boron, fluoride, arsenic, copper and Busan-30 can diffuse satisfactorily through the heartwood of *E. obliqua*.

2. Acid copper fluoroborate and Busan-30 pastes provide the best diffusion of commercial formulations tested.

3. Timbor + sodium fluoride, fluoroboric acid + arsenic acid, Timbor + arsenic acid, and arsenic acid + sodium fluoride are all suitable as potential diffusible pastes for centre-rot control.

REFERENCES

1. Barnacle, J.E. 1975. Forest Products Research Conference.

2. Smith, D.N. and Cockcroft, R. 1967. The remedial treatment of telephone and electric transmission poles: Part 2 - Treatment for internal decay. Wood 32(10): 37-40.

3. Greaves, H. 1980. Wood preservation research in Australia. International Reseearch Group and American Wood Prservers' Association Joint Symposium "Wood Preservation from Around the World". Nashville, Tenn., USA, April 29.

4. Ruddick, J.N.R. 1983. Fumigation as a remedial treatment. A review of North American Literature. International Research Group on Wood Preservation, Doc. No. IRG/WP/3253.

5. Cookson, L.J., Collett, O. and Greaves, H. 1981. Potential toxicants for controlling soft rot in preservative treated hardwoods. V. Laboratory assessment of some proposed commercial groundline maintenance treatments. Mater. Org. 16(1).

6. Chin, C.W., McEvoy, C. and Greaves, H. 1981. The development and installation of experimental fungitoxic pole bandages. International Journal of Wood Preservation, 2(2).

7. Greaves, H. 1977. Potential toxicants for controlling soft rot in preservative treated hardwoods. 1. Laboratory screening tests using filter papers. Mataer Org. 12(4): 1-15.

8. Da Costa, E.W.B. and Collett, O. 1979. Potential toxicants for controlling soft rot in preservative treated hardwoods. IV. Evaluation of combined diffusion and toxicity. Mater. Org. 14(3): 131-140.

9. Becker, G. 1959. Contribution to the knowledge of boron compounds against wood destroying insects and fungi. Holz roh-werkst 17: 484-488.

10. Greaves, H. 1978. Preliminary screening of diffusion formulations for the control of soft rot. International Research Group on Wood Preservation, Doc. No. IRG/WP/2113.

CHEMICAL MODIFICATIONS OF WOOD TO IMPROVE THE TOXICITY OF CCA PRESERVATIVES

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ABSTRACT

Bioassays have indicated that pretreatment of wood using sodium metabisulphite $Na_2S_2O_5$ before a normal CCA type pressure treatment, appears to enhance the toxicity of the CCA. A test designed to help determine the effect that $Na_2S_2O_5$ has on the distribution and toxicity of the CCA was initiated. *E. maculata* sapwood specimens, some of which were pretreated with $Na_2S_2O_5$ were treated with CCA or chromium compounds. These stakes were leached and results of CCA and chromium fixation determined. The stakes were installed in the CSIRO Accelerated Field Simulator in October 1982 and the twelve month inspection results are presented.

INTRODUCTION

It has been evident for some years that copper chromium arsenic (CCA) preservatives confer inferior protection against fungal attack to hardwood timbers compared to softwood timbers.

No environmentally aceptable fixed waterborne preservative with an enhanced performance over CCA for the protection of non-durable hardwoods in ground contact against decay and insect attack has yet been fully proved.

The alternative solvent or oilborne type preservatives, e.g. creosote, pentachlorophenol are often less attractive than CCA because of cost or environmental considerations. The non-waterborne systems are also usually

less efficacious in performance in hardwoods in ground contact compared to their performance in softwoods.

Several hypotheses have been advanced to explain the inferior performance of the preservatives in hardwoods.

A probable explanation which can be simply put forward is inadequate microdistribution penetration patterns of toxicants within the wood structure allowing fungal penetration. According to SEM studies the distribution of preservative absorption pattern is often characterised by gross disproportionation of toxicants relative to the composition of the treatment solution in particular zones of the timber.

Another theory is that the gross retention of the CCA preservative is too low to be effective overall in the different wood structures.

Studies carried out in the authors' laboratory and elsewhere suggest the poor performance of CCA in hardwoods is not necessarily corrected by massive increases in total preservative retention in a particular wood commodity. For example, increasing retention of CCA from 16 kg/m^3 to 45 kg/m^3 in eucalypt transmission poles has not proved effective in preventing heavy soft rot decay in the ground line zones.

Following earlier work in the authors' laboratory that indicated that the toxicity of chromium and its fixation mechanisms were a major factor in determining the efficacy of CCA preservatives in wood it was decided to explore ways of enhancing hexavalent chromium penetration into wood and maximising the degree of fixation of hexavalent chromium in wood.

It was also indicated from the earlier work that modification of basic CCA type formulations to initially partially inhibit the oxidative role of chromium in a vacuum pressure impregnation treatment might allow fixation of hexavalent chromium at additional sites within the wood structure. An improved microdistribution of hexavalent chromium within the wood structure could be expected to positively effect the efficacy of the preservative in preventing soft rot attack.

One approach in this area we have been developing is to monitor the effect of pretreating wood prior to a CCA impregnation with sodium bisulphite.

METHODS

MATERIALS

Specimens of *E. maculata* sapwood measuring 20 mm x 20 mm x 150 mm length were obtained from five trees. Selected specimens were subjected to a preliminary treatment with a 4% solution of sodium metabisulphite. After drying and conditioning periods the specimens along with non sodium bisulphite treated specimens were treated according to the schedules and schema outlined in Tables 1 and 2.

Treatment Schedules

The vacuum pressure impregnation schedules for the specimens whether for treatment with sodium bisulphite, Tanalith C, chromium trioxide, potassium dichromate or saturation with distilled water prior to leaching consisted of -85 kPa pressure for ½ hr, followed by 1400 kPa pressure for 1½ hrs.

Leaching

Duplicate jars containing five specimens (one specimen from each of five trees) were leached with distilled water at 25°C in a platform water bath shaker for periods of increasing duration. The cumulative leach periods for each treatment totalled 95 days. The seven leachates from each chromium containing treatment were analysed by an AAS method for chromium and also copper and arsenic where applicable. Control jars containing five specimens wach were included for each of the four conditioning treatments (see Table 1). All specimens were conditioned to equilibrium moisture content before and after leaching cycles.

Accelerated Field Simulator (AFS)

Following the final leaching cycle all specimens were air dried before being installed and partially buried in tanks of unsterile soil which contained a wide spectrum of decay microfungi including soft rotters. The AFS operating conditions were room temperature 25°C and RH 85%.

RESULTS AND DISCUSSION

The results in Table 3 show the level of chromium leaching from the various treatment schedules outlined in Table 1.

The most interesting observation on the leach results is the effect of a preliminary sodiuim bisulphite treatment on the fixation of chromium in Tanalith C, chromium trioxide and potassium dichromate treatments. A marked increase in the level of leaching from the chromium trioxide compared to the other two formulation treatments is evident.

For the CCA treatments sodium bisulphite pretreatment caused an increase in the amount of copper leached. The intermediate leaching step between the sodium bisulphite treatment and the CCA impregnation stage substantially modified the amount of copper leached.

The results of arsenic leaching from the CCA treated specimens shown in Table 5 show an improvement in arsenic fixation following sodium bisulphite treatment.

The reasons for the fixation differences presumably lie in a change of fixation sites effected by sodium bisulphite and the leaching of sodium bisulphite products of reaction with wood extractives.

Unreported and incomplete SEM studies on the treated specimens show retentions of sulphur in the wood structure after sodium bisulphite treatment schedules.

The results shown in Table 6 of the six and twelve months inspection of specimens installed in the AFS may be summarised as follows.

1. All CCA treatments are performing well after twelve months.

2. Chromium trioxide treated specimens with or without sodium bisulphite pretreatment appear to be performing better than potassium dichromate treatments.

3. Treatments with chromium trioxide and Potassium dichromate are attacked mainly by brown rot fungi with very little soft rot attack. This is probably due to absence of copper and arsenic).

4. Control specimens with pretreatments of sodium bisulphite decay quicker than untreated controls.

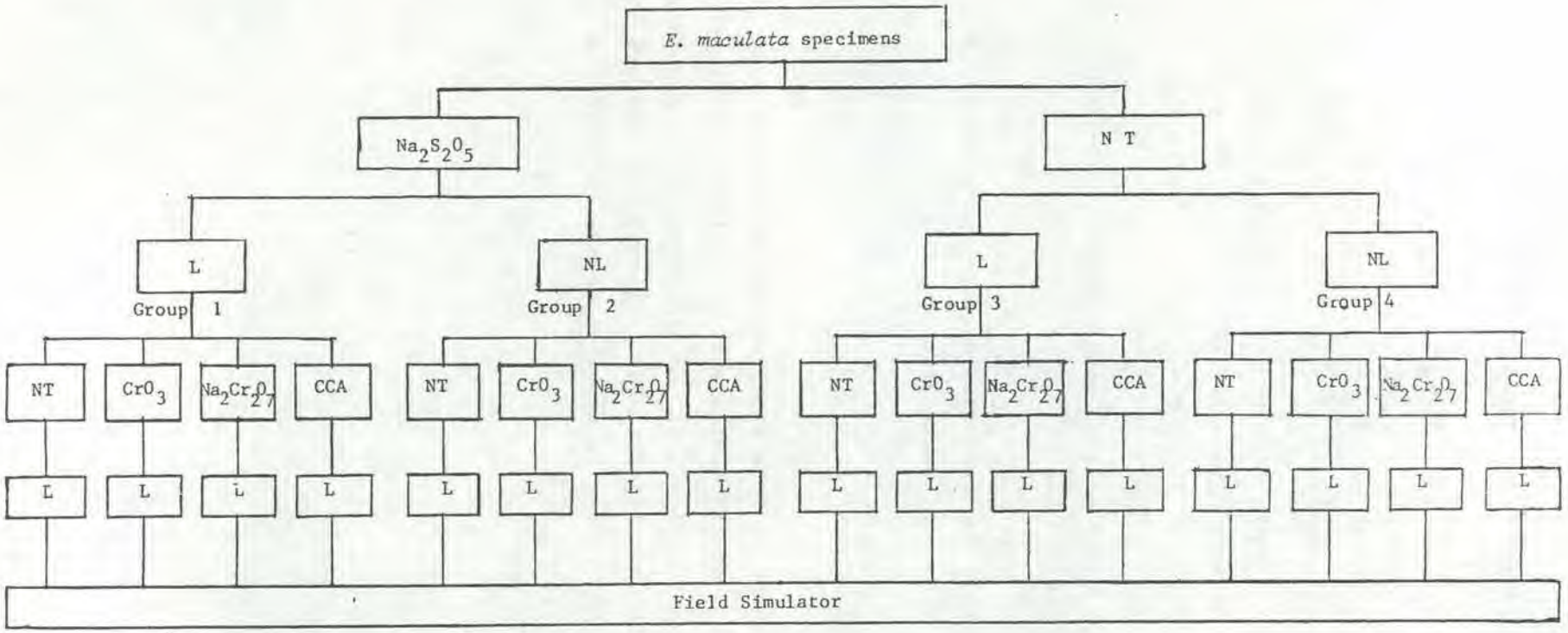
5. It is still too early to indicate the overall effect sodium bisulphite has on the wood treatments.

CONCLUSIONS

The results of this study are not sufficiently conclusive to endorse scout tests results that a sodium bisulphite pretreatment has a beneficial effect on the efficacy of CCA treatments in *E. maculata*. However, the state of the control specimens suggests that the AFS study should be continued and future inspections of the durability of the specimens carried out.

TABLE 1

Treatment schedule of *E. maculata*



Note: 1. NT = not treated
2. L = leached
3. NL = not leached.

TABLE 2

Time sequence in treatment schedules

Specimen group	Treated with $Na_2S_2O_5$	Time before initial leach	Duration of initial leach	Time between previous operation and Cr treatment	Time between previous operation and start of main leach
		days	days	days	days
1	Yes	17	8	17	66
Control (NT)	Yes	27	8	---------->	73
2	Yes	---------->		14	94
control (NT)	Yes	---------->			108
3	No	-	8	13	81
Control (NT)	No	-	8	---------->	94
4	No	---------->			94
Control (NT)	No	-	-	-	-

TABLE 3

Leaching of chromium
Per cent of chromium removed in leaching period

Days of leaching	Pre-treatment: Sodium bisulphite, Leached, Treatment: CCA	CrO_3	$K_2Cr_2O_7$	Sodium bisulphite, Unleached, Treatment: CCA	CrO_3	$K_2Cr_2O_7$	No treatment, Leached, Treatment: CCA	CrO_3	$K_2Cr_2O_7$	No treatment, Unleached, Treatment: CCA	CrO_3	$K_2Cr_2O_7$
3	0.2	3.3	2.4	2.0	5.1	0.5	0.3	1.8	1.8	0.7	1.3	2.3
7	0.5	4.8	2.6	2.6	7.2	0.7	0.4	3.0	2.0	0.9	2.0	2.6
14	0.7	6.0	2.8	3.4	9.3	1.0	0.7	3.7	2.1	1.3	2.7	3.0
22	1.0	6.8	3.0	3.9	10.7	1.3	0.9	4.2	2.4	1.6	3.1	3.3
39	1.3	7.7	3.3	4.5	12.1	1.6	1.2	4.8	2.7	2.3	3.5	4.3
60	1.6	8.3	3.6	5.0	13.4	2.1	1.5	5.1	3.0	2.8	3.9	5.0
95	2.0	9.4	4.2	5.4	14.4	2.4	2.0	5.6	3.7	3.1	4.2	5.6

TABLE 4

Leaching of copper
Per cent of copper removed in leaching period

Days of leaching	Pretreatment: Sodium bisulphite Leached	Sodium bisulphite Unleached	No treatment Leached	No treatment Unleached
	Treatment	Treatment	Treatment	Treatment
	CCA	CCA	CCA	CCA
3	3.9	15.0	1.1	1.8
7	5.2	17.9	1.7	2.4
14	6.1	21.5	2.1	3.7
22	6.8	23.6	2.5	4.8
39	7.7	26.3	3.0	5.8
60	8.1	27.8	4.5	6.4
95	8.5	28.8	3.8	7.0

TABLE 5

Leaching of arsenic
Per cent of arsenic removed in leaching period

Days of leaching	Pretreatment: Sodium bisulphite Leached	Sodium bisulphite Unleached	No treatment Leached	No treatment Unleached
	Treatment	Treatment	Treatment	Treatment
	CCA	CCA	CCA	CCA
3	1.4	3.8	1.6	1.6
7	2.3	5.2	3.4	2.1
14	3.6	7.2	5.5	5.8
22	5.2	8.6	7.6	8.2
39	7.4	10.8	10.4	11.7
60	9.4	13.0	12.9	15.0
95	12.6	15.8	16.7	18.5

TABLE 6

Condition of specimens with respect to decayh
6/12 months AFS results of $Na_2S_2O_5$/Cr containing preservative treatments

Control (NT)				CrO_3				$K_2Cr_2O_7$				CCA			
Group				Group				Group				Group			
1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
6 months															
3	3	3½	3½	4	4	4	4	3½	4	4	4	4	4	4	4
3½	3	3½	4	4	4	4	4	3½	4	3½	4	4	4	4	4
3½	3	3	3½	4	4	3½	4	3½	4	4	3½	4	4	4	4
3½	3	3½	3½	4	4	4	4	4	4	4	3½	4	4	4	4
3	3½	3½	3	4	4	4	4	3½	4	4	4	4	4	4	4
3	3	3½	3½	4	4	4	4	4	4	4	4	4	4	4	4
3	3	3½	3½	4	4	4	4	4	4	3½	3½	4	4	4	4
3	3	3	3½	4	4	4	4	3½	4	4	3½	4	4	4	4
3	3½	3	3½	4	4	4	4	4	4	3½	4	4	4	4	4
3½	3½	3½	3½	4	4	4	4	3½	4	4	4	4	4	4	4
12 months															
2½	2½	3	3	4	4	4	3½	3	4	4	3	4	4	4	4
2	2½	3	3½	4	4	4	3½	3½	3½	3½	3½	4	4	4	4
2½	3	3	3	4	4	3½	3½	3½	4	3½	3	4	4	4	4
3	2	3	3	4	4	4	4	4	3½	3½	3	4	4	4	4
3	2½	3½	3	3½	4	4	4	3½	3	4	3	4	4	4	4
3	3	3	3½	4	4	4	4	3½	3½	4	2½	4	4	4	4
2½	3	3	3½	3½	4	4	3½	3½	4	3	3	4	4	4	4
3½	3	3	3	4	4	4	3½	3	4	3½	3	4	4	4	4
3	3½	3	3	4	4	3½	4	3½	3½	3½	3½	4	4	4	4
3	3	3½	3	4	4	4	4	3½	3½	4	3½	4	4	4	4

Scheme: 4 = no decay, 3 = slight decay, 2 = moderate decay, 1 = severe decay, 0 = failed.

THE EFFECT OF COPPER, ARSENIC AND CHROMIUM ON THE CELLULOLYTIC ENZYMES OF THE BROWN-ROT FUNGUS, *Gloeophyllum trabeum* GROWN ON *Pinus radiata* SAPWOOD SHAVINGS

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ABSTRACT

The brown-rot fungus *Gloeophyllum trabeum* was cultivated on leached CCA-treated and leached untreated *Pinus radiata* sapwood shavings. Protein analyses and enzyme assays showed that CCA incorporated into wood did not kill the organism or inhibit its enzyme production or activity. Enzyme inhibition studies showed that neither copper nor arsenic totally inhibited the cellulase enzyme activities. Low concentrations stimulated both endo-glucanase and solubilizing activities. Chromium, in both valency states, was the most effective inhibitor of endo-glucanase activity.

INTRODUCTION

Wood-destroying fungi present the greatest hazard to the economic use of wood (1). Effective chemical preservation treatments not only increase the life of the material in service, but also enable less durable species, such as radiata pine, to be used in conditions otherwise favourable to decay. Copper-chrome-arsenate (CCA) is widely used in Australia and overseas to protect and extend the service life of timber. However, decay of CCA-treated timber has been reported (2). At present, there is insufficient information available to explain how preservative chemicals, including CCA, exert their mode of action. One means of preventing enzymatic degradation of cellulose in the wood would be to repress the formation or activity of cellulolytic enzymes of the fungi.

All wood-decaying fungi have in common the ability to produce and secrete enzymes called cellulases, capable of degrading the structural polysaccharides of wood. When suitable environmental conditions prevail, decay results from the enzymatic depolymerization of the cell-wall polysaccharides into soluble products that can be readily assimilated by the fungal cell. The enzymes degrading cellulose include the endo-ß-1,4-glucanases, exo-ß-1,4-glucanase and ß-glucosidase. These enzymes act synergistically to degrade cellulose to glucose. Considering these cellulases are the enzymes responsible for the breakdown of the structural material, not much information is available on the interaction of wood preservative chemicals with these enzymes. A better understanding of the interaction of the preservative formulation systems currently in commercial usage, with decay organisms could be expected to aid the development of improved formulations.

The research objectives of this study were:

(i) to determine the ability of the brown-rot fungus *G. trabeum* to grow on CCA-treated pine sapwood shavings in liquid shake culture

(ii) to determine whether filtrates from these cultures contain endo-ß-1,4-glucanase and solubilizing activites and hence establish whether CCA in wood inhibits either enzyme production or activity

(iii) to determine the effect of the individual components of CCA on the endo-glucanase and the solubilizing activities of culture filtrates from *G. trabeum*.

(iv) to determine the effect of pH on these enzyme activities.

In this research, shavings prepared from *P. radiata* sapwood blocks that had been impregnated with a 2.85 per cent CCA solution to a preservative retention of 20 kg per m^3 were used for the cultivation of *G. trabeum* in shake culture.

EXPERIMENTAL

(i) ORGANISM

The brown-rot fungus, *Gloeophyllum trabeum* isolate DFP 8437 was maintained on 1.25 per cent malt extract agar at 26°C.

(ii) MEDIUM

The composition of the liquid medium was as described by Pettersson *et al.* (3), but modified by substituting Munktells' cellulose with 1.5 per cent leached CCA-treated *P. radiata* sapwood shavings as the carbon source. Control flasks contained leached untreated shavings. The pH was adjusted to 5.0 with sulphuric acid. Culture vessels were Erlenmeyer flasks (250 mL) containing 1.5 g of sapwood shavings and 100 mL of culture media. All flasks were autoclaved at 121°C for 20 min, cooled and inoculated with 25 mL of the prepared blended inoculum. Incubation was at 26°C on a rotary shaker (100 rpm).

(iii) VIABILITY STUDY

After an incubation period of 14 weeks, two pieces of wood shavings were aseptically removed from each of three representative control flasks and flasks containing treated material. Each piece was placed on a sterile 1.25 per cent malt extract agar plate to determine the viability of the fungus. The plates were incubated at 26°C for a period of ten days after which time they were assessed for growth.

(iv) CULTURE FILTRATES FOR ENZYME STUDIES

The flasks containing leached CCA-treated material were vacuum filtered to remove the remaining wood shavings and fungal mycelia; the filtrates were combined, passed through a 0.45 µm membrane filter and concentrated by ultra-filtration through a PM-10 Amicon filter. Aliquots of this cell-free culture filtrate were then incubated with the substrates with and without the addition of inhibitors. Enzyme activities were measured as the amount of reducing sugars released from the substrates.

(v) INHIBITORS

The compounds tested as inhibitors were $CuSO_4.5H_2O$; As_2O_5 and $Na_2Cr_2O_7.2H_2O$. Each element was tested at the concentration in which they were present in the 2.85 per cent treatment solution of CCA used to treat *P. radiata* sapwood blocks to a retention of 20 kg per m^3. This solution had the following elemental composition, Cu,2.5; As,3.2; Cr, 4.4 mg per mL. Trivalent chromium, which is the valency state of chromium in the wood, was also tested at the same concentration as hexavalent chromium, 4.4 mg per mL. Trivalent chromium was assayed as chromic acetate, $Cr(C_2H_3O_2)_3$. All the elements were also tested at a lower concentration of 250 µg/mL.

The effect of these test compounds on enzyme activity was assayed from their effect on the reducing sugars formed when the culture filtrates were incubated with the substrates. The effect of chromium was only studied with the endo-glucanase component of the cellulase complex.

(vi) MEASUREMENT OF ENZYME ACTIVITY

(a) Activity on Carboxymethyl-Cellulose; i.e. Endo-ß-1,4-glucanase activity

Endo-ß-1-4,-glucanases (C_x) randomly attack ß-1,4-linkages in cellulose. The best substrate for the measurement of endo-ß-glucanase activity is a soluble cellulose derivative such as carboxymethyl-cellulose (CMC).

1.0 per cent solutions of CMC (Daicel-1190, Degree of substitution 0.45 to 0.55, ICI Australia) were prepared in McIlvaines buffers at pH 3.0 to 7.0 in steps of one pH unit. For enzyme assays, 0.50 mL of culture filtrate was incubated with 0.25 mL of CMC and 0.25 mL of appropriate buffer at 50°C. For assay of inhibitors, the buffer was substituted with the test compound. The reaction was stopped after 60 min and the amount of reducing groups produced was determined as described by Nelson (4) and

Somogyi (5) with glucose as a standard. Enzyme activity was expressed as micromoles glucose released per min per mg protein.

(b) Activity on Microcrystalline Cellulose: i.e. Solubilizing Activity

Enzymatic hydrolysis of crystalline cellulose is achieved by the synergistic action of the endo-ß-1,4-glucanase and exo-ß-1,4-glucanase components of the cellulase complex. This is referred to as solubilizing activity. Microcrystalline cellulose, Avicel, was used as the substrate in these experiments to assay the culture filtrates for solubilizing activity.

25.0 mg samples of Avicel were weighed into the individual assay tubes. This was combined with 0.50 mL buffer at the various pH values and 0.50 mL of culture filtrate and incubated at 50°C. For assay of inhibitors, 0.25 mL buffer and 0.25 mL of the compound under test were used. The reaction was stopped after 120 min; unhydrolysed Avicel was removed by centrifugation at 7000 x g (IEC CENTRA-3 centrifuge) for 15 min and the amount of reducing groups produced was determined as described by Nelson (4) and Somogyi (5) with glucose as a standard.

(vii) PROTEIN DETERMINATION

The protein concentration of the culture filtrates was determined by the method of Grossber and Sedmak (6). Bovine serum albumin (Sigma) was used as the standard.

RESULTS

(a) VIABILITY OF FUNGUS

TABLE 1

Colonisation and subsequent viability of *G. trabeum* Isolate, DFP 8437 cultivated on leached untreated and CCA-treated *P. radiata* sapwood shavings

Fungal Isolate	Flask No. (a)	CCA retention kg/m (b)	Colonisation on substrate	Viability after 14 weeks incubation (c)	Protein conc. µg/mL
G. trabeum DFP 8437	1	untreated	moderate	+	9.0
		20	moderate	+	8.5
	2	untreated	moderate	+	9.0
		20	moderate	+	8.5
	3	untreated	moderate	+	9.0
		20	moderate	+	8.5
Uninoculated control	1	untreated	no growth	0	0.0
		20	no growth	0	0.0
	2	untreated	no growth	0	0.0
		20	no growth	0	0.0
	3	untreated	no growth	0	0.0
		20	no growth	0	0.0

(a) shavings were sampled from 3 representative flasks after 14 weeks of incubation

(b) retention of CCA given is that prior to the leaching period

(c) +, growth after transfer to malt agar
0, no growth after transfer to malt agar

The results presented in Table 1 show that *G. trabeum* was still viable after an exposure period of 14 weeks to leached untreated sapwood shavings and leached shavings which had been originally treated with CCA to a retention of 20 kg per m^3. It can be seen that CCA did not inhibit protein production.

(i) Activity on Carboxymethyl-Cellulose: Endo-β-1,4-glucanase activity

Effect of Copper

The effect of two copper concentrations on enzyme activity was studied and the results are presented in Table 2. At a copper concentration of 2.5 mg per mL (which is equivalent to that present in a 2.85 per cent treatment solution of CCA), partial inhibition of endo-glucanase activity was observed at all pH values tested except at pH 7.0. Maximum inhibition occurred at pH 4.0.

At pH 7.0 there was an increase in activity in excess of 100 per cent when compared to the activity obtained for the control assay, the latter containing no copper. At an elemental copper concentration of 250 µg per mL, no inhibition of enzyme activity was observed. On the contrary, enzyme activity was stimulated by the presence of this low concentration of copper. This stimulation was apparent at all the pH values tested. Maximum stimulation of enzyme activity occurred at pH 3.0.

Effect of Arsenic

The results obtained with arsenic are included in Table 2 and show the same trend as the results obtained with copper. At an arsenic concentration of 3.5 mg per mL (which is equivalent to the arsenic content in a 2.85 per cent treatment solution of CCA), inhibition occurred at all pH values except pH 7.0. At this pH, there was an increase in enzyme activity when compared to the control assay which did not contain arsenic. Gratest inhibition occured at pH 3.0 and 4.0 and progressively decreased at pH 5.0 and 6.0. Minimum inhibition of 3 per cent occurred at pH 6.0. Stimulation of enzyme activity was observed at all the pH values tested when arsenic was present in the assay medium at a final concentration of 250 µg per mL. Per cent stimulation was considerably greater at pH 6.0 and 7.0 than at pH values 3.0, 4.0 and 5.0.

TABLE 2

The effect of elemental copper, arsenic and chromium at various concentrations on the Endo-glucanase activity of culture filtrates of *G. trabeum* DFP 8437

Initial pH of assay	Copper conc. 2.5 mg/mL % change in activity	Copper conc. 250 µg/mL % change in activity (a)	Arsenic Conc. 3.5 mg/mL % change in activity	Arsenic Conc. 250 µg/mL % change in activity (a)	Hexavalent chromium conc. 4.5 mg/mL % change in activity	Hexavalent chromium conc. 250 µg/mL % change in activity (a)	Trivalent chromium conc. 4.5 mg/mL % change in activity	Trivalent chromium conc. 250 µg/mL % change in activity (a)
3.0	-63	+172	-86	+51	-94	-100	-97	+41
4.0	-77	+35	-86	+53	-100	-100	-97	+16
5.0	-58	+48	-32	+78	-100	-100	-92	+23
6.0	-43	+73	-3	+127	-100	-100	-97	+24
7.0	+143	+48	+392	+112	-82	-100	-90	+10

(a) negative values indicate depression of enzymatic activity, positive values indicate stimulation of enzymatic activity

Effect of Chromium

The effect of chromium in two valency states was studied and the results are presented in Table 2. Hexavalent chromium, at a final concentration of 4.5 mg per mL (which is equivalent to the chromium content of a 2.85 per cent tratment solution of CCA) totally inhibited enzyme activity at pH values 4.0, 5.0 and 6.0 while at pH 3.0 and 7.0 per cent inhibition was 94.0 per cent and 82.0 per cent respectively. A concentration of 250 µg per mL hexavalent chromium totally inhibited endo-glucanase activity at all the pH values tested. This is in marked contrast to the effect of trivalent chromium when tested at the same concentration of 250 µg per mL. At this concentration, trivalent chromium stimulated endo-glucanase activity at every pH value with minimum per cent stimulation of 10 per cent occurring at pH 7.0. However, trivalent chromium at a final concentration of 4.5 mg per mL had a strong inhibitory effect on enzyme activity, effecting per cent inhibition ranging from a minimum of 90 per cent at pH 7.0 to a maximum of 97 per cent at pH values 30, 4.0 and 6.0.

(ii) Activity on Microcrystalline Cellulose: Solubilizing activity

Effect of Copper

TABLE 3

The effect of elemental copper and arsenic at various concentrations on the solubilizing activity of filtrates of *G. trabeum* DFP 8437

Initial pH of assay	Copper conc. 2.5 mg/mL % change in activity (a)	Copper conc. 250 µg/mL % change in activity (a)	Arsenic conc. 3.5 mg/mL % change in activity (a)	Arsenic conc. 250 µg/mL % change in activity (a)
3.0	-12	+34	-53	+88
4.0	-17	+25	-47	+66
5.0	-40	+55	-44	+45
6.0	-55	+141	-44	+66
7.0	+325	+192	-73	+146

(a) negative values indicate depression of enzymatic activity, positive values indicate stimulation of enzymatic activity

The results presented in Table 3, show that partial inhibition was observed at pH values 3.0, 4.0, 5.0 and 6.0 when copper was present at a final concentration of 2.5 mg per mL while at pH 7.0 considerable stimulation of the solubilizing activity occurred. The presence of copper in the assay medium at the lowest concentration of 250 µg per mL stimulated solubilizing activity as well as the endo-glucanase activity (Table 2). This increase in enzyme activity was observed at all the pH values tested with maximum stimulation occurring at pH values 6.0 and 7.0.

Effect of Arsenic

The results presented in Table 3 show that arsenic at a concentration of 3.5 mg per mL caused partial inhibition of enzyme activity at all pH values tested. Inhibition ranged from a minimum of 44 per cent at pH 5.0 and 6.0 to a maximum of 73 per cent at pH 7.0. However, an arsenic concentration of 250 µg per mL had a stimulating effect on enzyme activity irrespective of pH, with per cent stimulation being in excess of 100 per cent at pH 7.0 when compared to the control.

DISCUSSION

The objective of a chemical treatment of wood is to increase the life of the timber in service. Current wood preservation practice makes use of water-borne preservatives containing salts of copper, chromium and arsenic which form insoluble complexes when in contact with the wood. Copper-chrome-arsenate (CCA) is such a wood preservative and is considered to be one of the most versatile available (7) yet the interaction of its components with the decay-causing organisms and the wood-destroying cellulase complex these organisms produce, has not yet been fully elucidated.

It is not known with complete certainty how the fixed CCA components prolong the useful life of timber in service or how the fixed insoluble complexes are mobilized to act against decay organisms. It has been suggested that fungal solubilization of the insoluble components is the first step in the toxic action of CCA preservatives (8). These authors also suggest that prevention of decay in CCA-treated wood may be due, in

part, to the inhibition of action or production of cellulase enzymes.

The brown-rot fungus *G. trabeum* is reportedly sensitive to copper (9), but tolerant to arsenic (10). However, the strain DFP 8437 was able to tolerate a 20 kg per m^3 retention of a CCA preservative and the results showed that neither enzyme production nor activity were affected.

It has been reported (11,12) that copper does not inhibit the endo-glucanase activities of the brown-rot fungi *G. trabeum* and *P. placenta*. The results presented here demonstrate that copper, at the highest concentration tested, only partially inhibited endo-glucanase and solubilizing activities of filtrates obtained from *G. trabeum* DFP 8437 cultures grown on CCA-treated shavings. At copper concentration of 2.5 mg per mL (which is equivalent to that present in a 2.85 per cent treatment solution of CCA) there was partial inhibition of endo-glucanase activities at pH values 3.0, 4.0, 5.0 and 6.0. At pH 7.0 enzyme activities were greatly stimulated.

The endo-glucanase and solubilizing activities were both considerably less sensitive to inhibition at pH 7.0. In fact, pH 7.0 seemed to be conducive to the stimulation of both types of enzyme activities. Singh (13) reported that high pH (7.2) increased the toxicity of copper to *Penicillium nigricans* as measured by a marked decrease in mycelial yield. In other fungi, low pH is also known to reduce copper toxicity (9). Levi (14) found that a decrease in the pH of the culture solution increased the tolerance of the *Poria* species to copper sulphate. However, these reported results were from growth study experiments and cannot necessarily be related directly to enzyme inhibition studies.

From a practical viewpoint, it may be speculated that if treated wood is in ground contact, and the pH of the soil is such that the pH of the treated wood is made less acid, then cellulase activity and hence the probability of decay may be greatly increased. Copper concentrations of 250 µg per mL stimulated endo-glucanase and solubilizing activities at all pH values tested. If treated timber in service is severely leached for

a prolonged period, particularly in an acid environment, the resultant copper concentration may be contributory to more rapid and extensive decay.

G. trabeum, in comparison with other basidiomycetes is reported to be extremely resistant to arsenic (15). Arsenic is incorporated into the CCA formulation primarily as an insecticide and also to control organisms which are tolerant to copper, but sensitive to arsenic, and it has been reported that fungi are generally not tolerant to both of these compounds (14). The enzyme inhibition results presented here demonstrate that arsenic did not totally inhibit either endo-glucanase or solubilizing activites. A concentration of 3.5 mg per mL at pH 7.0 stimulated endo-glucanase activities of filtrates from cultures containing CCA-treated shavings. However, stimulation of the solubilizing activities was not observed. The results obtained with the lowest concentration of arsenic, showed that there was stimulation of both the endo-glucanase and the solubilising activities. Da Costa and Bezemer (16) reported that when arsenic was added to a copper-chromate preservative, the amount of decay caused by *Lenzites trabea* (syn. *G. trabeum*) was markedly increased. They suggested that it may be due either to chemical effects, the arsenic rendering the copper less toxic or due to a direct stimulation of the fungus by the presence of arsenic. The results presented here suggest that the marked increase in decay may have been due to the stimulation of cellulase activity.

Chromium in CCA is generally considered as a fixative not as a fungicide (14). Both the hexavalent and trivalent forms of chromium were assayed for their effect on endo-glucanase activities. Activities were inhibited by trivalent chromium at a concentration of 4.5 mg per mL (which is equivalent to the hexavalent chromium content of a 2.85 per cent treatment solution of CCA), but were stimulated by the low trivalent chromium concentrations of 250 µg per mL. However, at this concentration, hexavalent chromium totally inhibited the endo-glucanase activities. At the higher concentration of 4.5 mg per mL, hexavalent chromium was also inhibitory. Therefore, it can be seen that chromium, in either valency state is a more effective inhibitor of endo-glucanase activity than either copper or arsenic.

CONCLUSION

Studies with *G. trabeum* DFP 8437 demonstrated that this reportedly copper-sensitive fungus was able to tolerate a CCA salt retention of 20 kg per m^3 prior to leaching. Neither enzyme production nor subsequent *in vitro* activity was affected. Enzyme inhibition studies showed that neither copper nor arsenic totally inhibited enzyme activites. Low toxicant concentrations stimulated enzyme activity. Chromium, usually considered as a fixative of the CCA formulation and not as a toxicant, was the most effective inhibitor.

Recent copper tolerance studies at this laboratory have shown that *G. trabeum* DFP 8437 is sensitive to copper in agar. Yet in this study, it was able to tolerate a high concentration of a CCA formulation in wood shavings. This indicated that if the CCA is mobilized against decay fungi by solubilization of the fixed components, then there is a detoxification mechanism operating which renders toxic copper non-toxic. A detoxification mechanism may also exist which precipitates the solubilized chromium, and as a result, prevents it from inhibiting cellulase activity. The mechanism of metal tolerance in fungi is currently being investigated. It is envisaged that the practical applications of such a study may include not only the formulation of more effective preservatives, but the use of the metal tolerant fungi or their processes in industrial waste treatments.

REFERENCES

1. Purslow, D.F. 1976. Results of field tests on the natural durability of timber (1932-1975). Building Research Establishment Current Paper 6/67. Building Research Establishment, U.K., pp. 1-17.

2. Proceedings of the New Zealand Wood Preservers' Association. 1983. 23:p. 55.

3. Pettersson, G., Cowling, E.B. and Porath, J. 1963. Studies on cellulolytic enzymes. I. Isolation of a low molecular weight cellulase from *Polyporus versicolor*. Biochim. Biophys. Acta 67: 9-15.

4. Nelson, N. 1944. A photometric adaptation of the Somogyi method for the determination of glucose. J. Biol. Chem. 153: 375-380.

5. Somogyi, M.J. 1952. Notes on sugar determination. J. Biol. Chem. 195: 19-23.

6. Grossberg, S.E. and Sedmak, J.J. 1980. Assay for proteins and polypeptides. U.S. Patent 4,219,337.

7. Stranks, D.W. 1976. Wood preservatives: their depletion as fungicides and fate in the environment. Dept of the Environ. Can. For. Ser., For. Tech. Report 10, Ottawa, pp. 1-35.

8. Chou, C.K., Preston, R.D. and Levi, M.P. 1974. Fungitoxic action of a copper-chromium-arsenate wood preservative. Phytopathol. 64: 335-341.

9. Young, G.Y. 1961. Copper tolerance of some wood-rotting fungi. U.S. For. Ser. Dept. Agric. No. 2223.

10. Da Costa, E.W.B. 1967. Laboratory evaluations of wood preservatives. I. Effectiveness of waterborne preservatives against decay fungi after severe leaching. Holzforschung 21(2): 50-57.

11. Highley, T.L. 1975. Inhibition of cellulases of wood-decay fungi. USDA For. Ser. Res. Paper, FPL 247: 1-8.

12. Highley, T.L. and Wolter, K.E. 1982. Properties of a carbohydrate-degrading enzyme complex from the brown-rot fungus *Poria placenta*. Mater. Org. 17(2): 127-134.

13. Singh, N. 1977. Effect of pH on the tolerance of *Penicilliuim nigricans* to copper and other heavy metals. Mycologia 69(4): 750-755.

14. Levi, M.P. 1969. The mechanism of action of copper-chrome-arsenate preservatives against wood-destroying fungi. Br. Wood Pres. Assoc. Ann. Conven. 19: 113-127.

15. Kerruish, R.M. and Da Costa, E.W.B. 1963. Monocaryotization of cultures of *Lenzites trabea* (Pers.) Fr. and other wood-destroying Basidiomycetes by chemical agents. Annals of Bot. 27(108): 653-670.

16. Da Costa, E.W.B. and Bezemer, L.D. 1973. Anti-fungal effectiveness of copper-chrome-arsenic preservatives in a phosphatic environment. Int. Biodetn. Bull. 9:(1-2): 44-48.

THE PERFORMANCE IN EXPOSED SITUATIONS OF *PINUS RADIATA* TREATED WITH ORGANIC SOLVENT PRESERVATIVES

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INTRODUCTION

The benefits derived from the use of light organic solvent preservatives have been extensively reviewed both here and overseas (1), (2), (3), (4), (5).

Important considerations favouring the use of these preservatives are the elimination of a toxic waste wood disposal problem because of treatment after machining, and the reduction in splitting and checking due to the presence of water-repellents and bulking agents. The absence of renewed wetting and subsequent re-drying that occurs with water-borne preservatives is also an attractive feature of organic solvent preservatives.

A description of an exposure test at Pennant Hills, New South Wales to compare *Pinus radiata* treated with a variety of formulated organic solvent preservatives and copper chrome arsenic preservative has already been outlined (6) and some preliminary results reported (7).

Important factors that emerged in the preliminary report were that, after nearly five years' exposure:-

(1) The *P. radiata* treated with organic solvent preservative showed a different pattern of weathering from the wood treated with copper chrome arsenic salt.

(2) Components of copper chrome arsenic salt had minimised lignin and cellulose degradation but slight splitting was evident.

(3) The organic solvent preservatives had reduced splitting but had facilitated lignin and cellulose removal from the exposed face of the wood.

It would appear that suitable fungicides can be added to organic solvent preservatives to be equivalent in performance to the fungicidal components of copper chrome arsenic salt. Commercial formulations have generally utilised

pentachlorophenol, tributyl tin oxide, copper naphthenate, or combinations of these. To equate to the arsenical insecticide in copper chrome arsenic salt, it is usual to add one of the chlorinated hydrocarbons such as aldrin, dieldrin, chlordane or heptachlor.

Even with the above active components of organic solvent preservatives, it is generally considered that light organic solvent preservatives should only be used out of ground contact and given a paint or stain finish (8).

This report gives details of the performance of *P. radiata* exposed for ten years both in and out of ground without a supplementary surface coating.

