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Adequacy of H3 LOSP tin-based preservative treatment for exposed external structural uses

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Prepared for the

Forest & Wood Products Research & Development Corporation

by

L. Cookson and M. Hedley

EXECUTIVE SUMMARY

Objective

To collate and review the published scientific data available on the performance of LOSP formulations based on tin. To identify and describe further experimental work required to support the continued use of H3 LOSP in load-bearing applications.

Key Results

- Timber treatments with tributyl tin oxide (TBTO) or tributyl tin naphthenate (TBTN) appear to give useful service life to window joinery and other 'non structural' commodities (using New Zealand terminology, H3.1 applications) when painted.
- TBTO and TBTN degrade in treated wood, into breakdown products that are less fungicidal or more volatile (leading to loss of tin). Degradation occurs in treated wood used both indoors and outdoors.
- Painting TBT-treated timber prolongs service life, although some paint systems may be less effective at this than others.
- TBTN appears to be less stable than TBTO in service.
- Unfortunately, old decking trials that included CCA-treated decking for best comparison are not available. However, the oldest New Zealand trial does include copper naphthenate-treated decking for comparison. In this trial, a number of TBTN-treated decks treated to 0.08% m/m tin failed prematurely.
- In the oldest New Zealand decking trial, increasing retentions of elemental tin led to improved performance of the treated product. Although the retention was not tested, a plot of the data suggests that 0.16 % m/m tin will provide improved performance compared to 0.08% and 0.12% m/m tin.

Application of Results

Published reports show that TBTO and TBTN degrade prematurely in treated timber. Contrary to earlier opinions, TBTN appears to be less stable than TBTO in service. Accelerated decking trials suggest that TBTN-treated timbers with 0.08% m/m tin will fall short of the service lives normally expected with CCA-treated and copper naphthenate-treated decking. The retention of tin needed for H3 decking should either be increased from 0.08% m/m, or TBTN should be withdrawn from application to decking, as is the case in New Zealand. There is still some uncertainty as to the performance of 0.16% m/m tin (it has not been tested), although it should be a significant improvement over 0.08% m/m tin.

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Laurie J. Cookson and Michael E. Hedley

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INTRODUCTION

One of the most difficult issues of recent years facing the wood preservation industry in Australia has been reaching agreement on the appropriate retention of tributyl tin naphthenate (TBTN) needed to provide long term protection to H3 structural applications such as decking. At a time when restrictions are likely on copper chromium arsenic (CCA), this question casts doubt on whether light organic solvent preservative (LOSP) treatment with TBTN can be considered a suitable alternative. This document is not a review of whether LOSP treatments can match CCA in performance. A number of actives used in LOSP such as copper naphthenate have already given good long term performance. Future research is also likely to discover improved organic preservatives, often suited to LOSP formulation, in a long term trend away from metals and organo-metals to organics. This review concentrates on the tributyl tin preservatives used in Australia, which began as tributyl tin oxide (TBTO) in the 1980s, and then changed to TBTN when the pyrethroid insecticides were introduced into the formulations.

LOSPs are used to protect timbers placed above-ground. They are not accepted as in-ground preservatives. For H2 (indoor above-ground) exposure, the LOSP can be simply white spirit containing a pyrethroid such as permethrin or bifenthrin. H3 (outdoor above-ground) treated timbers are subject to decay and weathering as well as insect attack, so treatment formulations contain both fungicide and insecticide, and a range of additives that normally includes waxes and resins as water-repellents.

There are about 15 LOSP treatment plants in Australia, and most use H3 formulations containing TBTN. About 60,000 m^3 of H3 LOSP-treated timber is also imported from New Zealand (Greaves 2003, *pers. comm.*). Therefore, it is imperative that any weaknesses in the performance of TBTN be identified. The aim of this document is to provide a record of the information available on the performance of TBT relevant to Australia. In searching for references, it became clear that there was limited local information available on the performance of TBT when it was first approved some 25 years ago. The review concentrates on the Australian and New Zealand results currently available, and includes findings from some of the more significant overseas studies. The first part of the review lists each reference in chronological order and briefly discusses the main findings. These are bought together in the discussion.

RECOMMENDATIONS AND CONCLUSIONS

The retention of tin needed to protect low durability timbers as decking in H3 exposure should either be increased from 0.08% m/m, or TBTN should be withdrawn from application to decking, as is the case in New Zealand.

If the decision is to keep TBTN as a treatment for decking, the decision on whether to specify a tin retention of 0.12% or 0.16% m/m (in oven dry wood) needs to take account of both precautionary and commercial factors. There is no field test demonstration that 0.16% m/m will perform better than 0.12% m/m, or that either will perform similarly to H3 CCA-treated timber. The normal dose response reaction found in most wood preservatives is that improved performance can be expected with higher retentions. Such a dose response is shown in the 1986/1988 decking trial for TBTN (Hedley pers comm.). However, the counter argument is that health and safety risks will increase if timber is treated to 0.16% m/m elemental tin, due to higher retentions of solvent and preservative.