EXPERIMENTAL PROCEDURE

Samples for the Pennant Hills exposure test were impregnated with varying amounts of pentachlorophenol and tributyl tin oxide separately and in combination, with aldrin as the insecticide. A water repellent (paraffin wax) and bulking agent (resin) were also added. Two separate solvents were used, a solvent typical of commercial light organic solvent preservatives (mineral turpentine) and a non-volatile aromatic process oil. Replicates of the same wood samples were impregnated with copper chrome arsenic salt and an additional batch were commercially treated. The composition of the preservatives is given in Table 1.

Half of the samples (six replicates of each treatment) were exposed on north-aspected racks and the remaining half were installed in ground contact nearby.

In the inspection of September, 1984, samples were rated for fungal attack for both sets of samples (above and in-ground) on a 0 to 4 scale where 0 represented total failure and 4 no visible fungal degrade. A similar scale was used for estimating splitting where 0 indicated severe splitting and 4 no visible splits or checks. Termite attack on the in-ground samples was noted.

RESULTS AND DISCUSSION

As could be predicted, the untreated *Pinus radiata* without any form of protection failed in both situations during the ten-year period.

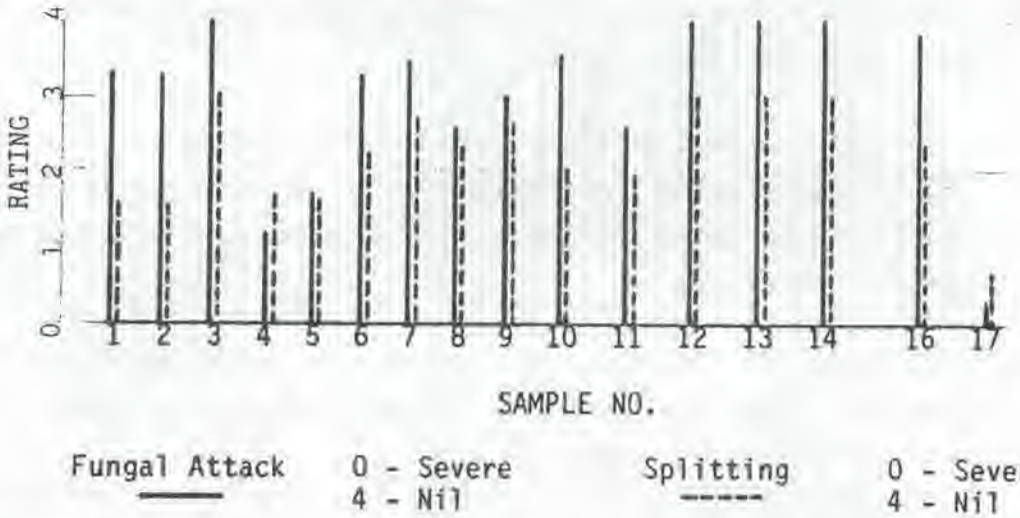
ABOVE GROUND PERFORMANCE - The preservatives that performed best above ground (Fig.1) were the non-volatile oil systems and the turpentine-based preservative with high pentachlorophenol. The samples treated with copper chrome arsenic salt showed just a trace of fungal attack.

Tributyl tin oxide appeared to contribute only slightly towards fungal protection when combined with pentachlorophenol and could be rated as relatively unsuccessful without fortification.

Splitting was controlled to some extent by the additives used in the test for that purpose but the success or otherwise of control measures appeared to be related more to the degree of fungal resistance than to the water repellent additives.

The commercially treated samples could be classed as only moderately successful as regards both fungal resistance and reduction in splitting.

Fig. 1. - Performance above ground

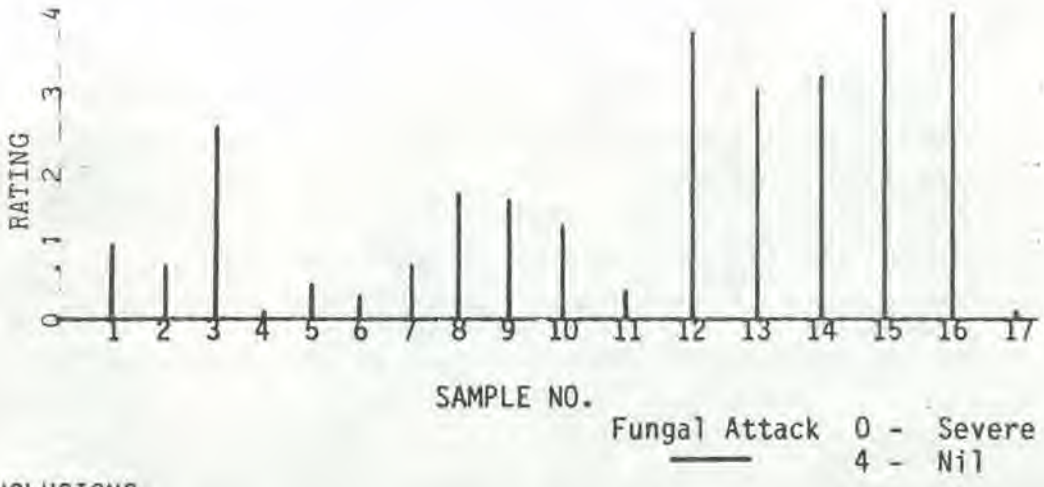


IN-GROUND PERFORMANCE - The best performers in ground contact (Fig.2) were the non-volatile aromatic oil systems and the copper chrome arsenic salt. The non-volatile aromatic oil without the addition of fungicides, insecticides, water-repellents, or bulking agents proved resistant to fungal and termite attack over the ten-year period.

The best of the light organic solvent systems was again the high pentachlorophenol product which proved moderately successful in ground contact. The commercial product performed unsuccessfully in this situation.

The level of aldrin achieved in the wood treated with light organic solvent preservatives (maximum of 0.28 kg m^{-3}) was insufficient to prevent termite attack.

Fig.2 - Performance in Ground Contact



CONCLUSIONS

(1) A number of formulations of organic solvent preservatives were successfully tested on *Pinus radiata* and compared to copper chrome arsenic salt and a commercial light organic solvent preservative over a period of ten years.

(2) Three of the formulations based on a non-volatile aromatic oil and one of the light organic solvent preservatives, in addition to copper chrome arsenic salt, proved successful in an exposed above-ground situation without a surface coating.

(3) Two of the non-volatile aromatic oil systems, including the non-volatile oil with no additives, and the copper chrome arsenic salt, gave substantial protection in ground contact.

(4) The commercial light organic solvent preservative - presumably designed to require the supplementary protection of a surface coating - proved unsuitable under both hazard conditions.

ACKNOWLEDGEMENTS

The assistance given by Mr. W.D. Gardner in preparing the treatment solutions and impregnating the wood samples is greatly appreciated.

REFERENCES

(1) Hatfield, Ira. (1954). Solvent Type Preservatives. Proceedings 1954 Convention of British Wood Preserving Association, Cambridge, U.K.

(2) Davies, D.L. and D.S. Belford (1965). Controlled Pressure Treatment with Organic Solvent Wood Preservatives. Proceedings 1965 Convention of B.W.P.A., Cambridge, U.K.

(3) Watson, R.W. (1970). Controlled Double Vacuum Treatment with Organic Solvent Preservatives. Proceedings 1970 Convention of B.W.P.A., Cambridge, U.K.

(4) Tamblyn, N. (1973). Organic Solvent Preservatives. Proceedings 16th Forest Products Research Conference, Melbourne, Australia.

(5) Tamblyn, N. (1975). Organic Solvent Preservatives. Proceedings 17th Forest Products Research Conference, Melbourne, Australia.

(6) Johnstone, R.S. and W.D. Gardner (1975). Developments in the Formulation of Organic Solvent Preservatives for Milled Radiata Pine. Proceedings 17th Forest Products Research Conference, Melbourne, Australia.

(7) Johnstone, R.S. and R.K. Bamber (1980). The Relationship between Preservative Type and Surface Degrade in *Pinus Radiata*. International Research Group on Wood Preservation Document No. IRG/WP/3158, 11th Meeting, Raleigh, U.S.A.

(8) Standards Assn. of Aust. 1974. Aust. Std. 1606. North Sydney, Australia.

Table 1. Preservative Composition

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
(1) P.C.P.($kg.m^{-3}$)	1.7	3.3	6.4	-	-	1.8	1.4	1.8	1.7	1.7	Composition Unknown	1.84	2.3	2.1	-	Copper Chrome Arsenic Salt ($8kgm^{-3}$)	Control (Untreated)
(2) T.B.T.O.($kg.m^{-3}$)	-	-	-	0.31	0.66	0.36	0.29	0.36	0.34	0.34		0.37	0.45	0.42	-		
ALDRIN($kg.m^{-3}$)	0.27	0.27	0.25	0.24	0.26	0.28	0.23	0.28	-	0.27		0.28	0.35	0.33	-		
PARAFFIN WAX(%w/w)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		0.65	0.65	0.65	-		
RESIN (%w/w)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	-		2.6	2.6	2.6	-		
SOLVENT	MINERAL TURPENTINE											NON-VOLATILE AROMATIC OIL				WATER	

(1) Pentachlorophenol

(2) Tributyl tin oxide.

PRELIMINARY TRIALS OF BUSAN 1009 AND CAPTAFOL AS ANTISAPSTAIN CHEMICALS IN PAPUA NEW GUINEA

By

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ABSTRACT

Freshly sawn sapwood of White Cheesewood (Alstonia scholaris (L) R. Br) was dip treated with Busan 1009 or Captafol, at one of four different concentrations of 0.5, 0.65, 1.0 and 1.25 percent with dipping times of 10,30 and 60 seconds. The effectiveness of each antisapstain, defined as a ratio of the difference between total stained surface of treated and untreated (water-treated) boards to stained surface of untreated control boards, were calculated after seven weeks' exposure. At concentrations of 0.5 and 0.65 percent, Busan 1009 and Captafol achieved an average effectiveness of 62 and 66 percent respectively. Busan 1009 with an average effectiveness of 91% at concentrations of 1 and 1.25 percent, was significantly better than captafol which achieved 82% effectiveness. For a protection period of seven weeks,a 1.25% product concentration with dipping time of 60 seconds prevented sapstain completely. For a two-week protection period, either of the two chemicals at 0.5% concentration dipped for 10 seconds was satisfactory.

INTRODUCTION

Discolouration of light coloured commercial timbers of Papua New Guinea (PNG) has emerged as a major contributing factor in degrading the quality of sawn timber for domestic and overseas markets. This in part is due to the more than 3000 millimetres of annual precipitation with accompanying high temperatures and humidity.

In the past,only Sodium pentachlorophenate (NaPCP) has been used with dip-diffusion salts (BFCA) to remedy the problem. Although, this chemical provided adequate sapstain protection for sawn timber, concern for environmental and health hazards was raised by staff of the Forest Products Research Centre in 1976 as a result of a recorded death (1). Since then, less toxic chemicals like Busan 1009 and Captafol have been advocated for use by wood treating industries.

Accordingly, this study was initiated to compare the effectiveness of Captafol (cis-N-1,1,2,2 - tetrachloroethyl thio-4-cyclohexene-1,2, dicarboximide) and Busan 1009 containing two active ingredients, methylene bis thiocyanate (MTC) and 2-thiocyanomethylthio benzothiazole (TCMTB), against sapstain fungi.

MATERIALS AND METHODS

The timber used in this trial was the sapwood of White Cheesewood (Alstonia scholaris (L.) R.Br). It was chosen because of its high susceptibility to sapstain fungi. It was obtained from the natural forest near Sabusa Sawmill, about 20 kilometres West of Port Moresby. The tree selected was of average diameter at breast height of 30 centimetres and consisted mainly of sapwood.

Immediately after felling, it was transported to the sawmill for conversion into the required dimensions of 800 x 100 x 25 millimetres. From the boards obtained, a total of 120 good quality boards free from any visible defects were selected. The boards were covered with polythene sheets and transported to the experimental site on the premises of Sabusa Sawmill. The site was selected for the experiment because of its nearness to the research centre, accessibility to the habitat of the species and more importantly because the climatic conditions resemble those in the other parts of the country.

The boards were unwrapped at test site and randomly assigned to each treatment group of four replicates. Each group was dip treated for 10,30 and 60 seconds at concentrations of 0.5, 0.65, 1.0 and 1.25%. Water dipped boards were used as controls. At the completion of dipping, each treatment group was wrapped in polythene sheets and left for 24 hours. They were then unwrapped and stickered on a rack in an open exposure for seven weeks during which a total rainfall of 74mm and an average diurnal temperature of 27.5^{o}C was recorded with a mean relative humidity of 82%. The boards were inspected weekly according to the technique of Butcher and Drysdale (2) whereby the amount of boards surface covered by stain fungi were rated on a weekly basis as follows:-

Rated as "Clean" if board surface had no stain or zero infection;
Rated as "Trace" if 1-5% of board surface was stained;
Rated as "Slight" if 6-10% of board surface was stained;
Rated as "Medium" if 26-50% of board surface was stained;
Rated as "Heavy" if 51-75% of board surface was stained;
Rated as "Severe" if 76-100% of board surface was stained;

The weekly evaluation was terminated at the beginning of the dry season as a result of significant reduction in rainfall and sharp decrease in relative humidity.

RESULTS

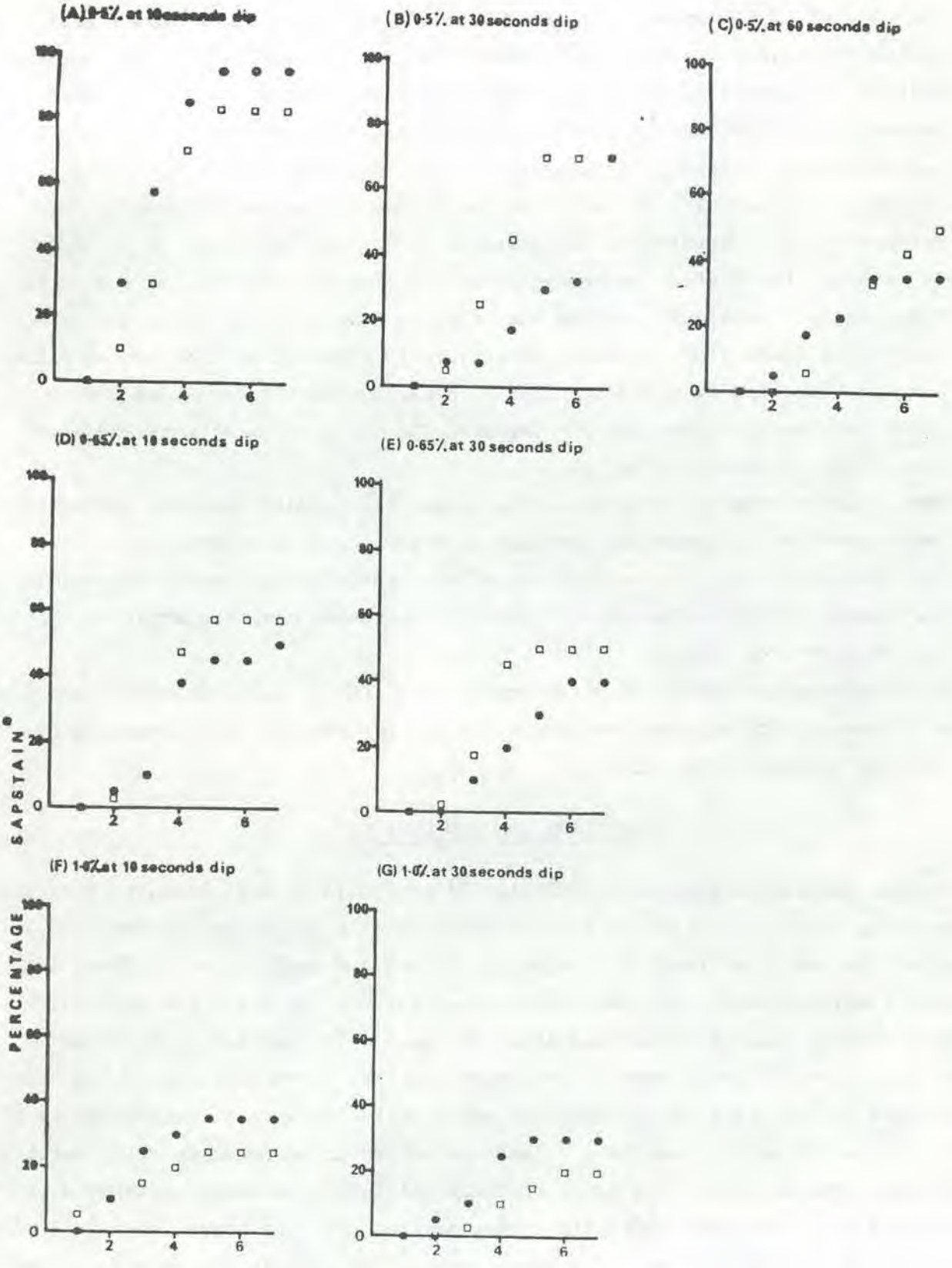
The results of the experiment, summarised in Figures 1 and 2 show that:-

1) All water treated control samples were 100% stained two weeks after exposure.
2) Each of two chemicals provided a 60% protection effectiveness at lowest concentration 0.5% but at 0.65% concentration, effectiveness of Captafol has increased to nearly 75% compared to 65% for Busan 1009 (Figs. 2A-2C).
3) At concentrations of 1.0% and 1.25%, percentage average effectiveness for Busan 1009 has increased to 91% compared to 82% for Captafol.
4) In general, the higher the concentration of chemical, the better its performance against sapstain. At the same dipping time of 30 seconds, the effectiveness of Busan 1009 increased progressively from 55% at 0.5% concentration through 0.65% and 1% concentrations to a maximum effectiveness of 94% at 1.25% concentration,whereas for Captafol the increase in effectiveness was from 75 to 82 percent (Fig. 2B).
5) For either of the two chemicals, the longer the dipping time the better the performance of antisapstain chemical at a particular concentration.
6) For both chemicals, the combination of shortest dipping time of 10 seconds and lowest concentration of 0.5% provided an almost complete sapstain protection for 14 days (Fig. 1A).
7) For a protection period of seven weeks Busan 1009 at 1.25% concentration with a 60-second dipping time provided a 100 percent protection as compared to 89% for Captafol (Fig. 2C).

DISCUSSION AND CONCLUSIONS

In New Zealand, Butcher and Drysdale (2) used 0.2% to 0.4% product concentration of Captafol to provide an 80-100% protection in Pinus radiata for 3 to 4 months. On the other hand, in Sweden, Dickinson and Henningson (3) found inadequate protection for the same species using a 0.1% to 0.15% for Captafol with a dipping time of 10 seconds after 10 weeks. The present study showed that 0.5% Captafol could provide an almost complete protection period for only two weeks but for periods in excess of seven weeks, a Captafol concentration of more than 1.25% may be necessary. These anomalies in performance of Captafol at different concentrations are not surprising and infact emphasize Butcher's (4) assertion that "the best chemicals in New Zealand have not proved best in Sweden and the U.K. and vice versa". In humid tropics, such as in PNG, where temperature in excess of 25°C and relative humidities well over 60% are usual throughout the year, sapstain and fungal decay hazards are even more acute because of the very favourable growth conditions. Thus, it would be unreasonable to expect results from temperate countries to be applicable in tropical environments even for identical wood species.

B 10


(A) 0·5% at 10 seconds dip
(B) 0·5% at 30 seconds dip
(C) 0·5% at 60 seconds dip
(D) 0·65% at 10 seconds dip
(E) 0·65% at 30 seconds dip
(F) 1·0% at 10 seconds dip
(G) 1·0% at 30 seconds dip
SAPSTAIN
PERCENTAGE
0
20
40
60
80
100
2
4
6

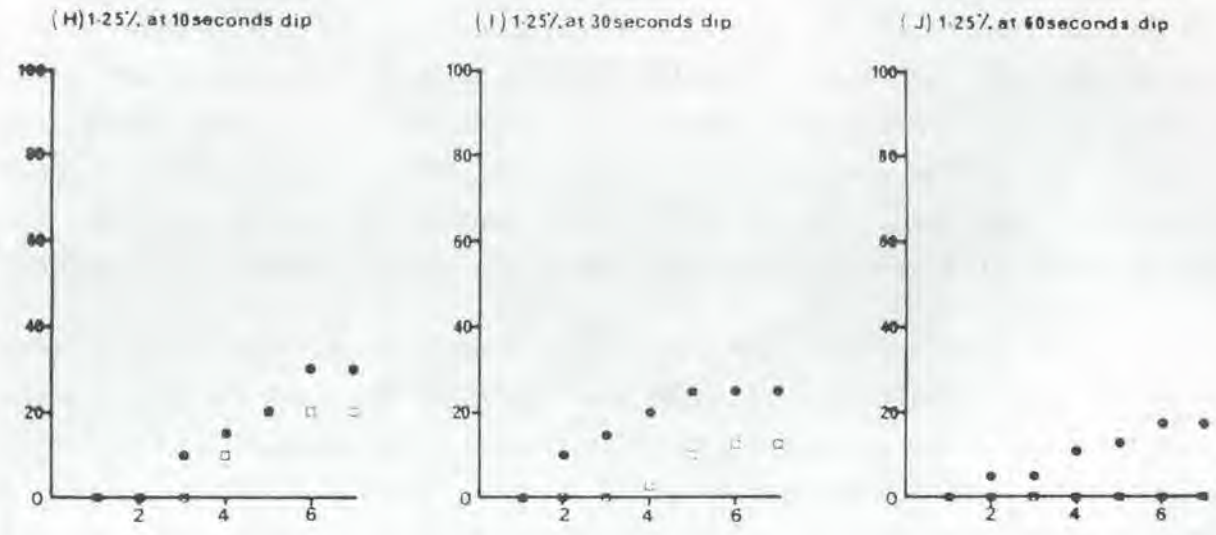


FIG 1 Relationship Between Percentage of Board Surface Stained and Weeks of Exposure After Treatment

● Sapstain Expressed as Percentage of Board Surface Affected by Sapstain Fungi

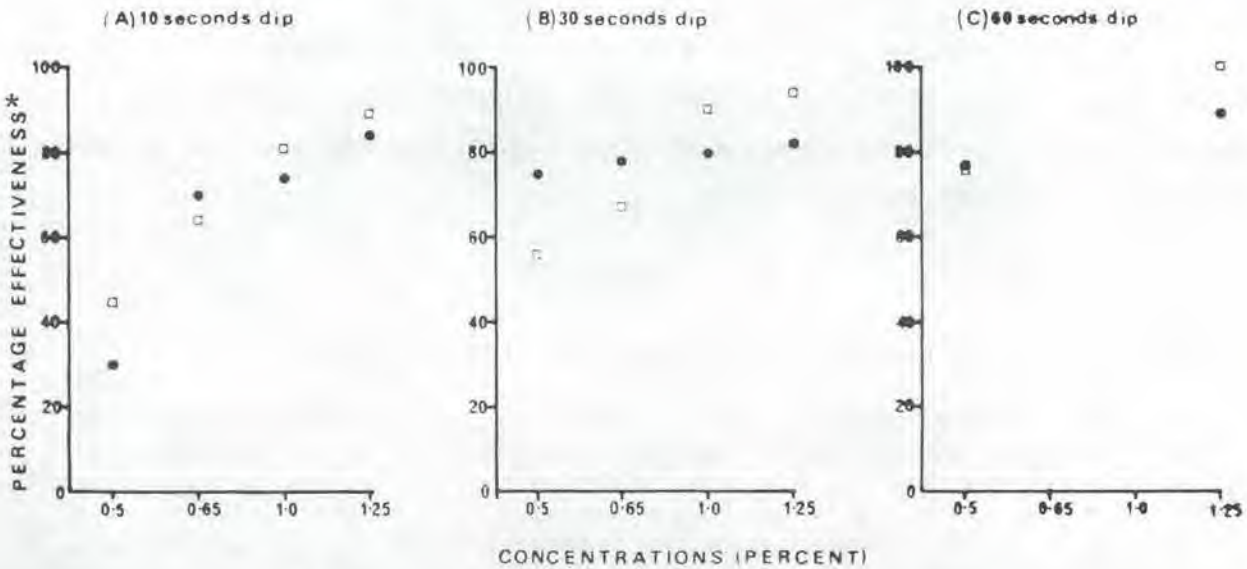


FIG 2 Relationship Between Percentage Effectiveness and Concentrations of Captafol and Busan 1009

● Captafol
Busan 1009

$$* \text{ Percentage Effectiveness} = \frac{A - B}{A} \times 100$$

where A is Total Percentage Surface Stain of Water Treated Samples

where B is Total Percentage Surface Stain of Antisapstain Treated Samples

Similarly, Drysdale (5) achieved a 95% stain free surface on Pinus radiata in New Zealand for a 6-week period using 0.5% Busan 1009 solution but in Canada, Plackett (6) had to use as much as a 2% product concentration to provide protection in hem fir. In this study, the use of 0.5% product concentration provided complete effective protection for only two weeks and a seven-week protection was only possible with a product concentration of 1.25% or better. This finding is partly in agreement with Buckman Laboratories (7) recommendation that for a concentration of 1.5% the protection period should not exceed 1 to 2 months.

It is also evident from this study that in addition to the choice of antisapstain and its concentration, dipping time could be important factor for sapstain control. This was particularly demonstrated by Busan 1009 which at 1.25% concentration and a dipping time of 60 seconds, offered a 100% protection compared to 89% and 94% for 10 and 30 seconds respectively. This trend was also true for Captafol at the same concentration.

Further studies are needed to confirm these findings before reasonable recommendations could be made to the wood treating industries.

ACKNOWLEDGEMENTS

We are very grateful to Beltek Laboratories and ICI Chemicals for the supply of chemicals, Busan 1009 and Captafol respectively. Many thanks also go to Sabusa Sawmill for their kind assistance in supplying the wood and allowing their premises to be used for the trial.

REFERENCES

1. Forest Products Research Centre, File No. 182-2-5

2. Butcher, J.A. and Drysdale, J.A. (1964) Field Trials with Captafol-An Acceptable Antisapstain Chemicals. New Zealand Forest Service. Reprint No: ODC 844.41.

3. Dickinson, D.J. and Henningson, B. (1984) Field Test with Antisapstain Chemicals on Sawn Pine Timber Stored and Seasoned Under Different Condition. Int. Res. Group on Wood Pres. Doc. No. IRG/WP/3245.

4. Butcher, J.A (1982) Int. Res. Group on Wood Pres. Doc. No. IRG/WP/3217.

5. Drysdale, J.A. (1983) Laboratory Evaluation of Potential Antisapstain Treatments for Pinus radiata. Int. Res. Group on Wood Pres. Doc. No. IRG/WP/3237.

6. Plackett, D.V. (1982) Field Evaluation of Alternative Antisapstain Chemicals, Int. Res. Group on Wood Pres. Doc. No. IRG/WP/3098.

7. Buckman Laboratories (1982) Product Data-Busan 1009. For sapstain and Mold control on Freshly cut Wood.

BEEKEEPING AND WOOD PRESERVATION IN AUSTRALIA

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INTRODUCTION

Over the past decade honey production in Australia has averaged about 19.5 thousand tonnes per year. Export earnings in the 1982-83 season were $12.7 million for 14.6 thousand tonnes of honey exported (1). Statistics for honey production in Australia are compiled by the Australian Bureau of Statistics and are based on apiarists that have more than 40 hives. The under 40 group (Table 1) may contribute up to an additional 2.5 thousand tonnes of honey on the domestic market (2). Bees are an important vector in crop pollination. Their value to the farming community and consequently their input to the national economy, although difficult to measure in monetary terms must be substantial (3,4).

Annual hive repair and maintenance costs were estimated in 1981 for a 900 hive apiary at $1500 (5). Today this figure may well be greater than $2000. Considerable variation in these costs are to be expected throughout the industry as the majority of Australian apiarists are either amateur, hobbyists or small commercial producers (6). About 80 per cent of apiarists operate less than 40 hives representing only 15 per cent, on the average, of the total number of hives in Australia (Table 1). There is considerable scope for these and other producers to utilize 'do-it-yourself' hive maintenance procedures that include wood preservation.

Construction of hive and hive components is mostly from softwood such as *Pinus* sp. and *Araucaria* sp. (7). Untreated wood parts of beehives have been reported to last up to 10 years in America depending on the climate (8), but under Australia conditions 2-5 years may be a reasonable estimate. Termites can be a problem (9). Considering that the replacement value (retail) of a two super, eight frame hive is about $55 any wood

preservative treatment that could extend the service-life of a hive before any remedial treatment, would have considerable economic impact on the bee industry (10,11,12). The authors have seen bee boxes claimed by their owners to be 40-50 years old, treated with various waxes and oils that were in excellent condition. Our experience with a number of commercial wood preservatives suggests that a 20 years or more minimum maintenance period is not an unattainable goal.

CHOICE OF WOOD PRESERVATIVE

Wood preservation systems can be classed as follows in order of effectiveness (13):

(i) paints or plastic film
(ii) surface layer treatment with a water repellent
(iii) surface layer treatment with an organic fungicide
(iv) pressure impregnation using organic solvent soluble or water soluble preservatives. (Some water soluble preservatives may be diffused into wood.)

We consider water repellency, fungicidal effectiveness and the effect on bees and hive products to be the main considerations when choosing a wood preservative system for wooden hive components.

Dry wood, that is wood with less than 20 per cent moisture content will not support decay organisms and where the moisture content of the wood remains relatively constant, swelling and shrinking, particularly in the joints, is minimized (14). For instance, window units dip-treated with a water repellent formulation containing paraffin wax, resin and mineral spirit were exposed to the weather and are still performing satisfactorily after 20 years exposure (15). There is a great likelihood of mechanical-damage occurring to a hive when prising supers apart or during transportation to honey flows. Galvanised iron straps are often used to secure supers. The straps may cut into the wood, breaching any surface treatment and allow the entry of moisture.

Bee boxes dip or brush treated with water-repellent formulations may need retreatment every 2-3 years to maintain repellency (16,17). Painting the outside surfaces of the hive with a suitable oil-based or acrylic paint will reduce this requirement (18).

Some apiarists have been experimenting with various hot wax bath treatments of supers and frames. Successful treatments are claimed to last in excess of 15 years before retreatment is required. Usually, paraffin wax, microcrystalline wax or beeswax are used, sometimes in combinations with mineral turpentine and linseed oil. Hives are generally given an external coat of paint immediately after the hot wax-bath treatment.

Commercial wood preservatives incorporating a fungicide, and in some cases an insecticide, are available for treatment of beehives (Table 2). Hive components may be brush-coated, dipped, soaked or subjected to a series of vacuum/pressure regimes (19,20). The most popular wood preservatives contain metallo-organic compounds dissolved in light organic solvents such as mineral turpentine. Generally, wood preservative treated hives are given at least one external coat of paint for additional protection. Painting alone will only give temporary protection (21).

Some wood preservatives available for beehive preservation may cause high bee mortality (22,23). The most recent information we have suggests that Pentachlorophenol (PCP), Bis-Tri-N-Butyl-Tin Oxide (TBTO) and Copper-Chromium-Arsenic (CCA) treatments have adverse effects on bees, leave residues of the chemicals in bees, honey or wax depending on the individual treatment and in all three treatments were associated with poor survival of colonies during their first winter (24). Painting the inside of beehives treated with CCA will reduce the risk of bees ingesting arsenic (25). Care should be taken in selecting a paint since some contain fungicidal components that may effect bees and/or their products (26). For instance, paints containing PCP or TBTO should be avoided.

Where protection from termite attack is desirable and the wood is not in contact with the bees, for instance in hive stands or cleats, a durable timber may be used or timber treated with a wood preservative containing

an insecticide such as in CCA (27,28). Pressure impregnated wood will generally provide the best protection against termite attack and decay.

DIP/SOAK SURFACE TREATMENTS - SOME PRELIMINARY RESULTS

1. MICROCRYSTALLINE WAX

A circular section (14 mm diam.) was cut from the centres of several metal vial lid (20 mm diam.). These lids were then glued onto the radial and tangential faces of *P. radiata* dressed wood blocks. A microcrystalline wax (m.p 74°C) coloured with a wax soluble dye was placed in the lids and each assembly placed in an oven at 135°C. After one hour the wood blocks were cooled at room temperature and then a one millimetre deep strip was shaved sequentially off each face. On average, the dye was just visible in the springwood at 2 mm on the radial face and up to 5 mm on the tangential face.

2. ALKYL AMMONIUM COMPOUND

P. radiata blocks (200 x 30 x 20 mm), ten per treatment, were dipped for 20 minutes in alcoholic solutions of benzalkonium chloride (Quatramine 80), 2.5% m/v, 5.0% m/v, 7.5% m/v and 10.0% m/v. Air-dried, treated blocks had 1 mm shaved from a tangential face and were placed vertically into moist soil at 26°C. Decay on each tangential face was assessed visually (29) after 4 months exposure. The scores obtained were ranked, with higher ranks indicating less decay, and the data analysed using the Kruskal-Wallis one-way analysis of variance (30,31). Briefly, there was no significant difference ($P>0.05$) between the treatments on the shaved face indicating that preservative penetration was largely confined to a shallow surface layer. Dye diffusion tests in fact confirmed this conclusion. Treatment differences were significant ($P<0.05$) on the unshaved tangential face. A Wilcoxon signed rank test on the data for both faces indicated that the unshaved face had significantly less decay ($p<0.01$) than the shaved face. The test was terminated after six months exposure. Almost 58% of the treated blocks were scored zero on the shaved face compared to 30% on the unshaved face.

3. ORGANIC FUNGICIDE

P. radiata blocks (see above), six per treatment, were dipped for 10 minutes in white spirit solutions of Copper naphthenate, 0.04% m/v, 0.08% m/v, 0.16% m/v and 0.32% m/v copper content. Air-dried blocks were placed vertically in soil and scored, after six months exposure, for decay as previously described in section 2 above. Treatment differences were only significant ($P<0.005$) on the unshaved tangential face. The wood blocks are still under test.

SOME CONCLUDING REMARKS

Throughout the bee-keeping industry there are many variations of surface treatments being used to protect hives from decay and insect attack. The most common brush-on or dip/soak treatment used is probably copper naphthenate. For instance, in Queensland 80-90% of apiarists use this wood preservative (T.F. Weatherhead, pers. comm.). Hot wax dip/soak treatments are also popular using either paraffin or microcrystalline wax. How important the use of vacuum/pressure impregnated wood is in the bee industry is unknown. Revision of current practices may be necessary in light of recently received information citing the detrimental effects of CCA, PCP and TBTO. The study (4) indicated that of the wood preservatives tested, copper naphthenate, copper-8-quinolinolate, acid copper-chromate and a water repellent dip treatment could be used without adverse effects on bees, honey or wax.

What we would like to quantify is the degree of maintenance associated with the various treatments, particularly surface treatments such as waxes and brush-on wood preservatives. We suggest that a questionnaire to the industry via the Australian Bee Journal may provide useful information.

CSIRO has had over 40 years experience in the field of wood preservation, and the development of new preservatives is ongoing. Thus, we consider that technology is currently available to substantially improve the service life of wooden hive components for the bee industry.

REFERENCES

1. Honey Board of Australia. Twentieth Annual Report. June, 1983.

2. Federal Council of Australian Apiarists Association. 1983. Submission to I.A.C. Inquiry into Honey Industry.

3. Victorian Apiarists Association. 1983. Submission to I.A.C. Inquiry into Honey Industry.

4. Kalnins, M.A. and Detroy, B.F. 1984. The effect of wood preservative treatment of beehives on honey bees and hive products. J. Agric. Food Chem. (in press).

5. Biddle, S. 1981. Costs and returns of honey production in Victoria. Dept Agric. Vic. Agnote No. 1740/81.

6. Victorian Apiarists Association (Melbourne Section). 1983. Submission to I.A.C. Inquiry into Honey Industry.

7. Weatherhead, T.F. and Kennedy, M.J. 1980. Adhesives and wood preservatives for the beekeeper in the 1980's. Aust. Beekeeper Oct.: 89-94.

8. Judd, J. 1981. FPL chemist studies bees, hives treated with preservatives. Forest Prod. J. 31(8): 10-12.

9. Weatherhead, T.F. and Kennedy, M.J. 1980. Op. Cit.

10. Ibid.

11. Kalnins, M.A. and Detroy, B.F. 1984. Op. Cit.

12. Cross, D.J. 1983. Preservative treatments of wood used in hives. Bee World, 64: 169-174.

13. Ibid.

14. Brown, W.H. 1979. Low cost methods of protecting timber from the elements. Wood Working Ind. 36(6): 28-30.

15. Brown, W.H. 1979. Op. Cit.

16. Weatherhead, T.F. and Kennedy, M.J. 1980. Op. Cit.

17. Cross, D.J. 1983. Op. Cit.

18. McCarthy, R., Chin, C.W. and Greaves, H. 1982. Above ground test of preservative treatments and surface coatings for timbers. Arch. Sci. Rev. 25(1): 1-9.

19. Weatherhead, T.F. and Kennedy, M.J. 1980. Op. Cit.

20. Cross, D.J. 1983. Op. Cit.

21. Beesley, J. and Rumball, B.L. 1977. Observations on the decay resistance of the impermeable heartwood of CCA-trated radiata pine. Division of Building Research Technical Paper (2nd Series) No. 12.

22. Kalnins, M.A. and Detroy, B.F. 1984. Op. Cit.

23. Harrison, D.L., Palmer-Jones, T. and Nairn, R.G. 1959. Danger of using arsenic-treated timber for beehives. N.Z. J. Agric. 98(3): 338-339.

24. Kalnins, M.A. and Detroy, B.F. 1984. Op. Cit.

25. Weatherhead, T.F. and Kennedy, M.T. 1980. Op. Cit.

26. Cross, D.J. 1983. Op. Cit.

27. Ibid.

28. Weatherhead, T.F. and Kennedy, M.J. 1980. Op. Cit.

29. Thornton, J.D., Walters, N.E. and Saunders, I.W. 1983. An in-ground natural durability field test of Australian timbers and exotic reference species. Mat. Und. Org. 18, 27-49.

30. Robinson, P.J., Thornton, J.D. and French, J.R.J. (Unpublished data).

31. Steel, R.G.D. and Torrie, J.H. 1960. Principles and Procedures of Statistics. McGraw-Hill, New York. pp. 406-7.

TABLE 1

Estimates of the number of apiarists and beehives in Australia*

State	Registrations	Total hives	Under 40 hives		More than 200 hives	
			Apiarists %	Beehives %	Apiarists %	Beehives %
Vic.	2628	116 787	79	15	7	63
N.S.W.	4151	243 657	71	10	10	68
S.A.	1366	110,420	70	10	12	68
Qld.+	3018	97,703	87	20	4	68
W.A.	1446	51,405	87	17	6	67
Tas.	600	18,000	88	14	1.0	71
	13,209	637,972	80	15	7	67

* Estimates obtained from 1982-4 registrations and various submissions to I.A.C. Inquiry (2).

+ S.E. Queensland only.

TABLE 2

Wood preservatives available for treatment of beehives*

Active ingredient

Copper Naphthenate
Copper-8-Hydroxy Quinolinolate (USA)
Zinc Naphthenate
Pentachlorophenol (PCP)
Tributyl-Tin-Oxide (TBTO)
Copper-Chromium-Arsenic (CCA)
Alkyl Ammonium Compounds
Copper-Chrome-Boron (NZ)
Acid Copper Chromate (USA)

* Not necessarily approved by various State Health Departments.

SOFT ROT IN TRANSMISSION POLES TREATED WITH HIGH RETENTIONS OF CCA

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ABSTRACT

Pole cross-sections of *E. obliqua*, *E. regnans* and *E. delegatensis* treated commercially to a minimum retention of 35 kg/m^3 have been analysed using atomic absorption spectrophotometry to determine the distribution and retention of CCA components within the sapwood. The results indicated that a significant disproportionation of copper, chromium and arsenic occurs, together with poor penetration of these elements at depth within the sapwood.

Small stakes cut from the sapwood of the pole sections were installed in CSIRO's Accelerated Field Simulator. After two years most of the specimens show signs of soft rot decay. Some failures have already been recorded and specimens containing up to 5.0 kg/m^3 of elemental copper in the outer zones have been severely attacked.

INTRODUCTION

Soft rot attack of treated hardwoods, especially eucalypts, in ground contact is a problem of worldwide concern. Many factors have been suggested which contribute to soft rot attack on hardwoods treated to seemingly adequate preservative retention levels. These factors include: poor microdistribution of the toxic preservative elements within the cells and cell walls (e.g. 1,2,3); an inadequate weight ratio of the toxicant in the wood substrate (i.e. copper in the CCA formulations) (4,5,6); the physico-chemical composition of wood cells; and the general level of treatment and fixation of the preservatives themselves.

In the three paper series by M.A. Hulme and J.A. Butcher (4,5,6) the hypothesis was put that "hardwoods need more chromated copper arsenate (CCA) than softwoods to protect them from soft rot attack, mainly because hardwoods are more readily consumed by soft rot fungi". This concept is in line with current thinking amongst some of the electrical supply authorities in Australia. These authorities believe that by increasing the retention levels of CCA in power poles above a dry salt retention of 20 kg/m^3, they will achieve adequate protection from soft rot attack and therefore increase in the service life of poles. A number of laboratory studies using evenly treated and homogeneously distributed CCAs in small blocks have been carried out. However, there has been little practical research into the field performance of commercially treated poles to examine whether high loadings of CCA fulfill the promise of better protection.

The Hydro Electricity Commission of Tasmania (HEC) is currently treating all new poles to minimum CCA dry salt retention levels of 40 kg/m^3. In 1978 cross-sections of two HEC poles treated to such levels were sent to CSIRO for examination. Atomic Absorption Spectrophotometer (AAS) analysis of these samples indicated high loadings of copper, chromium and arsenic throughout the sapwood. However, microanalysis of cell wall components using the Scanning Electron Microscope indicated poor microdistribution of the major elements in CCA within the cell walls. Samples cut from the treated sapwood of these poles were installed in soil troughs in one of our Accelerated Field Simulators (AFS). After one year these samples showed some signs of soft rot decay. These results were reported by us in 1980 (7) and, with further information, again in 1981 (8).

Cross sections of commercially treated poles containing high CCA retentions, have been used to establish a full scale trial, to comment further on the concept that increased retentions of CCA improved the woods' resistance to soft rot decay. Results from this trial are prevented and discussed in this paper.

MATERIALS AND METHODS

A 50 mm thick transverse disc of wood was cut from each of five commercially CCA-treated HEC transmission poles. The poles were new and had been located in a pole holding yard in Hobart, Tasmania for 12 months after treatment. The poles were treated in separate charges, to a nominal dry salt retention of 40 kg/m^3. The five poles represented three different species of eucalypt, i.e. *Eucalyptus obliqua* L'Herit. (3 poles), *E. regnans* F.Muell. (1 pole) and *E. delegatensis* R.T.Bak. (1 pole). In addition a disc was cut from one *E. regnans* pole which had been treated to a nominal dry salt retention of 20 kg/m^3 (treatment specification originally used in Tasmania). Fourteen specimens, measuring 100 mm along the grain, 22 mm tangentially x the entire sapwood thickness radially (this varied between 10-30 mm) were cut at 30 mm tangential intervals around the circumference of each cross-section. In this fashion, fourteen specimens were cut from each pole cross-section, providing a total of 84 specimens. Sixty of these specimens were randomly distributed and installed in a soil trough in one of our AFS. Five specimens of untreated messmate sapwood were also included as controls.

The remaining four specimens from each pole cross-section - selected from the discs at 90^o intervals - were split into small sections. Each section had 1 mm of its outer sapwood removed and discarded while the remaining sapwood was split into four incremental zones: Zone 1, 0-3 mm from the outside of the pole; Zone 2, 4-8 mm; Zone 3, 9-13 mm and Zone 4 which is included. These zones were extracted and analysed for elemental copper, chromium and arsenic using the method described by Johanson (9).

ATOMIC ABSORPTION SPECTROPHOTOMETER RESULTS

Atomic absorption spectrophotometric results are presented in Table 1.

All poles, with the exception of A and E, had copper loadings equivalent to dry salt retentions in excess of 35 kg/m^3 within all zones. Higher levels of copper in the outer 3 mm were present in all samples. However, a gradual decrease occurred radially within the sapwood.

TABLE 1

AAS analysis results showing elemental loadings within each zone of each pol

Pole+ Number	Zone 1 0-3 mm kg/m³ elemental			Zone 2 4-8 mm kg/m³ elemental			Zone 3 9-14 mm kg/m³ elemental			Zone 4 Remaining sapwoo kg/m³ elemental		
	Cu	Cr	As	Cu	Cr	As	Cu	Cr	As	Cu	Cr	As
A1	3.80	6.16	4.41	3.18	4.72	3.18	3.32	5.33	3.70	3.45	5.61	3.42
A5	5.21	9.16	4.66	3.77	5.48	3.88	2.58	4.47	2.44	1.55	2.61	1.10
A9	4.86	7.59	5.72	3.47	5.92	3.49	2.69	4.38	3.16	2.67	5.20	2.26
A12	4.34	7.36	5.55	3.38	6.00	4.25	2.59	4.67	2.52	3.04	5.26	2.61
Av. total retn*	51.09	47.56	45.14	38.72	34.76	32.83	31.37	29.62	26.22	30.05	29.35	20.83
B1	3.80	7.21	3.58	4.28	6.38	5.04	3.85	5.58	5.00	3.78	5.84	3.20
B5	3.71	7.30	6.03	3.18	5.82	4.58	3.37	5.49	3.57	2.66	4.54	2.61
B8	5.25	6.88	5.33	4.52	6.29	4.66	4.94	6.04	5.70	4.55	5.55	4.22
B40	4.55	6.52	4.92	5.24	5.89	4.87	5.06	5.82	4.41	4.75	5.88	4.81
Av. total retn*	48.57	43.85	44.05	48.31	38.31	42.98	48.32	36.03	41.44	41.16	34.27	31.52
C1	6.53	8.08	5.27	5.49	5.94	3.92	5.55	5.36	3.67	5.71	5.46	3.51
C4	5.09	6.68	3.76	4.12	4.57	3.57	5.55	5.31	4.14	5.19	4.89	3.95
C7	5.82	8.19	5.75	4.69	5.11	4.03	6.07	6.35	4.57	6.37	6.85	5.72
C11	5.83	9.83	4.55	4.05	4.74	2.64	4.54	4.73	3.11	4.33	4.92	3.48
Av. total retn*	68.09	51.51	42.88	51.49	31.99	31.41	60.91	34.17	34.36	60.61	34.76	36.96
D1	4.11	9.64	6.21	3.52	8.35	4.11	3.41	7.62	3.89	NA	NA	NA
D6	4.02	9.92	4.18	3.64	8.08	4.74	3.71	8.12	3.28	NA	NA	NA
D9	4.40	10.55	6.87	4.31	7.73	4.95	3.86	7.73	3.51	3.75	7.59	2.89
D13	4.18	8.61	5.55	3.88	7.64	5.04	3.80	7.83	3.91	3.35	7.19	3.31
Av. total retn*	46.89	60.84	50.60	43.07	49.97	41.79	41.64	49.18	32.36	39.84	46.47	27.51
E1	4.29	8.76	3.21	2.72	5.90	3.45	2.68	5.35	1.41	3.30	6.59	0.91
E4	4.44	8.75	3.45	2.65	5.92	2.41	2.56	4.93	2.15	2.39	4.52	0.78
E7	4.31	8.27	3.01	2.05	4.30	1.99	3.19	6.69	1.08	2.86	5.82	1.51
E11	4.61	8.57	2.87	3.01	5.89	1.21	3.54	6.87	1.74	2.71	5.11	0.82
Av. total retn*	49.52	53.97	27.82	29.26	34.26	20.10	33.59	37.45	14.11	31.59	34.63	8.92
F1	1.89	4.26	3.01	2.23	3.48	2.83	1.98	3.64	2.69	1.85	3.87	3.12
F5	2.20	4.27	3.71	2.42	3.99	3.10	2.23	3.99	3.61	1.82	2.88	3.22
F8	2.30	4.66	3.83	1.96	3.92	2.74	2.15	3.38	2.72	1.87	3.22	2.44
F11	2.21	3.95	3.17	2.35	3.39	2.86	2.14	3.50	2.88	NA	NA	NA
Av. total retn*	24.13	26.93	30.43	25.14	23.22	25.58	23.85	22.80	26.40	30.59	20.89	25.97

* Average total dry salt retention based on each element

\+ Poles A, B, C and F = *E. obliqua*, pole D = *E. regnans*, pole E = *E. delegatensis*

Poles A and E contained elements which were equivalent to loadings of less than 25 kg/m^3 at depth within the sapwood. Some outer zones of pole C contained elemental copper loadings in excess of 6.0 kg/m^3 (equivalent to a total dry salt retention of nearly 60 kg/m^3). Pole C also contained the highest overall CCA retentions with good penetration of copper, chromium, and arsenic at depth within the sapwood.

Chromium was relatively evenly distributed throughout the sapwood with most zones showing elemental chromium loadings in excess of 4 kg/m^3. Arsenic penetration was poor in most poles, with a large gradient of arsenic occurring from the outer to the inner sapwood. Retentions as low as 0.7 kg/m^3 elemental arsenic were present within the inner sapwood zones of some poles. Pole E contained the lowest overall arsenic retention within each zone.

All specimens analysed from the 20 kg/m^3 pole (which was included as a yardstick) were well treated with each zone analysed having dry salt retentions in excess of the required 20 kg/m^3.

ACCELERATED FIELD SIMULATOR RESULTS

The inspection results of the specimens during a two year exposure period in the AFS are presented in Table 2.

The results show that all samples were attacked to varying degrees by soft rot decay. Most soft rot decay occurred in the outer sapwood zone - the area of the pole which usually contained the highest overall CCA retention. Some specimens which analysis showed to contain more than 6 kg/m^3 of elemental copper in the outer zone suffered in excess of 5 mm of soft rot attack. Specimens from the *E. delegatensis* pole showed the most soft rot attack with a few specimens having nearly 50% of their cross-sectional area decayed by this group of fungi. Three of the specimens also contained pockets of brown rot decay.

TABLE 2

AFS results of specimens cut from poles treated to 40 kg/m^3*

Pole No.	Inspection made after 6 mo.	12 mo.	24 mo.
A	3.90 (4.0-3.5)	3.50 (3.5)	3.35 (3.5-3.0)
B	3.90 (4.0-3.5)	3.80 (4.0-3.5)	3.50 (3.5)
C	3.85 (4.0-3.5)	3.50 (4.0-3.5)	3.28 (3.5-3.0)
D	3.95 (4.0-3.5)	3.70 (4.0-3.5)	3.50 (3.5)
E	3.70 (4.0-3.5)	3.50 (4.0-3.0)	3.15 (3.5-2.5)
F	4.00 (4.0)	3.89 (4.0-3.5)	3.22 (3.5-2.5)
Control	2.78 (3.5-2.0)	1.64 (2.0-1.5)	0 (0)

4.0 = sound
0 = completely soft-rotted

* Average of 10 replicates (8 for controls), with range of scores shown in brackets.

Pole D (*E. regnans*) appeared to have the best resistance to decay even though it was treated to lower overall retentions than some of the other poles. It would seem that there is a marked species effect on both CCA preservative distribution and the overall soft rot susceptibility of the treated product.

The current observations from our AFS exposure component our initial results with the sapwood from the first batch of high-treated HEC poles (7,8). Leightley and Norton (10) have since confirmed these earlier findings with a view to providing further guidance on the subject of high retentions for pole users in Queensland. Earlier still in 1976 McNamara exposed specimens of *E. globulus* and *E. saligna* treated to 24 kg/m^3 CCA

oxide (~ 39 kg/m^3 salt) around the base of poles in Colombia, South America. The results obtained (11) indicated that poles treated to such retentions may still be unprotected from soft rot.

In all of the work on hign CCA retentions - other than the artificiality of small blocks in laboratory tests (e.g. 12) - we must conclude that such retentions will not prevent soft rot occurring in poles. However, the retentions may provide the user with an extended lag-phase before the attack begins or becomes critical, and this in itself could be significant in the overall economics of hardwood pole service lives. We would stress the need to properly ground-line maintain, no matter what retention is selected for the initial pole treatment; high retentions may delay the time to application of the first ground-line maintenance treatment, when compared with conventional retentions, but they will not necessarily provide a guaranteed long service life.

CONCLUSIONS

1. The sapwood of poles treated to both conventional (20 kg/m^3) and high (40 kg/m^3) CCA retentions will soft rot under exposure to suitable conditions.

2. There is strong evidence from the results to suggest that high CCA retentions have little effect in providing hardwood with better protection from soft rot decay in the long term; they may extend the lag-phase before decay begins.

3. Species of timber affects both CCA preservative retention and penetration and also has an influence on the severity of soft rot decay in poles which have been treated to high nominal CCA retentions.

4. AAS analysis indicates that arsenic distribution may be poor in poles treated to nominally high (40 kg/m^3) CCA retentions.

REFERENCES

1. Dickinson, D.J. 1974. The microdistribution of copper-chrome-arsenate in *Acer pseudoplatanus* and *Eucalyptus maculata*. Material u. Org. 9: 20-33.

2. Greaves, H. 1972. Structural distribution of chemical components in preservative treated wood by energy dispersion X-ray analysis. Material u. Org. 7: 277-286.

3. Greaves, H. 1974. The microdistribution of coppr-chrome-arsenic in preservative treated sapwoods, using X-ray microanalysis in scanning electron microscopy. Holzforschung 28: 193-200.

4. Hulme, M.A. and Butcher, J.A. 1977a. Soft rot control in hardwoods treated with chromated copper-arsenate preservatives. 1. Treatment problems. Material u. Org. 12(2): 81-95.

5. Hulme, M.A. and Butcher, J.A. 1977b. Soft rot control in hardwoods treated with chromated copper arsenate preservatives. II. Pattern of soft rot attack. Material u. Org. 12(3): 175-187.

6. Hulme, M.A. and Butcher, J.A. 1977c. Soft rot control in hardwoods treated with chromated copper arsenate preservation. III. Influence of wood substrate on copper loadings. Material u. Org. 12(5): 223-234.

7. Greaves, H. and McEvoy, C. 1980. Report to the Pole Industry Liaison Committee (Sept. 1979-Mar. 1980). DBR Int. Rept, 9 pp.

8. McEvoy, C., Chin, C.W., Greaves, H. and D.F. McCarthy, 1981. Report to the Pole Industry Liaison Committee (Jan. 1981-Jul. 1981). DBR Int. Rept, 11 pp.

9. Johanson, R. 1973. Determination of Cu-Cr-As in preserved wood by atomic absorption spectroscopy. Holzforschung 27(4): 126-132.

10. Leightley, L.E. and Norton, J. 1983. High CCA retentions and the protection of Eucalypt power poles. Internat. Res. Group Wood Pres., Doc. No. IRG/WP/3226.

11. McNamara, W.S., Greaves, H. and Triana, J.F. 1981. Tropical field exposure of CCA treated eucalypt stakes. Material u. Org. 16: 81-94.

12. Lewis, D.A. and Brooks, F.V. 1983. The performance of hardwoods treated to high retentions with CCA wood preservatitves. Rec. Annu. Conv. Br. Wood Pres. Assoc. 16-23.

WHY THE WORLD'S MOST FAMOUS WOOD-DESTROYING FUNGUS WORKS FASTEST IN AUSTRALIA

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Serpula lacrymans (formerly *Merulius lacrymans*) is the world's earliest described, best known and most destructive timber decay fungus. It is almost universally rstricted to man-made structures, particularly buildings. Because its optimum temperature for growth is within the unusually low region of 18-22°C inclusive (Bavendamm, 1951) it is THE building fungus. Although it has been stated that "the environment in Australia is generally too warm" (Hadlington & Cooney, 1971), known cases have been mapped (Thornton, 1982) and to date total in excess of 100 outbreaks. Being a "private" fungus, the full extent of its distribution in Australia is not known.

The speed of attack of flooring timbers in Australia by this fungus can be quite remarkable. A former colleague Neville Walters reported that "in favourable conditions it can destroy a new pine floor, of hundreds of square feet, in a year or so" (Walters, 1972). In 1976 he and I examined a collapsed, larger than normal, floor of a nursing home in Melbourne together with the repairer - the latter informing us that he had also replaced the same flooring area (bearers and joists included) almost to the day for each of the previous two years! However, the fastest attack known to the author is a period as short as three months recorded beween successive collapse of original and replacement timbers within the same floor area (Thornton, 1982). Though in all three particular cases, subfloor ventilation was inadequate, and modern houses ought to be adequately ventilated - in practice sufficient attention is not always paid with renovations, extensions and alterations (Thornton, 1981).

The rapidity of failures has raised the question as to whether Australian strains of *S. lacrymans* could be more active than the well-

investigated northern hemisphere strains. In order to be able to carry out direct comparative studies four overseas strains (English, German, Polish and Japanese) were imported. Growth tests on nutrient medium were carried out by Prof. Jerzy Wazny, visiting scientist from Warsaw Agricultural University, and show that growth rates ranged from 4.8 to 7.2 mm diameter per day for overseas and from 6.4 to 8.1 mm for four Australian strains. With corresponding fungal dry weight production of 13 to 20 and 10 to 16 mg respectively there is no evidence of outstanding differences in growth characteristics between Australian and overseas isolates (Thornton and Wazny, in preparation). In a previous experiment each of the eight strains was placed in contact with sapwood blocks of *Pinus radiata* in covered jars which were then incubated in the subfloor spaces of both a brick-veneer and a weatherboard building throughout the Melbourne summer season. Decay rates at those temperatures within subfloor spaces were not significantly different from those obtained at optimum growth temperatures in the laboratory, with rates being very high in all cases (Thornton, 1985, in preparation). A recently-completed direct comparative test has shown that there is no difference in susceptibility between *P. radiata* and *P. sylvestris* sapwoods to either European or Australian strains (Thornton and Wazny, unpublished data).

From our tests it is deduced that the reason for the rapid flooring failures recorded (in certain buildings in certain parts of Australia) must be the suitability of the subfloor temperatures (Thornton, 1984) of Australian buildings and is not due to any outstanding behavioural properties of Australian strains. Some evidence to support this claim is presented in Table 1, which comprises subfloor temperatures of Melbourne buildings during summer and winter (Thornton 1984, 1985) together with similar data from a Japanese house (Doi, Sato & Arima, 1983,1984). When interpreting the values given in Table 1 it should be borne in mind that *S. lacrymans*, although having an optimum temperature for growth of 18-22^{o}C (Bavandamm, 1951) will grow between 3^{o}C and 26^{o}C (Segmuller & Walchli, 1978). Gaumann (1939) reported some growth for one strain at -2^{o}C. In laboratory tests, Australian strains grew well at 12^{o}C (Thornton & Collett, 1983) and all eight strains tested by the author did not grow at 27^{o}C (Thornton, 1985 in preparation). However, below and above its growth limiting temperatures this fungus will not die, since 40^{o}C for 15 minutes

TABLE 1

Minimum and maximum temperatures recorded with the subfloor spaces of several Melbourne buildings and one Japanese building; a comparison of summer and winter months.

SUMMER temperatures

Type[1]	Ventilation area[2]	Minimum temp. °C	Maximum temp. °C	Month	Year
Australian buildings in Melbourne					
AC	300	16	24	Feb.	1979
BV	5 000	17	26	Feb.	1981
WB	126 000	14	32	Feb.	1981
BV	7 915	16	29	Feb.	1984
WB	126 000	14	33	Feb.	1984
Japanese building in Hokkaido[3]					
Wooden - below Japanese style room		16	24	Jul.	1981
" - " " " "		12	20	Jun.	1982
" - below living room		16	24	Jul.	1981
" - " " "		12	29	Jun.	1982
" - below kitchen		15	23	Jul.	1981
" - " "		17	28	Jun.	1982

WINTER temperatures

Type[1]	Ventilation area[2]	Minimum temp. °C	Maximum temp. °C	Month	Year
Australian buildings in Melbourne					
AC	300	9	15	Jul.	1979
BV	5 000	9	15	Jul.	1981
WB	126 000	7	15	Jul.	1981
BV	7 915	6	13	Jul.	1984
WB	126 000	3	16	Jul.	1984
Japanese building in Hokkaido					
Wooden - below Japanese style room		-1	5	Feb.	1981
" - " " " "		-3	4	Feb.	1982
" - below living room		3	5	Feb.	1981
" - " " "		2	6	Feb.	1982
" - below kitchen		-2	-2	Feb.	1981
" - " "		-6	-2	Feb.	1982

[1] AC, clad with asbesstos-cement sheeting; BV, brick-veneer; WB. weatherboard.
[2] Ventilation areas are expressed as mm^2 free air space per metre length of external wall. [3] Ventilation area of Japanese house not stated, but ventilation rate must have been poor since damage due to *S. lacrymans* occurred to some floor areas in August 1979 and August 1981.

Note all buildings had 500 to 600 mm clearance between soil and bearers. All Japanese data comes from English translation of the papers of Doi, Sato and Arima, 1982, 1983. Australian data from author's investigations (see text).

(Liese, 1931) or longer (Miric & Willeitner, 1984) exposure is needed to kill *S. lacrymans*. [As a point of interest, the author has not determined the relationship between optimum temperature for fungal growth and optimum temperature for decay of wood, but has assumed the values to be closely similar based on the findings (with this fungus) of Cartwright & Findlay (1958), Walchli (1977) and Doi (1981)]. When the values in Table 1 are considered against the foregoing discussion of the unique temperature relationships of this fungus it can be seen that although the Australian summer subfloor temperatures would be expected to support growth at rates little different from those under Japanese buildings, in the winter Australian subfloor temperatures are far more suitable. In fact, there would be times (Table 1) when the fungus would cease to grow under the Japanese building in winter, whereas the fungus would grow and could cause decay all the year round (Thornton, 1984) under certain Australian subfloors. Hilditch (1983) states that "*Serpula lacrymans* cannot survive in hot climates and it is therefore a pest of temperate zones especially Northern Europe. It is not found in the tropics or hotter parts of the world." However, the evidence presented and discussed in this paper strongly suggests that *S. lacrymans*, the most famous wood-destroying fungus, can (given sufficient moisture and high humidity) work fastest in the uniquely suitable temperatures of the subfloor spaces of buildings (at least in one, densely, populated area) of Australia.

REFERENCES

Bavandamm, W. 1951. Holzschadlingstafeln. Holz Roh Werkst. 9, 251-252.

Cartwright, K. St.G. & Findlay, W.P.K. 1958. Decay of timber and its prevention. DSIR For Prod. Res. Lab. London, HMSO.

Doi, S. 1981. Conditions for growing *Serpula lacrymans* isolated in Japan. 17th IUFRO World Congress, Kyoto, Japan.

Doi, S., Sato, M. & Arima, T. 1983. (The measurement of the temperature and relative humidity of a house damaged by *Serpula lacrymans*). Proc. Hokkaido Japan Wood Res. Soc. 14: 69-73.

Doi, S., Sato, M. & Arima, T. 1984. Temperature and relative humidity on the house damaged by *Serpula lacrymans*. J. Hokkaido For. Prod. Res. Inst. 384: 12-14.

Gaumann, E. 1940. Uber die Temperaturanspruche des Hauschwammes. Zbl. Bakt. Abt. 2(101): 409-410.

Hadlington, P.W. & Cooney, N.G. 1971. A guide to pest control in Australia. 1st Edn. Sydney, NSW Univ. Press, p.140.

Hilditch, E.A. 1983. The enemies of timber. Cuprinol Ltd., Frome, UK.

Liese, J. 1931. Beobachtungen uber die Biologie holzzerstorender Pilze. Angew. Bot. 13: 138-150.

Miric, M.L. & Willeitner, H. 1984. Lethal temperature for some wood-destroying fungi with respect to irradication by heat treatment. Internat. Res. Group on Wood Pres., IRG Doc. No. IRG/WP/1229. Stockholm, IRG Secretariat.

Segmuller, J.R., Walchli, O. 1978. Monographic information on *Serpula (Merulius) lacrymans* (Schum. ex Fr.) S.F.Gray according to the "Model questionnaire for preparation of monographic cards for wood-destroying fungi". IRG Doc. No. IRG/WP/170. Stockholm, IRG Secretariat.

Thornton, J.D. 1981. Before you renovate ... consider subfloor ventilation. Rebuild 6(6): 2.

Thornton, J.D. 1982. Recent occurrences of the dry rot fungus *Serpula lacrymans*, in Australia. Trans. Br. Mycol. Soc. 79: 26-28.

Thornton, J.D. 1984. The survival of *Serpula lacrymans* in Australian buildings. Mater. Org. (in press).

Thornton, J.D. 1985, in preparation. The survival and wood-rotting abilities of eight *Serpula lacrymans* strains incubated during the summer season within the subfloor spaces of two Australian buildings.

Thornton, J.D. & Collett, O. 1983. The growth and behaviour of Australian isolates of dry rot fungi, mainly *Serpula lacrymans* (Schum. ex Fr.) S.F.Gray. A comparison with the world literature. Internat. Res. Group on Wood Pres., IRG Doc. No. IRG/WP/1190. Stockholm, IRG Secretariat.

Thornton, J.D. & Wazny, J. (In preparation). Comparative laboratory testing of strains of the dry rot fungus *Serpula lacrymans* (Schum. ex Fr.) S.F.Gray. 1. Growth and decay capacity.

Walchli, O. 1977. (The influence of temperature on the decay of wood by fungi). Holz Roh Werkst. 35: 45-51.

Walters, N.E.M. 1972. Case histories of the dry rot fungus *Serpula lacrymans* Gray. CSIRO For. Prod. Newsletter 387: 4-7.

FUNGI ASSOCIATED WITH SAPSTAIN OF PINE IN SOUTH-EAST QUEENSLAND

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ABSTRACT

A small survey in 1982-83 at ten hoop and slash pine sawmills in south-east Queensland sought some explanations for the reported poor performance of chemical anti-sapstain treatments. Samples were collected from stacks seasoning in the open for laboratory isolation studies and determination of the origin of fungal infection. At most mills, some sapstain was already in the wood when cut from the log. Fourteen genera of fungi were isolated from the samples, eight of which caused sapstain in laboratory tests. Treatment at the mill (Na PCP or captafol) appeared not to delay infection by some fungi for even one month. When tested at recommended concentrations on small wood blocks in the laboratory, Na PCP, captafol and TCMTB did not control all eight sapstainers identified in the survey, but MBT and MBT + TCMTB did; thus providing another explanation for failures of Na PCP and captafol in the field, and demonstrating the usefulness of laboratory studies in the evaluation of anti-stain chemicals.

INTRODUCTION

In Queensland, sawmillers have reported significant sapstain in stacks of seasoning pine despite treatment immediately after sawing with sodium pentachlorophenate (Na PCP) or captafol. Possible explanations for the failure of these treatments include pre-existing infection in the log, problems with formulation or maintenance of the chemical, unsatisfactory seasoning practices and excessive periods of storage of treated timber in the open. Another is Na PCP and captafol do not prevent infection by some

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fungi that commonly cause sapstain in Queensland. Only one staining fungus has been reported previously from Queensland, viz Diplodia pinea (= Sphaeropsis sapinea), which was identified on both hoop pine (Araucaria cunninghamii) and slash pine (Pinus elliottii) (1). However, Botryodiplodia theobromae, Cladosporium, Fusarium, Hormonema dematioides and Penicillium have been isolated in routine investigations of stained pine sapwood, suggesting a range of fungi is causing the degrade in Queensland.

To seek some explanation for the reported poor performance of the anti-stain treatments, a small survey of sawmills cutting hoop or slash pines in south-east Queensland was undertaken in 1982-83 to determine origins of fungal infections (i.e. log or board), to assess the apparent efficacy of the treatments and to isolate fungi from sapstained wood for laboratory studies. In the laboratory, these fungi were tested for sapstaining ability on hoop and slash pines, and five anti-stain chemicals (including Na PCP and captafol) were tested on small pine blocks at recommended concentrations, against those fungi with demonstrated sapstaining ability. We report the results of this work.

SURVEY FOR FUNGI ASSOCIATED WITH SAPSTAIN

In July 1982 and February 1983, 94 samples (5-15 cm long) were cut from stained boards in stacks of hoop or slash pines seasoning in the open at ten sawmills (four hoop pine, three slash pine, and three sawing both species) in south-east Queensland. Samples were placed into separate polythene bags together with a report form giving timber species, anti-stain chemical applied, date of stack construction and date of sampling. Laboratory isolation studies commenced within 48 hr of collection, but first samples were examined to determine, from the pattern of stain (3), if infection arose in the stack or was already present in the log when sawn. For isolation of fungi, several small chips from below the surface of each sample were plated on malt-extract agar and incubated at 25°C in the dark. Isolations were repeated on a sample where fungi

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emerged from none or only a few of the chips. Cultures of fungal species isolated, particularly those with pigmented hyphae, were forwarded to the Commonwealth Mycological Institute for identification.

There was only one sample in which the pattern of stain would not allow determination of the origin of infection. Although results for individual mills are not given here, the survey revealed that at most mills, sapstain was already present in some boards when cut from the log. Fifteen fungal species, from 14 genera, were isolated during the survey (TABLE 1). While most species were identified in both timbers, there were some noteworthy exceptions, e.g. Botryosphaeria ribis, the cause of dieback in young plantations of hoop pine, was isolated only from hoop pine; and Sphaeropsis sapinea, the cause of dieback of Pinus spp. (2), only from slash pine. Table 1 also shows that boards in the stack were infected by a broader range of fungal species than were logs; and a broader range of species was isolated from samples collected in winter.

Eight of the sawmills routinely applied anti-stain chemicals to freshly sawn boards: five used Na PCP (concentrations ranged from 0.2-0.5% a.i.); and three, captafol (0.2-0.5% a.i.). To assess the apparent efficacy of these chemicals, fungal species from individual samples were listed by anti-stain treatment the board had received and age class (0-1, 1-2 and 2-3 mo) of the stack from which the sample was taken; only data from samples in which infection originated during seasoning was considered (Table 2). Where no anti-stain chemical was used, a broad range of fungal species infected boards in the first month of seasoning. Both anti-stain chemicals appeared to limit infection in the first month, only Botryosphaeria ribis, Cladosporium cladosporioides and Phoma sorghina being recorded in boards treated with Na PCP, and Trichoderma sp in those treated with captafol. In the long term, only six species were isolated from captafol-treated boards whereas eleven were isolated from Na PCP-treated boards, which was as broad

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TABLE 1

Fungi found infecting Logs and Seasoning Stacks of Hoop and Slash Pines, in Winter and Summer 1982-83.

Fungal species	Hoop pine				Slash pine			
	Win.		Sum.		Win.		Sum.	
	L	S	L	S	L	S	L	S
Bipolaris specifer			+					
Botryodiplodia conorum			+					
Botryodiplodia theobromae	+	+	+	+			+	
Botryosphaeria ribis		+	+	+				
Cladosporium cladosporioides		+				+		
Curvularia lunata		+				+		
Epicoccum nigrum		+		+		+		+
Fusarium fusarioides		+		+		+		+
Hormonema dematioides								+
Khusia oryzae		+		+				
Penicillium sp		+				+		
Phoma sorghina		+				+		
Pleospora infectoria		+				+		
Sphaeropsis sapinea					+	+		
Trichoderma sp		+		+		+		+

Win. - winter; Sum. - summer; L - logs; S - seasoning stacks

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a range as that recorded in untreated boards. Thus, results of the survey suggest that neither chemical protected boards from fungal infection, even in the short term, but captafol appeared more efficacious than Na PCP.

ABILITY OF SELECTED FUNGI TO CAUSE SAPSTAIN

Twelve of the 15 fungi isolated during the survey were selected for tests of sapstaining ability (Table 3). For each fungus, five squares each of hoop and slash pine veneers (25 x 25 x 3 mm) were autoclaved to sterilize and wet the wood and placed, one per dish, on the surface of malt-extract agar (MEA) in 90 mm Petri dishes with 30 ml medium. Each dish was then inoculated near the edge with a 4 mm plug of MEA carrying mycelium of the test fungus, cut from the margin of growing cultures. The plug was placed so that the advancing margin of the culture would grow on to the end grain of the wood. Inoculated dishes were incubated at 25°C in the dark. After six weeks incubation, veneers were removed and scraped free of superficial mycelium and rated (nil, light, moderate or heavy) for intensity of sapstain. Sections from the centre of the veneer were prepared to examine hyphal penetration under the microscope. The sapstain rating was confirmed only when pigmented hyphae penetrated to the centre of the veneer.

Eight fungi caused sapstain, in both hoop and slash pines (Table 3). Stain intensity, the severest rating recorded among the five replicates in each treatment, varied with both wood and fungal species. The stain caused by five fungi was more intense in hoop pine; that of the other three was equally intense in both pines.

TABLE 2

Fungi infecting Boards in the Stack, by Age of Stack and Anti-stain Treatment applied at the Mill

Fungal species [1]	Anti-stain treatment: Nil			Na PCP			Captafol		
	Age of stack (months): 0-1	1-2	2-3	0-1	1-2	2-3	0-1	1-2	2-3
B. specifer	+								
B. theobromae	+		+		+				
B. ribis	+			+	+				
C. cladosporioides	+		+	+	+	+		+	+
C. lunata						+		+	+
E. nigrum	+				+	+		+	+
F. fusarioides	+	+			+			+	
K. oryzae	+		+						
Penicillium sp			+		+				
P. sorghina	+		+	+		+		+	
P. infectoria	+				+	+		+	+
S. sapinea						+			
Trichoderma sp	+					+	+		

[1] For genera, refer to TABLE 1.

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TABLE 3

Intensity of Stain induced by Selected Fungi in Veneers of Hoop and Slash Pines after Six Weeks Incubation

Fungal species[1]	Hoop pine	Slash pine
B. specifer	**	**
B. conorum	***	**
B. theobromae	***	***
B. ribis	***	**
C. cladosporioides	**	**
E. nigrum	-	-
F. fusarioides	-	-
H. dematioides	***	*
K. oryzae	-	-
P. sorghina	-	-
P. infectoria	***	*
S. sapinea	***	**

[1] For genera, refer to TABLE 1.

Stain intensity: nil, -; light, *; moderate, **; heavy, ***

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EFFICACY OF SELECTED ANTI-SAPSTAIN CHEMICALS

Five fungicides were tested in the laboratory, on both hoop and slash pines, for efficacy in preventing infection by each of the proven sapstainers from the previous study. The fungicides, formulations and concentrations used were: Na PCP (1.0% Pentabrite^{R} buffered to pH 9 with Na_2CO_3; 0.5% a.i.), captafol (1.0% Haipen Liquid Fungicide^{R}; 0.5% a.i.), 2-thiocyanomethylthiobenzothiazole (TCMTB) (1.0% Busan^{R} 30; 0.3% a.i.), methylene bisthiocyanate (MBT) (1.0% Busan^{R} 110; 0.1% a.i.), and TCMTB + MBT (0.5% Busan^{R} 1009; 0.05% a.i. each of TCMBT and MBT). Concentrations used of Na PCP and captafol were based on current useage in Queensland; and of the Busan products, on manufacturer's recommendations. Blocks, 2.5 (along the grain) x 1.0 cm (across the growth rings) x 0.5 cm, were cut from one board each of hoop pine and slash pine fresh from the log, and immediately immersed and agitated for 30 sec in the fungicide. Additional blocks immersed only in distilled water served as controls. Three blocks of each wood species from the one fungicidal treatment were placed in a 90 mm Petri dish of water agar, supported on 4 mm dia glass rods, and left overnight to dry. Blocks were then sprayed with macerated aqueous mycelial suspension of the test fungus - ensuring thorough application to the top face, sides and ends of the blocks - and incubated at 25°C in the dark. After seven weeks, each block was split lengthwise and examined, under 40 x if necessary, for internal penetration of pigmented mycelia. The experiment was repeated.

Results are presented in Table 4 (similar results were obtained in both experiments). Both wood species were infected by all eight fungi in the nil fungicide treatment. Of the fungicidal treatments, only MBT and MBT + TCMBT protected both wood species against all fungi. TCMBT failed against *B. specifer* on hoop pine; and captafol, against *B. specifer* and *C. cladosporioides*, again only on hoop pine. Na PCP gave the worst result, failing against *B. theobromae* and *H. dematioides* on both hoop and slash pines, and *B. conorum* on slash pine.

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TABLE 4

Fungi observed to cause Sapstain in Blocks of Hoop and Slash Pines, in Nil and Five Anti-stain Treatments, after Seven Weeks Incubation

Fungal species[1]	Anti-stain treatment[2]											
	Nil		Na PCP		Captafol		MBT		TCMTB		MBT + TCMTB	
	Wood Species											
	H	S	H	S	H	S	H	S	H	S	H	S
B. specifer	+	+			+				+			
B. conorum	+	+		+								
B. theobromae	+	+	+	+								
B. ribis	+	+										
C. cladosporioides	+	+			+							
H. dematioides	+	+	+	+								
P. infectoria	+	+										
S. sapinea	+	+										

[1] For genera, refer to TABLE 1

[2] For concentrations used consult text
H - hoop pine; S - slash pine

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DISCUSSION

The survey comprised just a single sampling at mills in winter and summer of the one year, so too many firm conclusions can not be drawn from this work. Two that appear valid are: there is a problem with pre-infection by sap-stainers in the log at most mills; and the Na PCP or captafol treatments given freshly sawn timber at the mill are not preventing fungal infection in seasoning stacks, even for one month. A wide range of fungi were isolated during the survey, eight of which were shown to be capable of causing sapstain; thus expanding the list of known sapstainers from Queensland. Undoubtedly there are many others a more comprehensive study would bring to light. Because only a small number of samples were collected overall, the survey gave no reliable indication of the relative importance of the various fungi. One unexpected result was a broader range of species was isolated from samples collected in winter. This was probably due to the 1982-83 summer being unusually dry and highlights the importance of observations over a longer period.

The laboratory studies on selected fungicides gave one explanation why the anti-stain treatments applied at the mills might not be effective: certain fungi in south-east Queensland may not be controlled by Na PCP or captafol at the concentrations used. They also suggested that MBT or MBT + TCMTB, and perhaps TCMTB, might be more effective. Some contamination by Trichoderma occurred in these studies, which appeared later during incubation and did not affect inoculations. This contamination occurred in all eight dishes of the captafol treatment, but only in four of the nil-fungicide treatment and in up to four of the other fungicide treatments, suggesting captafol may promote the development of Trichoderma, the only fungus found infecting captafol-treated timber in the first month of seasoning. We found evidence of this fungus causing sapstain, the pigmented spores being produced in sufficiently large voids in

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the wood. This work demonstrated the usefulness of laboratory studies in the evaluation of anti-stain chemicals, which should be considered as a necessary adjunct to field trials.

REFERENCES

1. Young, H.E. 1948. Blue stain in hoop pine logs. Qld. J. Ag. Sci. 5. 125-140.

2. Simmonds, J.H. 1966. Host index of plant diseases in Queensland. Publication of the Queensland Department of Primary Industries. Brisbane. 186 pp.

3. Miller, D.J. and Swan, S. 1980. Blue stain in sprinkled log decks and timber piles of Ponderosa pine. For. Prod. J. 30. 42-48.

THE USE OF ^{13}CCP/MAS NMR IN THE CHEMICAL IDENTIFICATION OF DECAYED AND UNDECAYED, TROPICAL TIMBER SPECIES

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ABSTRACT

^{13}C CP/MAS NMR has been found to be an extremely powerful tool for elucidating the chemical composition of *Eucalyptus maculata*, *Pinus elliottii* and *Alstonia scholaris*. The differences in lignin composition were different for each timber and discussed in relation to decay caused by soft-rot and white rot fungi. In particular the presence of syringyl and guaiacyl lignin types are discussed.

INTRODUCTION

Current knowledge on the chemical structure of wood has been mostly gained from studies of its components using wet chemical methods. The latter methods are destructive and result in structural changes to the isolated components. The

changes have been characterized by high resolution solid-state ^{13}C NMR (6). These studies were extended to study solid wood using high resolution solid-state ^{13}C NMR and cross-polarization magic-angle spinning techniques (CP/MAS) (4).

In the present study ^{13}C CP/MAS NMR has been used to examine the chemical structure of three tropical timber species commercially important in Queensland. The timbers were examined before and after decay by soft-rot, white rot and brown rot fungi.

MATERIALS AND METHODS

The sapwood of the hardwoods Eucalyptus maculata Hook (Spotted gum) and Alstonia scholaris R. Br. (Milky pine) and the softwood Pinus elliottii Engelm (Slash pine) were used in decay and ^{13}C NMR studies.

DECAY STUDIES

Small blocks (5 x 15 x 30mm) of each timber species were used to assess decay caused by the soft rot fungi Phialophora mutabilis Schol. Schwarz Phialophora sp A., the white rot fungus Trametes lactinea and the brown rot Serpula lacrymans. Test blocks were exposed for 12 weeks in vermiculite/mineral salts. The amount of decay was expressed as % weight loss.

^{13}C NMR

Ground samples of undecayed and decayed wood were examined in a Bruker CXP-300 spectrometer using an Andrews type, single coil magic-angle spinning probe. The solid-state ^{13}C NMR spectra were obtained under identical conditions. The method is not quantitative, but peak intensities within any spectrum may be compared on a relative basis.

RESULTS

UNDECAYED WOODS

The ^{13}CP/MAS/TOSS spectra of E. maculata, P. elliottii and A. scholaris are shown in Fig. 1.

The carbohydrates dominate the spectra, resonating in the region 60-110 ppm. Cellulose may be regarded as providing amophous and crystalline forms, providing two peaks for C_4 and C_6. The resonance at 62 and 64 ppm may be assigned to the amorphous and crystalline regions of C_6, respectively. Similarly, for the peaks at 84 and 89 ppm for C_4. The carbohydrate spectra are similar for the three timbers examined.

The lignin present can be assigned at 152, 148, 135, 123 and 56 ppm. The three timbers differ markedly in the spectra produced at these resonances. The aromatic methoxy groups may be assigned to 56 ppm, when it can be seen that A. scholaris and E. maculata especially, are more highly methylated than P. elliottii. The resonance at 135 ppm in all timbers and at 123 ppm in A. scholaris may be assigned to aromatic and methoxylated carbons. The lignin resonances at 152 and 148 ppm differ significantly in the three timbers.

The resonances at 148 and 152 ppm may be assigned to guaiacyl and syringyl respectively. The intensities of the reasonances allow assignment to be made to either guaiacyl and syringyl lignin types.

In E. maculata the spectrum indicates a syringyl type lignin dominating. This is in accord with angiosperm timber possessing syringyl lignin. In comparison the spectrum for P.elliottii exhibits guaiacyl lignin typical of gymnosperms. The specrum for A.scholaris is particularly interesting since it exhibits the presence of syringyl and more especially guaiacyl lignin in significant amounts. The distinct differences in lignin composition of the timbers may influence the delay caused by fungi.

DECAYED TIMBER

The % weight losses of the three timbers decayed by white and soft rot fungi were as follows:-

FUNGUS	TIMBER SPECIES		
	E. maculata	P. elliottii	A. scholaris
P. mutabilis	15.51	2.78	7.65
P.A.	3.25	2.15	7.12
T. lactinea	34.56	10.97	27.55

The spectra for decayed E. maculata, P. elliottii and A. scholaris are presented in Fig's. 2, 3 and 4.

The fungi caused a similar chemical alteration to E. maculata as can be seen in Fig. 2. The cellulose component was distinctly altered as evidenced by a loss in associated signal intensities. The alteration to lignin by the different fungi was very similar in effect. The lignin methoxy peak was reduced, whilst guaiacyl was lost.