The main priority from the health and safety viewpoint is that treated timber should perform as expected, especially in critical structures such as decking. This review illustrates that 0.08% m/m tin is unlikely to provide the service life expected for decking, in comparison to other established preservatives. Unusual service failure rates from TBT-treated timber are not being reported at present. However, recommendations have been made from some quarters (within Australian Standards discussions) that the specified retention for H3 structural (decking) should be doubled to 0.16% m/m tin as a precaution, with the expectation that it will improve performance over 0.12% m/m tin. In the future, field tests of new preservatives for decking should make comparisons with H3 CCA-treated timber, for which customer knowledge and experience exists. In the shorter term, the heartwood/sapwood decking trial installed in 1996 at Beerburrum State Forest and Coopernook State Forest should be inspected, as this test is most relevant to the performance of treated decking in Australia, and includes useful comparative preservatives. The last inspection of this trial was in 2000 (Johnson and Thornton, unpublished data): an inspection in 2005 should therefore yield important additional data.

ANNOTATED BIBLIOGRAPHY

Published articles

E.W.B. Da Costa and L.D. Osborne (1969). An evaluation of preservatives for the superficial treatment of wood. J. Institute of Wood Science, No. 24: 3-5.

Pinus radiata sapwood blocks 51 x 20 x 20 mm were dipped twice in various preservative solutions, dried, and exposed to four decay fungi in the laboratory. A mineral turpentine solution containing 1% TBTO plus water repellent was amongst the best treatments examined and controlled all fungi, except for minor decay by the white rot fungus *Perenniporia tephropora* after 16 weeks.

E.W.B. Da Costa and L.D. Osborne (1971). Laboratory evaluations of wood preservatives. VI. Effectiveness of organotin and organolead preservatives against decay and soft rot fungi. Holzforschung 87: 119-125.

A soil-block decay test using 17 basidiomycetes and 11 soft rotting fungi against TBTO-treated *P. radiata* found that soft rotting fungi were most tolerant, followed by white rotting fungi, with brown rotting fungi most susceptible to TBTO. The TBTO retention of 0.51 kg/m^3 (0.04% tin, assuming *P. radiata* oven dry density of 450 kg/m^3) controlled all brown rotting fungi, but not most white rotting fungi. The retention of 1 kg/m^3 TBTO (0.09% tin) controlled all fungi.

E.W.B. Da Costa and L.D. Osborne (1972). Laboratory evaluations of wood preservatives. VII. Effect of chemical structure on toxicity of organotin and organolead compounds to wood-destroying fungi. Holzforschung 88: 114-118.

Describes a soil-block decay test of ten trialkyl tin analogues against the more organo tin tolerant fungi *Postia placenta (Poria placenta), Coniophora olivacea* and *P. tephropora (Fomes lividus).* None of the compounds were any better than TBTO in fungitoxicity, although several such as tributyl tin acetate (TBTA), tripropyl tin oxide and tripentyltin oxide performed similarly. TBTA has been identified as a common breakdown product of TBTO, and is about four times more volatile (Archer and Meder, 1987). TBTN was not examined.

Australian Standard (1974). Code of practice for water-repellent treatment of timber and joinery. AS 1606-1974.
Australian Standard (1974). And specification for water repellents for the treatment of timber, joinery and other timber products. AS 1607-1974.

These standards were produced for LOSP treatments applied by dipping or brushing. The treatments were described as improving timber stability, but providing a level of protection against decay and insects that could not be entirely relied upon compared to the established preservatives such as CCA and creosote. The forward states that ‘Where effective protection against decay and insect attack is required, treatment in accordance with AS 1604 …. should be employed’, i.e. using preservatives other than those listed in these water-repellent standards. The composition of the water repellents could contain pentachlorophenol (PCP), copper naphthenate, TBTO, zinc naphthenate + PCP or copper-8-hydroxyquinolinate (Cu-8). The TBTO treating solution was to contain not less than 1.0% (m/m) TBTO.

B.G. Henshaw, R.A. Laidlaw, R.J. Orsler, J.K. Carey and J.G. Savory (1978). The permanence of tributyltin oxide in timber. British Wood Preservers Association Annual Convention, pp 19-29.

Previous work at the Princes Risborough Laboratory on small unpainted wood samples treated with TBTO found 25-50% loss of tin after indoor storage, presumably due to volatilisation and the presence of oxygen. Most depletion occurred near the wood surface. Redwood (*Pinus sylvestris*) sapwood dipped in 1% TBTO and placed in painted L-joint tests were slightly decayed after five years, suggesting TBTO breakdown. After seven years in a T-joint field test of unpainted *P. sylvestris*, all of the TBTO had degraded to breakdown products or was lost. In agar tests, the breakdown product dibutyltin oxide had about one-tenth the fungitoxicity of TBTO. Monobutyltin appeared to be a relatively stable breakdown product, as inorganic tin was not found in aged wood. Painting was an effective method for reducing the loss and breakdown of TBTO. In summary, unpainted TBTO-treated wood may not provide long term protection, due to evaporation and degradation of TBTO. Degradation occurs mainly near the wood surface, where there is access to oxygen. Durability is significantly improved by painting.

E.W.B. Da Costa (1979). Comparison of three organic fungicides as light oil solvent preservatives. Holzforschung 88: 65-67.

P. radiata, *E. regnans* and *Gonystylus* sp. (ramin) sapwood blocks were treated with PCP, TBTO or Cu-8 and exposed to four fungi in a soil-block decay test. TBTO performed best. In *P. radiata*, 0.3% m/m TBTO (0.12% m/m tin) controlled all fungi, while 0.9 % m/m (0.35% m/m tin) was required in *E. regnans* and *Gonystylus* sp.

TPAA (Timber Preservers' Association of Australia) (1979). Standard specification for light organic solvent preservative treatment of timber by vacuum/pressure methods.

The Timber Preservers' Association of Australia and the Radiata Pine Association published an industry standard for LOSP. Apart from PCP, the other actives used in LOSP such as TBTO, copper naphthenate and Cu-8 were not listed in the 1974 or 1980 editions of AS 1604. As the LOSPs contained water repellents, the industry could claim treatment according to AS 1606-1974. The TPAA standard was for vacuum pressure impregnation where improved treatment could be obtained over dipping and brushing applications, so that it was felt that greater reliability should be assigned to LOSP-treated wood. The treatment was targeted at 'cladding and timber products such as window and door joinery and exterior architectural features manufactured from timber'. The uses did not target important H3 structural uses such as decking. Retention requirements were given in terms of minimum charge retentions in kg/m^3, or they could be determined by chemical analysis (AS 1604 now accepts chemical analysis only). The retentions would also vary according to the severity of hazard faced during exposure. For TBTO the retentions were 0.8, 1.0 and 1.2 kg/m^3 for low, moderate and high hazards respectively. These retentions equate to 0.07, 0.09 and 0.10% m/m tin for timber with oven dry density of 450 kg/m^3.

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

This paper describes a laboratory soil-block decay test of treated *P. radiata* sapwood blocks, 20 x 20 x 10 mm. Four of the preservatives tested were listed in the 1979 industry standard on LOSPs, and the highest retention tested was the 'high hazard' retention in the standard. The TBTO retentions tested were 0.3, 0.6 and 1.2 kg/m^3 or about 0.025, 0.05 and 0.10% m/m tin. In this trial, TBTO was the most effective preservative, with all fungi controlled by 0.05% m/m tin. The 0.025% m/m tin retention controlled all but for slight decay by *P. tephropora* and *C. olivacea*. This result was better than for PCP, PCP+TBTO, copper naphthenate, Cu-8 and copper nonanoate.

J. Jermer, M.-L. Edlund, W. Hintze and S. Ohlsson (1983). Studies of the distribution and degradation of tributyltin naphthenate in double-vacuum treated wood. The Internat. Res. Group on Wood Preserv. Document No. IRG/WP/3230.

In 1981 in Sweden there were 26 LOSP plants treating some 25,000 m^3 of joinery with organotin compounds. Some plants installed low temperature kilns to drive off the solvent after treatment so that it could be handled and processed more easily. Studies in Sweden on double vacuum TBTN-treated *P. sylvestris* found considerable losses (about 25%) of TBTN when air dried for 38 days at 10-20^oC or low temperature kiln dried at 30 or 40^oC for 21 hours and 15 hours respectively.

J. Jermer, M.-L. Edlund, B. Henningsson, W. Hintze and S. Ohlsson (1983). Chemical and biological investigations of double-vacuum treated windows after 5 years in service. The Internat. Res. Group on Wood Preserv. Document No. IRG/WP/3219.

P. sylvestris windows from a hospital in Sweden were examined after five years service. The outer 10 mm of sapwood had been treated to at least 0.1% m/m TBTO (0.039% m/m tin). The windows had been painted with a dark coloured paint, which probably raised the average temperature of the wood. Only 23-32% of the remaining organotin was TBTO, with the balance the breakdown products dibuytl tin and monobutyl tin. This finding shows that not all methods of painting will prevent TBTO degradation, and suggests that paint coatings should be a certain thickness, type, and lighter colour to reduce heat absorption. Fungitoxicity is mostly due to TBTO rather than the breakdown products, and when TBTO is less than 0.05-0.06% m/m (0.020-0.023% m/m tin) decay can occur.

K. Archer and R. Meder (1987). An investigation into the stability of TBTO in LOSP-treated radiata pine. The Internat. Research Group on Wood Preserv. Document No. IRG/WP/3459.