In comparison to E. maculata, the spectra obtained for P. elliottii reveal little alteration to the chemical nature of the timber (Fig. 3).

The spectra for decayed A. scholaris were similar for the three fungi (Fig. 4). The major alteration was seen in the lignin peaks, when decayed by P. mutabilis and T. lactinea. The latter fungus also caused a marked decrease in intensity of peaks assigned to lignin.

Fungal decay in the timbers caused alterations to the chemical structure similar to that previously reported (2), (5) and (3). The spectra indicate that qualitatively soft-rot and white rot fungi are similar in their degrade of timber. This is consistent with previous work and illustrates the manner in which white rot fungi appear to remove the major wood components at a similar rate. This is supported by the observation that for white rot, high weight losses were accompanied by an overall reduction in peak intensities of the major components. In comparison, lower weight losses were caused by soft-rot fungi, but structural alterations were similar.

Unfortunately, spectra for S. lacrymans have not proved suitable at the time of writing and will be available at the Conference. It is expected that the spectra will indicate the different manner in which this group of fungi decay timber.

The information obtained on the structural analysis of three tropical timbers using ^{13}C NMR illustrates the potential of the technique. In particular, the chemical alteration to the timber may be easily seen, without the need for destructive analyses.

A significant finding in the present work is the difference in lignin composition between the timbers and its subsequent alteration during decay. Alteration through demethoxylation was found through reduction in intensity of peaks assigned to methoxy groups. Alteration to lignin assignments were also apparent in syringyl in E. maculata by all fungi; guaiacyl in P. elliottii and both types in A. scholaris by P. mutabilis and T. lactinea. The difference in lignin content in the three timbers may be considered together with weight losses caused by the fungi.

P. elliottii was decayed far less than A. scholaris and E. maculata. The latter timber suffering the highest weight losses. T. lactinea caused the highest weight losses for all timbers. These results are consistent with the suggestion that lignin is the major component restricting chemical alteration to timber by fungi (5). The guaiacyl content has been implicated in conferring resistance to timber from fungal degrade (1).

The specific lignin types present in timber may also influence preservative treatment. In CCA treated timber the guaiacyl lignin has been implicated as copper fixation sites. This would place conifer species at an advantage in terms of sum chemical reaction sites when treated with CCA. However, after CCA treatment, the hardwood A. scholaris exhibited excellent resistance to soft-rot (1). This indicates that the guaiacyl content is high enough to afford fixation of copper and resistance to soft-rot decay. The wood cell wall would possess a low syringyl to guaiacyl ratio, as is indicated by ^{13}C NMR. The presence of syringyl lignin may not affect the performance of CCA treated A. scholaris since the guaiacyl content (and copper fixation) is higher than the threshold allowing soft-rot decay.

It is obvious that the lignin content and composition affect decay by soft-rot and white rot fungi. Further work is required to clarify the role of the lignin types in conferring resistance to timber degrade and their activity during CCA treatments of hardwoods.

REFERENCES

1. Butcher, J.A. and Nilsson, T. (1982) Influence of variable lignin content amongst hardwoods on soft-rot susceptibility and performance of CCA preservatives. Inter. Res. Gr. on Wood Preserv. Document No. IRG/WP/1224.

2. Cowling, E.B. (1965) Chemical modification of wood during microbial deterioration. Mat. und Organismen, Beihefte 1, 13-26.

3. Kirk, T.K. (1973) Chemistry and biochemistry of decay. In: Nicholas, D. (ed.), Wood deterioration and its prevention by preservative treatments. p149-181. Syracuse Univ. Press.

4. Kolodzlejski, W., Frye, J.S. and Maciel, G.E. (1982) C^{13} NMR spectrometry with CP/MAS for analysis of lodge pole wood. Anal. Chem. 54, 1419-1424.

5. Levi, M.P. and Preston, R.D. (1965) A chemical and microscopic examination of the action of the soft-rot fungus Chaetomium globosum on Beechwood (Fagus sylv.). Holzforschung 19 (6), 183-190.

6. Maciel, G.E., O'Donnell, D.J., Ackerman, J.H., Hawkins, B.H. and Bartuska, V.J. (1981) A ^{13}C NMR study of four lignins in the solid state and solution state. Makromol. Chem. 182, 2297-2304.

FIG. 1. ^{13}C NMR SPECTRA FOR TIMBERS

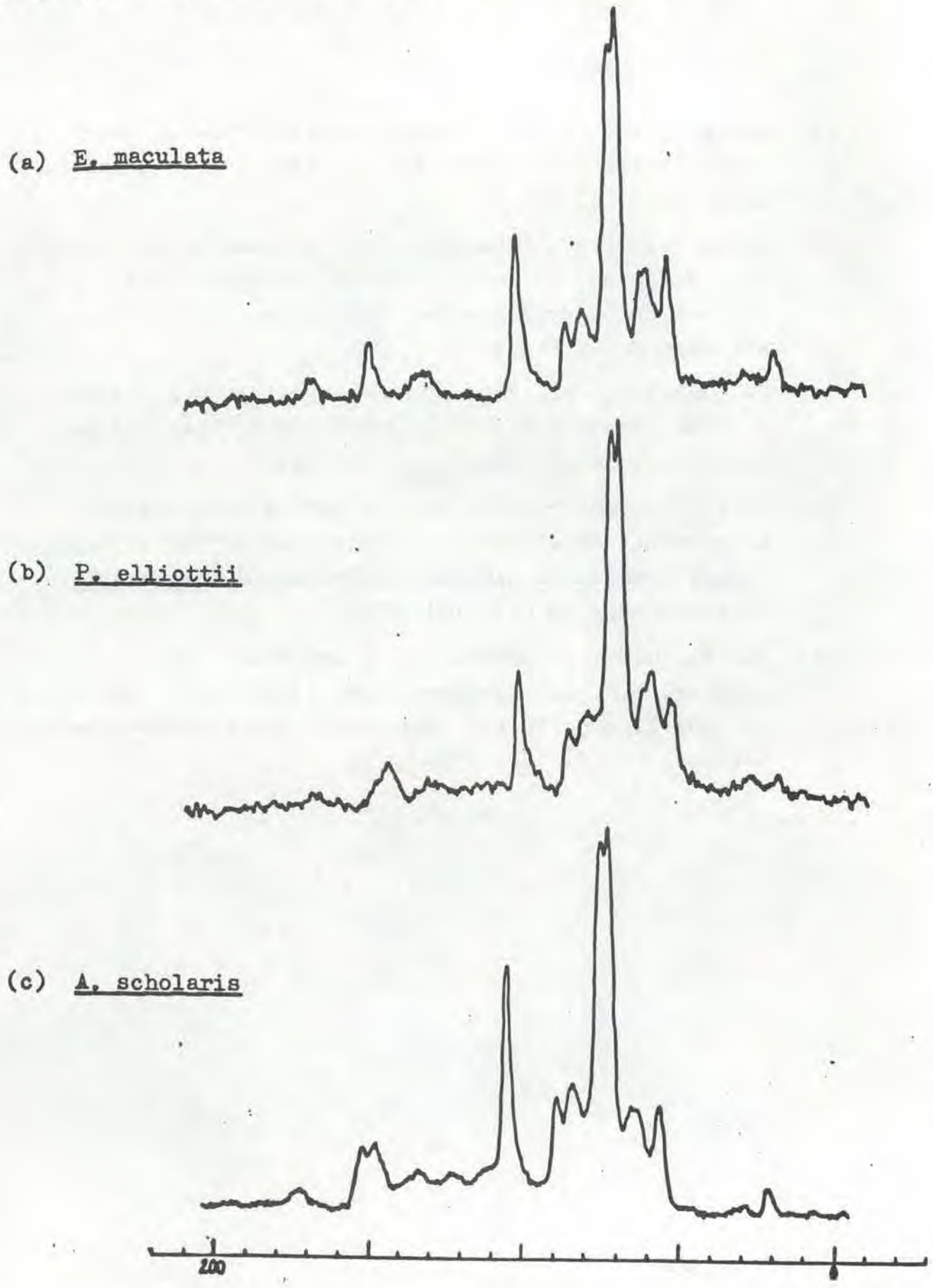


FIG. 2. ^{13}C NMR SPECTRA FOR E. MACULATA

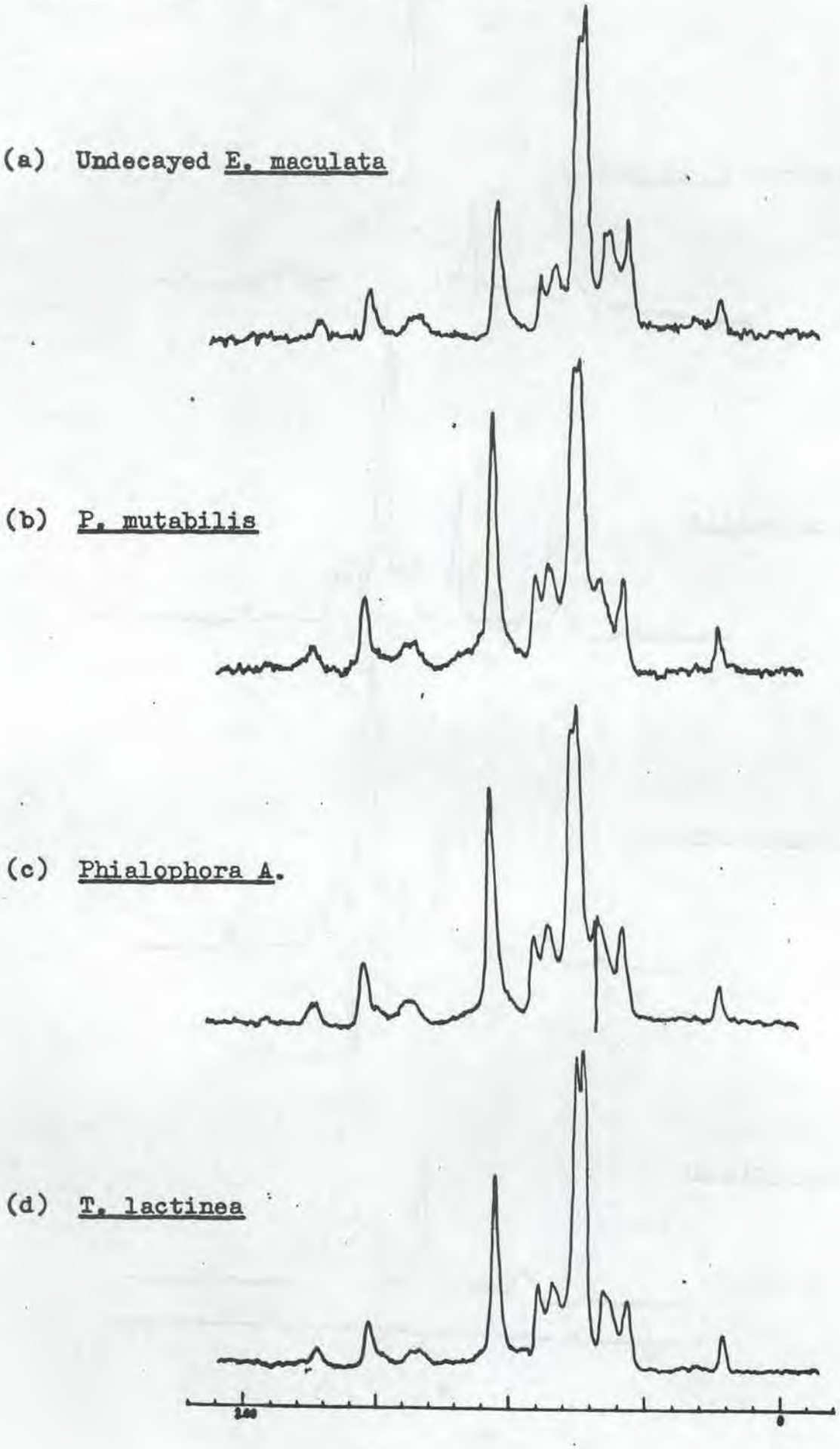


FIG. 3. ^{13}C NMR SPECTRA FOR P. ELLIOTTII

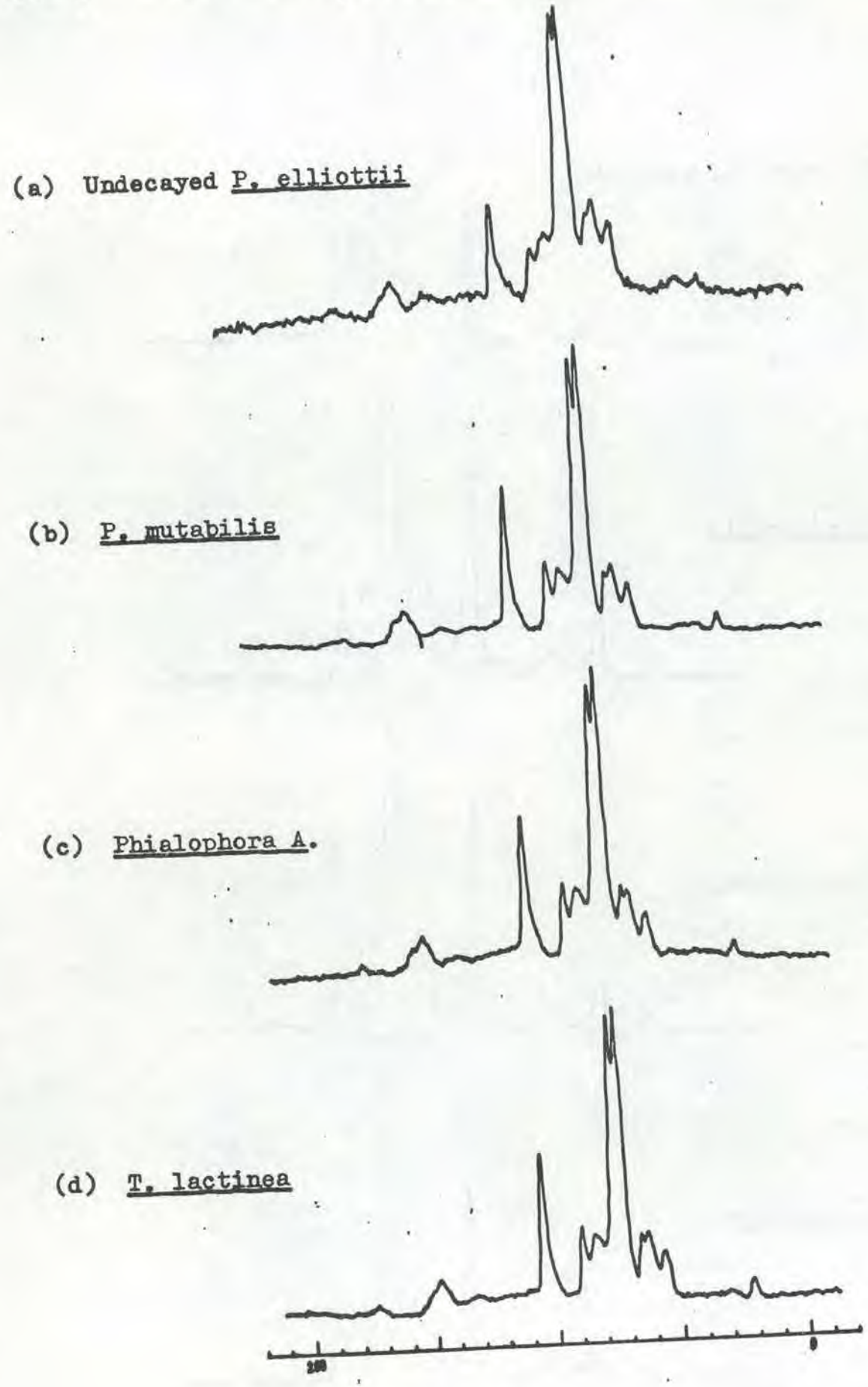
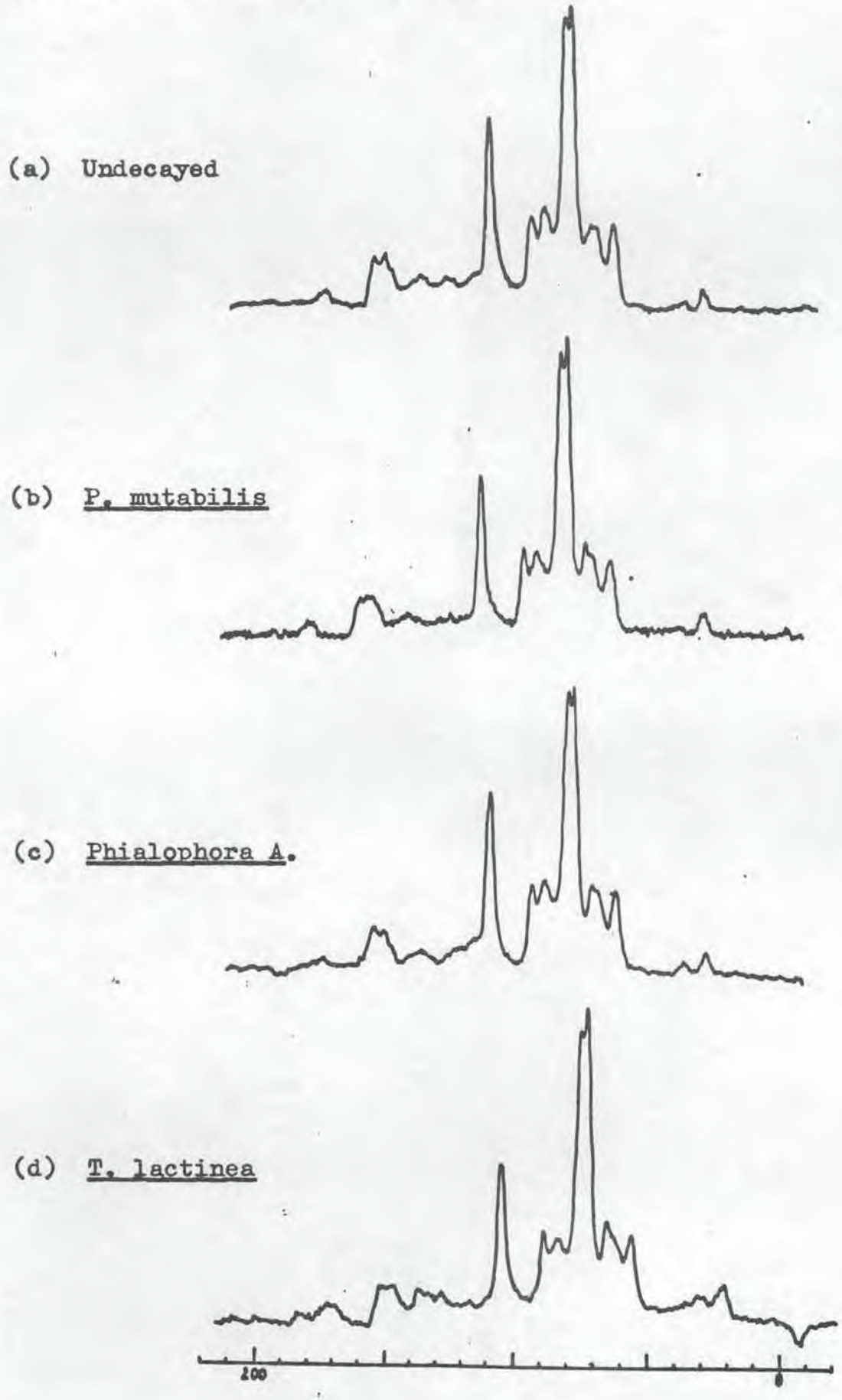


FIG. 4. ^{13}C NMR SPECTRA FOR A. SCHOLARIS



EDIBLE MUSHROOM PRODUCTION USING COMPOSTED SAWDUST

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ABSTRACT

The use of composted eucalypt sawdust has been examined as a substitute for imported peat moss in edible mushroom production. In initial laboratory trials yields achieved with the compost are comparable to those with peat moss.

INTRODUCTION

Each year in Australia, over 1 million cubic metres of eucalypt sawdust are produced as a waste product by the sawmilling industry. Traditionally, this sawdust has been disposed of either by burning, or by dumping. With the advent of stricter environmental controls the disposal of sawdust has become an increasingly serious problem. Hence interest in alternative uses of sawdust has increased. Our aim is both to solve a waste disposal problem and to produce a useful end-product from this material.

Various researchers have produced sawdust composts either by a combination of chemical and biological methods or by biological methods alone. Most of the literature reviewed on the uses of sawdust refers only to waste from European species of timbers. In Australia only a few investigations have been carried out on eucalypt sawdust. These include its use, with the addition of slow release fertilisers, as a soil conditioner; as an animal feed, as a fuel and more recently as a filler in bricks and acoustic tiles (9).

Taking environmental, conservation and cost factors into account it would seem desirable to use the sawdust at the sawmill as a substrate in a simple "on site" composting process. Our initial project endeavoured to determine the optimal conditions for composting sawdust, a material with an extremely high C:N ratio, low levels of essential elements and low inherent population of microorganisms. A previous study (9) indicated that composting in a well aerated drum or compostumbler(R) would be suitable. With such a system it is possible to control accurately aeration and moisture content and achieve peak heat in just a few days.

The question of when the composting process is finished has received some attention in recent years. Physical characteristics have been the criteria for compost maturity for many years, but the advent of accelerated composting systems has led to more sophisticated methods of determining maturity. These include pH determinations and sulphide test and radish seed growth trials. In the present study a combination of physical characteristics and growth studies with either radish seeds or *Agaricus bisporus* was used to determine maturity of the compost.

MATERIALS AND METHODS

1. ADDITIVES AND THEIR RATIOS

Several sources of organic and inorganic nitrogen were tested at several different concentrations. Other additives that were thought beneficial were also tested. Table 1 lists the mixtures used to determine the optimal levels of nitrogen and microorganisms.

TABLE 1

Ratios (V:V) of various components for determining optimal nitrogen and microorganism levels

Trial No.	Sawdust	Nitrogen	Soil	Other
1	45 messmate	-	-	
2	40 "	2 chicken manure	-	
3	40 "	2 " "	2 unsterile	
4	40 "	-	2 "	
5	40 "	4 chicken manure	4 "	
6	40 "	4 " "	4 sterile	
7	40 "	4 " "	4 unsterile	
8	40 "	-	4 "	
9	40 "	4 chicken manure	4 unsterile	
10	40 "	4 NH_4NO_3	4 "	
11	40 "	4 NH_4SO_4	4 "	
12	40 "	4 urea	4 "	
13	40 "	10 chicken manure	5 "	
14	40 "	6.7 " "	5 "	
15	40 "	5 " "	5 "	
16	40 "	4 " "	5 "	
17	40 "	8 " "	5 "	2 sugar
18	40 "	8 " "	5 "	2 sugar
19	40 "	8 " "	5 "	
20	40 "	8 " "	5 "	
21	40 "	8 " "	5 "	
22	40 "	8 " "	5 "	
23	40 mixed eucalypts	8 " "	5 "	
24	40 " "	8 " "	5 "	
25	40 messmate	8 " "	5 "	2 cannery waste
26	40 "	8 " "	5 "	2 " "
27	40 "	8 " "	5 "	2 " "
28	40 "	8 " "	5 "	2 " "
29	40 "	8 " "	5 "	
30	40 "	8 " "	5 "	
31	40 mixed hardwoods	8 " "	5 "	
32	40 " "	8 " "	5 "	

2. MATURITY OF THE COMPOST

Other authors have suggested various testing methods for determining the maturity of compost (9,11,15,18,19). Initially, in this study the maturity of the end-product was judged both by the appearance of the mass and by its ability to support the growth of radish seeds or bean seeds. Both soil and freshly-cut sawdust were used as controls. Replicate samples of each compost and the controls were placed in glass petri dishes or

planter pots and moistened. Radish seeds or bean seeds were sprinkled onto the samples and daily records of germination and amounts of growth were made. In later trials certain of the compost mixes[1] were used as a casing material[2] for *Agaricus bisporus* fruit body production. Ten replicates of each compost were set up in small (350 mm x 280 mm) trays. Commercially composted and spawned substrate was spread in each tray and allowed to colonise. After colonisation was optimal ten replicate boxes were cased with a number of different ages of composted sawdust. Picking was done daily when the cap diameter was 40 mm or more. Both total wet weight and numbers of fruit bodies were recorded and mass/mushroom calculated. Control boxes using either peat moss or uncomposted sawdust were included.

RESULTS

1. ADDITIVES AND THEIR RATIOS

Of all the mixtures tested those containing chicken manure as a nitrogen source achieved peak heat faster and gave a better end product in regard to maturity and suitability as a supporter of growth of radish or bean seeds or as a casing for the mushroom *Agaricus bisporus*.

Additives such as cannery waste, while accelerating the initial heating up of the mix produced an end product that proved less suitable as a casing.

2. MATURITY OF THE COMPOST

Although several more trials using the composted sawdust as a casing are required, results to date indicate that the compost needs to be well aged before it is suitable for use as casing material (see Table 2).

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[1] Selection based on physical characteristics, seed germination trials, etc.

[2] A layer of inert material placed on top of colonised substrate which induces fruiting.

TABLE 2

Yields of *Agaricus bisporus* produced from various casing materials. (Trials 29 and 30) and controls (Average of ten replicates)

Casing	Total wet wt. of picked mushrooms g/box	No. of fruiting bodies No./box	Av mass/mushroom g/unit
Sawdust	36	1	23
Peat moss	477	37	14
28 day old compost	143	5	29
60 day old compost	356	32	11
120 day old compost	401	28	14

DISCUSSION

Much of CSIRO's effort to date has been to utilize a waste product (i.e. sawdust) to both relieve a disposal problem and to produce a useful resource. Our success in simply and cheaply composting the sawdust then led to an investigation of its use as a replacement for peat moss as a casing for *Agaricus bisporus*. Mushrooms are a useful bioassay organism as they grow quickly and are very susceptible to toxins in the sawdust. Table 2 shows the very low yield when sawdust alone is used. As the composting process proceeds the sawdust loses its toxicity and the material is more suitable as a casing. Results from the casing tests, while not complete, are encouraging. The yields achieved on both 60 day old and 120 day old composted sawdust are comparable to those achieved on peat moss. One advantage of the composted sawdust is its neutral pH. Peat moss itself is quite acid and requires the addition of lime before it can be used as casing. While more research will be done on a substitute for peat moss we feel that some investigation is urgently needed into other edible fungi. A literature search to ascertain the progress made in cultivating alternative edible species showed that remarkable little research has been done that could be exploited commercially in Australia (4,12,17). One review (4) states "... there is a need to promote the cultivation of mushrooms, especially to introduce more varieties ...". Species such as *Pleurotus* have an added advantage in that they can be grown on a variety of agricultural and industrial wastes. Our initial efforts in this area will concentrate on shiitake (*Lentinus edodes*). Shiitake is the major edible mushroom in Asia and is Japan's major agricultural export.

ACKNOWELDGEMENTS

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REFERENCES

1. Chang, S.T. and Miles, P.G. 1984. A new look at cultivated mushrooms. Bioscience Vol. 34, No. 6 358-362.

2. Jann, G.J., Howard, D.H. and Salle, A.J. 1960. Method for determining completion of composting. Compost Sci. 1: 31-34.

3. Keller, P. 1961. Methods to evaluate maturity of compost. Compost Sci. 2: 20-26.

4. Leatham, G.F. 1982. Cultivation of shiitake, the Japanese forest mushroom, on logs: a potential industry for the United States. Forest Products Journal Vol. 32(8): 29-35.

5. Poincelot, R.P. 1972. The biochemistry and methodology of composting. Conn. Agric. Exp. Sta., Bull 727.

6. San Antonio, J.P. 1981. Cultivation of the shiitake mushroom. Hortscience 16(2): 151-156.

7. Spohn, E. 1969. How ripe is compost? Compost Sci. 10(3): 24-26.

8. Spohn, E. 1978. Determnation of compost maturity. Compost Sci/Land Util.

9. Tighe, M.A. 1980. Microbial aspects of composting eucalypt sawdust. M.Sc. (Prelim) Thesis.

10. Whiteside, P. Gardening the natural way. Osborne Metal Industries. Instruction Booklet accompanying tumbler.

EFFICACY OF FIRE RETARDANTS ON THE EARLY FIRE HAZARD OF TIMBER AND WOOD-BASED PANEL PRODUCTS

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ABSTRACT

The treatment of timber and wood-based panel products with fire retardants has permitted their use in applications where regulations require specific fire hazard performance. The influence of some veneers, laminates, surface coatings and fire retardant chemicals on the Early Fire Hazard of various timber and wood-based panel products is discussed. Ongoing research is necessary if these products are to be used with safety.

INTRODUCTION

The treatment of timber and wood-based panel products with fire retardants has permitted their use in architectural applications where regulations require a specific fire hazard performance. In order, however, for timber and wood-based panel products to retain a position as finishing and lining materials in public halls, schools, hotels, motels, blocks of flats and other buildings, to the fire safety provisions of Ordinance No. 70 (7), there is a need for research into the early burning properties of timber and wood-based panel products, and how these properties are affected by veneers, laminates, surface coatings and fire retardant chemicals.

In 1980, the Wood Technology and Forest Research Division commissioned equipment for determining the early burning properties of these materials according to Australian Standard 1530, Pt.3 "Test for Early Fire Hazard Properties of Materials" (8). The early burning properties of a material when determined by this test are described by four Reaction to Fire parameters: time to ignition, heat evolved integral, flame spread time and optical density of

smoke developed. These parameters are used to derive the respective Early Fire Hazard Indices:

II - Ignitability Index
HE - Heat Evolved Index
SF - Spread of Flame Index
SD - Smoke Developed Index

Ignitability Index is rated on a scale 0-20, whilst the others are rated on a scale 0-10. Higher indices signify a higher Early Fire Hazard. It is important to note that these indices are inter-related, as they are obtained as a result of a single fire test.

This paper gives a brief outline of the Early Fire Hazard research carried out by W.T.& F.R.D. since the equipment was commissioned.

EFFICACY OF AN AMINO RESIN FIRE RETARDANT

The inorganic salts which have been commonly used as fire retardants have several disadvantages:-

(i) the salts are readily leached from the wood;
(ii) the occurrence of surface blooming can affect the paintability of the treated wood;
(iii) the salts may be hygroscopic;
(iv) corrosion of metal fixtures in treated wood may be increased; and
(v) treatment may affect the appearance of the wood.

An amino resin fire retardant, developed by Eastern Forest Products Laboratory, Canada, and having a basic formula of urea: dicyandiamide: formaldehyde: phosphoric acid (1:3:8:4), is claimed to be leach resistant, non-blooming, non-hygroscopic, decay resistant, and to have no effect on the appearance of the wood (2), (3), (4), (5). The amino resin may therefore have potential within the Australian Forest products industry for use as a fire retardant in situations exposed to the weather.

To assess the efficacy of the resin as a fire retardant, boards of *Pinus radiata* were machined to 600 x 90 x 12mm and graded into groups consisting of backsawn heartwood, quartersawn heartwood, backsawn sapwood, quartersawn sapwood, quartersawn mixed heartwood/sapwood and backsawn mixed heartwood/sapwood.

These boards were treated with solutions of 20%, 12% and 4% w/w resin in water, and test panels consisting of boards having similar retentions from each above group were constructed. The early burning properties of the panels were then determined according to AS1530, Part 3.

Scattergrams of each Reaction to Fire parameter except flame spread time were plotted against average resin retention. Flame spread time was not plotted because few treated panels registered any flame spread. No trend was evident for optical density of smoke developed except that it increased markedly with resin retentions greater than about 40 $kg.m^{-3}$. Trends were evident for time to ignition and heat evolved integral (Figs. 1 and 2).

Regression equations of time to ignition versus average resin retention were calculated for various combinations of the timber groups listed above. The equation with the greatest application to industry is that for all timber groups combined, shown in Fig. 1. The high correlation coefficient obtained shows that the time to ignition of treated *P. radiata* boards, irrespective of direction of cut or heartwood/sapwood content, could be accurately predicted by measuring retention. From Fig. 1, it is apparent that the resin does not retard ignition until the average retention becomes greater than about 40 $kg.m^{-3}$.

Similarly, regression equations of heat evolved integral versus average resin retention were calculated for various combinations of the timber groups. Combining the data for all timber groups again yielded an equation with a very good fit (Fig. 2). This equation could be used for predicting the heat evolved integral of *P. radiata* boards irrespective of direction of sawing or sapwood/heartwood content. The confidence limits in Figs. 1. and 2. are those for the average performance which would be expected upon testing a number of panels of similar average resin retentions.

The amino resin is an effective fire retardant in either sapwood or mixed heartwood/sapwood boards of *P. radiata*, irrespective of direction of sawing. Studies on the resin's leach resistance and fungicidal efficacy are underway, and the results will be published in a forthcoming paper.

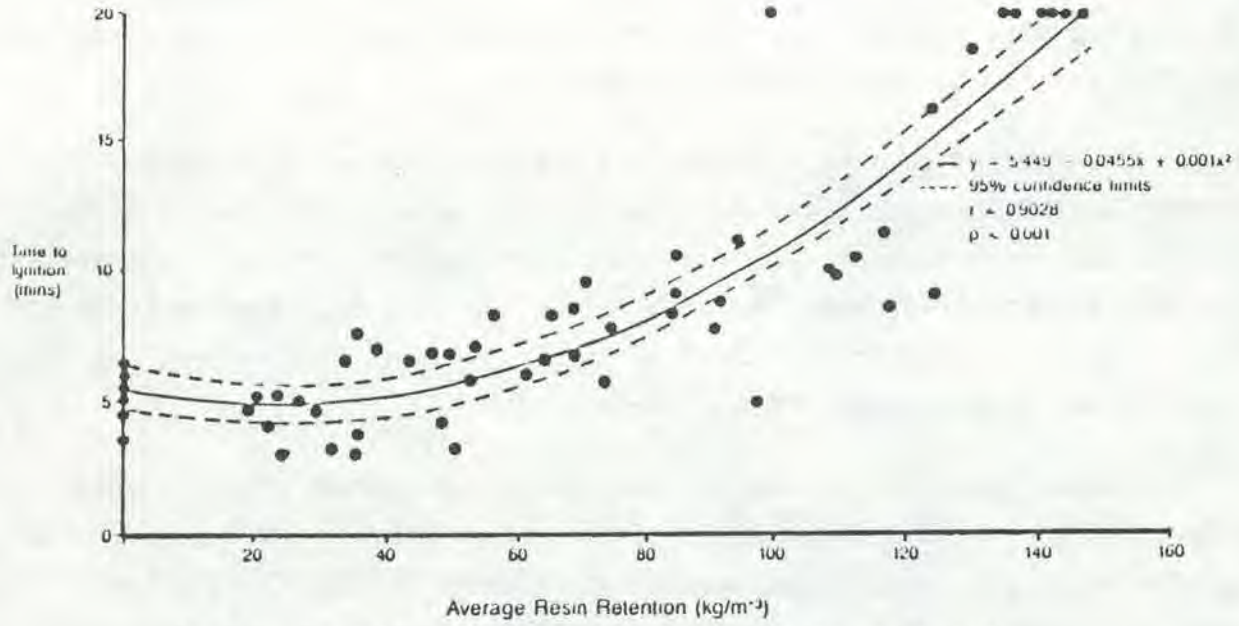

Figure 1. Effect of amino resin retention on time to ignition for sawn radiata pine.

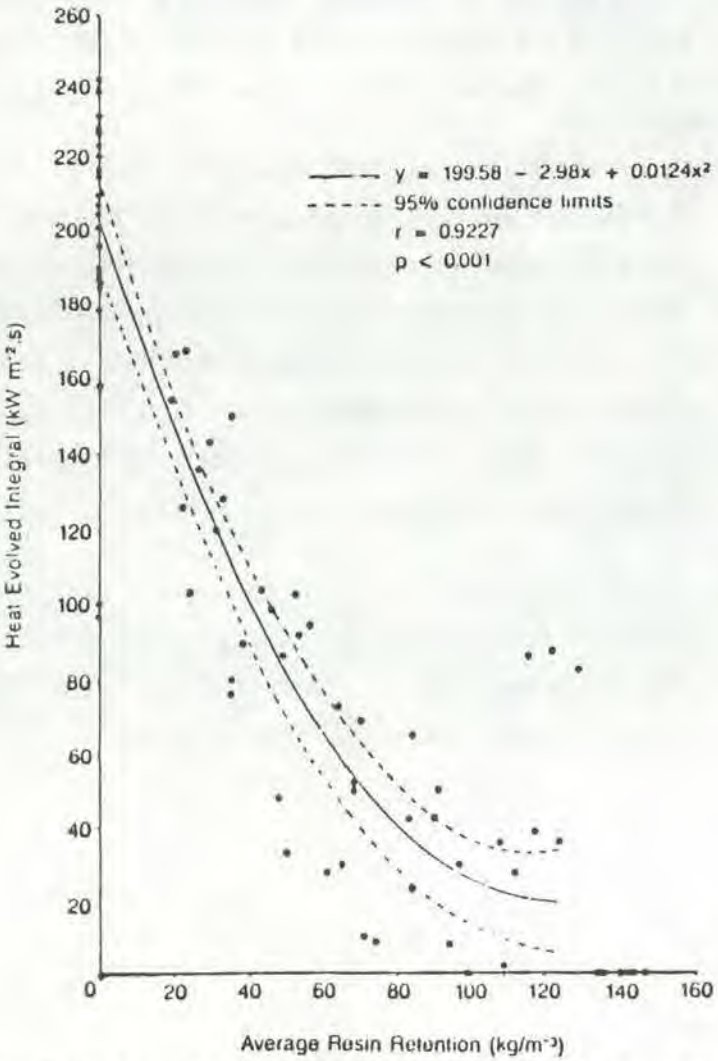

Figure 2. Effect of amino resin retention on heat evolved integral for sawn radiata pine.

EFFECT OF LAMINATES, SURFACE COATINGS AND VENEERS ON THE EARLY BURNING PROPERTIES OF WOOD-BASED PANEL PRODUCTS

(a) FACTORS AFFECTING THE EARLY BURNING PROPERTIES OF PARTICLEBOARD

The increasing use of particleboard products as components of interior furnishings have highlighted the need for a better understanding of the properties of particleboard that affect its early burning properties. A representative range of commonly used particleboard products were tested to AS1530, Pt. 3. The results indicated that the early burning properties of particleboard may be influenced by a number of factors. For particleboards of similar composition, it appears that:

(i) thicker particleboard has a reduced Early Fire Hazard when compared to thinner particleboard;

(ii) applying a white acrylic coating to thin particleboard will delay the time to ignition and decrease the heat evolved, but will cause an increase in both flame spread and development of smoke;

(iii) the effect of melamine coatings depends on colour -

  (a) a white melamine coating will delay the time to ignition, but increase the development of smoke,

  (b) a brown melamine coating may decrease the heat evolved and spread of flame, when compared to particleboard without a melamine coating.

(iv) on flooring grade particleboard, a wattle-tannin with urea-formaldehyde surface adhesive may reduce the ignitability and development of smoke when compared to a phenolic surface adhesive.

(b) EFFICACY OF FIRE RETARDANT SURFACE COATINGS AND LAMINATES

It is not usually practicable to treat wood-based panel products such as particleboard with fire retardant chemicals using vacuum-pressure impregnation techniques. Also, occasions arise when the Early Fire Hazard of materials which are already in service needs to be reduced. The efficacy of two forms of treatment which can be applied to a wider range of substrates whilst they are in service were studied. The treatments consisted of coating with an intumescent paint and overlaying with a fire retardant grade laminate.

Intumescent paints are readily leached by water, rendering them unsuitable for exterior use. If the intumescent paint is protected by a subsequent acrylic

coating, however, it may be possible to effectively use intumescent paints outdoors. The early burning properties of 18 mm standard particleboard coated with Dulux "Firebrake" intumescent paint by itself, Dulux "Timber Colour" acrylic stain in Mission Brown by itself, and intumescent paint overcoated with the acrylic stain were determined by testing to AS1530, Pt. 3. Table 1 indicates that a single coating of the intumescent paint (applied at the rate of 4-5m^2/L was a very effective fire retardant. No additional benefit was obtained by applying a second coat. Applying a subsequent coating of acrylic stain (at the rate of 16m^2/L) did reduce the efficacy of the intumescent paint, but particleboard treated with this combination still constituted a greatly reduced Early Fire Hazard when compared to untreated particleboard or particleboard coated only with the acrylic stain.

TABLE 1
Results for Intumescent Paint

Treatment	Early Fire Hazard Indices			
	II	ME	SF	SD
Nil (Control)	15	6	7	3
One coat Timber Colour	15	8	8	3
One coat Firebrake	9	0	0	4
Two coats Firebrake	9	0	0	4
One coat Firebrake plus one coat Timber Colour	12	0	0	4
Two coats Firebrake plus one coat Timber Colour	16	1	0	4

Formica FS4 fire retardant grade laminate was bonded to 18 mm and 3.6 mm standard particleboard using three brands of contact adhesive and one brand of urea-formaldehyde adhesive, all specified as being suitable by Formica Plastics Pty. Ltd. The panels were then tested to AS1530, Pt.3, except that the number of replicates was less than that specified in the standard. Delamination occurred in all panels, exposing the adhesive film and particleboard substrate. The results for 18 mm particleboard indicate that the laminates retard ignition whilst they remain an effective barrier to radiation, but once delamination and cracking occurs, the particleboard substrate and adhesive film ignites, yielding

greater heat and a faster spread of flame than the control panels. The Early Fire Hazard of 3.6 mm particleboard was reduced by the laminates, however, as they offered some protection even after delamination had occurred.