TBTO was first approved for use in New Zealand in 1982. TBTO can degrade rapidly in wood in a stepwise debutylation from tributyl to dibutyl and monobutyl tins, and finally to inorganic tin. These breakdown products are less fungitoxic than TBTO. Crystals containing TBTA were also found on the surface of the latewood bands of TBTO-treated *P. radiata* stored for three weeks. Analysis of TBTO solutions collected from the work tanks of commercial treatment plant showed that most of the TBTO had degraded and reacted with *P. radiata* and its extractives to produce tributyl tin esters of resin acids, dibutyl tin ethers and chlorides, and monobutyl tin compounds. Some esters such as TBTA are more volatile than TBTO which may lead to tin depletion in treated wood.

S.J. Blunden and R. Hill (1987). The compatibility of tributyltin fungicides and synthetic pyrethroid insecticides as wood preservatives. The Internat. Research Group on Wood Preserv. Document No. IRG/WP/3414.

At the solution concentrations normally used in wood preservation of 1-3% TBTO, this compound has limited efficacy against insects. Therefore, an insecticide should be included with organotin formulations. The incompatibility of synthetic pyrethroids with TBTO had been reported by others previously. This study showed that TBTN, and all other tributyl tin compounds except TBTO, were compatible with permethrin, cypermethrin and deltamethrin.

J. Wazny, H. Greaves and L.J. Cookson (1988). Laboratory tests on light organic solvent preservatives for use in Australia. Part 3. Evaluation of fully formulated commercial preservatives. J. Institute of Wood Science 11: 140-144.

The bioassay was conducted using similar methods to part 1 of this series. In this paper, TBTO as a fully formulated preservative (Vacsol) was examined, so included water repellents and a low level of mouldicide. Vacsol retentions were 10, 5, 2.5 kg/m^3 or about 0.05, 0.03 and 0.01 % m/m tin. This treatment controlled all seven test fungi in the soil-block bioassay at the 0.05 and 0.03% m/m tin retentions, and all except the white rotting fungus *P. tephropora* at the lowest retention. This result was slightly better than for unformulated TBTO in the part 1 study, although direct comparison between bioassays is not always reliable.

K. Archer, P. Walcheski, D. Fowlie and A. Preston (1989). Above ground testing of preservatives – a comparative evaluation of three experimental procedures. Canadian Wood Preservers' Association No. 10: 225-234.

This American trial examined southern yellow pine (simulated decking) and ponderosa pine (L-joints). Exposure was at a wet tropical site at Hilo in Hawaii. Treatments were without water repellent. The unpainted 'decking' timbers treated with 0.25% TBTO failed at Hilo after two years, while specimens treated with 0.5% and 1.0% TBTO solutions were severely decayed. This result compares to PCP and copper naphthenate treatments which were in good condition after two years. Less decay was found in painted L-joints than in the 'decking'.

R. Meder and K.J. Archer (1991). Degradation of TBTO preservative in *Pinus radiata*. Holzforschung 45: 103-108.

P. radiata sapwood, heartwood and resinous heartwood blocks 150 x 40 x 40 mm were either air dried, kiln dried at 70^{o}C and 60% relative humidity (r.h.) or high temperature kiln dried at 120^{o}C and 70% r.h. before treatment. They were then treated with a 2.5% w/v solution of TBTO in kerosene. The drying regime affected the distribution and stability of TBTO. TBTO breakdown products can react with wood resin and fatty acids, which are more common in high temperature dried timber and in resinous heartwood, to form tin-bearing esters that are more volatile and less fungitoxic than TBTO. The worst example was 31% loss of tin from high temperature dried heartwood after seven months storage indoors.

R.P. Bratt, D.J. Squirrell, S. Millington, G. Manton, W. Hoskins (1992). Comparison of the performance of several wood preservatives in a tropical environment. International Biodeterioration & Biodegradation, 29: 61073.

Five different fungicides used in LOSP were exposed for 20 months in above-ground trials at Innisfail, northern Queensland. The test was by UK researchers, which is why the timber substrate was *P. sylvestris*. Test specimens were 100 x 10 x 10 mm, and treated by three minute dip. Exposure was amongst jungle under-story, on a cleared site, or under a carport. Treated specimens were placed on the ground, on a concrete pad, or suspended in a vertical or horizontal orientation. In terms of mass loss, best performance was by a 2% solution of copper naphthenate, and worst was by 1% TBTO plus insecticide treatment. The three middle performers were 2% zinc naphthenate, 5% PCP and 2% Cu-8. Mass loss for all preservative treated timbers exposed above-ground was generally lower for vertically aligned specimens than horizontally aligned specimens, although the difference did not appear to be significant.

G.C. Johnson, M.A. Tighe and J.D. Thornton (1995). Laboratory tests on light organic solvent preservatives for use in Australia. Part 5. Efficacy of three fully formulated preservatives on different timber substrates. J. Institute of Wood Science 11: 140-144.

Vacsol containing 6.2% m/m TBTO in solution was tested in seven different timber substrates at the retentions of 5, 2.5 and 1 kg/m^3 Vacsol or 0.31, 0.16 and 0.06 kg/m^3 TBTO. The timber substrates were *P. radiata* sapwood, *P. elliottii* sapwood, *Pseudotsuga menziesii* heartwood, *Thuja plicata* heartwood, *Eucalyptus regnans* heartwood and high and low density *Shorea* spp. In *P. radiata*, Vacsol controlled five of the seven decay fungi at the 0.31 kg/m^3 TBTO retention (about 0.03% m/m tin), with most severe decay caused once more by *C. olivacea* and *P. tephropora*. The most difficult timber substrate to protect from fungi was *E. regnans* heartwood, with four fungi able to cause some decay at the 0.31 kg/m^3 TBTO retention (about 0.02% m/m tin).

J.K. Carey (2002). L-joint trials: Part 3: Relative performance of a range of preservative products. The Internat. Research Group on Wood Preserv. Document No. IRG/WP/02-30292.

The paper describes long-term L-joint field trials in the UK of treated and painted *P. sylvestris*. The oldest trial was installed in 1982 and showed that double vacuum treatments with 1% TBTO and 5% PCP gave similar performance. These preservatives lacked water repellent additives. Half of the L-joints protected with either treatment had failed after twelve years. Another L-joint trial installed in 1985 of painted *P. sylvestris* examined formulations that included water repellents. Half of the replicates treated with 1.8% TBTN had failed after 14 years, whereas the majority of replicates treated with 1% TBTO (tin equivalent in TBTN) were still serviceable after 16 years.

Figure 1. Example of L-joint tests.

D.K. Scown, L.J. Cookson, K.J. McCarthy and N. Chew (2004). Accelerated testing of window joinery made from eucalypts. FWPRDC Project Number PN98.702. http://www.fwprdc.org.au/content/pdfs/PN98.702.pdf

This project included an examination of the performance of LOSP treatments in window joinery, which is the traditional application for LOSP. A window survey found a wide range of performances. A total of 187 meranti (*Shorea* spp.) window frames were inspected, and over half of these were believed by the purchaser to have been LOSP-treated. They were 4-25 years old, and during this time the most common LOSP treatment was with TBTO and later TBTN. Preservative penetration is not likely to have been as deep as for *P. radiata* treatments. Of the 187 windows examined, only 9 (5%) were found to have some form of biodeterioration, generally brown rot. Where brown rot was evident, it was confined to the lower joints. These affected windows faced north, and at least three had been LOSP-treated. Maintenance had been neglected in many of the decaying windows, as most had not been repainted for 15 years.

Nine failed windows in the yard of a window repairman were also examined. One of the windows was a 22 year old *Shorea* spp. window that was found to contain tin when analysed by EDX scanning electron microscope, suggesting that it had been treated with LOSP.

Several treatment systems were examined in a trial of model windows exposed for three years to a combination of the Accelerated Field Simulator (AFS) and natural weathering on a roof. Heavy decay was found in painted untreated *E. regnans* (mountain ash), *E. delegatensis* (alpine ash) and *Shorea* spp.

window frames. Only minor decay was detected in untreated *E. sieberi* (silvertop ash) and *E. obliqua* (messmate) frames, while there was no decay in untreated *T. plicata* (western red cedar) windows. One *E. regnans* window frame treated with a LOSP formulation containing TBTN had slight decay. There was no decay in windows treated with an azole-containing LOSP, including those treated by three minute dip. The decay test was considered to be faster than could be obtained by field testing, although a direct calibration was not made.

Unpublished L-joint trial

Forest Research L-joint test of painted and unpainted units after 15-16 years' exposure.

P. radiata L-joints were treated with formulations containing TBTO or TBTN, and lacked water repellent additives. They were exposed near Rotorua, New Zealand, in both a painted or unpainted condition. The paint was a three coat system (primer, undercoat and white alkyd top coat). Latest inspection results are for 15 years (TBTN) and 16 years (TBTO). The rating system used and the mean ratings obtained are given in Table 1.

Rating Scale	Extent of decay
10	Sound
9	Minor decay, <3% cross section
8	Light decay established, 3 – 10%
7	Established decay, 10 – 30%
6	Deep decay, 30 – 50%
4	Severe decay, more than 50%
0	Failed, disintegrating

Formulation	Retention	Mean Rating	
	% m/m tin	Painted	Unpainted
TBTO	0.03	4.0	6.8
TBTO	0.05	5.6	7.3
TBTO	0.08	5.8	6.7
TBTO	0.11	5.1	7.5
TBTO	0.13	5.6	8.0
TBTN	0.03	1.2	0.8
TBTN	0.05	4.8	4.2
TBTN	0.08	4.2	6.3
TBTN	0.11	5.2	7.3
TBTN	0.13	6.7	7.7
Untreated		0.0 (av. life 9 years)	0.6
Solvent only		0.0 (av. life 8.5 years)	1.0

Table 1. Rating scale, and mean rating of L-joints exposed for 15-16 years at Rotorua.