(c) EFFECT OF UNTREATED FACE VENEERS ON FIRE RETARDANT TREATED PLYWOOD

Fire retardant treated plywood destined for decorative use is sometimes manufactured using treated back and core veneers overlaid with face veneers that have not been treated with fire retardants (1). This is done to avoid any undesirable colour changes or staining that may be exhibited by the treated veneers. This practice may adversely affect the early burning properties of the plywood. Overseas research in this field has given inconsistent results that differ according to the method used (6).

The Early Fire Hazard of treated and untreated 6 mm (3 ply) and 9 mm (5 ply) Lauan structural plywood was determined by testing to AS1530, Pt.3. Results are given in Table 2. Overlaying untreated face veneers on fire retardant treated plywood resulted in substantially higher Heat Evolved and Spread of Flame Indices. In fact, spread of Flame Index became identical to that of the wholly untreated controls, indicating that the fire retardant present in the back and core veneers had no effect in retarding flame spread over the untreated face veneer.

(d) EFFECT OF CLEAR LACQUERS ON THE EARLY BURNING PROPERTIES OF WOOD-BASED PANEL PRODUCTS

Clear finishes are widely used to enhance and protect interior timber and wood-based panel products. Work was carried out to evaluate the influence of two commercially available clear lacquers, one a conventional nitrocellulose and the other a water-based, acrylic system, on the early burning properties of wood-based panel products.

Three panel products (4 mm, 3 ply *Shorea* plywood; 15 mm particleboard with 0.6 mm Tasmanian Oak face veneer; and 5mm standard hardboard) were tested in lacquered and unlacquered states to AS1530, Pt.3. The results demonstrated that both lacquers increased the Early Fire Hazard of the three substrates tested. The increase was slight with the acrylic lacquer, but quite serious with the nitrocellulose lacquer.

TABLE 2

Results for Untreated Face Veneers

Fire retardant treatment	Thick-ness (mm)	Early Fire Hazard Indices II	HE	SF	SD
Fully treated plywood	6	13	2	0	5
	9	13	0	0	5
Untreated face veneers	6	13	7	9	3
	9	13	6	9	4
Nil(Controls)	6	14	10	9	4
	9	14	10	9	3

Further tests were carried out using the same lacquers on fire retardant treated plywood. The efficacy of the fire retardant treatment was reduced by the application of either lacquer. Application of the nitrocellulose lacquer to the fire retardant treated plywood had a major effect on the ignitability of those panels. When applied to treated plywood overlaid with untreated face veneers, the nitrocellulose lacquer also increased the rate of flame spread. Application of the acrylic lacquer to the fire retardant treated plywood had a lesser effect on ignitability than did the nitrocellulose lacquer, but greatly increased the heat evolved from those panels once ignition had occurred.

CONCLUSIONS

The above results indicate the effect that some veneers, laminates, surface coatings and fire retardant chemicals may have on the early burning properties of various timber and wood-based panel products. If timber and wood-based panel products are to be used safely and effectively in situations requiring specific Early Fire Hazard performances, a continuing study of factors that affect their early burning properties is necessary.

ACKNOWLEDGEMENTS

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REFERENCES

1. Chen, C.M. 1975. "Gluing Study of Pyresote-Treated Fire-Retardant Plywoods. Part 1." For. Prod. J. 25(2): 33-37.

2. Juneja, S.C. 1972. "Stable and leach resistant fire retardants for wood." For. Prod. J. 22(6):17-23.

3. Juneja, S.C. and Richardson, L.R. 1974. "Versatile fire retardants from amino resins." For. Prod. J. 24(5):19-23.

4. Juneja, S.C. and Shields, J.K. 1973. "Increased fungal resistance of wood treated with modified urea-based fire retardant resins." For. Prod. J. 23(5):47-49.

5. King, F.W., and Juneja, S.C. 1974. "New fire retardant treatment for western red cedar shingles." For. Prod. J. 24(2):18-23.

6. Larsen, M.L. and Yan, M.M. 1969. "Meeting Fire Hazard Requirements with Wood-Base Panelboards." For. Prod. J. 19(2): 12-16.

7. New South Wales - Parliament. Local Government Act (1919). Ordinance 70 (1973). Part 16.

8. Standards Association of Australia. 1976. AS1530, Part 3. "Test for Early Fire Hazard Properties of Materials." North Sydney.

THE OCCURRENCE OF *LIMNORIA* IN AUSTRALIA

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There are about twenty different species of the marine wood-boring crustaceans *Limnoria*. Perhaps the best known species is *L. tripunctata* Menzies, largely because it can cause premature failure of creosote-treated timber in warm temperate waters (Hochman *et al.*, 1956). These timbers are used extensively as piles in America. Although *Limnoria* is common around Australia's coastline (Anon., 1972), the only species identified has been *L. tripunctata* from Sydney Harbour (Jones *et al.*, 1972). Many early Australian publications (e.g. Iredale *et al.*, 1932; Watson *et al.*, 1936) referred to *L. lignorum* (Rathke); however, this occurrence has yet to be confirmed for Australia. Prior to the comprehensive review on limnoriid taxonomy by Menzies (1957), few species were recognised and most limnoriids were called *L. lignorum*. It is now known that *L. lignorum* occurs mainly in cold waters such as in the Arctic-boreal region (Menzies, 1957). Recently, *L. quadripunctata* Holthuis was found at Hobart and (in association with *L. tripunctata* and *L. indica* Becker and Kampf) at Goat Island, Sydney, attacking various CCA-treated hardwoods and radiata pine (Barnacle *et al.*, 1983). *L. tripunctata* and, more commonly, *L. quadripunctata* have been recorded from New Zealand (McQuire, 1965).

Because the success of timber preservative/protection systems in a particular port is often greatly influenced by the species and activity of marine borers present, a knowledge of the distribution of *Limnoria* in Australia is being sought.

This paper reports the species of wood-boring limnoriids so far identified (in the absence of a detailed survey), from a limited number of sites. The following table summarises the specimens identified and the structure or timber from which they were recovered.

Distribution of *Limnoria* in Australia

Site	State	Date collected	Where found and comments
(i) *L. quadripunctata*			
Hobart	Tas.	Dec. 1981	*E. globulus* pile (unknown age), 12 yr old CCA-treated (32 kg/m^3) *E. obliqua* pile, 10 mm deep holes in patches by *Limnoria*, light teredinid.
Williamstown (Hobson's Bay)	Vic.	Feb. 1983 Apr. 1983	Boat keel *P. radiata* bait block, 60 cm below water (attached to float).
Lakes Entrance	"	May 1983	Boat, 1 cm deep in wood adjacent to caulking.
Brighton	"	May 1983	Red gum piles, 50-60 yr old, destroyed *Limnoria* and teredinid. *Limnoria* from midtide to mudline (about 4 m deep).
Sandringham	"	Apr. 1983	*E. pilularis* cross brace, in tidal zone, destroyed *Limnoria*. In eucalypt piles, to mudline (3 m deep).
Port Welshpool	"	Aug. 1983	Stringybark - probably messmate - pile in No. 2 light. Hit by boat. Built 1939, renovated 1951.
Point Cook	"	Sept. 1983	Eucalypt, 5 m deep (from low tide).
Queenscliff	"	" "	Huon pine from sunken ferry, in water less than 10 years, 4.3 m deep.
		Dec. 1983	*P. radiata* bait block, 30 cm below low tide after 6 weeks.
St Kilda	"	Oct. 1983	Eucalypt pile
Cape Woolami	"	" "	Eucalypt pile from launch ramp.
Hastings	"	Nov. 1983	Grey gum pile from slipway.
Port Arlington	"	Feb. 1984	Red gum piles, more than 50 yr old, midtide to mudline (3 m deep).
Hanns Inlet, HMAS Cerberus	"	July 1984	Eucalypt pile, tidal zone.
Rhyll, Phillip Island	"	" "	*E. obliqua* pile, 37 yr old, from low tide zone.
Inner Harbour, Pt Adelaide	SA	Dec. 1983	*P. radiata* bait block, 30 and 60 cm below low tide, after 6 weeks.

Sydney	NSW	Dec. 1982 Nov. 1983	Untreated and CCA-treated timbers: small specimens just below low tide.
(ii) *L. tripunctata*			
Williamstown	Vic.	July 1935	Dockyard and pier.
Williamstown (Hobson's Bay)	"	Apr. 1983	*E. obliqua* cross brace in tidal zone. *P. radiata* bait block, 30, 60 and 150 cm below a float. Heaviest attack 1.5 m below float (near mud at low tide).
Sandringham	"	Apr. 1983	*E. pilularis* cross brace, in tidal zone, destroyed *Limnoria*.
Hanns Inlet	"	July 1984	Eucalypt pile, tidal zone.
Rhyll	"	" "	*E. obliqua* pile, 37 yr old, from low tide zone.
Arno Bay	SA	Dec. 1983	*P. radiata* bait block, 30 cm below low tide.
Tumby Bay	"	" "	*P. radiata* bait block, 60 cm below low tide.
Albany	WA	" 1961	-
Geraldton	"	Oct. 1961	-
Bunbury	"	May 1961	-
Roebourne	"	Apr. 1961	-
Port Hedland	"	Sept. 1961	-
Sydney	NSW	Dec. 1982 Nov. 1983	Untreated and preservative treated timbers.
Port Stephens	"	Nov. 1983	Untreated and preservative treated timbers.
Bowen	Qld	May 1984	Double treated *Araucaria* sp. (hoop pine) attack around knot after 12 years.
Cairns	"	May 1984	*E. maculata* treated with 5% arsenic in HTC, after 10 years.
(iii) *L. indica*			
Sydney	NSW	Dec. 1982 Nov. 1983	Untreated and CCA treated timbers: small specimens just below low tide.
Port Douglas	Qld	May 1984	*S. glomulifera* pile, light attack after about 12 years.

L. quadripunctata is an ubiquitous species, which, according to Menzies (1959) is found everywhere in the world where the sea water temperature averages between 11.4°C and 16.2°C for at least five successive months of the year. In Australia, this species is most common on the southern coastline, occurring in South Australia and from Hobart to Sydney. Sydney approaches the northerly limit for this species. In November 1983, fewer specimens of *L. quadripunctata* were found in Sydney than in December 1982, and none have yet been found at Port Stephens. At Sydney, the mean surface water temperature is about 23°C in February, and 17°C in August (Knox, 1963).

L. tripunctata is also found worldwide, preferring warmer waters than *L. quadripunctata*. In Australia, this species has been found in various sites south of, and including, Port Hedland and Cairns. Victoria may approach the southerly limit for *L. tripunctata*. It is not yet known if it occurs in Tasmania, where the surface water temperature range is between about 11°C and 15°C (Knox, 1963). *L. tripunctata* does not breed at 10°C, although some breeding occurs at 15°C (Beckman and Menzies, 1960). On the east coast of America, *L. tripunctata* was found at Massachusetts, which is about the northerly limit for this species. The mean annual sea water temperature at Massachusetts is about 11°C, and for five months of the year it rises above 15°C (Beckman and Menzies, 1960). It is noteworthy that in Victoria, *L. tripunctata* has so far only been taken mainly from the slightly warmer upper water layers, whereas *L. quadripunctata* has also been found down to 5 m, i.e. the greatest depth from which destroyed wood has been collected.

L. indica occurs at Sydney and Port Douglas (and possibly between these sites). *L. indica* has previously been recorded from Madras in India, Hong Kong, and the Philippines (Kühne, 1976).

Creosote-treated blocks of *Pinus radiata* have failed due to *Limnoria* (probably *L. tripunctata*) within ten years at Sydney and Kwinana. However, creosote-treated *P. radiata* piles are reported to be in good condition in South Australia after 12 to 20 years (L. Pitcher pers. comm., 1984), even though *L. tripunctata* has been found in South Australia. The difference in performance between these sites appears to be due mainly to differences in

water temperature and thus borer activity. The mean annual temperature in South Australia is about 16°C (range = 14-19°C) and in Sydney is about 20°C (range = 17°-23°C) (Knox, 1963). According to Vind and Hochman (1961), when the mean annual water temperature does not exceed 15°C to 16°C, creosote-treated softwoods may last more than 25 years.

Some creosote-treated and double-treated eucalypts are much more resistant to *L. tripunctata* than similarly treated softwoods. For example, creosote-treated sapwood (320 kg/m^3) of red stringybark (*Eucalyptus macrorhyncha* F.Muell. ex Benth.) remains unattacked after 24 years at Sydney Harbour. At Baker's Marina in Pittwater at Bayview, Sydney, double-treated piles of spotted gum (*E. maculata* Hook) remain in good condition after 12 years (R. Garland, pers. comm., 1984).

In the tropical-subtropical regions of Australia (north of approximately Brisbane and Carnarvon), *Limnoria* attack appears to be much less severe than in temperate regions, even though the hazard from marine borers, in general (e.g. *Martesia*, Teredinids, *Sphaeroma*), is higher in the more northerly regions. The light attack produced by *Limnoria* in this area may indicate that other borers attack susceptible wood before *Limnoria* can become established, or that there is a lower population of *Limnoria* in this region, or that the dominant limnoriid species is less destructive than their more southerly relatives. Breeding by *L. tripunctata* is retarded at temperatures above about 28°C (Kampf, 1957); these temperatures are reached in the tropical regions of Australia. This factor was used by Becker and Kampf (1959) to explain the meagre occurrence of *Limnoria* in Indian waters.

Approximately 3000 to 4000 eucalypt piles have been treated with CCA in Tasmania. Some attack by *L. quadripunctata* has been found in CCA-treated (32 kg/m^3) messmate piles pulled from Hobart after twelve years (Barnacle *et al.*, 1983); however, some of these piles were considered good enough for re-use as mooring dolphin piles. Other similar piles are still in good condition after 23 years at the mouth of the Tamar River in Tasmania. These results indicate that the hazard from *Limnoria* is lower in the southern waters than at Sydney and Kwinana where CCA-treated eucalypts have been heavily attacked after ten years.

It should be remembered that temperature and salinity, and thus marine borer hazard, can change near a particular pier when, for example, warm effluent is released from factories, or water diversions such as dams and irrigation systems are made up-river.

At a recent workshop, primarily for harbour engineers, the participants indicated that more comprehensive data on marine borer distribution in Australian waters is required, essentially as a pre-requisite for more appropriate protection systems. We agree with that view.

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REFERENCES

Anonymous 1972. Survey of marine borers, 1970-1972 Report. CSIRO and The University of New South Wales.

Barnacle, J.E., Cookson, L.J. and McEvoy, C.N. 1983. *Limnoria quadripunctata* Holthius - a threat to copper-treated wood. Internat. Res. Group on Wood Preserv. Doc. No. IRG/WP/4100.

Becker, G. and Kampf, W.D. 1959. The wood-destroying isopod genus *Limnoria* at the continental coast of India and description of *Limnoria indica* sp. n., J. Timb. Dryers and Pres. Assoc., India 5: 12-17.

Beckman, C. and Menzies, R. 1960. The relationship of reproductive temperature and the geographical range of the marine woodborer *Limnoria tripunctata*. Biol. Bull. 118: 9-16.

Hochman, H., Vind, H., Roe Jr., T., Muraoka, J. and Casey, J. 1956. The role of *Limnoria tripunctata* in promoting early failure of creosoted piling, Technical Memorandum M-109. US Naval Civil Engineering Laboratory, Port Hueneme, California.

Iredale, T., Johnson, R.A. and McNeill, F.A. 1932. Destruction of timber by marine organisms in the Port of Sydney, Sydney Harbour Trust, Sydney.

Jones, E.B.G., Kühne, H., Trussell, P.C. and Turner, R.D. 1972. Results of an international cooperative research programme on the biodeterioration of timber submerged in the sea. Material u. Organismen 7: 93-118.

Kampf, W.D. 1957. Über die Wirkung von Umweltfaktoren auf die Holzbohrassel *Limnoria tripunctata* Menzies (Isopoda), Z. angew. Zool. 44: 359-375.

Knox, G.A. 1963. The biogeography and intertidal ecology of the Australasian coasts. Oceanogr. Mar. biol. Ann. Rev. 1: 341-404.

Kühne, H. 1976. Zur geographischen Verbreitung hobzzerstorender Crustaceen und Systematik der Untergattung *Limnoria* S. str. Menzies. Beihefte zu Material u. Organismen 3: 543-553.

McQuire, A.J. 1965. Occurrence of marine borers in NZ. NZ Timb. J. 12: 34,36,39.

Menzies, R.J. 1957. The marine borer family Limnoriidae (Crustacea, Isopoda). Bull. Mar. Sci. Gulf and Caribbean 7: 101-200.

Menzies, R.J. 1959. The identification and distribution of the species *Limnoria*. In 'Marine and Fouling Organisms', D.L. Ray ed. Seattle, University of Washington Press.

Vind, H.P. and Hochman, H. 1961. Effect of temperature on the boring activity of *Limnoria*, Technical Report 117. US Naval Civil Engineering Laboratory, Port Hueneme, California.

Watson, C.J.J., McNeill, F.A., Johnson, R.A. and Iredale, T. 1936. Destruction of timber by marine organisms in the Port of Brisbane. Queensland Forest Service, Brisbane, Bull. No. 12, 107 pp.

THE INFLUENCE OF LABORATORY MAINTENANCE ON LIGNIN DEGRADATION BY *NASUTITERMES EXITIOSUS* (HILL)

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ABSTRACT

Two hardwoods, *Acer rubrum* L. and *Eucalyptus regnans* F.Muell., were labelled with ^{14}C almost exclusively in their lignin components. The ability of termites from several colonies of *Nasutitermes exitiosus* (Hill) to degrade these lignins was found to decrease after about four months of laboratory maintenance. Termites maintained for six months did not retain radioactive lignin or its breakdown products in their bodies as long as freshly collected termites from the field. These differences may be due to changes in the bacterial flora of the termite gut. Laboratory maintained termites also had less workers/g of termites than fresh termites from the same colony. It is recommended that termites be used within three months of their collection from the field.

INTRODUCTION

Recently it was demonstrated that *Nasutitermes exitiosus* (Hill) could degrade small amounts of certain lignins (3,5,12). Estimates for the degradation of side chains in lignin ranged from 12-17% for maize and synthetic lignins (3) to 5-6% for hardwood lignins (5). These studies were made possible through the development of methods for the preparation of ^{14}C-labelled lignins (7,15). Other lignin substrates and methods for lignin analysis often produced only ambiguous results in biodegradation studies (8,14).

The results for *N. exitiosus* were obtained from termites freshly collected from the field. However, *N. exitiosus* is often maintained in the laboratory for periods of up to eighteen months (13), although in practice

termites are used in our laboratories for pesticide bioassays within three months of collection (Creffield, pers. comm.). *N. exitiosus* and *Coptotermes acinaciformis* (Froggatt) do not form substitute reproductives (neotenics) in the laboratory. This compares with many species of Kalotermitidae, Termopsidae, *Heterotermes* and *Reticulitermes* which readily form neotenics and can therefore be bred in the laboratory, rather than only maintained (1).

It was considered that prolonged laboratory maintenance, especially in the absence of reproductive castes, could be detrimental to the vitality of *N. exitiosus*. This possibility was examined using ^{14}C-lignin degradation as an indicator.

MATERIALS AND METHODS

i. PREPARATION OF ^{14}C-(LIGNIN)-LIGNOCELLULOSES

The lignin component of *Eucalyptus regnans* F.Muell. and *Acer rubrum* L. (red maple) was selectively labelled in small branchlets by infusing them with [3'-^{14}C(side chain)] cinnamic acid dissolved in distilled water. The branchlets were held upright in test tubes containing water and left to metabolize the cinnamic acid for seven days under an artificial light/dark cycle. They were then stripped of bark and leaves, sliced into 50% methanol, and extracted for 4 h. Four hourly extractions with 50%, 75%, and 100% methanol followed. The slices were dried (80°C), ground to pass a 60 mesh sieve, and the wood meal thoroughly extracted with water, ethanol and ethanol:benzene (1:1) (9).

Eucalyptus sp. are unusual in that not all of the polyphenolic extractives are removed by the above extraction procedure, therefore, a 0.5% NaOH extraction at 98°C for 1 h was used to remove these from *E. regnans* (4).

Analyses were performed on samples of the wood meals to determine the proportions of radioactivity located in the Klason lignin (10), polysaccharides (17), and aromatic amino acids (6). Esterified phenolic acids remaining in *A. rubrum* were removed from a sample using 1N NaOH and

collected by acidifying the hydrolysate to pH 2 and extracting with diethyl ether (11). The ^{14}C present in the ether was then determined.

ii. BIOASSAYS

A total of six different colonies of *N. exitiosus* were collected from Tallarook, Victoria, at various times during the year (Table 1). The termites were maintained as 50 g groups in the mound material of *Coptotermes lacteus* (Froggatt) contained in 1 litre jars (13).

TABLE 1

The influence of laboratory maintenance on caste numbers/g of *N. exitiosus* (mean of 5 replicates). W = workers. S = soldiers, N = nymphs.

Colony No.	Date collected	Period of laboratory maintenance (weeks) 0			7			10		16		51	
		W	S	N	W	S	N	W	S	W	S	W	S
1	4-11-81	256.4	11.8	0								193.2	32.3
2	26-3-82	212.4	34.6	8.6	200.6	41.8	12.6						
3	29-7-82												
4	1-10-82	258.4	1.2	0									
5	1-12-82	257.4	12.0	0									
7	12-3-83	229.0	12.4	0				215.6	13.8	197.8	11.0		

Termites (from several jars) from the same colony were removed after various periods of laboratory maintenance and placed in 1 g groups in Erlenmeyer flasks in order to determine their ability to degrade lignin. Each flask was sealed with a rubber bung (equipped with gassing ports) from which a vial was suspended that contained a saturated solution of KH_2PO_4 to produce a relative humidity of 96% in the flask. Incubation was at 26°C. After three days, when all of the ^{14}C-(lignin)-lignocelluloses that were offered had been eaten, moist vermiculite (250% M.C.) and a small block of *E. regnans* were added to each flask.

The degradation of the ^{14}C-(lignin)-lignocelluloses by *N. exitiosus* was determined by finding the percentage of ^{14}C offered to the termites that was converted to $^{14}CO_2$ after fourteen days. The flasks were flushed with

air every 2-4 days (100 ml/min. for 15 min.) and the CO_2 collected directly into ethanolamine-containing scintillation fluid (15).

RESULTS

The amount of radioactivity located in the non-lignin components of *A. rubrum* and *E. regnans* was less than 2% and 1% respectively (Table 2). Degradations above these figures indicate lignin degradation.

The caste ratios were determined for three colonies of *N. exitiosus* after laboratory maintenance (Table 1). The number of workers/g of termites decreased with laboratory maintenance.

TABLE 2

Distribution of radioactivity in extracted ^{14}C-(lignin)-lignocelluloses (mean of 3 replicates)

Lignocellulose	Radioactivity (%)					
	Klason lignin	Klason filtrate	Polysaccharides	Aromatic amino acids	Bound phenolic acids	Total non-lignin
E. regnans	78.0	14.2	0.4	0.5	0	0.9
A. rubrum	81.6	12.3	0.3	0.3	1.2	1.8

The survival in the flasks of workers from two colonies maintained for seven and sixteen weeks was 94.3% and 92.2% respectively, which was similar to the survival of freshly collected workers. However, the population maintained for fifty-one weeks had a significantly lower survival (83.5%) compared to fresh termites (94.4%).

Termites that had been previously maintained in the laboratory for periods ranging from 4 to 12 months, in each case had a significantly lower lignin degrading ability compared to freshly collected termites (Tables 3 and 4). One colony (No. 5) was sampled monthly for six months following its collection from the field. After maintenance periods of 1, 2 and 3 months, degradation was as great as when the termites were first collected. At least 7% of the label was degraded, of which at least 5%

represented lignin degradation. After one month of laboratory maintenance there was actually a slight increase in lignin degradation (95% significant). After maintenance periods (colony No. 5) of 4-6 months there was a progressive decline in lignin degrading ability. Termites maintained for six months degraded 3.10% of the label, of which at least 1.1% was lignin degradation, i.e. a 78% decrease from the lignin degradation by freshly collected termites.

TABLE 3

Influence of laboratory maintenance of *N. exitiosus* on its ability to degrade ^{14}C-(lignin)-*A. rubrum*. Mean (%) of ^{14}C released as $^{14}CO_2$ over 14 days (5 replicates)

Colony No.	Period of laboratory maintenance (months)						
	0	1	2	3	4	5	6
5	7.01*	8.34	7.30	7.49	6.05	4.18	3.10
7	7.29		7.24		5.11		3.82

* 3 replicates

TABLE 4

Influence of laboratory maintenance of *N. exitiosus* on its ability to degrade ^{14}C-lignin. Mean (%) of ^{14}C released as $^{14}CO_2$ over 14 days (5 replicates)

Colony No.	*A. rubrum* Period of lab. maint. (mths)			*E. regnans* Period of lab. maint. (mths)		
	0	8	12	0	6	12
Several	6.91**			5.05***		
2					1.05	
3			2.72			2.04*
4		4.60				

* 3 replicates ** mean of 5 colonies *** mean of 3 colonies

Populations of *N. exitiosus* that had been maintained for six months, were found not to contain ^{14}C in their bodies after they had fed for fourteen days on ^{14}C-(lignin)-*E. regnans*. This compares to a similar bioassay using freshly collected termites. After fourteen days the fresh termites contained a mean of 48.7 dpm/10 workers. This represented about 2.0% of the total original ^{14}C that had been added as food.

DISCUSSION

The number of workers/g of termites tended to decrease for *N. exitiosus* after laboratory maintenance, due to a change of instar-range distribution as workers developed and the early instars were not replaced. Presumably this would not occur in laboratory bred termites due to the production of eggs by reproductives.

As lignin degradation by *N. exitiosus* requires the presence of endosymbiotic bacteria (Cookson, unpubl. data), the decrease in lignin degradation after prolonged laboratory maintenance suggests that the gut flora has changed. After a long period of laboratory maintenance, *Anocanthotermes* sp. (16) and *Reticulitermes flavipes* (Kollar) (2) contained differences in the relative abundance of their gut bacteria compared to freshly collected termites from the field.

If some gut bacteria in fresh termites are able to assimilate ^{14}C-lignin breakdown products, an alteration of the gut flora could also explain the lack of radioactivity found in six month laboratory maintained termites after day 14 of the bioassays. On the other hand, it is possible that trophallactic exchange or coprophagic behaviour was less frequent in the six month maintained termites, factors which would recirculate food in freshly collected termites.

Previous reports have shown that methane production (19) and nitrogen fixation (18) by termites decreased after they were introduced into the laboratory.

CONCLUSIONS

The ability of *N. exitiosus* to degrade lignin was found to decrease after laboratory maintenance periods of four or more months. For example, a population maintained for six months degraded 78% less lignin than freshly collected termites from the field. Therefore, bioassays using *N. exitiosus* that were maintained for these periods may also become less relatable to field results.

REFERENCES

1. Becker, G. 1969. Rearing of termites and testing methods used in the laboratory. In "Biology of Termites". Vol. 1 (Eds K. Krishna and F.M. Weesner). New York, Academic Press, pp. 351-385.

2. Breznak, J.A. and Pankratz, H.S. 1977. In situ morphology of the gut microbiota of wood-eating termites [*Reticulitermes flavipes* (Kollar) and *Coptotermes formosanus* Shiraki]. Appl. Environ. Microbiol. 33: 406-426.

3. Butler, J.H.A. and Buckerfield, J.C. 1979. Digestion of lignin by termites. Soil Biol. Biochem. 11: 507-511.

4. Cohen, W.E. 1934. The chemistry of Australian timbers. Part 4 - A study of the lignin determination II. CSIR Pamphlet No. 51.

5. Cookson, L.J. 1983. The role of lignin in the nutrition of several Australian termites. Internat. Res. Group on Wood. Pres. Document No. IRG/WP/1191.

6. Crawford, D.L. 1978. Lignocellulose decomposition by selected *Streptomyces* strains. Appl. Environ. Microbiol. 35: 1041-1045.

7. Crawford, D.L. and Crawford, R.L. 1976. Microbial degradation of lignocellulose: the lignin component. Appl. Environ. Micriobiol. 31: 714-717.

8. Crawford, R.L. 1981. Lignin biodegradation and transformation. New York, John Wiley & Sons.

9. Crawford, R.L. and Crawford, D.L. 1978. Radioisotopic methods for the study of lignin biodegradation. Dev. Ind. Microbiol. 19: 35-49.

10. Effland, M.J. 1977. Modified procedure to determine acid-insoluble lignin in wood and pulp. Tappi 60: 143-144.

11. El-Basyouni, S.Z., Neish, A.C. and Towers G.H.N. 1964. The phenolic acids in wheat III. Insoluble derivatives of phenolic cinnamic acids as natural intermediates in lignin biosynthesis. Phytochem. 3: 627-639.

12. French, J.R.J. and Bland, D.E. 1975. Lignin degradation in the termites *Coptotermes lacteus* and *Nasutitermes exitiosus*. Material u Organismen 10: 281-288.

13. Gay, F.J., Greaves, T., Holdaway, F.G. and Wetherly, A.H. 1955. Standard laboratory colonies of termites for evaluating the resistance of timber, timber preservatives, and other materials to termite attack. Bull. CSIRO No. 277.

14. Kirk, T.K. 1971. Effects of microorganisms on lignin. Ann. Rev. Phytopathol. 9: 185-210.

15. Kirk, T.K., Connors, W.J., Bleam, R.D., Hackett, W.F. and Zeikus, J.C. 1975. Preparation and microbial decomposition of synthetic [^{14}C] lignins. Proc. Natl. Acad. Sci. USA 72: 2515-2519.

16. Krasil'nikov, N.A. and Satdykov, S.I. 1970. Bacteria of termites' intestines. Microbiologiya 39: 562-564.

17. Moore, W.E. and Johnson, D.B. 1967. Procedures for the chemical analysis of wood and wood products. USDA Forest Service, Forest Products Laboratory, Madison.

18. Prestwich, G.D., Bentley, B.L. and Carpenter, E.J. (1980). Nitrogen sources for neotropical nasute termites: fixation and selective foraging. Oecologia (Berl.) 46: 397-401.

19. Zimmerman, P.R., Greenberg, J.P., Wandiga, S.O. and Crutzen, P.J. 1982. Termites: a potentially large source of atmospheric methane, carbon dioxide, and molecular hydrogen. Science 218: 563-565.

TERMITICIDAL EFFECTIVENESS OF PERMETHRIN AND FENVALERATE - QUARANTINE IMPLICATIONS

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ABSTRACT

This paper reports results obtained from laboratory evaluations of the termiticidal efficacy of permethrin and fenvalerate-treated wood blocks. Comparison between artificially weathered permethrin-treated blocks and unweathered blocks is given. The effect of a 6-week soil burial period on pyrethroid-treated blocks at a retention of 0.08 kg/m^3 is also reported. Toxic or protection threshold values for the two pyrethroids are summarised. The significance of these is discussed with reference to their acceptance by the Australian Department of Health (Plant Quarantine) for the treatment of timber components in shipping containers.

INTRODUCTION

In the 35 years since allethrin was first produced (1), the effectiveness of both natural and synthetic pyrethroids has become well established. Their high insecticidal efficacy combined with relatively low mammalian toxicity make them suitable for use against a wide range of insects. As alternatives to the persistent organochlorine insecticides, some of the more recently produced stable synthetic pyrethroids have shown much promise.

In 1975, the authors' initiated laboratory assessments to determine the termiticidal effectiveness of a number of candidate synthetic pyrethroids. Reported here are detailed results obtained with two such stable pyrethroids, permethrin and fenvalerate, against three species of Australian subterranean termite. Later, these results led to the acceptance of permethrin and fenvalerate by the Australian Department of Health (Plant Quarantine) for use in permanently immunising the exposed timber components of shipping containers (2). Approval of permethrin and fenvalerate was on the basis of a minimum retention of 0.12 kg/m^3 and 0.18 kg/m^3 respectively. There has since been considerable discussion about the difference in retention between the two approved insecticides (3, Paton pers. comm.).

Three series of bioassays are reported in this paper. Bioassay series 1 was designed to establish protection or toxic threshold data for permethrin in wood and to evaluate the effects of a leaching/volatilisation schedule. Bioassay series 2 compared permethrin and fenvalerate at 0.08 kg/m^3. In addition, it was designed to assess the effect on pyrethroid treated blocks of a 6-week soil burial period. Bioassay series 3 was conducted to establish protection or toxic thresholds for fenvalerate in wood.

MATERIALS AND METHODS

INSECTICIDES

The permethrin used in bioassay series 1 was a 40:60 cis:trans isomeric formulation supplied by Wellcome Research Laboratory, Berkhamsted, U.K. The permethrin used in bioassay series 2 was a 25:75 cis:trans isomeric formulation supplied by Wellcome Australia Ltd. Cabarita, New South Wales. Fenvalerate used in bioassay series 2 and 3 was supplied by Shell Chemical (Australia) Pty. Ltd., Melbourne, Victoria. Technical aldrin was used in all bioassays for comparison and was also supplied by Shell Chemical.

TIMBER

Sapwood blocks of Pinus radiata D. Don (radiata pine) and outer heartwood blocks of Eucalyptus regnans F. Muell (mountain ash) were used. The blocks were prepared from strips of similar radial position and then assigned at random for insecticidal treatment. Blocks for bioassay series 1 measured 15 x 25 x 100 mm while those for bioassay series 2 and 3 were 15 x 25 x 50 mm.

INSECTICIDAL TREATMENT

Blocks were treated by vacuum-pressure impregnation to the following nominal retentions:

Bioassay series 1 - permethrin 0.0016, 0.008, 0.04, 0.08 and 0.16 kg/m^3.
- aldrin 0.016, 0.08 and 0.80 kg/m^3.

Bioassay series 2 - permethrin 0.08 kg/m^3.
- fenvalerate 0.08 kg/m^3.
- aldrin 0.80 kg/m^3.

Bioassay series 3 - fenvalerate 0.02, 0.04, 0.08, 0.12 and 0.16 kg/m^3
- aldrin 0.80 kg/m^3.

Control blocks for each bioassay were treated with solvent only (mineral turpentine plus 0.5% paraffin wax) and untreated control blocks were also prepared.

ARTIFICIAL WEATHERING OF BLOCKS

The weathering schedule used for the bioassays was as follows: Five days vacuum oven-drying (-95 kPa) at 50°C; vacuum-pressure impregnation with water; one day water soaking at 50°C; one day oven-drying at 50°C followed by a further five days vacuum oven-drying at 50°C; a second vacuum-pressure impregnation with water, soaking and drying and finally another five days in the vacuum oven at 50°C.

In bioassay series 1, a set of treated blocks was subjected to the above leaching/volatilisation schedule and their performance compared with that of a replicate set of unweathered blocks.

In bioassay series 2, a complete set of weathered blocks was subjected to a soil burial period of 6-weeks, using unsterile soil which contained a rich fungal and microbial flora. A replicate set of blocks was kept sterile at 3°C. At the end of the 6-week period, all specimens were again vacuum oven-dried and weighed; mass losses being calculated for those exposed to soil burial. Termite bioassays then compared the performance of those blocks which had been given the 6-week exposure, with those which had not.

In bioassay series 3, all blocks were subjected to the weathering schedule only.

TERMITE BIOASSAYS

Three species of Australian subterranean termites were used in the bioassays: Mastotermes darwiniensis Froggatt, Coptotermes acinaciformis (Froggatt) and Nasutitermes exitiosus (Hill).

The bioassays with M. darwiniensis were conducted in accordance with the technique described by Howick and Creffield (4). The bioassays with C. acinaciformis and N. exitiosus were conducted according to the techniques described by Gay et al. (5) but with the modifications of Howick et al(6). P. radiata blocks were not used in the N. exitiosus bioassays because this termite does not attack Pinus species. For each treatment regime, five replicate blocks of each insecticide retention were tested against 10 gram groups of termites. Solvent-treated and untreated controls were also included. M. darwiniensis groups were maintained in an insectary at 32°C, 80% RH and C. acinaciformis and N. exitiosus groups at 26°C, 80% RH.

Exposure periods varied between the 3 bioassay series. M. darwiniensis series 1 bioassay was run for 8 weeks and series 2 and 3 for 4 weeks. With C. acinaciformis, exposure periods were 8 weeks also, but P. radiata blocks were run for 12 weeks in bioassay series 3. All N. exitiosus bioassays were run for 8 weeks.

RESULTS

Details of termite attack (expressed as percentage mass loss of blocks) are given in Tables 1-3.

Tables 4-6 show details of termite survival at the conclusion of the bioassays. Survival is expressed as a percentage of the original 10 g group or as the mean number of days before death of the 10 g groups.

DISCUSSION

A limited statistical analysis has been performed on the data presented in this paper. For the analysed results, 5 per cent mean mass loss was used as the level of attack in determining the protection or toxic threshold. Thus any retention of insecticide which allowed more than a 5 per cent mean mass loss of the treated blocks was considered ineffective.

BIOASSAY SERIES 1

The mass loss figures given in Table 1 indicate the effect of the artificial weathering schedule on treated blocks. Clear differences between leached and unleached blocks have occurred at retentions of 0.0016 and 0.008 kg/m^3 permethrin against N. exitiosus and 0.016 kg/m^3 aldrin against both C. acinaciformis and N. exitiosus. There are no such differences in any of the other insecticide retentions.

A study of survival data in Table 4 shows that the weathering schedule reduces the toxicity to N. exitiosus of permethrin and aldrin. In contrast such an effect was not present in the M. darwiniensis and C. acinaciformis bioassays.

The results highlight the desirability of such artificial weathering before biological assessments if bioassays are to simulate the extent of protection which is likely to occur after several years of service life. Therefore, considering only the leached insecticide treated blocks the following threshold values were obtained:

	M. darwiniensis	C.acinaciformis	N. exitiosus
Permethrin (kg/m^3)	0.04	0.008-0.04	>0.008*
Aldrin (kg/m^3)	0.08-0.80	0.08-0.80	0.08

The toxic threshold values thus obtained formed the basis for bioassay series 2 in which the retentions were 0.08 kg/m^3 for permethrin and 0.80 kg/m^3 for aldrin. For comparison, fenvalerate was included also at a retention of 0.08 kg/m^3.

BIOASSAY SERIES 2

Mass loss of blocks exposed to soil burial for 6 weeks was less than 0.5 per cent and therefore considered to be insignificant and not recorded in this paper. This was an unexpected result as the mean moisture contents of the blocks after soil burial ranged from 60 to 84 per cent. This indicated that for some time during the 6-week exposure period, conditions must have been suitable for decay. Perhaps an explanation for the lack of decay to the blocks may be the weathering schedule which could have removed wood nutrients necessary for the natural microbial succession to have progressed. However, the blocks which had been given the 6-week soil burial were compared in their performance against termites with blocks which had not, in case some detoxification had occurred.

The results (Table 2) show little effect, if any, of soil burial on insecticidal efficacy. Although this series of bioassays did not produce conclusive evidence of the sensitivity of permethrin and fenvalerate to microbial degradation, valuable information on threshold values was obtained. The results demonstrate that against the three termite species used, a retention of 0.08 kg/m^3 permethrin compares similarly to aldrin at ten times the concentration.

Clearly, 0.08 kg/m^3 of fenvalerate was inadequate in protecting hardwood blocks against M. darwiniensis. On the other hand, this level of fenvalerate appears to be relatively toxic or repellent to the other two termite species, C. acinaciformis and N. exitiosus.

* Due to an anomolous result obtained with this termite species at a retention of 0.08 kg/m^3 (Table 1), an accurate threshold value was unable to be determined.

Survival figures shown in Table 5 confirm the mass loss data obtained in these bioassays. M. darwiniensis groups were able to survive the test period when exposed to the fenvalerate-treated blocks whereas the groups exposed to permethrin died within 14 days. N. exitiosus also survived exposure to fenvalerate. In the case of the high survival figures for C. acinaciformis exposed to both pyrethroids, the repellent action of the compounds is clearly demonstrated as the termites were able to utilise the alternative food source in the jars containing the highly nutritious matrix in preference to feeding on treated wood.

BIOASSAY SERIES 3

The extent of attack by M. darwiniensis on hardwood blocks treated with fenvalerate (Table 3) at the three lowest retentions (0.02, 0.04, 0.08 kg/m^3) was substantial and comparable with the level of attack on untreated and solvent-treated control blocks. The marked dosage response with fenvalerate clearly indicates that the toxic threshold to M. darwiniensis is 0.08-0.12 kg/m^3 and, furthermore, appears close to the 0.12 kg/m^3 retention. The relatively low attack of the P. radiata solvent control blocks was an unexpected effect for which no satisfactory explanatation has been determined.

Against C. acinaciformis, the threshold value lies between 0.02 kg/m^3 and 0.04 kg/m^3. Again, the repellent effect that this pyrethroid exhibits against this termite species is clearly shown (see Table 6).

ACCEPTANCE OF PERMETHRIN AND FENVALERATE FOR USE IN THE TREATMENT OF CARGO CONTAINERS

Early in 1981, the Assistant Director General (Plant Quarantine) of the Australian Department of Health issued a statement indicating that migration of organochlorine insecticides from treated wooden components of cargo containers could result in contamination of their contents. He foreshadowed that recommendations for the use of organochlorine insecticides in treating sawn timber components would not appear in the 1981 edition of "Cargo Containers - Quarantine Aspects and Procedures". Thus, as from January 1982, new containers would not be registered for immediate delivery in Australia if the exposed sawn timber components were treated with aldrin, chlordane, dieldrin, heptachlor or lindane.

This led the Australian Department of Health to seek suitable alternative (non-arsenical) insecticides. Permethrin and fenvalerate were considered and the results of work presented in this paper formed the basis for discussion with the Department of Health officials. For permethrin the upper protection limit (after weathering) for Australian termites is 0.08 kg/m^3 (with the exception of N. exitiosus which in two cases recorded a mean mass loss of up to 7.3 per cent) and for fenvalerate 0.12 kg/m^3; the increased retention for fenvalerate being a result of the response by M. darwiniensis in bioassay series 2 and 3.