In nearly every case, including untreated and solvent-only treated controls, painting has a deleterious effect on performance. Thus, while it may be true that TBT preservatives breakdown under the action of UV light, the relative performance of painted versus unpainted seems to be more related to water entrapment, which occurs more readily in painted units than in unpainted units. A part of the L-joint test involves moving the mortise and tenon pieces before exposure, so that the seal of the paint film around the joint is broken. In normal service, a well maintained paint system should reduce this problem of water penetration. At the lower retentions of 0.03% and 0.05% m/m tin, TBTN has performed less effectively than TBTO, even though the TBTO-treated specimens were a year older. Differences in performance are less clear at the higher tin retentions.

Unpublished decking trials

Unpublished decking trial installed in Rotorua December 1986 with additions in March 1988 (Hedley pers. comm).

This trial was prepared by NZ Forest Research. *P. radiata* sapwood decking 1000 x 90 x 40 mm was exposed unpainted near Rotorua. Decking installed in 1986 had been treated with either TBTO or copper naphthenate (CuN), while TBTN-treated material was added in 1988. There were five retentions of each preservative. Bearers supporting the decking rested on the ground, therefore grass was able to grow between the decking. The LOSP formulations were non-formulated, so lacked water repellents. Inspection results are for 16 years exposure for TBTO and CuN, and 15 years for TBTN. Mean ratings are given in Table 2.

Rating Scale	**Extent of decay**
10	Sound
9	Minor decay, <3% cross section
8	Light decay established, 3 – 10%
7	Established decay, 10 – 30%
6	Deep decay, 30 – 50%
4	Severe decay, more than 50%
0	Failed, disintegrating

Preservative	**Retention (metal % m/m)**	**Mean rating**
TBTO	0.04	4.0
TBTO	0.06	5.1
TBTO	0.09	5.8
TBTO	0.11	5.8
TBTO	0.14	5.9
CuN	0.04	4.5
CuN	0.07	7.1
CuN	0.10	8.5
CuN	0.13	8.4
CuN	0.16	8.8
TBTN	0.03	0.0 (av. life 12years)
TBTN	0.05	0.4
TBTN	0.08	3.0
TBTN	0.11	4.8
TBTN	0.13	6.1
Untreated	-	0.0 (av. Life 6.7 years
Solvent only	-	0.0 (av. Life 8.4 years)

Table 2. Rating scale, and mean rating of decks exposed at Rotorua since 1986-1988.

Figure 2. Example of decking test near Rotorua

In practical terms, a rating of 6 or less means the sample, if it had been part of an actual deck, would be unserviceable. Results indicate that TBTO is more effective than TBTN, although there is a more pronounced dosage response with the latter. Figure 3 shows several failed TBTN-treated deck specimens which contained 0.08% m/m tin. Copper naphthenate is superior to both at currently approved retentions (Fig. 4). This trial is one of the more relevant available for assessing the performance of TBTN in decking. Copper naphthenate is a useful comparative preservative.

Figure 3. TBTN-treated *P. radiata* decking with 0.08% m/m tin after 13 years, underside.

Figure 4. Copper naphthenate-treated *P. radiata* decking with 0.07% m/m copper after 13 years, underside.

Unpublished decking trial installed in 1994

This decking trial was sponsored by Koppers Arch, and used TBTN as the approved comparative preservative. TBTN was unformulated, so lacked water repellents. Test timbers were *P. radiata* sapwood 1000 x 90 x 42 mm, and were exposed unpainted (as is usual for decking trials). Bearers supporting the decking rested on the ground, therefore grass was able to grow between the decking. Mean ratings for decking adjacent to bearers are given in Table 3. The Beerburrum site was inspected in September 2002 after 8 years 3 months, while the Rotorua results are for the five year inspection.

The rating system was slightly different at Queensland (inspected by Queensland Forest Research Institute) and Rotorua (inspected by NZ FRI) (Table 3).

Rating Scale	**Beerburrum, extent of decay**	**Rotorua, extent of decay**
10	Sound	Sound
9	<5% decay	<3% decay
8	5 – 10%	3 – 10%
7	10 – 25%	10 – 30%
6	25 – 50%	30 – 50%
4	50 – 75%	50 – 75%
0	Fail > 75%	Fail > 75%

Elemental tin % m/m, approx.	**Rating at Beerburrum**			**Rating at Rotorua**	
	Top face	**Bottom face**	**Ends**	**Against untreated bearer**	**Against treated bearer**
0.04	7	9	4	7	8
0.04	7	9	4	6	7
0.04	8	9	8	8	9
0.04	6	9	6	6	7
0.04	4	8	0	7	7
0.04	6	9	4	7	7
0.04	8	9	4	7	7
0.04	4	8	0	6	8
0.04	8	9	6	7	8
0.04	6	8	4	6	8
Mean	6.4	8.7	4.0	6.7	7.6
0.08	8	9	9	9	7
0.08	8	9	8	9	7
0.08	9	9	9	9	6
0.08	8	9	8	9	8
0.08	8	8	9	7	8
0.08	8	9	8	7	7
0.08	8	9	9	8	8
0.08	7	8	7	9	7
0.08	9	9	8	7	6
0.08	9	8	8	8	7
Mean	8.2	9.0	8.3	8.2	7.1

Table 3. Rating scale, and individual and mean ratings of decks exposed at Rotorua since 1994.