The main aim of quarantine treatments for timber is to exclude exotic insect pests such as the Formosan subterranean termite C. formosanus (3,7). C. formosanus has been reputed as being highly tolerant to insecticides, requiring higher retention levels than other termites to prevent attack*. In view of this (and any variability within timber and treatments that may occur), a 50 per cent safety factor has been applied to the threshold values presented here for permethrin and fenvalerate in order to give complete security against the introduction of exotic insect pests into Australia.

* This claim is now subject to a current investigation in collaboration with CSIRO Division of Entomology (Australia) and the Guangdong Entomological Institute (Peoples Republic of China).

REFERENCES

(1) Schecter, M., Green, N. & La Forge, F., (1949). Constituents of pyrethrum flowers - XXIII Cinerolone synthesis of related cyclodentenolones. J. Am. Chem. Soc., 71, 3165 - 3173.

(2) Anon, (1981). Cargo containers - Quarantine aspects and procedures. Australian Government Publishing service, Canberra, Australia.

(3) Paton, R. (1982). Australian plant quarantine requirements for preservative treatments. Proc. Br. Wood Preserv. Assoc. Annu. Conv. pp 3-9.

(4) Howick, C.D. and Creffield, J.W. (1975). The development of a standard laboratory bio-assay technique with Mastotermes darwiniensis Froggatt (Isoptera: Mastotermitidae). Z. Angew. Entomol. 78, 126-138.

(5) Gay, F.J., Greaves, T., Holdaway, F.G. and Wetherly, A.H.(1955). Standard laboratory colonies of termites for evaluating the resistance of timber, timber preservatives, and other materials to termite attack. Bull. Commonw. Sci. Ind. Res. Organ. No. 277, 1-60.

(6) Howick, C.D., Creffield, J.W., Butcher, J.A. and Greaves, H. (1982). Evaluation of the efficacy of a quaternary ammonium compound and a tertiary amine salt in the protection of wood against termite attack. Mater. Org. 17 (2), 81-92.

(7) Howick, C.D. (1981). Insecticides for the protection of wooden components of shipping containers. Proc. 20th Forest Prod. Res. Conf. Melbourne, Australia. Topic WP1, 1-5.

TABLE 1. Mass loss (mean of 5 replicates) to treated and untreated blocks in bioassay series 1.

Insecticide	Nominal Retention Kg/m^3	*M. darwiniensis* Unleached % (SD)	*M. darwiniensis* Leached % (SD)	*C. acinaciformis* Unleached % (SD)	*C. acinaciformis* Leached % (SD)	*N. exitiosus* Unleached % (SD)	*N. exitiosus* Leached % (SD)
Permethrin	0.0016	NT	NT	NT	NT	5.1 (0.8)	33.8 (3.2)
	0.008	31.8 (3.8)	28.7 (4.0)	10.1 (3.3)	6.9 (2.1)	5.3 (0.6)	28.6 (3.8)
	0.04	5.5 (1.3)	4.7 (1.3)	1.4 (0.2)	1.0 (0.2)	4.5 (0.6)	2.6 (0.5)
	0.08	1.4 (0.5)	1.3 (0.5)	1.3 (0.1)	0.7 (0.1)	4.3 (0.3)	7.3 (3.5)
	0.16	0.6 (0.2)	0.3 (0.5)	1.3 (0.3)	0.6 (0.1)	NT	NT
Aldrin	0.016	8.6 (1.9)	11.4 (2.5)	12.6 (3.2)	24.8 (3.1)	2.3 (0.4)	25.2 (2.8)
	0.08	5.0 (0.5)	6.8 (0.9)	8.8 (2.3)	12.3 (2.4)	2.6 (0.2)	4.7 (1.2)
	0.80	0.6 (0.1)	1.2 (0.4)	1.2 (0.1)	0.8 (0.2)	2.5 (0.3)	0.5 (0.1)
Solvent controls		35.2 (4.3)	33.0 (2.9)	44.2 (4.5)	39.4 (2.9)	27.6 (4.9)	36.9 (2.0)
Untreated controls		38.2 (5.7)	NT	50.6 (3.5)	NT	39.2 (2.0)	NT
Timber & bioassay duration		*P. radiata* for 8 weeks		*P. radiata* for 8 weeks		*E. regnans* for 8 weeks	

Key: SD = Standard deviation

NT = Not tested

TABLE 2. Mass loss (mean of 5 replicates) to treated and untreated blocks in bioassay series 2.

Insecticide	Nominal Retention Kg/m^3	*M. darwiniensis* NME % (SD)	*M. darwiniensis* ME % (SD)	*C. acinaciformis* NME % (SD)	*C. acinaciformis* ME % (SD)	*N. exitiosus* NME % (SD)	*N. exitiosus* ME % (SD)
Permethrin	0.08	2.7 (0.2)	2.8 (0.2)	2.5 (0.2)	2.7 (0.2)	7.1 (0.9)	5.4 (0.3)
Fenvalerate	0.08	32.1 (4.2)	38.6 (3.8)	2.5 (0.2)	3.9 (0.8)	3.2 (0.1)	6.1 (0.9)
Aldrin	0.80	2.8 (0.1)	4.2 (0.6)	3.7 (0.3)	3.8 (0.2)	6.4 (0.6)	6.7 (0.6)
Solvent controls		53.1 (2.1)	53.9 (3.2)	56.5 (0.5)	60.8 (1.8)	46.5 (1.6)	53.9 (1.3)
Untreated controls		50.2 (2.6)	55.1 (1.0)	54.7 (2.2)	56.2 (1.7)	50.2 (2.5)	54.9 (1.2)
Timber & bioassay duration		*E. regnans* for 4 weeks		*E. regnans* for 8 weeks		*E. regnans* for 8 weeks	

Key: NME = No microbial exposure

ME = Microbial exposure of 6 weeks prior to termite bioassay

SD = Standard deviation

TABLE 3. Mass loss (mean of 5 replicates) to treated and untreated blocks in bioassay series 3.

Insecticide	Nominal Retention kg/m3	M. darwiniensis P. radiata %	(SD)	M. darwiniensis E. regnans %	(SD)	C. acinaciformis P. radiata %	(SD)	C. acinaciformis E. regnans %	(SD)
Fenvalerate	0.02	49.8	(7.7)	52.3	(4.1)	11.4	(5.7)	7.6	(1.5)
	0.04	13.3	(3.8)	47.3	(3.3)	3.9	(0.6)	3.1	(1.0)
	0.08	11.7	(3.0)	45.2	(6.8)	3.9	(0.3)	2.2	(0.1)
	0.12	1.1	(0.3)	1.3	(0.3)	2.6	(0.1)	1.7	(0.9)
	0.16	0.7	(0.1)	3.0	(0.8)	2.5	(0.2)	1.0	(0.0)
Aldrin	0.80	0		0		2.0	(0.7)	0.3	(0.1)
Solvent controls		15.3*	(2.1)	47.7	(2.6)	74.5	(10.6)	49.4	(4.7)
Untreated controls		53.9	(3.6)	49.0	(3.5)	92.1	(8.5)	61.4	(4.6)
Bioassay duration		4 weeks		4 weeks		12 weeks		8 weeks	

Key: SD = Standard deviation

* = Suspect contamination of blocks

TABLE 4. Termite survival (mean of 5 replicates) in bioassay series 1.

Insecticide	Nominal Retention Kg/m^3	M. darwiniensis		C. acinaciformis		N. exitiosus	
		Unleached % or d (SD)	Leached % or d (SD)	Unleached % (SD)	Leached % (SD)	Unleached % or d (SD)	Leached % or d (SD)
Permethrin	0.0016	-	-	-	-	12 d (0)	67% (3)
	0.008	54% (5)	50% (4)	91 (3)	90 (4)	13 d (2)	64% (4)
	0.04	34 d (5)	31 d (6)	91 (2)	92 (3)	18 d (3)	31 d (2)
	0.08	16 d (4)	18 d (3)	93 (3)	92 (3)	18 d (0)	17% (16)
	0.16	12 d (2)	13 d (2)	92 (6)	90 (3)	-	-
Aldrin	0.016	30 d (3)	34 d (4)	84 (5)	88 (4)	11 d (5)	60% (4)
	0.08	24 d (2)	26 d (3)	81 (4)	88 (2)	7 d (0)	33 d (3)
	0.80	8 d (1)	13 d (1)	67 (4)	73 (1)	5 d (0)	12 d (0)
Solvent controls		68% (9)	66% (7)	92 (3)	96 (3)	58% (13)	74% (3)
Untreated controls		63% (9)	-	97 (5)	-	77% (2)	-
Unfed controls		42 d (2)		92 (3)		12% (12)	

Key: d = days before death of 10 g group
SD = Standard deviation.

TABLE 5. Termite survival (mean of 5 replicates) in bioassay series 2.

Insecticide	Nominal Retention Kg/m3	M. darwiniensis NME % or d (SD)	M. darwiniensis ME % or d (SD)	C. acinaciformis NME % (SD)	C. acinaciformis ME % (SD)	N. exitiosus NME % or d (SD)	N. exitiosus ME % or d (SD)
Permethrin	0.08	14 d (1)	14 d (1)	92 (1)	91 (0)	48 d (8)	57 d (1)
Fenvalerate	0.08	44% (6)	59% (1)	87 (1)	87 (1)	65% (14)	70% (7)
Aldrin	0.80	14 d (0)	16 d (1)	76 (1)	75 (2)	50 d (1)	47 d (2)
Solvent controls		85% (3)	82% (10)	86 (1)	89 (1)	70% (1)	76% (1)
Untreated controls		80% (5)	86% (3)	88 (1)	90 (1)	72% (2)	76% (1)
Unfed controls		37% (17)		91 (1)		39% (8)	

TABLE 6. Termite survival (mean of 5 replicates) in bioassay series 3.

Insecticide	Nominal Retention kg/m3	M. darwiniensis P. radiata % of d (SD)	M. darwiniensis E. regnans % of d (SD)	C. acinaciformis P. radiata % (SD)	C. acinaciformis E. regnans % (SD)
Fenvalerate	0.02	70% (5)	76% (1)	86 (4)	89 (2)
	0.04	26% (3)	72% (11)	84 (3)	91 (1)
	0.08	26 d (2)	65% (14)	87 (2)	88 (4)
	0.12	15 d (1)	17 d (1)	81 (4)	85 (2)
	0.16	17 d (1)	20 d (2)	71 (10)	88 (2)
Aldrin	0.80	6 d (0)	6 d (0)	48 (6)	61 (12)
Solvent controls		27 d (2)	76% (7)	94 (5)	88 (2)
Untreated controls		81% (5)	75% (7)	98 (2)	92 (3)
Unfed controls		27 d (2)		89 (4)	

Key: d = days before death of 10 g group

SD = Standard deviation.

BAITING TECHNIQUES FOR TERMITE CONTROL

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ABSTRACT

In the search for substitutes with less environmental hazard than organochlorines and arsenicals in subterranean termite control, baiting methods have come under greater scrutiny. The object is simple, namely, to aggregate termites to a point source using attractive baits, and administer a toxin. Toxins may be incorporated within the bait or added to the infested bait, such as by dusting a toxin onto the termites. Dusted termites are in turn 'cleaned' by the grooming of other termites, and so the toxin is moved through the colony. The ultimate aim is to produce a suitable bait-substrate and toxin that may be used by the pest control industry and the public.

In this paper we report the development of methods for screening potential bait substrates attractive to field colonies of Coptotermes acinaciformis and C. lacteus. Our recent baiting techniques also allow other aspects of the biology of C. lacteus to be studied. These include foraging, recruitment, feeding preferences, caste composition and biomass analysis, gas exchange, and seasonal variations in termite activity and temperature-within mounds.

INTRODUCTION

Continuing our search for termiticides with low environmental hazard, greater emphasis has been given to baiting methods and bait substrates. An important consideration in screening potential bait substrates is whether to use laboratory or field bioassays. In Australia, techniques have been devised over many years using both laboratory and field termites (1,2).

However, the question of acclimation and vigour has always been of concern with the use of termites in the laboratory, which are usually orphaned groups of soldiers, workers and nymphs (3,4). We feel, as does Esenther (5), that the best nutritional and social conditions for termites are most likely to occur in field colonies. But one of the major problems in field testing insecticides, wood preservaties, and natural durability of timber against subterranean termites is ensuring a reasonable uniformity of termite hazard throughout the test site. However, this difficulty may be overcome by aggregating large numbers of subterranean termites to a point-source, using attractive bait substrates, and so maintaining a continuously high termite hazard.

Although the use of the organochlorine, mirex, is cancelled in the United States of America, in Australia mirex is registered for use in a bait against Mastotermes darwiniensis Froggatt in the Northern Territory (6). But this baiting system has not proved effective against Coptotermes acinaciformis (Froggatt), a termite species that is considered to be responsible for greater economic losses in the aggregate than all other Australian species combined (7). Thus, C. acinaciformis is the preferred termite species for use in bioassays in Australia, even though this species does not build above-ground mound colonies in Victoria. Nevertheless, this aspect of C. acinaciformis behaviour has been overcome, and large numbers of this termite have been aggregated into 54 L perforated steel drums packed with toilet rolls when buried near trees infested with C. acinaciformis (8). This technique is also effective in aggregating C. lacteus and Nasutitermes exitiosus Hill foragers when such baited drums are placed alongside active mounds.

Over the years we have modified termite baiting techniques developed by researchers in Australia (9,10,11), in North America (12,13,14) and from Africa (15,16).

In this paper we report the development of our modified methods, with several variations, for screening potential bait substrates attractive to field colonies of C. acinaciformis and C. lacteus.

MATERIALS AND METHODS

SCREENING POTENTIAL BAIT SUBSTRATES AT WALPEUP

Bait techniques for aggreagating large numbers of C. acinaciformis in the Mallee Research Station at Walpeup (300 km N.W. of Melbourne) using toilet rolls as a substrate have been reported (17,19). More recently, this technique has been modified in order to accelerate the location and feeding of the bait substrate. A trickle-irrigated-water system has been installed to ensure maximum termite attractancy.

Following the success of a method designed to rapidly screen potential bait substrates using C. lacteus mounds (19), similar techniques are under test at Walpeup for C. acinaciformis. Bait-containers with wood substrates (usually Pinus radiata D.Don., blocks, 100 x 1.8 x 1.8 mm) are inserted into the side of steel drums infested with C. acinaciformis. Termites quickly forage into the containers from the drum and contact the baits. (These bait containers are described in detail in the following Section).

Another baiting system under test is the use of bait-containers inserted into live branches of Eucalyptus socialis which are infested with C. acinaciformis. Holes (25 mm diam.) are drilled into the infested heartwood-centre of an infested branch and the bait-container inserted.

SCREENING POTENTIAL BAIT SUBSTRATES AT BOOLA BOOLA STATE FOREST

PREPARATION OF BAIT-CONTAINERS

Bait containers were prepared in the laboratory prior to installing them into C. lacteus mounds in the Boola Boola State Forest in central Gippsland (120 km east of Melbourne). Four types of bait-containers were developed, namely, (a) tube, (b) box, (c) T-piece and (d) pipe. However, all containers were adaptations or extensions of the tube container.

TUBE CONTAINER

This container comprised a length of plastic conduit (200 mm long; 25 mm O.D. diam.) with an adaptor and coupling at one end to which a further plastic conduit (120 mm long; 32 mmO.D. diam.) was connected. Bait material was placed inside the widest conduit, and the end sealed with a rubber stopper. A piece of single-backed corrugated cardboard paper (220 mm long; 70 mm wide) was rolled (with the corrugations facing in) and inserted into the 25 mm diam. conduit, through its entire length.

On locating an active C. lacteus mound in the forest, a 27 mm diameter hole was drilled about 120 mm into the side of the mound. Thus penetrating the outer clay wall and into the inner nest material. The 25 mm diameter conduit section of the bait-container was inserted into this hole and wedged firmly in place with moist soil. This served to keep the conduit in place and prevented intrusion by unwanted insects, particularly ants. The termites did not seal off this inner conduit, but moved freely along the corrugated cardboard paper core (either wet or dry) and made contact with the bait.

BOX CONTAINER

An oblong plastic container (265 x 195 x 65 mm) had a 26 mm hole drilled into the centre of each of the 195 mm long sides, about 10 mm from the base of the container. A plastic conduit (400 mm long; 25 mm O.D. diam.) with holes (10 mm diam.) drilled at 60 mm intervals along its length, was inserted through the holes in the plastic container with about 15 mm protruding outside. Into this end a rubber stopper was fitted. Epoxy resin adhesive sealed the conduit to the container. A thin layer of washed river sand (ca. 40 g) was evenly distributed into the bottom of the container. Pieces of corrugated cardboard paper were cut and laid on the sand, contacting the holes in the centrally located conduit. Baits, such as wood-blocks, were then placed onto the cardboard and the lid of the container put in place.

This system was designed to provide a multi-choice situation for foraging termites, not only to examine feeding preferences and

attractancy, but perhaps in assessing threshold toxicity levels of preservatives and/or insecticides impregnated into wood blocks.

T-PIECE CONTAINER

This container was similar to the tube container, except that instead of a 32 mm O.D. diameter coupling, a T-piece (32 mm O.D. diam.) was attached to the adaptor on the conduit that protruded from the mound. Two lengths of plastic conduit (120 mm long; 32 mm O.D. diam.) were inserted into each end of the T-piece, baits placed within each tube contacting the corrugated cardboard paper cores, and sealed with a rubber stopper. This arrangement allowed a dual choice for the foraging termites.

PIPE CONTAINER

Again, the procedure was similar to the construction of the tube container except that the lid of a plastic petri dish (90 mm O.D. diam.) was drilled at its centre, and sealed with expoxy resin adhesive to the coupling at the end of the conduit. A length of plastic drain pipe (190 mm long; 90 mm O.D. diam.) was attached, and rolled corrugated cardboard paper (10 mm in width) was inserted into the pipe. The open end was sealed with another plastic petri dish lid which contained a single filter paper. The corrugated cardboard paper core in the mound conduit was in contact with the corrugated cardboard paper in the pipe container.

GAY à la PLASTIQUE

Recently, a new field technique, which is a modification of the 'Gay method' of field testing termite activity (20) has been developed and installed at Boola Boola State Forest, and shortly, for installation at Walpeup.

Basically, lengths of 25 mm diameter plastic conduit, drilled with 8 mm diameter holes at 15-20 mm intervals, are placed in a shallow trench (200-250 mm deep; 100-150 mm wide) dug in a square shape around an active C. lacteus mound. Four elbow joints connect the frame and seven T-pieces inserted approximately evenly around this frame. At each T-piece, the

horizontal lengths are connected, and a tube-container is connected vertically to protrude above the ground when the trench is back-filled.

Cork baits are inserted into each of the seven outer conduits of the vertical tube-containers and corrugated cardboard paper inserts are installed within the entire conduit-frame.

Within two weeks of installing this technique around four C. lacteus mounds in July and August this year, foragers were found eating the cork baits. The intention is to keep renewing these 'bait-stations', not just with cork, but other bait substrates, with and without toxins.

BAIT SUBSTRATES

A variety of bait substrates has been used, and others will be screened in the near future. Substrates include sound wood blocks of P. radiata ~~D.Don~~ and Eucalyptus regnans F.Muell. (100 x 18 x 18 mm) and wood blocks of these timbers extracted with (a) methanol, and (b) shaken in water for 8 h.

Small glass vials containing agar, and various carbohydrates, such as amylose, fructose, galactose, glucose, sucrose and xylose were prepared and placed in the tube containers. Also, mixtures of these carbohydrates incorporated into beeswax and polyurethane baits were offered to C. lacteus mound populations.

While placing tube-containers (which held P. radiata wood blocks as substrate) into C. lacteus mounds we ran short of rubber stoppers to plug the outer conduit. Our colleague, Don Ewart of La Trobe University, substituted cork stoppers. On inspecting these bait containers after one week, termites were not found feeding on the sound wood blocks, but on the cork stoppers. Every cork had been attacked and eaten. It seemed that field colonies of C. lacteus, when given the choice, preferred cork to sound P. radiata wood blocks (21).

This discovery has led us to use cork as the main bait substrate. Oblong pieces (100 xz 18 x 18 mm) of raw cork cut from oak, Quercus suber

L., were put into the outer tube of the plastic conduit bait-containers which were protruding from the C. lacteus mounds. Within days, termites actively pass along the corrugated cardboard paper inserts and feed on the cork baits. After three to four weeks the cork baits were hollowed out with only an oblong lattice-shape remaining. Fresh cork baits may be inserted into the outer conduit, after tapping termites from the eaten-cork bait, which is removed.

Underway at present are methods to impregnate the cork baits with toxins, and/or using these baits to aggregate large numbers of termites, and then dust them with candidate toxins in the form of fine powder.

RESULTS AND DISCUSSIONS

The bait containers were readily prepared in the laboratory, easily transported and installed in the forest into active termite mounds or tree stumps by one person. Irrespective of the bait container used, termites (soliders and workers) quickly moved into the conduits from within the mound and made contact with the baits. Alates were found in these bait containers just prior to their flight. It made no difference to foraging behaviour of C. lacteus whether or not the corrugated paper cores were wet or dry. It seemed that inserting conduits into active mounds caused only temporary disturbance, because within days of installation C. lacteus contacted the baits, and began to bring in moist soil and cover the bait-substrates. These termites have always coated the inside of the bait containers regardless of the time of year. So even during high summer temperatures (above 30°C, termites foraged throughout the bait containers.

Even though sound and extracted wood blocks in the containers were not in ground contact, C. lacteus always covered these wood blocks with moist soil. In the box containers, it took three months from the time the wood blocks were completely covered with soil till the time termites attacked the blocks. We suggest that this delay in feeding on the sound wood blocks indicates a 'conditioning process'. That is, moisture and soil microorganisms play a role in 'conditioning' or making more palatable wood substrates. Although C. lacteus has been described as a 'sound dead wood feeder' (22) our limited experience with this termite in the Boola Boola

State Forest suggests that they prefer decayed dead wood, particularly P. radiata. On the other hand the colony of C. lacteus from the Canberra region housed in the Accelerated Field Simulator at Highett under constant conditions of between 25-27°C, and relative humidity varying from 85-95%, readily attacks and eats sound, dead P. radiata timber billets (J.W. Creffield, *pers. comm.*).

Cork baits have proved attractive and palatable to the foraging workers of C. lacteus and N. exitiosus in the field, and to workers from laboratory cultures of C. acinaciformis, C. lacteus and M. darwiniensis. The development of the 'Gay à la plastique method' allows other aspects of the biology of subterranean termites to be studied. These include recruitment, caste composition and biomass analysis, gas exchange, and seasonal variations in termite activity and temperature-within-mounds.

REFERENCES

1. Gay, F.J., Greaves, T., Holdaway, F.G., and Wetherley, A.H. 1955. Standard laboratory colonies of termites for evaluating the resistance of timber, timber preservatives, and other materials to termite attack. Bull. Commonw. Sci. Ind. Res. Organ. No. 277, pp 60.

2. Gay, F.J., Greaves, T., Holdaway, F.G. and Wetherley, A.H. 1957. The development and use of field testing techniques with termites in Australia. Bull. Commonw. Sci. Ind. Res., Organ. No. 280, 1-31.

3. French, J.R.J., Robinson, P.J., Turner, G.L. and Pahl, P.J. 1984. Changes in fat, moisture contents and nitrogen fixation in laboratory maintained termites. 15th IRG Meeting, Ronneby, Sweden, May 28-June 1, 1984 (IRG/WP/1242).

4. Su, N-Y and La Fage, J.P., 1984. Differences in survival and feeding activity among colonies of the Formosan subterranean termite (Isoptera: Rhinotermitidae). Z. ang. Ent. 97: 134-138.

5. Esenther, G.R. 1979. Termite bioassay show greatly varied tolerance to insecticides in bait blocks. For. Prod. J., 29: 55-56.

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

7. French, J.R.J. 1984. Termites and their economic importance in Australia. In - Biology, economic importance and control of social insects. S.B. Vinson and J.K. Mauldin (eds.), Texas A. & M., University.

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

9. Gay *et al.* 1955, op. cit.

10. Gay *et al.* 1957, op. cit.

11. La Fage, J.P., Su, N-Y, Jones, M.J. and Esenther, G.R. 1983. A rapid method for collecting large numbers of subterranean termites from wood. Sociobiology. 7: 305-309.

12. La Fage, J.P., Nutting, W.L. and Haverty, M.I. 1973. Desert subterranean termites: A method for studying foraging behaviour. Environ. Entomol. 2: 954-956.

13. Haverty, M.I., Nutting, W.L. and La Fage, J.P. 1975. Density of colonies and spatial distribution of foraging territories of the desert subterranean termite, Heterotermes aureus (Snyder). Environ. Entomol. 4: 105-109.

14. Haverty, M.I., Nutting,W.L. and La Fage, J.P. 1976. A comparison of two techniques for determining abundance of subterranean termites in an Arizona desert grassland. Insects Sociaux. 23: 175-178.

15. Usher, M.B. and Ocloo, J.K. 1975. Testing the termite resistance of small wood blocks treated with water-borne preservatives. Holzforschung. 29: 147-151.

16. Williams, R.M.C. 1972. Field microtests of materials against subterranean termites attack. Int. Union Study Social Insects, VII Int. Congr. Entomol. London, Sept., pp. 405-410.

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

18. French and Robinson 1981, op. cit.

19. French J.R.J. and Robinson, P.J. 1984. A method for screening termite baits using Coptotermes lacteus mounds. 15th IRG Meeting, Ronneby, Sweden, May 28-June 1, 1983. (IRG/WP/1237), pp. 7.

20. Gay *et al.* 1957, op. cit.

21. French, J.R.J., Robinson, P.J. and Ewart, D.M. 1984. Cork as a bait substrate for some Australian subterranean termites, pp. 7. Sociobiology (submitted).

SOLID STATE ^{13}C NMR OF INSECT FRASS AND WOODS

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Abstract: Wood of Araucaria cunninghamii and frass from Dysthaeta anomala, Calymmaderus incisus, Cryptotermes brevis and C. primus attacking this wood were analysed by solid state carbon-13 nuclear magnetic resonance spectroscopy. A similar analysis was conducted for Eucalyptus maculata sapwood and frass from Lyctus brunneus, C. incisus, Cryptotermes brevis and C. primus attacking this wood. Results indicated spectral differences between the wood types and between the beetle and drywood termite frass.

Introduction: Solid state ^{13}C NMR has been used successfully to analyse a variety of substances such as clay, soils, coals and more recently, woods (Kolodziejski et al., 1982). The ease of sample preparation far outweigh the signal loss caused by this technique (Doimo, 1984). Information obtained includes the presence of carboxylated hemicelluloses (Taylor et al., 1983), lignin (Barron et al., 1984) and cellulose (Atalla et al., 1980). Analysis of insect frass using this technique was first attempted by Barron et al. (1984).

Experimental: Conditions were similar to those in Barron et al. (1984) but without 'depolar decoupling'. All analyses were carried out using a Bruker CXP-300 spectrometer. Frass were analysed untouched and woods were reduced to powder (<1 mm) using a hammer mill. Spectra of the frass from the beetles, Dysthaeta anomala (cerambycidae) and Calymmaderus incisus (anobiidae) were compared to the host wood species, Araucaria cunninghamii (gymnosperm). Similarly the spectra of the frass from the beetles Lyctus brunneus (lyctidae) and C. incisus were compared to the host species, Eucalyptus maculata (angiosperm). Frass from two species of drywood termite, Cryptotermes brevis and C. primus (kalotermitidae) were analysed from both host species.

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Many other wood species and insect frass were also analysed by ^{13}C NMR but are not presented here. They include drywood termite and beetle attack in Toona australis, Eucalyptus henryi, Brachychiton discolor. Several pines including Pinus elliottii, P. caribaea, P. radiata were also analysed. Experiments are progressing with timber species such as Eucalyptus bancroftii, E. grandis, Shorea sp., Picea excelsa, Litsea sp. and Flindersia brayleyana attacked by drywood termites and beetles such as Heterobostrychus aequalis (bostrychidae) and Minthea rugicollis (lyctidae).

Results/Discussion:

(a) Woods: Comparing spectra (a) from appendices I and II, differences were noted at 27, 135 and 175 ppm regions. These differences exist for all angiosperms and gymnosperms so far tested. The 27 and 175 ppm peaks are probably due to hemicelluloses and the 135 ppm peak, to lignin.

(b) Insect Frass: Initial results on the frass examined so far indicated two distinct groups: the first is the starch/hemicellulose feeding insects; spectra (b) and the second group is the cellulose feeding insects represented by the drywood termites; spectra (d) and (e). Another group which appears close to starch/hemicellulose feeding insects; labelled spectra (c) and this group represents the frass of Calymmaderus incisus. This beetle attacked both host species although attack in eucalypt is uncommon (M. Hockey, personal communication). There were marked differences in carbohydrate utilisation between the two host species of this group. Frass from E. maculata sapwood, spectrum II(c), appears much lower in carbohydrate (72-78 ppm region) than the pine frass, spectrum I (c).

Further results not included in this report for drywood termite frass from attack in other species produce spectra similar to (d) and (e). They consist mainly of lignin.

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References

ATALLA, R.H., GAST, J.C., SINDORF, D.W., BARTUSKA, V.J., MACIEL, C.E. (1980). ^{13}C NMR Spectra of Cellulose Polymorphs. J. Amer. Chem. Soc. 102(9):3249-3251.

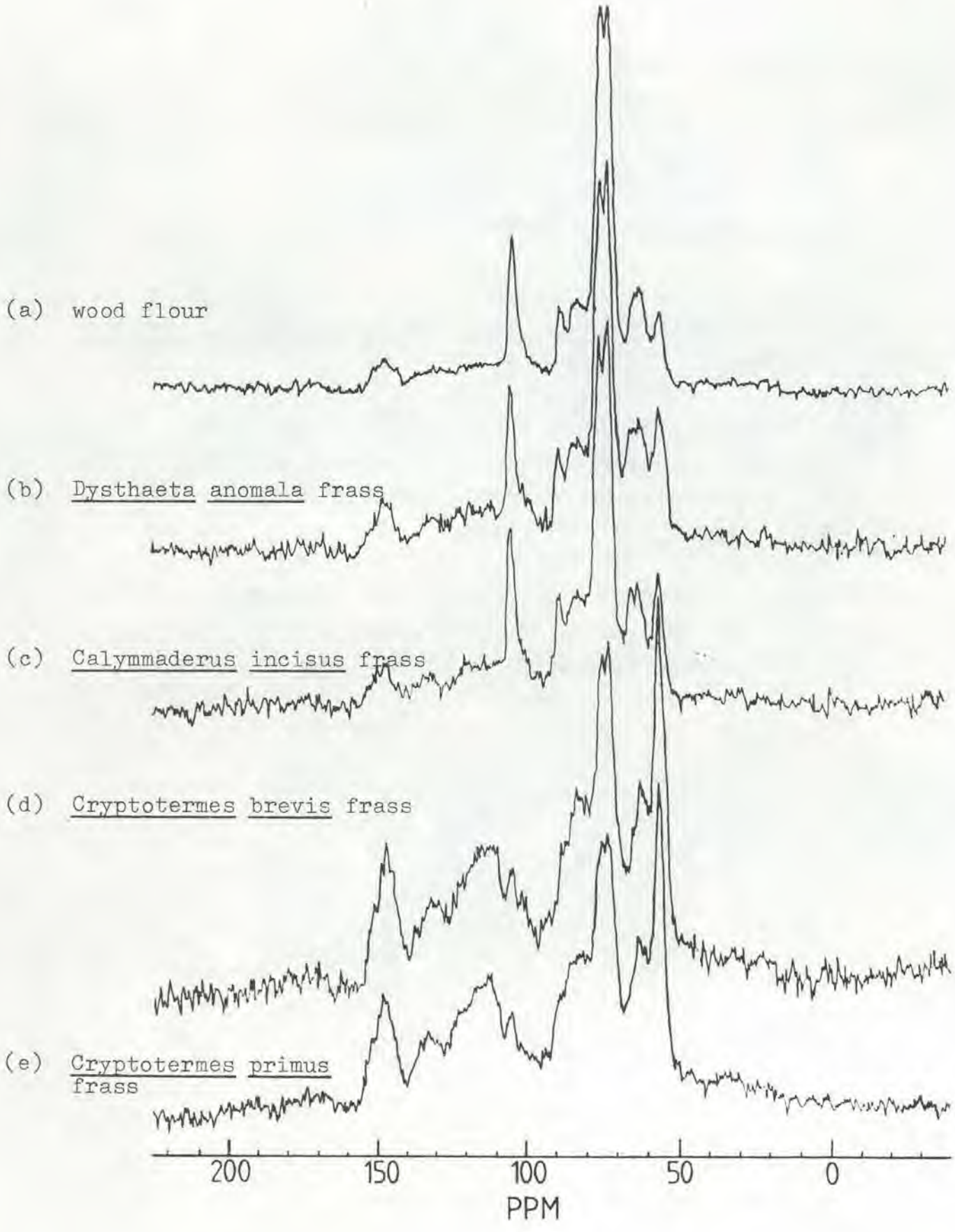
BARRON, P.F., FROST, R.L., DOIMO, L. and KENNEDY, M.J. (1984). ^{13}C CP/MAS NMR Examination of Some Australian Woods and their Chemical and Biochemical Degradation Residues. Macromolecules (submitted for publication) 27 pp.

DOIMO, L. (1984). What is Wood? A Review of the Major Chemical Components. Technical Paper No. 32 Qld. Dept. Forestry 20 pp.

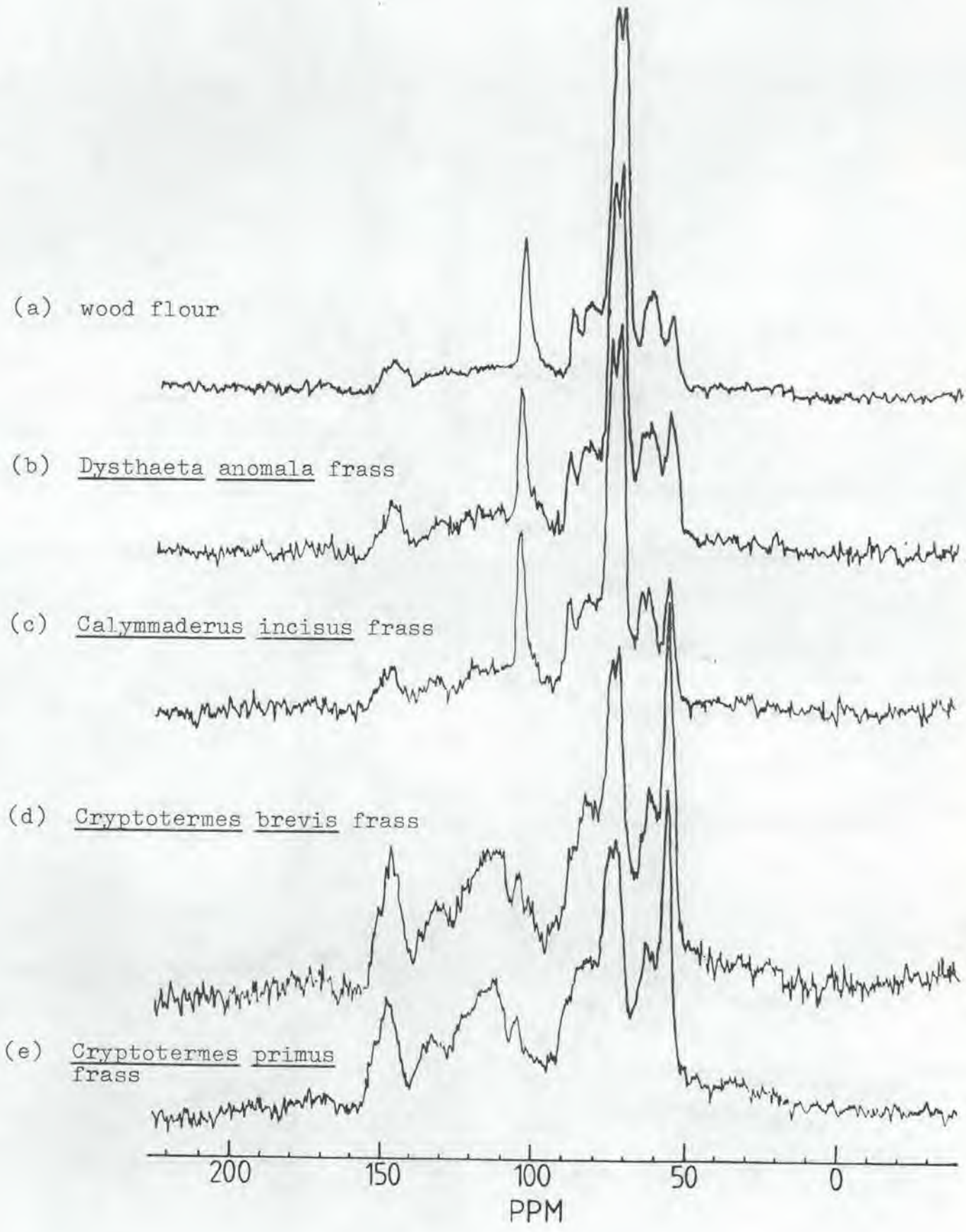
KOLODZIEJSKI, W., FRYE, J.S. and MACIEL, G.E. (1982). Carbon-13 Nuclear Magnetic Resonance Spectrometry with Cross Polarization and Magic-Angle Spinning for Analysis of Lodgepole Pine Wood. Anal. Chem. 54(8):1419-1424.

TAYLOR, M.G., DESLANDES, Y., BLUHM, T., MARCHESSAULT, R.H., VINCENDON, M. and SAINT-GERMAIN, J. (1983). Solid State ^{13}C NMR Characterization of Wood. Tappi 66(6):92-94.

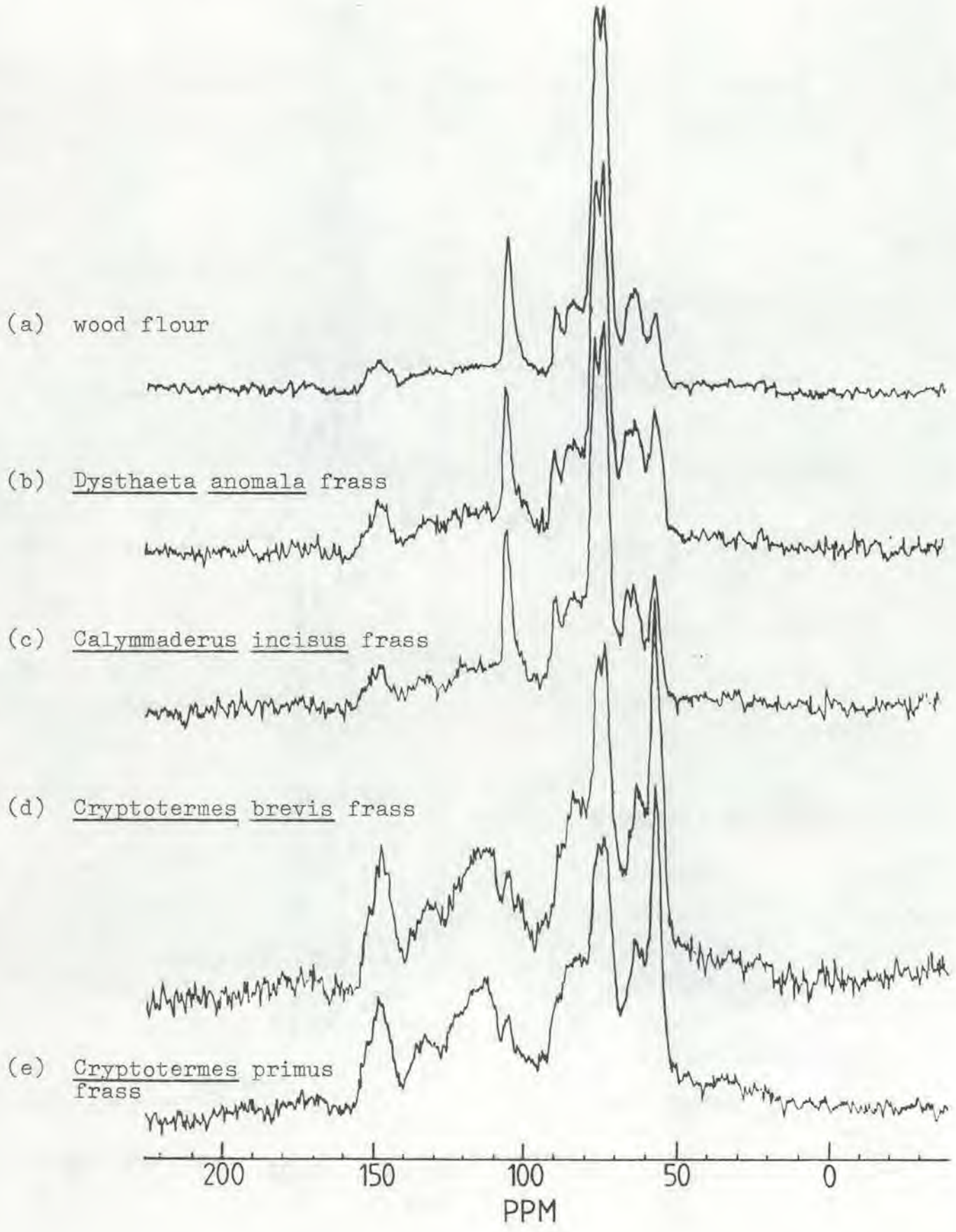
APPENDIX I: Araucaria cunninghamii frass series



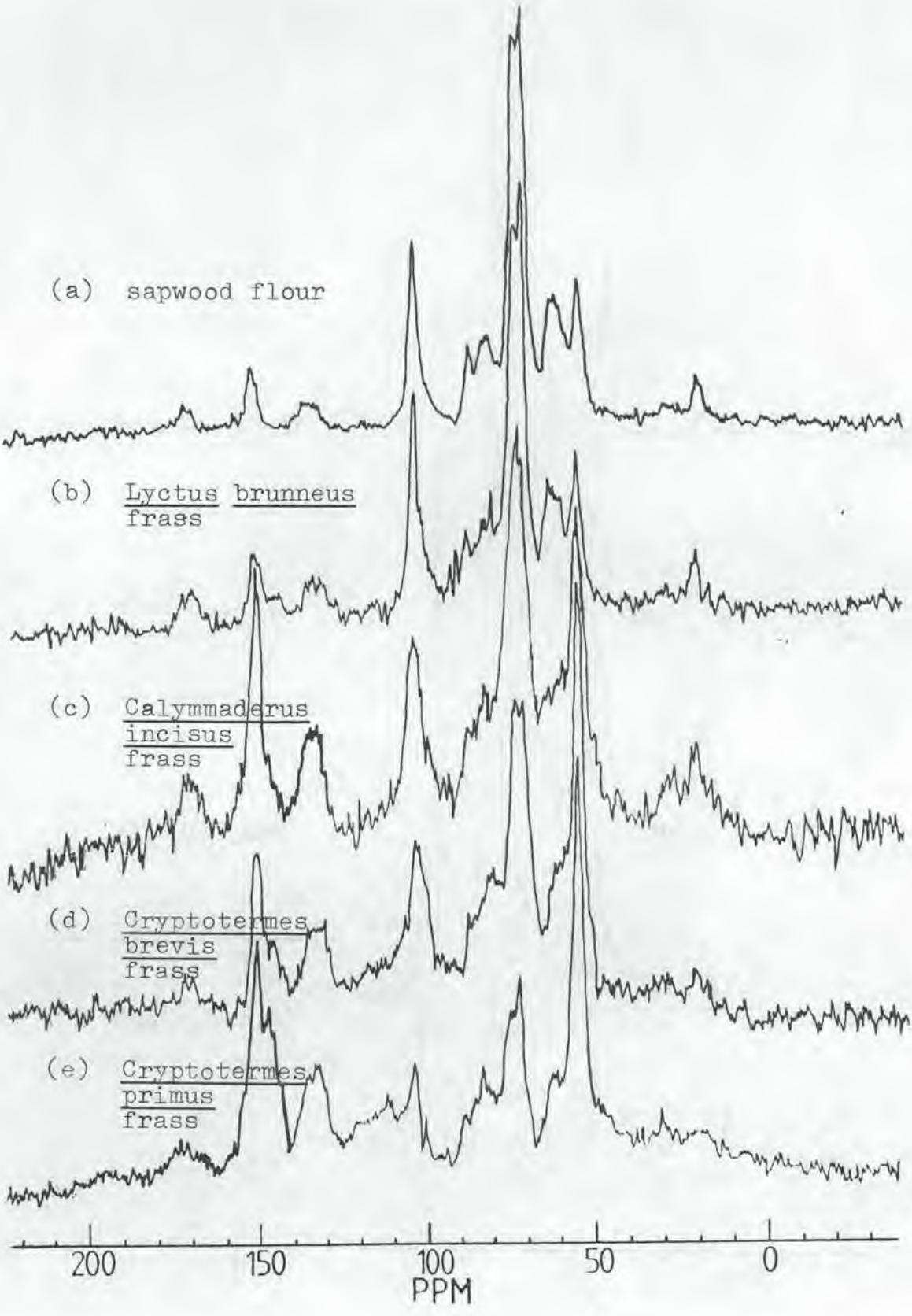
APPENDIX I: Araucaria cunninghamii frass series



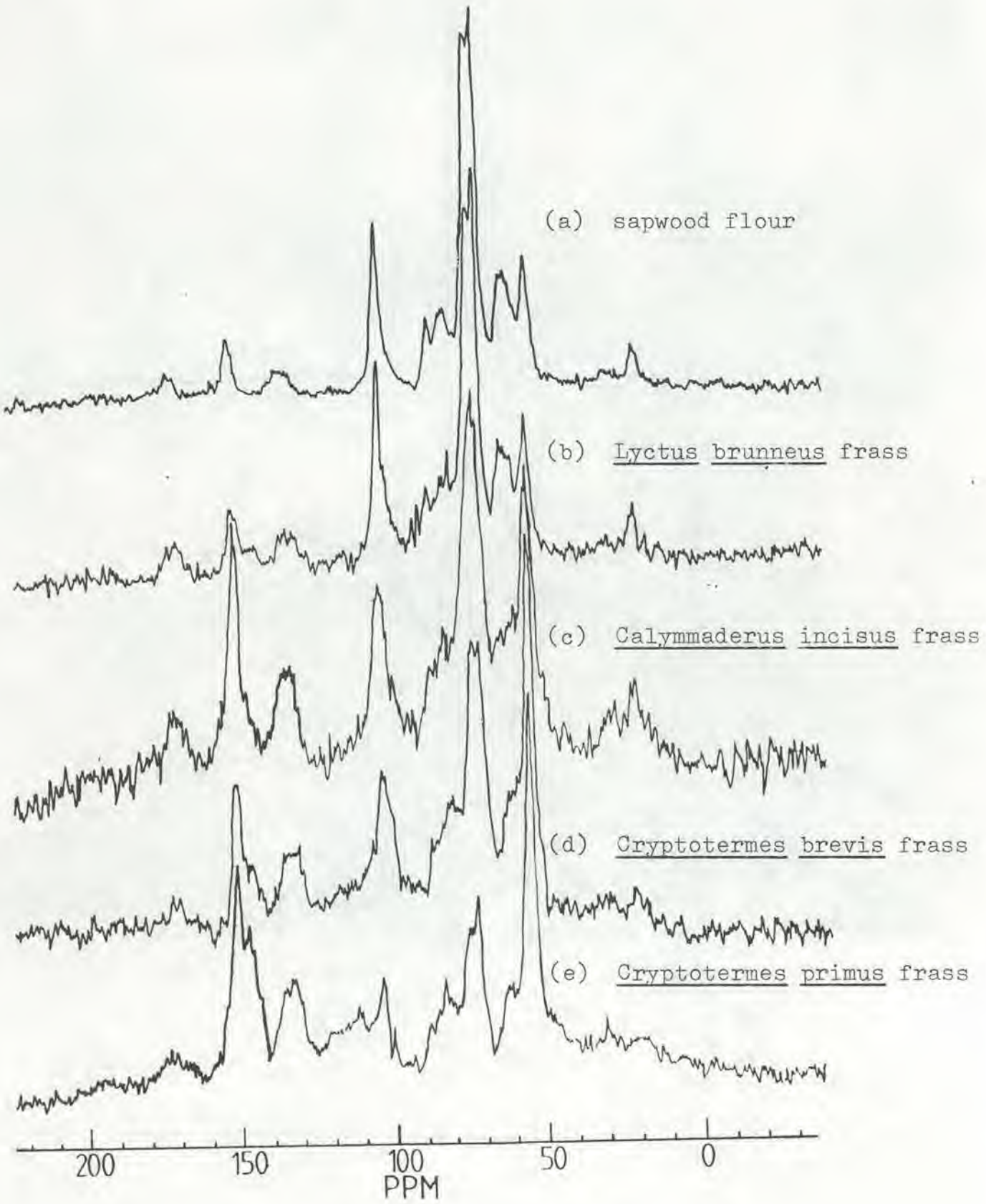
APPENDIX I: *Araucaria cunninghamii* frass series



APPENDIX II: Eucalyptus maculata frass series



APPENDIX II: Eucalyptus maculata frass series



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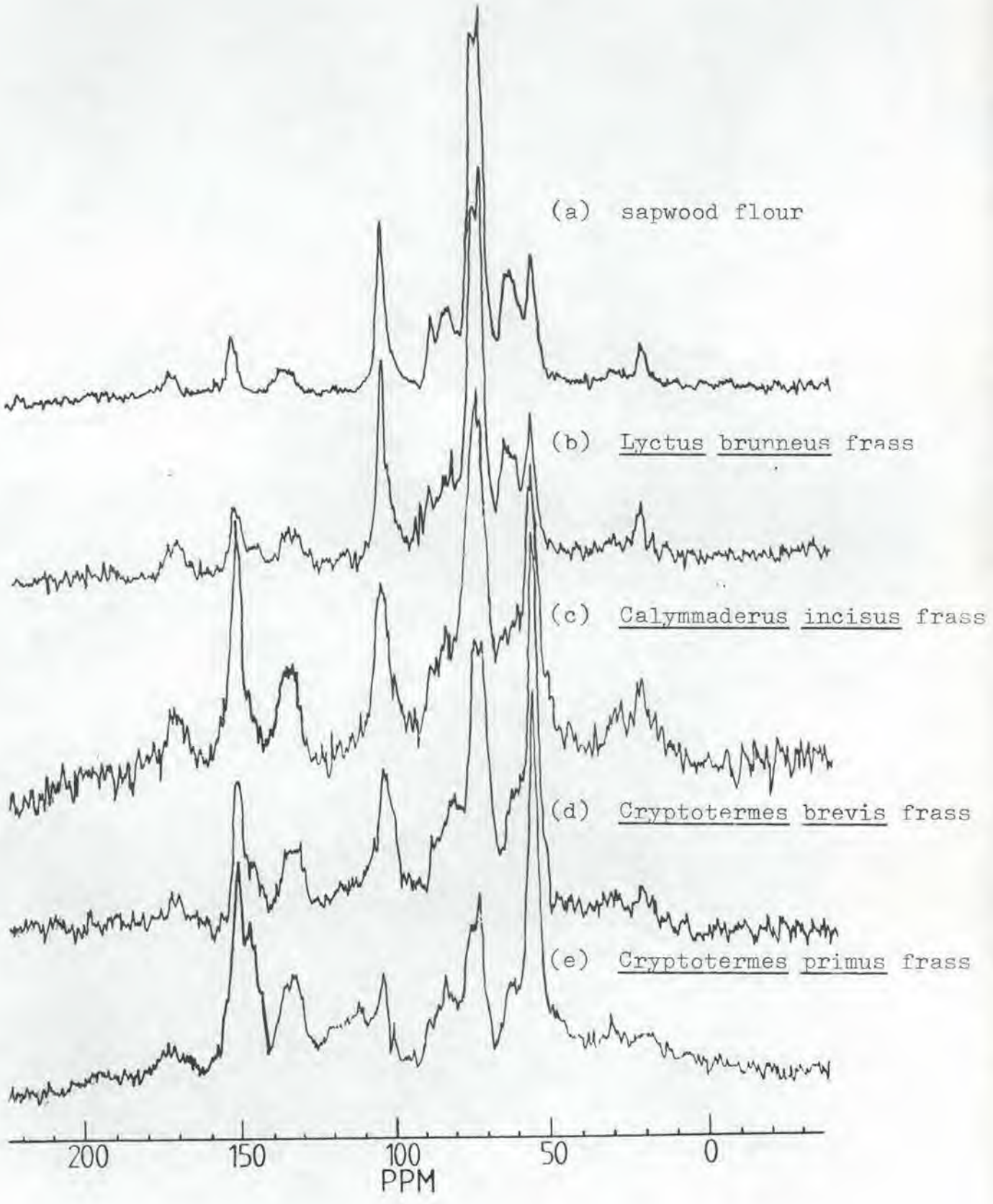
APPENDIX II: Eucalyptus maculata frass series



STARCH CHARACTERIZATION AND QUANTITATION BY HIGH PERFORMANCE GEL PERMEATION CHROMATOGRAPHY.

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ABSTRACT

Analysis of kurrajong wood for starch was carried out by high performance gel permeation chromatography (H.P.G.P.C.) on microbondagel columns. It was necessary to separate amylose from amylopectin before chromatography using KI/I_2 solution. Molecular weight maxima for amylopectin were about 4.0×10^7 and for amylose about 1.0×10^5. Kurrajong contained about 6.3% starch, 32% being amylose. This is a higher percentage amylose than found in most cereal starches. H.P.G.P.C. offers several advantages over other methods for starch determination.

INTRODUCTION

Research into starch analysis of wood arose during a breeding programme for Lyctus brunneus (Stephens). The lack of breeding potential of the host species, kurrajong (Brachychiton discolor F. Muell.) was thought to be due to unusual amounts or composition of the starch. Data from tests with cereal pests overseas (1, 2, 3) suggest grain borers prefer high amylopectin diets, due to the ability of amylase to simultaneously attack the many branch terminations of the amylopectin molecule. This fraction is not detected visually be the routine KI/I_2 test, which gives the characteristic blue-black colouration only with the unbranched (linear) amylose fraction. No data exist on the composition of starch in Australian woods, nor on the starch preferences of Lyctus.

Timell (4) found dimethyl sulphoxide (DMSO) dissolved some hemicelluloses and Gaillard (5) found the KI/I_2 reaction could precipitate some straight chain hemicelluloses. Wolf et al (6) used DMSO/water solutions for their corn starch analysis. Minor (7) and Sargeant (8) used gel permeation chromatography to separate polysaccharides. Minor used microbondagel and microstyragel columns. This paper introduces simple isolation and separation techniques for kurrajong wood starch analysis using DMSO dissolution, KI/I_2 amylose precipitation, and H.P.G.P.C. with microbondagel columns.

EXPERIMENTAL

MATERIALS

Amylose and amylopectin were obtained from potato and supplied by Sigma Chemical Co. A.R.DMSO was used without prior removal of water. Molecular Weight standards were dextrans supplied by U.S. Biochemical Co. in four ranges: $15\text{-}20 \times 10^3$, $35\text{-}50 \times 10^3$, $100\text{-}200 \times 10^3$ and $5\text{-}40 \times 10^6$. Kurrajong sapwood was obtained from a growing tree at S.F.637, Deer Reserve, near Mt. Mee, Queensland, sawn within one day and rapidly air-dried.

INSTRUMENTAL CONDITIONS

1.0 ml/min distilled water was supplied by a Waters model 6000A pump through a Waters U6K injector and two gel permeation columns in series (Waters microbondagel E-125 and E-1000). The effluent passed through a Waters R-301 refractive index detector at 8X attenuation. The detector output was processed by a Hewlett Packard 3388A computing integrator into 0.1 minute area slices.

METHODS

To 0.10 g starch or 2.00 g wood flour was added 20 ml 90:10 V/V DMSO:water solution before placing in an ultrasonic bath for one hour at 50°C. The mixtures were vacuum filtered through Whatman 542 paper before starch precipitation by addition

to 60 ml absolute ethanol, to remove co-extractives. The centrifuged starch precipitates were re-dissolved in 20.0 ml DMSO (90:10, ultrasonic, 1 hr, 50°C) and a small sample reserved for total starch determination. To the remainder was added 5 ml distilled water and 10 ml iodine/iodide reagent (12 $g1^{-1}$ KI and 6 $g1^{-1}$ I_2). Amylose precipitated as a blue iodide complex and was removed by centrifugation (20 min at 4000 rpm). The remaining amylopectin was precipitated from the supernatant liquid by addition to 60 ml absolute ethanol, centrifuged, and re-dissolved in 20 ml 90:10 DMSO.

Fifty microlitre samples of the DMSO solutions before amylose removal and after amylopectin re-dissolution were injected manually after filtration through 1.0 micron PTFE filters. Amylopectin was determined by summation of the area slices under the curve of the chromatogram of the latter sample, and comparing with potato amylopectin standards. Amylose was determined by subtracting this area from the area of the total starch extract (the former sample, before amylose precipitation) and comparing the difference with potato amylose standards.

RESULTS AND DISCUSSION

Selected chromatograms shown in Figure 1 represent molecular size distribution of the polymers in solution. Calibration using dextran standards indicated that area slices 20 to 45 covered the range 40 x 10^6 to 15 x 10^3. This can only be approximate since dextrans are 1-6 homopolymers whereas starches are 1-4 homopolymers (amylose) and 1,4-1,6 homopolymers (amylopectin). They thus differ in effective size in solution for the same molecular weight. Amylose and amylopectin are shown to overlap in molecular size range in solution. However, amylopectin molecular weights of the order of 40 x 10^6 predominate, whereas amylose tends to consist of smaller molecules, approximately 100 x 10^3.

A: Total starch from 2.0 g kurrajong

B: Residual amylopectin from 2.0 g kurrajong after iodine/amylose precipitation

C: Difference between A and B, attributed to kurrajong amylose

D: Total starch from a mixture of 0.1 g potato amylopectin and 0.1 g potato amylose

E: Residual amylopectin from mixture in D after iodine/amylose precipitation

F: Difference between D and E, attributed to 0.1 g potato amylose

G: Actual chromatogram from 0.1 g potato amylose

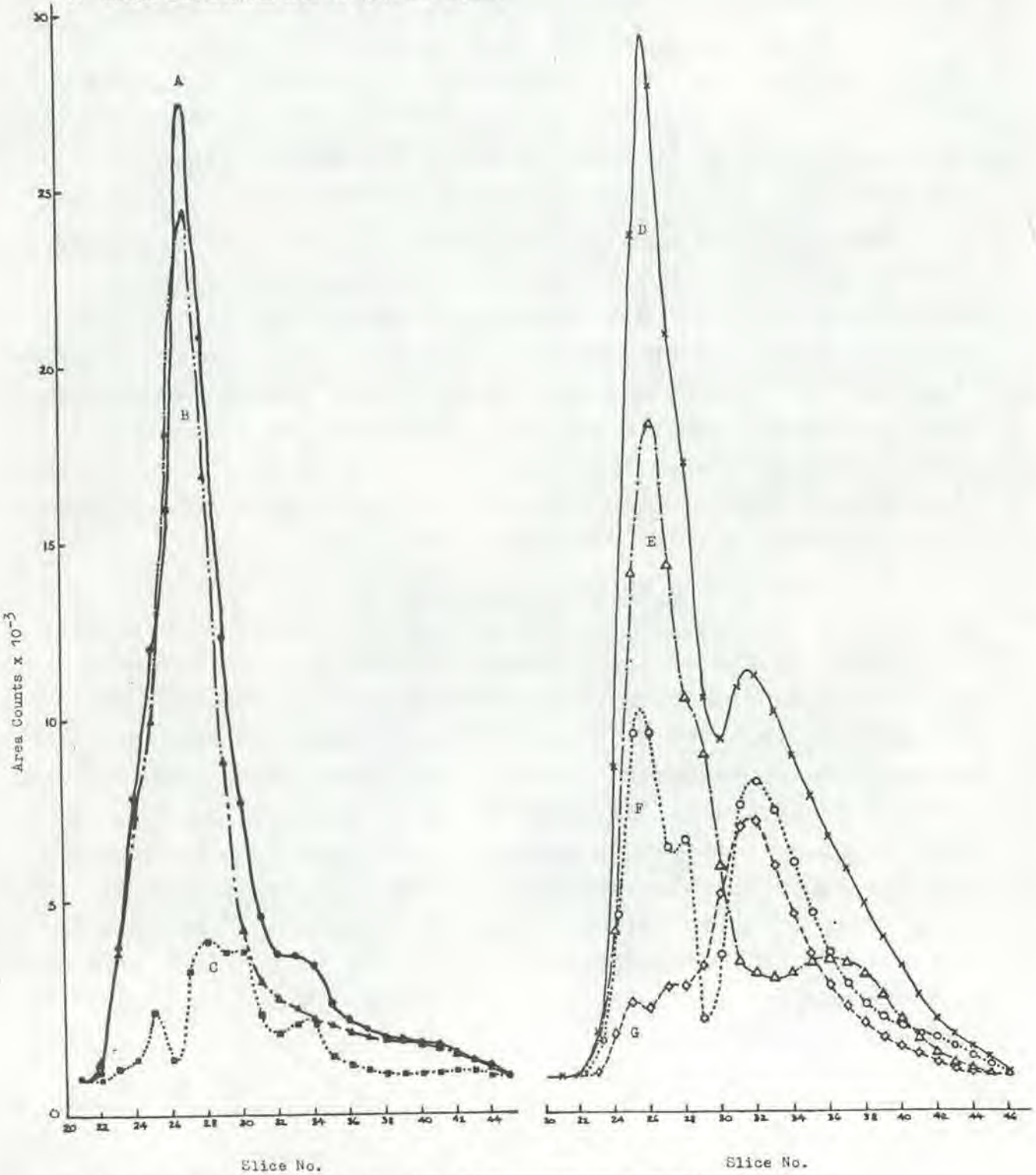

FIG. 1 CHROMATOGRAMS AND DIFFERENCE CHROMATOGRAMS OF THE LISTED SOLUTIONS IN 90:10 DMSO.

The iodide/iodine amylose precipitation depends (9) on the presence of sufficient water in the DMSO for complex formation, hence the addition of 5 ml water before 10 ml of reagent. Standards containing 0.1 g amylose alone were found to contain 0.004 g amylose remaining after iodide/iodine precipitation : effectiveness of the separation is thus better than 95%. However, a comparison of the difference between curves D and E (curve F, which should represent 0.1 g amylose) with curve G, which was produced by a 0.1 g amylose solution, shows that some potato amylopectin has been lost during the potato amylose precipitation procedure. This effect with potato starch is not observed in the kurrajong starch data, possibly because of our gentle processing of the wood starches compared with the conventional dissolution and drying process used by Sigma on their potato starches.

Preliminary estimates of starch concentrations in the kurrajong samples indicate concentrations of 2.0% m/m amylose and 4.3% m/m amylopectin (with wood at e.m.c. and not oven dried, to minimise starch denaturation). These would indicate the amylose fraction is some 32% of total starch, somewhat higher than characteristic of most cereal starches (20-25%)(2). If Lyctus can utilize amylopectin more readily than amylose, similarly to cereal pests, the high amylose content may help to explain the poor performance of Lyctus cultures on kurrajong.

ADVANTAGES OF THIS METHOD

1. The dissolution technique does not denature starch. Any damage would be immediately detected by unusual changes to molecular size distribution.
2. Using H.P.G.P.C. provides detailed information on size distribution not obtainable from alternative techniques such as viscometry, polarimetry or spectrophotometry.

3. The technique is rapid. A batch of four wood samples may be put through the entire procedure in five hours, requiring operator attention for only 25% of this time. Chromatographic run time is 4.5 minutes, with 14 minutes between successive injections.

REFERENCES

1. Chippendale, G.M. (1972). Polysaccharide requirements of the Angoumois grain moth. J. Nutrition 102(2):187-194

2. Chippendale, G.M. and Reddy, G.P.V. (1974). Dietry carbohydrates: Role in feeding behaviour and growth of the southern corn borer. J. Insect Physiol 20:751-759

3. Dobie, P. (1974). The laboratory assessment of inherent susceptibility of maize varieties to post harvest infestations by Sitophilus zeamais. J. Stor. Prod. Res. 10:183-197

4. Timell, T.E. (1964). Wood hemicelluloses: Part 1. Adv. Carbohydrate Chem. 19, 247-302

5. Gaillard, B.D.E. (1965). Comparison of hemicelluloses from plants belonging to two different families. Phytochem 4:631-634

6. Wolf, M.J., Melvin, E.H., Garcia, W.J. Dimler, R.J. and Kwolek, W.F. (1970). Amylose determination in dimethyl sulphoxide extracts of maize. Cereal Chem. 47:437-446

7. Minor, J.L. (1979). Gel permeation chromatography of polymers from wood. J. Liquid Chromatography 2(3):309-318

8. Sargeant, J.C. (1982). Determination of amylose:amylopectin ratios of starches. Starch/Starke 34(3):89-93

9. Ono, S., Watanabe, T., Ogawa, K. and Okazaki, N. (1965) Amylose-iodine complex IV: The complex in dimethyl sulphoxide - water mixtures. Bull. Chem. Soc. Japan 38(4):643-648.

BIOLOGICAL ATTACK ON POLE STUBS - WEDDING BELLS STATE FOREST FIELD TRIAL

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Forestry Commission of New South Wales

INTRODUCTION

The location of the field test site at Wedding Bells State Forest near Coffs Harbour, New South Wales, was selected after examinations of hardwood and softwood test stakes installed at six sites in New South Wales (1). The selection was based on the existence of active soft rot attack in the area and the presence of termites.

A field test of round timber was installed in 1976 (2) with two major objectives, (a) to examine means of reducing the incidence of soft rot in poles by groundline treatments and, (b) to compare with untreated poles the performance of different preservative types and species of timber currently in use as electricity poles.

This paper outlines the extent of the biological degrade in the pole stubs with no groundline treatments (controls) after eight years, with specific reference to termite and soft rot attack.

INSPECTION PROCEDURE

Eight replicates of each of the following pole types were examined:

(1) *Eucalyptus maculata* treated with pentachlorophenol in oil.
(2) *E. maculata* with no sapwood treatment.
(3) *Pinus radiata* treated with copper chrome arsenic salt.
(4) *E. maculata* treated with copper chrome arsenic salt.
(5) *E. maculata* treated with high temperature creosote.
(6) Class 1 durability eucalypts with sapwood removed.

Each of these poles was examined visually between the groundline and 450 mm from the groundline around the full perimeter. At the same time, sample plugs were taken for retention analyses and microscopic examination for soft rot attack. The poles were rated on the standardised basis of 4, where no fungal degrade was present down to 0, where no sound sapwood remained.

In the case of the desapped durables, a comparable rating system was devised for fungal penetration into the heartwood, the difference being that each unit less than 4 represented 5 mm of fungal attack. The maximum rating of 4 indicated no visible degrade and 0 represented a peripheral fungal depth of 20 mm.

A detailed examination of each of the poles was carried out for termite activity and identifications made where possible.

Microscopic examinations were made of the preservative-treated poles for the presence of soft rot attack and preservative retentions were determined on the *E. maculata* pole stubs treated with copper chrome arsenic salt.

RESULTS AND DISCUSSION

The results of the visual inspection are shown in the accompanying Table (Table 1).

Table 1. Fungal Degrade and Termite Activity

Pole No.	Species/Pole Type	Component Number								
		1	2	3	4	5	6	7	8	Ave.
1H	*Eucalyptus maculata*/PCP in oil (1)	4.0	3.7	3.2	4.0	3.2	4.0	3.9	3.9	3.7
2H	*E. maculata*/untreated	0*	0*	0*	0*	0*	0	0*	0	0
3H	*Pinus radiata*/C.C.A.(2)	4.0	4.0	3.6	4.0	4.0	4.0	4.0	4.0	3.9
4H	*E. maculata*/C.C.A.(2)	4.0	4.0	4.0	4.0	3.8	4.0	4.0	4.0	4.0
5H	*E. maculata*/creosote	3.5	3.5	3.5	3.1	3.3	4.0	3.7	3.7	3.5
6H	Class 1 eucalypt/untreated	4.0	4.0*	4.0	3.4*	2.5*	2.7*	3.4*	4.0	3.5

* Signs of termite activity
(1) Pentachlorophenol
(2) Copper chrome arsenic salt.

FUNGAL ATTACK - As expected, all untreated sapwood in the *E. maculata* poles was destroyed by basidiomycetes (white rot). Degrade caused by basidiomycetes was also in evidence in the Class 1 durability poles.

Visual evidence indicated slight soft rot attack in the *E. maculata* poles treated with pentachlorophenol in oil and creosote. Microscopic examination confirmed the presence of typical soft rot cavities. Soft rot attack in both *E. maculata* and *P. radiata* treated with copper chrome arsenic salt was negligible.

No attempt was made to identify the fungi present although white-rot fungi and the soft rot fungus *Phialophora mutabilis* had previously been identified at the test site (3).

TERMITE DAMAGE - There were signs of termite activity in six of the eight *E. maculata* poles with untreated sapwood. Positive identifications were made of *Coptotermes* sp. and *Schedorhinotermes* sp. in these poles. There was evidence of termite attack on the surface of five of the eight Class 1 durability poles. No attack was confirmed on the treated poles.

Glyptotermes sp. and *Nasutitermes exitiosis* were identified as being present in other poles within the test site (see Appendix 1).

C.C.A. RETENTIONS - *E. maculata* POLES - Analyses of the copper chrome arsenic retentions of the *E. maculata* poles produced results in the range 19.0 to 29.2 kg per metre^3. These retentions in *E. maculata* poles appear to have controlled soft rot attack in a proven high soft rot area for eight years. More predictably, there was no basidiomycete attack or termite damage at these treatment levels.

CONCLUSION

(1) Severe basidiomycete and termite attack have destroyed the untreated sapwood of *Eucalyptus maculata* after eight years.

(2) There are signs of some termite activity and basidiomycete attack on the Class 1 durability eucalypts but none on the treated poles.

(3) Soft rot attack in both *E. maculata* and *Pinus radiata* treated with C.C.A. Salt is negligible after eight years.

ACKNOWLEDGEMENTS

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REFERENCES

(1) Edwards, D.W., R.S. Johnstone and W. Pitt (1975) - Evaluation of soft rot field test sites in N.S.W. Proceedings of the 17th Forest Products Research Conference, Melbourne, Australia.

(2) Johnstone, R.S. (1977) - Remedial treatments to prevent soft rot in poles. Proceedings of the 18th Forest Products Research Conference, Melbourne, Australia.

(3) Leightley, L.E. and R.S. Johnstone (1980) - I.R.G. soft rot stake test - Site : 03 Australia - Progress Report, Report prepared for the 11th Meeting, Raleigh, U.S.A.

APPENDIX 1

TERMITE COLLECTIONS - WEDDING BELLS TEST SITE

Vial	Block	Pole	Notes
-	4	6P	Termites in shakes - no activity. Old galleries beneath bandage below ground level - *Coptotermes* sp.
-	4	6N	Termite galleries in shakes, galleries beneath outer and inner wrappings beneath ground - no activity - galleries occupied by ants. Remains of large galleries on surface of pole.
-	4	6M	Remmants of external termite gallery and nibbles beneath wrap. Galleries in shake - no activity.
1	4	6J	Nest on top of pole stub. Galleries on outside of pole, superficial damage.
-	4	6B	No termites - black ant activity between pole and polythene foam wrap - actually "eaten" away.
-	4	6A	Termite Galleries in wood underneath concrete collar - Galleries in shakes taken over by black ants.
-	4	2Q	Sapwood below ground gone. Termite galleries in sapwood full length of pole - *Coptotermes* sp.
2	4	2N	Sapwood destroyed - decay and *Glyptotermes* sp. in sap and heart.
3	4	2M	Sapwood decayed - little termite workings.
-	4	2H	Sapwood below groundline gone. Extensive termite workings in sapwood above ground - *Coptotermes* sp.
-	4	2D	Termite entry from soil into pole sapwood at groundline. Sapwood above ground destroyed. Sapwood below ground under bandage not penetrated by termites - *Coptotermes* sp.
-	3	2H	Sapwood below ground gone. Sapwood above ground heavily attacked by termites and bostrychids.
-	7	6H	Remains of surface galleries chewed into pole from g.l. to 15 cm. below. One gallery entering pole at g.l at base of shake. No activity current.
-	7	2H	Sapwood below ground gone. Heavy termite attack above ground - restricted to sapwood. Damage similar to *Schedorhinotermes* sp.
-	4	2C	Sapwood beneath collar extensively decayed and attacked by termites. Termite entry beneath collar 35 cm. below ground. Termite galleries to butt of pole.

-	4	2B	Old termite galleries through foam rubber - now occupied by black ants - superficial damage to sapwood only at g.l. - deep decay pocket in sapwood from g.l. to 8 cm. below ground.
-	4	2A	Sapwood below ground and under concrete extensively decayed and attacked by termites. Sapwood above g.l. extensively attacked by termites - *Coptotermes* sp.
4	5	6P	Nasute galleries in sapwood remnants and around knots above ground.
5	5	6A	Nasute galleries above ground on pole surface and in shakes.
-	5	6H	Termite plastering in shake - no current activity - *Coptotermes* sp.
-	1	2H	Sapwood below ground eaten, some penetration into heartwood below ground. Sapwood above ground eaten out - *Coptotermes* or *Schedorhinotermes*
-	5	2H	Sapwood below ground gone, above ground - badly decayed - old termite workings above ground in sapwood - appears like *Schedorhinotermes* - no current activity.
-	6	6H	Surface nibbles - 8 cm. below ground only.
-	2	2H	Sapwood below ground gone. Some deep termites galleries into heartwood from g.l. to 45 cm. below ground.
-	2	2H	Termite gallery in sapwood above g.l. no activity - *Coptotermes* sp.
-	2	6H	Surface nibbles in sapwood remnants below ground only.
-	3	2H	Sapwood below ground gone. Old termite workings evident in sapwood remnants. No current activity.
-	4	3N	Some termite galleries heading through crack in heartwood - *Coptotermes* sp.
-	4	6H	Signs of past termite attack.

Identification:

1. *Nasutitermes exitiosis.*
2. *Glyptotermes* sp.
3. *Nasutitermes exitiosis.*
4. *Nasutitermes exitiosis.*

Note: H designates poles with no groundline treatment

THE PERFORMANCE OF CSIRO FUNGITOXIC POLE BANDAGES AFTER 5 YEARS IN SERVICE

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ABSTRACT

The performance of bandages installed on power transmission poles at Gatton, Queensland was monitored by inspections at 12, 24, 48 and 60 months after installation. During these inspections the physical condition of the bandages were noted, and core samples were taken from beneath the bandage for analysis. Bioassays and microscopic examinations were used to determine the bandages fungitoxic effectiveness in inhibiting soft rot decay. These results are discussed and recommendations on bandage design and fungitoxicants are made.

INTRODUCTION

The soft rot problem of treated hardwoods in ground contact has been known for sometime (1,2,3,4,5) and extensive effort is being made to produce effective preservatives to combat the problem, e.g. copper ethanolamine nonoate (6) which will be applied as initial treatments for new timbers. Meanwhile an urgent need is required to develop *in situ* remedial treatments to protect the present population of in-service hardwood transmission poles from soft rot decay. The CSIRO Division of Chemical and Wood Technology has concentrated efforts towards the development of fungitoxic bandages (7). After experimentation with different materials and formats, a bandage consisting of compartments of foam backed by an outer cover of crosslinked polyolefin (XLPE) was developed (8). After the foam is impregnated with a fungitoxic chemical the bandage is wrapped around a soft rot infected pole at the critical

groundline decay zone. Heat is then applied to the outer cover, which shrinks to conform with the pole surface (9,10). In this fashion highly waterproof upper and lower seals are also achieved, which prevent the likelihood of rain and ground-water leaching the fungitoxicants from the bandage.

The CSIRO Mark IV bandage is under trial at various sites along the east coast of Australia. The largest of these sites is situated at Gatton, Queensland, where in October 1978, 120 bandages were installed on CCA-treated *Eucalyptus maculata* (Hook) power transmission poles. Before bandaging, the poles had been in service for 10-15 years and were infected with varying degrees of soft rot, with an average radial infection of 5-10 mm. Twenty replicate bandages containing each toxicant listed in Table 1, together with twenty bandages without toxicant were installed on the test poles, which were spread over a 100 km^2 area. A further twenty poles were selected as controls and left unbandaged.

TABLE 1

Preservatives and concentrations used in the Gatton bandages

Preservative used in bandage	Concentration of active ingredients*	Number of replicate bandages
50% m/m Busan 30 + 50% Busperse 47	0.40 g/cm^3	20
Blue-7	0.29 g/cm^3	20
Basilit B.F.B.	0.39 g/cm^3	20
Permapruf-T	0.47 g/cm^3	20
33% PCP/67% hexylene glycol	0.49 g/cm^3	20
No chemical	-	20

* All the concentrations used were much higher than those found to be toxic to soft rot fungi in laboratory tests.

MONITORING THE PERFORMANCE OF GATTON BANDAGES

(a) BANDAGE PERFORMANCE

To monitor the effectiveness and durability of the CSIRO bandages at Gatton, inspections were undertaken at 12, 24, 48 and 60 months after installation.

After 12 months the physical condition of all bandages was very good. The 24 month inspection found 6 bandages had been accidently damaged by machinery (e.g. agricultural tractor), but this damage was restricted to the above-ground portion of the bandage. With one exception all bandages were still effectively sealed and the damage was repaired. Eight bandages were found to have loose upper seals due to ineffective installation. However, they shrank back tightly when reheated. At the 48 and 60 month inspections all bandages were found to be still effectively sealed. After 60 months most bandages were still in very good condition with only one bandage no longer operative since it had been destroyed by fire.

(b) SAMPLING

To facilitate an examination of the efficacy of the bandage fungitoxicants, a wad punch was used to remove two 40 mm diameter wads from each bandage at 100 mm below groundline and 180^{o} apart. The pole surface exposed by removal of the wads was probed to ascertain the approximate depth of soft rot. This depth was recorded for comparison with the initial extent of soft rot in the pole, before bandaging. Two cores 17 x 40 mm (the 40 mm radial depth included all sapwood and some heartwood) were extracted from the pole, through each opening in the bandage. (Subsequent samples were taken in exactly the same way 50 mm tangentially from the previous sampling points.)

Sample cores were split into half; one half was used for microscopic examination to determine the extent of soft rot decay, the other matched half was bioassayed. The bioassay technique, which is a modification of that described by Greaves 1978 (12), helps to determine at which radial

depth sufficient fungitoxicant is present in a pole, to inhibit growth of soft rot microfungi.

(c) RESULTS OF MICROSCOPIC EXAMINATION

Comparison between the initial extent of decay in each pole with visual and microscopic examinations in corresponding poles at 12, 24, 48 and 60 months failed to provide conclusive results on the extent of soft rot; because of the variability in severity of soft rot decay both within and between each pole, it was impossible to determine distinctly whether soft rot attack in either the bandaged poles or the unbandaged controls had increased after the initial inspection. Additional inspections over the next 5-10 years may be necessary to determine this. However, fungal isolations from samples taken at 12, 24, 48 and 60 months indicated a significant reduction in the microflora present in most of the bandaged poles compared with unbandaged controls and initial samples taken from the same poles before bandaging. In some poles bandaging had caused a complete sterilisation of the wood (Leightley, pers. comm.).

(b) BIOASSAY RESULTS

Trends of the bioassay results are presented in Table 2. The bioassay results for individual samples from the Gatton trial indicate a large variation in diffusion depths of chemicals between poles bandaged with the same preservative type. The variability in soft rot attack existed both between poles and within individual poles, which often contained soft rot pockets up to 15 mm in depth. The decayed wood probably allows easier and quicker diffusion of preservatives, therefore variability in decay would influence bioassay results. The same bioassay technique was used on all cores taken at each inspection. Replicate bioassays on the spare set of samples always produced similar results indicating that the technique was reproducible.

TABLE 2

Summary of bioassay results of cores taken from bandaged poles in Gatton, Queensland

Preservative		12 months	24 months	48 months	60 months Unreplenished	60 months Replenished
BUSAN 30 50% Busan 30/ 50% Busperse 47	No. of samples bioassayed.	39	38	40	17	18
	Mean diffusion depth of effective fungitoxicant.	12.9	13.0	14.4	17.3	21.5
	Range.	6-30	6-30	5-30	10-26	8-28
PENTACHLOROPHENOL 33% PCP/ 66% Hexylene glycol	No. of samples bioassayed.	40	40	40	17	18
	Mean diffusion depth of effective fungitoxicant.	6.9	7.4	17.4	17.3	21.5
	Range.	2-18	1-14	8-24	10-24	10-28
PERMAPRUF-T	No. of samples bioassayed.	38	39	40	16	20
	Mean diffusion depth of effective fungitoxicant.	9.9	8.0	11.1	16.3	17.4
	Range.	0-18	0-24	0-26	4-28	8-28
BLUE-7	No. of samples bioassayed.	38	40	40	20	15
	Mean diffusion depth of effective fungitoxicant.	6.2	10.5	0.6	1.2	6.4
	Range.	2-30	4-30	0-16	0-4	4-28
BASILIT BFB	No. of samples bioassayed.	40	36	37	20	18
	Mean diffusion depth of effective fungitoxicant.	11.4	13.8	1.7	1.9	9.4
	Range.	0-18	0-30	0-4	0-4	0-16

It appears that both the water soluble fungicides Blue-7 and Basilit BFB diffuse rapidly through the sapwood of bandaged poles initially. However, the depth of diffusion of these two formulations decreased after 48 months. Some poles with bandages containing Blue-7 and Basilit BFB showed toxicant diffusion to depths in excess of 26 mm after 24 months.

After 48 months these same poles were showing a protective effect only close to the pole/foam interface. This was due to a depletion of chemical from the bandage reservoir. These results suggest that if Blue-7 or Basilit BFB are to be used as bandage chemicals, the bandage should be replenished after about 24 months.

Busan 30, Permapruf-T and pentachlorophenol (PCP) gradually increased their depth of diffusion, and after 60 months were still showing levels of chemicals capable of providing most poles with good protection from soft rot decay. At the fourth inspection, i.e. 48 month, it was decided that half of the twenty original replicates for each preservative bandage type would be replenished with the original chemical. It was anticipated that this would reactivate the bandages containing waterborne preservatives and help to determine whether the diffusion rate of Busan-30, pentachlorophenol and Permapruf-T could be enhanced. Therefore, at the 48 month inspection ten randomly selected bandages per preservative type were cut at the groundline, and preservative in the form of paste was pumped into the bandage at the foam/pole interface. The bandages were resealed with a band of heat shrink polyolefin.

The comparison of the effect of replenishment against non-replenished bandages is also presented in Table 2, where it will be seen that poles with little or no protection from soft rot decay at the 48 month inspection had fungitoxicant present at depths up to 28 mm one year later.

Only a slight increase in diffusion was apparent in poles with bandages which had been replenished with Busan 30, PCP and Permapruf-T. However, replenishment might help to increase the service life of these bandages. The results also indicate that replenishment of bandages containing the above three chemicals may not be necessary even after five years.