When this trial was installed, TBTN was considered to be a valid reference preservative. Therefore, a second reference preservative such as CCA was not included. As the performance of TBTN is now under question, these results are difficult to interpret. Seven out of ten specimens treated with 0.04% m/m tin have been heavily decayed after 8.25 years at Beerburrum, with ratings of 4 or less. This compares to test specimens treated to a retention of 0.08% m/m tin that have only light or light-moderate decay. Untreated *P. radiata* decks at Beerburrum had nearly all failed, with only 2 of 8 remaining and these were in very poor condition. Unlike Beerburrum, no specimen treated to 0.04% m/m tin had failed at Rotorua, although the exposure period was only five years at this site. Nevertheless, decay was well established in most test specimens. Decay was more severe on 0.08% m/m treated *P. radiata* at Rotorua, with a mean decay rating at the worst end of 7.1, compared to Beerburrum with a mean decay rating of 8.2 (for top face).

Unpublished heartwood/sapwood decking trial installed in 1996 (W.D. Gardner, J.F. Marchant, and L.G. Page, 1997, Establishment Report, The effect of preservative penetration in heartwood on the performance of preservative-treated *Pinus radiata* exposed externally above ground, State Forests of NSW), (J.D. Thornton and G.C. Johnson, 2000, Report of the four year inspection, John Thornton and Associates).

This trial was prepared by NSW State Forests and sponsored by Osmose and Koppers Arch. *P. radiata* decking specimens were 1000 x 90 x 45 mm. One of the aims of the test was to examine the influence on performance of poorly penetrated heartwood. Therefore, one set of test specimens contained 50 to 100% heartwood, and another set of treatment controls contained all sapwood. The preservatives examined included a fully formulated TBTN (Protim 235WR), and there were useful comparative preservatives in copper naphthenate (Protim 70WR), CCA (Tanalith O) and ACQ 2100 Type B. All were treated to approved H3 retentions in the sapwood. The decking was installed at Beerburrum in south east Queensland and Coopernook near Taree in NSW in 1996. Bearers supporting the decks rested on the ground, therefore grass could grow through the decking. About half of the decks were exposed (uncovered), and the remainder was covered with shade-cloth placed just above the decking, to reduce evaporation after rain (and accelerate decay). The latest inspection was after four years of exposure. The rating scale and mean decay ratings obtained are shown in Table 4. For this comparison, the average of the scores obtained for uncovered and covered decks are given.

Rating scale	Depth (mm) of softening
8	No softening
7	Up to 3
6	>3 – 6
5	>6 – 9
4	>9 – 12
3	>12 – 15
2	>12 – 18
1	>18 – 21
0	>21 – 22.5

Preservative	Deck type	Mean rating at Beerburrum	Mean rating at Coopernook
Protim 235WR (TBTN)	Sapwood	6.5	5.9
	Heartwood	6.0	5.9
Protim 70WR (CuN)	Sapwood	6.7	6.5
	Heartwood	5.8	6.1
Tanalith O (CCA)	Sapwood	6.6	6.5
	Heartwood	6.0	5.9
ACQ 2100	Sapwood	6.7	6.7
	Heartwood	5.9	6.0
Untreated	Sapwood	1.5	1.2
	Heartwood	3.0	3.8

Table 4. Rating scale, and mean rating of decks installed in 1996 in Australia.

After four years, untreated sapwood decking has failed and rated 1.2 and 1.5. Untreated heartwood showed more resistance to decay, although it was still seriously deteriorated. Treated decking was generally in good condition, with on average up to 3 to 6 mm depth of softening. Treated heartwood generally had slightly more softening than treated sapwood, probably due to the reduced preservative penetration that would have occurred in heartwood. At this early stage in the trial, there is no clear difference between the preservatives in performance. This well replicated and designed experiment is overdue for inspection, and is the trial where future inspections should give clearest indication on the relative performance of TBTN.

Unpublished decking trial installed in 1998

This decking trial was sponsored by Koppers Arch to test new azole based formulations, and used TBTN as the approved comparative preservative. The TBTN formulation included permethrin, but lacked water repellents. Test timbers were *P. radiata* sapwood 1000 x 90 x 40 mm, exposed unpainted. Bearers supporting the decking rested on the ground. Mean ratings for decking adjacent to bearers are given in Table 5.

Rating Scale	Extent of decay
10	Sound
9	Minor decay, <3% cross section
8	Light decay established, 3 – 10%
7	Established decay, 10 – 30%
6	Deep decay, 30 – 50%
4	Severe decay, more than 50%
0	Failed, disintegrating

Preservative	Mean rating after 4 years at Beerburrum	Mean rating after 4 years at South Johnstone near Innisfail	Mean rating after 6 years at Rotorua, NZ
Untreated control	3.4	1.6	0.4
Solvent control	2.1	0.9	4.7
0.02% TBTN*tin + 0.02% permethrin	7.9	4.9	2.8
0.04% TBTN*tin + 0.02% permethrin	8.2	7.2	4.5
0.08% TBTN*tin + 0.02% permethrin	8.8	7.8	6.9

- Elemental tin retention.