CONCLUSIONS

The CSIRO Mark IV bandage which is easily installed on soft-rotted transmission poles, is an effective *in situ* groundline maintenance method. It appears that sufficient fungitoxicant from such bandages can diffuse through the sapwood of CCA treated hardwood poles providing a pole with

protection from soft rot decay for at least 24-60 months depending on the type of chemical used. The most effective long term (five years) protection against soft rot is provided by a CSIRO Mark IV bandage containing Busan-30, PCP or Permapruf-T. All the test chemicals control soft rot, but the waterborne formulations Blue-7 and Basilit BFB diffuse at a rate which depletes the bandage reservoir after about two years. The results also indicate that bandages (especially depleted bandages containing waterborne preservatives) can be reactivated successfully.

REFERENCES

1. Greaves, H. 1977. An illustrated comment on the soft rot problem in Australia and PNG. Holzforschung 31: 71-79.

2. Levy, C. 1978. Soft rot. American Wood Pres. Assoc. Proc. 74: 145-163.

3. Butcher, J.A. 1978. An examination of the soft rot problem in treated hardwoods. IUFRO Div. 5 Meeting, Mexico, July 1978, 15 pp.

4. Aston, D. and Watson, R.W. 1976. The performance of preservative treated hardwoods in ground contact. Rec. Annu. Conv. Br. Wood Pres. Assoc. 41-53.

5. Liese, W. and Peter, G.A. 1977. Über mögliche Ursachen des Befalls von CCA-imprägniertem Laubholz durch Moderfäule pilze. Mater. Org. 12: 263-270.

6. McCarthy, D. 1983. Ethanolamine *et al.* based wood preservative compositions. Australian Patent No. 519146.

7. Greaves, H. 1979. Bandages as groundline maintenance treatments for poles. 19th Forest Products Res. Conf. Topic 3/1, 10 pp.

8. Dale, F.A., Greaves, H. and Thornton, J.D. 1978. A preservative bandage for the protection of wooden transmission poles. Aust. Patent No. 517087.

9. Greaves, H., Chin, C.W. and McEvoy, C. 1981. Development of fungitoxic bandages for groundline maintenance of soft rot in hardwood poles. Proc. Elect. Supply Assoc. of Aust., Pole symposium, April, 12 pp.

10. Chin, C.W., McEvoy, C. and Greaves, H. 1982. The development and installation of experimental fungitoxic pole bandages. Internat. J. Wood Pres. 22: 55-61.

11. Greaves, H. 1978. Preliminary screening of diffusion formulations for control of soft rot. In "Screening techniques for potential wood preservative chemicals". Int. Res. Group on Wood Pres. Doc. IRG/WP/2113.

THE AUSTRALIAN TEST OF THE IN-GROUND DURABILITY OF HEARTWOOD - ITS AIMS, CURRENT STATUS, LIMITATIONS AND POTENTIAL

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ABSTRACT

The CSIRO test of the in-ground durability of the heartwood of over 75 timber species at five sites around Australia is discussed. The current status of the test, 16 years after installation, is mentioned and 13 year data is presented. The potential of the test to provide data on the variability of timber performance is discussed. The test's limitations and its future are considered.

INTRODUCTION

The CSIRO field test is the only large-scale study of in-ground natural durability of heartwood in Australia. It was designed to obtain data on the durability of Australian species which, at the time the test was installed, were considered of commercial value. For comparison, a number of timbers of known reputation overseas were included as well as radiata pine sapwood stakes treated with creosote or CCA. The species included in the study are listed in Table 1.

The test was sufficiently replicated to be able to provide data on variability of performance rather than simply furnishing discrete classes of durability. The present CSIRO durability classification, now in use in most states of Australia, is the four class system according to Tamblyn (1966), which relates to in-ground performance of heartwood where the cross-section is in excess of 40 mm: (continued on p.4)

TABLE 1

Timber species in test and their tentative durability
(Nomenclature according to AS 2543-1983 and AS 1148-1971)

Scientific name(a)	Common name(b)	Tentative durability(d)
Australian hardwoods (*Myrtaceaeb*)		
Eucalyptus acmenoides Schau.	White mahogany (b)	2
E. amygdalina Labill.	Black peppermint	3
E. astringens (Maiden) Maiden	Brown mallet	3
E. bosistoana F. Muell.	Coast grey box	1-
E. botryoides Sm.	Southern mahogany	2
E. calophylla R. Br. ex Lindl.	Marri	3+
E. camaldulensis Dehnh.	River red gum	2+
E. capitellata Sm.	Brown stringybark(b)	3+
E. cladocalyx F. Muell.	Sugar gum	2
E. cloeziana F. Muell.	Gympie messmate	1-
E. consideniana Maiden	Yertchuk	2
E. cornuta Labill.	Yate	2+
E. cypellocarpa L. Johnson	Mountain grey gum	3+
E. diversicolor F. Muell.	Karri	3
E. dives Schau.	Broad-leaved peppermint	3+
E. elata Dehnh.	River peppermint	3
E. eugenioides Sieb. ex Spreng.(a)	White stringybark (b)	2
E. eugenioides Sieb. ex Spreng.(a) formerly *E. wilkinsoniana* R.T. Bak.	Wilkinson's stringybark (b)	2
E. fastigata Deane et Maiden	Brownbarrel	3-
E. globulus Labill. *var. stjohnii* R.T. Bak.	Gippsland blue gum	3+
E. gomphocephala DC.	Tuart	2
E. goniocalyx F. Muell. ex Miq.	Long-leaved box	3
E. grandis W. Hill ex Maiden	Rose gum	3
E. guilfoylei Maiden	Yellow tingle	2
E. haemastoma Sm.	Scribbly gum (b)	2-
E. henryi S.T. Blake	Spotted gum	2-
E. jacksonii Maiden	Red tingle	2
E. leucoxylon F. Muell.	Yellow gum	1-
E. longifolia Link et Otto	Wollybutt	2
E. macrorhyncha F. Muell. ex Benth.	Red stringybark	3+
E. maidenii F. Muell.	Maiden's gum	3+
E. marginata Donn ex Sm.	Jarrah	2+
E. megacarpa F. Muell.	Bullich	3-
E. melliodora A. Cunn. ex Schau.	Yellow box	1-
E. microcorys F. Muell.	Tallowwood	1
E. moluccana Roxb.	Grey box (b)	1+
E. muellerana Howitt	Yellow stringybark	2
E. obliqua L'Herit	Messmate	3
E. paniculata Sm.	Grey ironbark (b)	1+
E. patens Benth.	Western Australian blackbutt	2-
E. pilularis Sm.	Blackbutt	2-
E. polyanthemos Schau.	Red box	2

E. radiata Sieb. ex DC.	Narrow-leaved peppermint (b)	3
E. regnans F. Muell.	Mountain ash	4
E. resinifera Sm.	Red mahogany (b)	2+
E. rubida Deane et Maiden	Candlebark	3-
E. saligna Sm.	Sydney blue gum	3+
E. salmonophloia F. Muell.	Salmon gum	2D,3T
E. sideroxylon A. Cunn. ex Woolls	Red ironbark	1
E. sieberi L. Johnson	Silvertop ash	3+
E. tereticornis Sm.	Forest red gum(b)	2+
E. viminalis Labill.	Manna gum	3
E. wandoo Blakely	Wandoo	1+
Syncarpia glomulifera (Sm.) Niedenzu	Turpentine	2
S. hillii F.M. Bail.	Satinay	2
Tristania conferta R. Br.	Brush box	3D,1 or 2T
T. suaveolens (Soland. ex Gaertn.) Sm.	Swamp box	1

Australian hardwoods other than *Myrtaceae*

Acacia acuminata Benth.	Raspberry jam	2
A. harpophylla F. Muell. ex Benth.	Brigalow	2
Casuarina luehmannii R.T. Bak.	Bull oak	1
Litsea reticulata (Meissn.) F. Muell.	Bollywood (b)	3
Nothofagus cunninghamii (Hook.) Oerst.	Myrtle beech	4

Exotic hardwoods

Anisoptera polyandra Bl.	Garawa	3+
Intsia bijuga (Colebr.) O. Ktze	Kwila	1
Pterocarpus indicus Willd.	New Guinea rosewood	2+
Quercus alba L.	American white oak	4
Tectona grandis L.f.	Teak (Burmese)	1

Australian softwoods

Agathis robusta (C. Moore ex F. Muell.) F.M. Bail.	Queensland kauri pine	4
Athrotaxis selaginoides D. Don	King William pine	2
Callitris columellaris F. Muell. sens. lat.	White cypress pine	2
Dacrydium franklinii Hook. f.	Huon pine	2
Phyllocladus asplenifolius (Labill.) Hook. f.	Celery-top pine	2
Prumnopitys amara (Bl.) de Laubenfels	Black pine	4

Exotic softwoods

Pinus radiata D. Don	Radiata pine	4-
Pseudotsuga menziesii (Mirb.) Franco	Douglas fir	4+
Sequoia sempervirens (D. Don) Endl.	Redwood	1
Thuja plicata D. Don	Western red cedar	1

Preservative-treated softwood

CCA-treated *Pinus radiata* sapwood (12 kg/m^3, Celcure A)
Creosote-treated *Pinus radiata* sapwood (175-210 kg/m^3 K55)

(a) At the time timber was selected for this test *E. eugenoides* and *E. wilkinsoniana* were considered to be separate species. They now form the one species *E. eugenoides*.

(b) Indicates that the same common name is applied to species other than the one listed here under its scientific name.

(c) Tentative durability ratings: 1, highly durable; 2. durable; 3. moderately durable; 4, not durable; +, more durable than most of this class; −, less durable than most of this class. Where decay resistance and termite resistance were expected to vary markedly, durability in termite areas (T) is given separately to that in areas where only decay (D) is present. NOTE: tentative durability ratings were those assigned by CSIRO before the test started and are not an expression of interim results. For the most part the ratings shown are those currently under consideration in the revision of AS1604-1980. In some cases our results already indicate that tentative ratings for certain species could be changed (see Table 3).

(continued from p.1)

Class 1 - timbers of the highest natural durability which may be expected to resist both decay and termite attack for at least 25 years and sometimes 50 years.

Class 2 - Timbers of high natural durability which may be expected to have a life of about 15 to 25 years.

Class 3 - Timbers of only moderate durability which may be expected to have a life of about 8 to 15 years.

Class 4 - Timbers of low durability which may last from about 1 to 8 years. These timbers have about the same durability as untreated sapwood, which is generally regarded as Class 4, irrespective of species.

In general, this classification specifies similar specimen life ranges as others used in Australia and Europe (see Table 2). However, it differs markedly from specimen lives expected in India, Papua New Guinea, Fiji, Indonesia and Japan.

TABLE 2

Durability classes and expected life (in years) for timbers exposed in ground[1]

Country and Author	Hazard (D, Decay; T, Termite)	Classes (bracketed) and related life in years Highest durability			Lowest durability
AUSTRALIA					
Tamblyn, 1966; Greaves, 1979; Bootle, undated	D + T	(1) >25-50	(2) 15-25	(3) 8-15	(4) 1-8
Boyd, 1961	D	(1) >35	(2) 20-35	(3) 8-20	(4) 2-8
Aplin, unpublished	D + T	(1) 20-30	(2) 12-20	(3) 8-12	(4) 3-8
Da Costa & Howick, unpublished	D + T	(1) >25	(2) 15-25	(3) 5-15	(4) 1-10
CSIRO, undated (for poles)	D + T	(1) 22-35	(2) 16-22	(3) 8-15	(4) <8
CSIRO, undated (for sleepers)	D + T	(1) >30	(2) ≥15	(3) 10-15	
EUROPE					
Purslow, 1976; Liese, 1977	D	(I) >25	(II) 15-25	(III) 10-15	(IV) 5-10 (V) 5 or less
INDIA					
Purushotham & Mascarenhas, 1952	D	(I) >15	(II) 10-15	(III) 7-10	(IV) 5-7 (V) 2-5 (VI) 0-2
Das, Chandola & Ramola, 1965	D	(I) >12	(II) 5-12	(III) <5	
PNG					
Colwell, 1965	D	(C1) >5	(C2) 3	(C3) 2-3	(C4) 1-2 (C5) <1
FIJI					
Alston, 1966	D	(A1) >10	(A2) 5-10	(A3) 2-5	(A4) 2 or less
INDONESIA					
Juta, 1954	D	(R1) 8	(R2) 5	(R3) 3	
JAPAN					
Matsuoka *et al.*, 1984	D	(I) >9	(II) 7-8.5	(III) 5-6.5	(IV) 3-4.5 (V) <2.5

[1] Note that many of these classifications were proposed, but neither derived nor verified experimentally.

Information on natural durability, which can be provided by the CSIRO field test, is required for inclusion in Australian Standard such as "Preservative-treated sawn timber, veneer and plywood" (AS 1604-1980 under revision, see Footnote C of Table 1), "Timber poles for overhead lines" (AS 2209-1979) and "Light timber framing code" (AS 1684-1975). Also States require information on durability which would readily be disseminated in such publications as "Mechanical properties of timbers commonly used in Western Australia" (Shedley and Challis, 1984).

CURRENT STATUS

Stakes have now been exposed for 16 years at four sites (Innisfail, Brisbane, Sydney and Walpeup) and for 15 years at the fifth site (Melbourne). Under the CSIRO classification 15 years' exposure would allow separation of timbers belonging to Classes 3 and 4, with those in Classes 1 and 2 remaining in test. Because the 15 year data is still being processed and therefore is not yet available, results after 13 years of exposure (Thornton *et al.*, 1983) are presented (see Table 3).

As well as records of the condition of each stake at each site with respect to attack by fungi and termites, data on the identity of species of termites found attacking each timber species has been assembled[1]. We also have collected information on the types of rot found on the various timbers. At the most recent inspection samples were collected for microscopic confirmation or correction of decay typing made in the field. The most frequently recorded rot type and the most destructive one has been soft rot. Next in significance is white rot, with brown rot rarely observed. It should be noted that tentative durability ratings, as set out in Table 1, were assigned when white rot and brown rot decays were considered the major cause of failure (together with termites). Our results suggest that these ratings which ignored the effects of soft rotting organisms need to be reviewed.

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[1] Termites identified by J.W. Creffield

TABLE 3

Estimated average specimen life (years) of timbers, where all replicates have become unserviceable (a,b,c).

Species and tentative durability	Site				
	Brisbane	Innisfail	Pennant Hills	Walpeup	Mulgrave (d)
Australian hardwoods (Myrtaceae)					
E. amygdalina (3)	4.5(1.0)D	2.2(0.4)T			6.9(0.9)D
E. botryoides (2)	6.0(1.0)D	5.1(1.5)T			
E. calophylla (3+)	4.3(0.9)D	4.8(1.0)T			
E. capitellata (3+)	4.8(0.9)D	2.5(0.8)T			
E. cornuta (2+)		5.1(0.5)T			
E. cypellocarpa (3+)	4.5(1.1)D	2.3(0.8)T			
E. diversicolor (3)		1.3(0.3)T			
E. dives (3+)	5.2(0.9)D	2.6(0.6)T			
E. elata (3)	1.2(0.3)D	1.6(0.4)T	5.0(1.0)D	5.8(1.2)T	
E. eugenioides (2)	4.5(1.1)D	3.9(0.7)T			
E. eugenioides formerly *E. wilkinsoniana* (2)	7.0(1.7)D	5.8(1.4)T			
E. fastigata (3-)	4.7(1.0)D	2.7(0.8)T	7.7(1.2)D		
E. globulus var. stjohni		1.1(0.2)T			
E. goniocalyx (3)		3.6(1.0)T			
E. grandis (3)		6.4(1.1)T			
E. guilfoylei (2)		4.2(1.3)T			
E. haemastoma (2-)	6.1(0.8)D	4.5(1.3)T			
E. jacksonii (2)	4.0(0.8)D	1.6(0.6)T	8.1(1.3)D	7.0(1.3)T	
E. maidenii (3+)	5.2(1.0)D	1.8(0.4)T			
E. megacarpa (3-)	6.3(1.4)D	1.6(0.6)T			
E. muellerana (2)	6.4(0.8)D	2.4(0.6)T			
E. obliqua (3)	4.6(1.1)D	1.5(0.3)T	7.8(0.8)D		
E. patens (2-)		3.5(1.1)T			
E. pilularis (2-)	5.3(1.0)D				
E. radiata (3)	4.0(0.9)D	1.9(0.6)T	8.5(0.8)D		
E. regnans (4)	2.3(0.5)D	1.3(0.3)T	7.1(1.0)D	6.3(1.1)T	
E. rubida (3-)	2.8(0.9)D	2.5(0.8)T	6.0(1.1)D		7.4(1.3)D
E. saligna (3+)	4.6(0.8)D	4.8(0.8)T			
E. sieberi (3+)	6.0(1.4)D	2.1(0.8)T			
E. viminalis (3)	2.4(0.6)D	1.3(0.3)T	4.1(0.8)D	4.7(1.1)T	5.2(1.0)D
S. hillii (2)	7.5(0.9)D				
T. conferta (3D,1or2T)	2.7(0.5)D	4.2(0.9)D			
Australian hardwoods other than Myrtaceae					
L. reticulata (3)	3.5(0.5)D	4.6(0.9)T			
N. cunninghamii (4)	2.6(0.8)D	1.5(0.3)T	6.1(1.2)D	2.8(0.8)T	
Exotic hardwoods					
A. polyandra (3+)	5.1(1.1)D	6.3(1.2)D			
P. indicus (2+)	7.0(0.8)D	6.0(0.9)D	9.2(1.0)D		
Q. alba (4)	2.6(1.0)D	1.6(0.6)T	9.5(1.0)D	8.8(1.6)T	5.3(1.2)D

Australian softwoods					
Agathis robusta (4)	1.8(0.8)D	1.1(0.2)D&T	2.3(0.8)D		4.1(0.7)D
A. selaginoides (2)	7.7(1.7)D	7.7(1.0)D&T	9.5(1.0)D		10.9(0.2)D
D. franklinii (2)	8.6(1.5)D	4.2(0.6)T	10.3(1.1)D	8.0(0.8)T	
P. asplenifolius (2)	9.4(1.7)D	5.5(1.2)D&T	8.4(2.1)D		11.3(0.4)D
P. amara (4)	1.2(0.3)D	1.1(0.7)T	2.2(0.6)D		6.2(0.9)D
Exotic softwoods					
P. radiata sap (4-)	1.0(0.4)D	1.1(0.7)T	1.6(0.5)D&T		2.8(0.9)D
P. radiata heart (4-)	NT	NT	2.6(1.9)T		NT
P. menziesii (4+)	3.6(0.7)D	1.1(0.2)T	4.8(0.6)D	3.0(0.6)T	
S. sempervirens (1)	5.0(1.3)D	5.5(1.1)D			
T. plicata (1)		5.7(1.1)D&T	7.7(1.0)D		

(a) Estimated standard error of mean in parentheses.

(b) For unserviceability definition see Thornton, Walters and Saunders, 1983.

(c) D, majority of replicates have become unserviceable because of decay
T, " " " " " " termites
D&T approximately equal numbers of replicates have become unserviceable against decay and termites.

(d) No termites have yet been detected at this site.

(e) Most of the *P. radiata* stakes in this test were untreated sapwood controls for the preservative treatments. However, at the Pennant Hills site 3 heartwood and 7 sapwood stakes were included.

NT - not tested

LIMITATIONS

1. As test specimens were cut from the outer heartwood of the butt log of each tree, durability determined here is based on the most durable part of the sample trees. In all, five trees were used and, wherever possible, were collected over the geographic range of each species. This selection could only be ensured for the Australian species. Less control could be exercised with the overseas material. Unfortunately, the precise location of each tree cannot be given as the accession records were lost. However, the authors consider that confidence can be placed in the selection procedures followed. The validity of our results as a measure of species durability are only as good as the sample used.

2. Many timbers originally selected for the field test were from slow grown trees whose heartwood may differ in durability from faster grown regrowth or plantation material.

3. Termites have not proved to be a significant hazard at all five sites.

4. Field tests are expensive and time-consuming to install and inspect. Also, considerable time elapses before useful results emerge.

5. As no unexposed heartwood specimens were retained, additional field work is impossible.

6. The test cannot provide accurate information for extrapolating durability ratings for above-ground use; indeed the test was not designed for this purpose.

FUTURE STUDIES

1. Inspections

The authors hope to continue inspection of all test sites during the next ten years in order to obtain data for Class 1 (i.e. 25 years of exposure) determination.

2. Prediction

Purslow (1976), who was concerned with a decay hazard only, used a mathematical formula to predict the life for species whose replciates had not yet all failed. For this CSIRO study with its dual hazards of both decay and termites, no predictive analysis will be conducted.

3. Final Presentation of Data

Many alternatives, inluding the following, exist for the presentation of performance data:

(i) To present a lifespan which encompasses all replicates (= range), as well as the mean (in years).

(ii) To present the standard error of the mean together with the mean (in years).

(iii) To give (i) in terms of class - using either the current system or another.

(iv) To give (ii) in terms of a class.

4. Accelerated Field Simulator Studies

In order to provide additional data on durability against decay, tops of stakes were removed at two of the field sites and exposed in soil troughs at 27°C and high humidity in CSIRO's Accelerated Field Simulator (AFS). As a result of these on-going decay studies, we believe that we now have adequate methods for quick and direct comparative testing of old growth and regrowth material of any timber species.

Replicate portions of the stake tops have also been exposed, with and without a predecay period, to the subterranean termite *Coptotermes lacteus* (Froggatt) in the AFS (Johnson *et al.*, 1983). Results to date indicate that it will be possible to obtain durability ratings from AFS work to augment those obtained from the field.

Further AFS studies of natural durability are proposed.

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REFERENCES

Alston, A.S. 1966. Natural heartwood durability. Fiji timbers and their uses. Dept. For., Suva.

Bootle, K.R. Undated. Building timbers of New South Wales. For. Comm. N.S.W., Tech. Pub. No. 6, p.2.

Boyd, J.D. 1961. Efficient engineering with round timbers. J. Inst. Eng., Australia 33: 27-36.

Das, N.R., Chandola, L.P. and Ramola, B.C. 1965. Data on the natural durability of timber species (installed in the test yard at New Forest, Dehra Dun) according to 1964 inspection. J. Timb. Dev. Assoc. India 11: 6-12.

Greaves, H. 1979. The natural durability of various Australian wood pole species to soft-rotting microfungi. Internat. J. Wood. Pres. 1: 15-20.

Johnson, G.C., Thornton, J.D., Creffield, J.W. and Howick, C.D. 1983. Natural durability studies in an accelerated field simulator - a novel approach. Int. Res. Group on Wood Pres. Doc. No. IRG/WP/2197. Stockholm, IRG Secretariat.

Juta, E.H.P. 1954. Pemungutan hasil hutan. Timun Mas. N.V. Bogor, Indonesia.

Liese, W. 1977. Natural durability of timber. Proc. Internat. Workshop on Wood Pres. Ibadan, Nigeria, 39-40.

Matsuoka, S., Inoue, M., Shoji, Y., Suzuki, K. and Yamamoto, K. 1984. Stake test at Asakawa Experiment Forest. VII. Inspection data and service life of Japanese and tropical woods set in the field. Bull. For. & For. Prod. Res. Inst. No. 329, 73-106.

Purslow, D.F. 1976. Results of field tests on the natural durability of timber (1932-1975). BRE Curr. Pap. CP6/76. Build. Res. Establ., U.K., 17 pp.

Purushotham, A. and Mascarenhas, M.J. 1952. Standardization of accelerated durability tests on timber species. Commonw. For. Conf., Ottawa, Canada.

Shedley, P.N. and Challis, D.J. 1984. Mechanical properties of timbers commonly used in Western Australia. Tech. Pap. No. 7. For. Dept. W.A.

Standards Association of Australia. Nomenclature of commercial timbers imported into Australia. AS 1148-1971. Stand. Assoc. of Aust., Sydney.

Standards Association of Australia. SAA Light timber framing code. AS 1684-1975. Stand. Assoc. of Aust., Sydney.

Standards Association of Australia. Timber poles for overhead lines. AS 2209-1979. Stand. Assoc. of Aust., Sydney.

Standards Association of Australia. Preservative treatment for sawn timber, veneer and plywood. AS 1604-1980. Stand. Assoc. of Aust., Sydney.

Standards Association of Australia. Nomenclature of Australian timbers. AS 2543-1983. Stand. Assoc. of Aust., Sydney.

Tamblyn, N. 1966. Natural durability ratings. CSIRO For. Prod. Newsl. No. 335.

Thornton, J.D., Johnson, G.C. and Saunders, I.W. 1983. An in-ground natural durability field test of Australian timbers and exotic reference species. II. Progress report after approximately 13 years' exposure. Int. Res. Group on Wood Pres. Doc. No. IRG/WP/1189. Stockholm, IRG Secretariat.

Thornton, J.D., Walters, N.E.M. and Saunders, I.W. 1983. An in-ground natural durability field test of Australian timbers and exotic reference species. 1. Progress report after more than 10 years' exposure. Mater. Org. 18: 27-49.

POOR PERFORMANCE OF SPOTTED GUM SLEEPERS IN A RAILWAY LINE IN SOUTH-EAST QUEENSLAND

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ABSTRACT

Three levels of decay hazard were recognised in a railway line in south-east Queensland. Sleeper replacement was necessary earliest on ballast of river sand. The hazard was low on metal ballast where sleepers are expected to give a service life of 15+ years. An intermediate hazard existed on granite or granite + ash. Spotted gum, about 80 per cent of sleepers currently being installed in the line, was being replaced within 2 - 3 years on the river sand. Other species, viz red bloodwood, forest red gum, grey ironbark and white mahogany were performing satisfactorily. Brown cubical rot, white pocket rot and white "fibrous" rot were identified in failed sleepers, all three commonly occurring in the one sleeper. Sleepers often did not meet the Queensland Railways specifications for the line, especially those concerning the presence of sapwood and heart, and this undoubtedly exacerbated the decay problem. Options for minimising decay in the line are given.

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INTRODUCTION

In 1982 and 1983, Queensland Railways (QR) reported sleeper failure, through decay, in less than two years in a line between Mundubbera and Monto in south-east Queensland. The wood of samples accompanying the reports was spotted gum (*Eucalyptus maculata*). There were indications that sleepers did not meet QR specifications for the line (1) with respect to extent of sapwood and heart[1], and because failure was recorded so early, they might have contained advanced decay when installed. Sleepers at six sites on the line were inspected in late 1983 to identify the types of decay present, and also factors which might account for the premature decay. The findings of this inspection are reported here.

DECAY TYPES IDENTIFIED

Brown cubical rot, white pocket rot and a white fibrous rot were recognised, and all three commonly were found in the one sleeper. The brown cubical rot occurred mostly on the top face, edges and ends of sleepers; the other two, on the lower face and also on the ends. Associated with the brown cubical rot were a superficial grey mycelial growth, and fruiting bodies of *Gloeophyllum abietinum*. Fruiting bodies of *Pycnoporus coccineus* and *Trametes hirsuta* were associated with the white rot.

FACTORS INVESTIGATED

Factors investigated, which might account for the premature decay, were ballast type, timber species, timber source, failure to meet QR sleeper specifications for the line, presence of pre-existing decay and line topography.

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[1] "Heart" is defined in the QR specifications as the portion of a log that includes the pith and the associated defective wood.

Ballast Type

Four types of ballast were used on the line and all were represented among the six sites inspected: sand from a nearby river (at 3 sites), granite (1 site), granite + ash (1 site) and road base metal (1 site). Three levels of decay hazard were recognized among them.

Sleepers were performing satisfactorily on the metal: even the sapwood on those installed three years previously appeared sound and local QR officers anticipated a service life of at least 15 years from them.

On the river sand (which comprised gravel, sand and a substantial proportion of silt), decay in some sleepers was apparently proceeding very rapidly, failure being recorded in less than three years after installation. The ballast and the wood surfaces in contact with it were very moist, and the superficial mycelium mentioned previously was very well developed at these sites. New sleepers which had been stood on end, against the sides of cuttings, on this ballast only four weeks earlier already carried the mycelium.

The hazard on granite or granite + ash appeared to be intermediate between those on the other two ballast types. Sleepers were moist and bore some superficial grey mycelium.

Timber Species

About 80 per cent of replacement sleepers were spotted gum. Other species identified were red bloodwood (Eucalyptus spp.), forest red gum (Eucalyptus tereticornis), grey ironbark (Eucalyptus drepanophylla) and white mahogany (Eucalyptus acmenioides). To assess the performance of these species, sleepers which had been installed about 1 - 1½ years previously were examined. On river sand ballast, decay was considerably more extensive in spotted gum than in the other species. On granite or granite + ash, decay was present on the ends of all spotted gum sleepers inspected, but was absent on ironbark and mahogany, the only other species identified at these sites.

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Timber Source

Local QR officers believed sleepers were failing because they might now be cut from fast growing regrowth trees of less durable wood. Forestry marketing officers in the region advised that the timber would have come almost exclusively from first crop trees, and not regrowth.

Sleeper Specifications

It has been the contention of officers in our Department that many of the sleepers installed into railway lines in Queensland do not meet QR specifications, especially with regard to maximum permissible limits of sapwood and heart. The use of sub-standard sleepers might exacerbate the decay problem. Examination of new replacement sleepers beside the line revealed that sleepers, especially of spotted gum, commonly did not meet the specifications. Further, of six sleepers in a row installed 2 - 3 years previously on river sand ballast, four (all spotted gum) were regarded as failures. None of the four met the specifications. The two sleepers which were still serviceable (one each of spotted gum and forest red gum) had met them.

Pre-existing Decay

No evidence was found of pre-existing advanced decay in sleepers being installed into the line. However, early decay might have been present, especially in the heart defect of some sleepers.

Line Topography

There was no indication on sleepers on river sand ballast that the decay was any more extensive on water-gaining sites (e.g. depressions in cuttings) than on well drained sections of the line (fill).

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DISCUSSION

Two factors which appeared significant in the premature decay of sleepers in the railway line were ballast type and timber species. In sleepers of similar age, decay was considerably more extensive in spotted gum than in other species on river sand, and this ballast appeared to present a greater decay hazard than the other types encountered. On river sand, spotted gum was failing through decay in less than three years. There was also evidence that failure to meet the QR specifications of maximum permissible sapwood and heart might be exacerbating the decay problem in some sleepers. Studies have been initiated, or are planned, to obtain more definitive information on the influence of the above factors.

Red bloodwood, forest red gum, grey ironbark, white mahogany and spotted gum are all recommended for use as sleepers (1, 2). All but spotted gum are species of high durability (durable in contact with ground or in continuously damp situations); spotted gum is regarded as moderately durable (durable fully exposed to weather, well drained and ventilated) (2). Our observations suggest that spotted gum should not be used on poorly drained ballast such as river sand, granite or granite + ash.

Virtually nothing can be done to control the existing decay. Therefore action is limited to what can be achieved during replacement of failed sleepers. The following appear to be the options for minimizing decay in the Mundubbera to Monto line.

(i) Use only sleepers which conform to QR specifications, especially with respect to the presence of sapwood and heart.

(ii) Replace the river sand with metal ballast wherever possible.

(iii) Install only sleepers of highly durable timbers at sites of higher decay hazard, viz on the river sand, granite and granite + ash.

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(iv) Where the use of timber species of lower durability on the more hazardous sites is unavoidable, install only sleepers which have been impregnated with an oil-based preservative such as creosote.

Option (i) should be adopted as a matter of policy. Cost constraints may render option (ii) untenable; and in the light of the preponderance of spotted gum among sleepers currently available, option (iii) might not be feasible. Option (iv) appears to be the most practical alternative.

REFERENCES

1. Anon. 1973. Specification for sleepers standard size 115 mm thickness. Queensland Railways Chief Engineer Branch Specification No. CE.BT-106-1973. 15pp.

2. Watson, C.J.J. 1964. Queensland building timbers and specifications for their use. Queensland Department of Forestry Pamphlet No. 5. 68pp.

EFFECT OF PRE-TREATMENT CONDITIONING ON THE PRESERVATION OF *PINUS RADIATA*

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INTRODUCTION

Sawn *Pinus radiata* is normally dried to a moisture content of less than 30% before preservative treatment with copper chrome arsenic salt (CCA). A reduction in the pre-treatment drying schedule would reduce the production costs of CCA treated *P. radiata*.

The effect on preservative retention and penetration of pressure steaming green sawn *P. radiata* prior to CCA treatment has been examined extensively, particularly in New Zealand (1), (2), (3), (4), (5), (6), (7), (8).

In this project, the influence of pressure pre-steaming is considered for two steaming schedules on timber of two thicknesses, from two sources, of three cutting patterns, and two post-treatment kiln drying schedules. The influence of pressure pre-steaming on the quality of the preservative treatment was assessed by comparison to similarly preservative treated material that had been dried to 30% moisture content before treatment by conventional means.

EXPERIMENTAL OUTLINE

The following variants were considered:-

Thickness	-	25 mm and 50 mm.
Source	-	Tumut (T) and Oberon (O)
Cutting pattern	-	Backsawn (B), mixed sawn (M), quarter sawn (Q),
Treatments	-	Pre-steam green at 175 kPa, CCA treatment (T1)
"	-	Pre-steam green at 350 kPa, CCA treatment (T2)
"	-	Air-dry to 30% M.C., CCA treatment (T4)
"	-	Kiln dry (70-12°C) to 30% M.C., CCA treatment (T5)
Post treatment drying	-	(70-12°C) at 2.5 m/s/steam (K1).
Post treatment drying	-	(120-50°C) at 5 m/s/steam (K2)

The 25 mm boards were maintained at the required steaming pressure for two hours and the 50 mm boards were maintained at the required steaming pressure for four hours.

The boards were cooled in a block stack following steaming, for a period of sixteen hours. They were then preservative treated with CCA solution at approximately 2.5% w/v by one of the following schedules:

Vacuum (85 kPa)	25mm - 40 minutes 50mm - 60 minutes.	Pressure (1350 kPa)	25mm - 60 minutes 50mm - 90 minutes.

The scheduled times were maintained after treatment conditions had been achieved.

RESULTS AND DISCUSSION

(a) PRESERVATIVE RETENTION

The mean preservative retentions achieved by boards of each directions of cut for both thicknesses, all treatments and both drying schedules are given in Table 1. The data are further sub-divided into sources - Tumut (T) and Oberon (O). The mean preservative retention for all samples of each combination of thickness, treatment and drying schedule is also given.

Table 1 - Preservative Retention (kg m^{-3}).

	Backsawn (B)			Mixed (M)			Quarter (Q)			All Boards
	T.	O.	Mean	T.	O.	Mean	T.	O.	Mean	
25mmT1K1	9.0	7.8	8.4	8.0	7.1	7.6	6.5	6.8	6.7	7.5
" T1K2	7.4	6.3	6.8	6.8	5.0	5.9	4.0	6.2	5.1	6.0
" T2K1	11.1	8.0	9.6	8.3	7.9	8.1	10.5	9.2	9.9	9.2
" T2K2	9.1	7.7	8.4	8.1	6.7	7.4	5.7	7.4	6.6	7.5
" T4K1	13.8	13.4	13.6	12.0	11.0	11.5	9.0	12.5	10.7	12.0
" T4K2	18.2	18.8	18.5	17.1	14.2	15.6	19.6	17.5	18.6	17.6
" T5K1	17.6	17.5	17.6	15.5	14.1	14.8	16.6	15.5	16.0	16.1
" T5K2	17.5	16.9	17.2	17.1	14.2	15.7	16.0	16.9	16.5	16.5
50mmT1K1	5.1	5.3	5.2	6.9	6.1	5.5	6.0	5.9	6.0	5.6
" T1K2	7.3	8.0	7.6	5.4	7.0	6.2	6.2	7.9	7.0	6.9
" T2K1	10.5	7.5	9.0	6.1	8.7	7.4	7.7	6.3	7.0	7.8
" T2K2	9.8	6.9	8.4	7.9	6.5	7.2	7.4	8.1	7.8	7.8
" T4K1	11.7	13.2	12.4	15.8	10.6	13.2	15.5	15.5	15.6	13.8
" T4K2	13.6	12.8	13.2	9.1	13.6	11.4	13.4	9.8	11.6	12.1
" T5K1	15.7	14.8	15.2	15.5	14.1	14.8	11.6	15.9	13.8	14.6
" T5K2	18.0	17.6	17.8	16.3	17.2	16.7	20.0	16.9	18.4	17.7

From an analysis of the data above, the following observations were made:

(1) Higher retentions were achieved in backsawn boards than quarter sawn boards. Boards classified as mixed sawn had lower mean preservative retentions then quarter sawn boards.

(2) The source of the *P. radiata* did not significantly affect the preservative retentions.

(3) Higher preservative retentions were recorded in 25mm thick boards than in 50mm thick boards.

(4) Boards dried after treatment by the high temperature schedule, K2, recorded higher preservative retentions than those dried by the low temperature schedule, K1.

(5) The preservative retentions for the boards dried to a moisture content of less than 30% before preservative treatment (T4 & T5), were significantly higher than those for the boards that were pressure pre-steamed (T1 & T2) before preservative treatment. The preservative retention for boards treated by the high pressure (T2) pre-steaming schedule were higher than those for the low pressure pre-steaming (T1) schedule, but significantly less than the retentions for material treated to T4 or T5.

(b) PRESERVATIVE PENETRATION

The preservative penetration in each board was determined by examining the full cross-section of a sample cut from the board. One face of the sample was sprayed with Chromazurol S to indicate penetration of the preservative. The reverse side of the sample was examined for the presence of heartwood. When heartwood was present, its boundary with the sapwood was marked and the proportion of heartwood and sapwood in the cross-wood section was noted. The sample was classed as having passed the penetration requirements if the sapwood was fully treated and the heartwood was penetrated to a minimum of 10mm from each face.

A summary of the preservative penetration results is given in Table 2.

Observations on the preservative penetration data are as follows:-

(1) SAPWOOD PENETRATION. From Table 2, the number of samples failed for inadequate sapwood penetration is significantly greater for both 25 mm and 50 mm

Preservative penetration in 25 mm T2 samples was better than 25 mm T1 samples, equal to T4 boards of equal thickness, but worse than treatment T5.

For 50 mm thick boards, the same treatment efficacy for sapwood penetration was true.

(2) HEARTWOOD PENETRATION. The percentage of samples failed for inadequate preservative penetration of the heartwood (Table 2) is greatest for treatment T1 in the 25 mm boards. Treatments T2 and T4 were more effective at achieving heartwood penetration than T1 but less than T5.

The differences in efficacy of preservative penetration of heartwood are similar in the 50mm thick boards.

(3) OVERALL PENETRATION. The results indicate that on a total sample basis, treatment T1 was inferior to both T2 and T4 and that T5 was the most effective treatment. The overall treatment efficacy of 25 mm and 50 mm boards was very similar.

(4) EFFECT OF POST TREATMENT DRYING SCHEDULES. For treatments T2, T4 and T5, the post treatment drying schedule did not influence the efficacy of the treatments with respect to preservative penetration.

Table 2 - Penetration Assessment.

Treatment Program	Total No. of Samples	No. of Samples of Failed Sapwood	No. of Samples of Failed Heartwood	% Samples - Pass
25mm T1K1	21	7	3	52
" T1K2	24	6	5	54
" T2K1	24	1	2	88
" T2K2	22	4	3	68
" T4K1	24	0	3	88
" T4K2	14	0	4	71
" T5K1	21	0	1	95
" T5K2	24	0	2	92
50mm T1K1	24	9	4	46
" T1K2	23	9	6	35
" T2K1	24	3	2	78
" T2K2	24	1	4	79
" T4K1	24	1	4	79
" T4K2	21	0	3	86
" T5K1	24	1	0	92
" T5K2	24	0	0	100

CONCLUSIONS

(1) Low pressure pre-steaming (T1) was not an effective conditioning schedule for CCA preservative treatment of green *Pinus radiata*.

(2) High pressure pre-steaming (T2) was more effective as a conditioning treatment than low pressure steaming, but the preservative penetration and retention achieved indicate that the schedule was less effective than conventional air drying. However, modification of preservative solution strengths and pre-steaming schedule plus a vacuum at the conclusion of the steaming stage should enable green *P. radiata* to be commercially treated.

(3) It must be noted that this report covered only preservative treatment aspects and that severe drying degrade occurred in some of the 50 mm boards that had been high pressure pre-steamed and high temperature kiln dried.

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REFERENCES

(1) Rudman P., *et al*. (1962). The impregnation of green *P. radiata* D. Don with an unfixed waterborne preservative by steam-vacuum drying and intermittent pressure treatment. C.S.I.R.O. (Div. For. Prod.) Project P.7, Sub-project P.7-13, Progress Report No. 1, Melbourne, Australia.

(2) McQuire, A.J. and R.P. Kibblewhite (1962). Steam conditioning for the treatment of radiata and corsican pine by the oscillating pressure method. New Zealand Forest Products Interim Research Release, Rotorua, New Zealand.

(3) Mason, C.G.W. (1963). Preservation of green timber by steam-pressure-diffusion treatment. N.Z. Timber J. 9(7), New Zealand.

(4) Rudman, P. (1964). The pressure preservative treatment of green radiata pine. C.S.I.R.O. (Div. For. Prod.) Newsletter No. 307. Melbourne, Australia.

(5) McQuire, A.J. (1964). The oscillating pressure method for the impregnation of New Zealand grown timber. For. Res. Inst. New Zealand, Technical Paper No. 44.

(6) Johnstone, R.S. (1967). Pre-steaming an aid to pressure preservation of green radiata pine. Australian Timber J., 33(9). Sydney, Australia.

(7) Johnstone, R.S. (1968). Pre-steaming and the pressure impregnation of green natural round *Pinus radiata*. Australian Timber J., 34(1). Sydney, Australia.

(8) Bamber, R.K. and R.S. Johnstone (1968). The effect of pressure pre-steaming on the ray parenchyma cell walls of *Pinus radiata* wood. J. Instit. of Wood Science No. 21, London, U.K.