Table 5. Rating scale, and mean rating of decks installed in 1998.

Once more, a second reference preservative such as CCA was not included in the trial, because TBTN was considered suitable for this purpose when the trial was initiated. As the performance of TBTN is now under question, these results are again difficult to interpret. The results show that decay is faster in the wet tropics at South Johnstone compared to Beerburrum. The greater severity of decay found at Rotorua may be due simply to six rather than four years of exposure. The results also show that decay is now established in TBTN-treated decking containing 0.08% m/m tin after six years at Rotorua, while only light decay has established in treated timber at the Queensland sites.

DISCUSSION

LOSP treatment by vacuum pressure impregnation was first introduced into Australia in the 1980s mainly for the treatment of window joinery, weatherboards and architectural timbers. The treatments were not expected to prevent deterioration on their own, but were used in applications that were semi-protected with paint or through water-shedding design, or they were non-critical structures. Window joinery treatment was mainly for hardwoods such as meranti, and being mainly heartwood, were not likely to meet the penetration requirements of AS 1604. Therefore, the industry developed primarily in the southern states such as Victoria, where timber treatment results were not governed by state legislation. Instead, treatment to a water repellent standard could be claimed.

Australia appears to have extended the use of LOSP into non-water shedding categories more than occurs elsewhere. This in itself is not a problem, if field trials have demonstrated acceptable performance. In the USA, LOSP is used mainly as a dip or spray treatment for external joinery. In Europe, as in Australia, LOSP is often applied by vacuum pressure impregnation. The old UK standards (surpassed by European standards) note that LOSP-treated timber exposed outdoors should be painted or stained. Similarly, Queensland's TUMA regulations required TBTO-treated timber to be painted. However, this requirement was dropped for TBTN as it was thought to be more stable against UV.

New Zealand's MP 3640 was first published in 1992 and placed no conditions on the use of TBT preservatives in H3 situations. However, an amendment made in 1993 stated that roof shingles and decking were not suitable for LOSP treatments. It also stated that weatherboards to be used unpainted were not suitable for LOSP treatment except with specially approved formulations which contained water repellents. The only "specially approved" formulation at that time was Protim 235 WR. These limitations on shingle roofs, decking and weatherboards were not carried over when MP 3640 was revised as NZS 3640, published in 2003. This was because the new standard does not specify anything which is beyond the control of the treatment plant. However, in a related standard (NZS 3602: 2003 "Timber and wood-based products for use in buildings"), TBT-treated weatherboards, fascia, barge- and cover-boards are required to be painted in service. Decking timbers are also excluded from products which may be treated with TBT. Thus, the two new standards restrict TBT-treated products to non-structural components which will be painted in service (Hazard Class H3.1).

A requirement for painting TBTN-treated timber has not been placed in AS 1604, because once the timber has been sold this aspect falls beyond the auspices of the standard. A recommendation for painting would also become difficult to specify, enforce and interpret in building codes.

Soon after the publication of AS 1604-1993 (which only lists TBTO), application was made to recognise that 1 part TBTO (39% tin) was equivalent to 1.8 parts TBTN (22% tin), based on similar tin contents. This change was shown in AS 1604-2000 which specifies organo tin as TBTO or TBTN, with the elemental tin retention specified of 0.08% m/m in oven dried wood.

TBTO and TBTN are clearly effective preservatives when examined in laboratory trials with freshly treated timber. The problem for TBTO and TBTN is that they can degrade prematurely once impregnated into wood due to a variety of agencies such as UV, oxygen, free radicals and volatility. Degradation is to dibutyl and monobutyl tin, and other compounds such as TBTA. These breakdown products are less effective than TBTO and TBTN, or are more volatile. Degradation can be reduced by painting, although whether all common paint systems are effective at reducing the degradation is unclear.

Given that TBTN is reported to degrade in wood in service, a key question concerns what retention is needed to provide a sufficient reservoir of active for long term performance? Decking trials in New Zealand show unsatisfactory performance for 0.08% m/m tin, with failure of some samples after eight years. It should be noted however, that this trial represents a severe H3 exposure hazard and is designed to be accelerated, as it is placed in close proximity to the ground and its often higher humidity. Accelerated testing is needed if companies are to invest in preservative development. Unfortunately, directly comparable decks made from H3 CCA-treated timbers were not included in the trials, although experience from other decking trials at Rotorua (where the deck was about 750 mm above-ground) is that H3 CCA-treated *P. radiata* will last at least 20 years. Copper naphthenate-treated decking was included for comparison in the oldest decking trial noted above, and has performed much better than TBTN.

In New Zealand, TBTN-treated *P. radiata* decking treated to 0.13% m/m tin (1986/1988 trial) performed somewhat better than 0.08% m/m tin, although after 15 years deep decay was present in treated specimens and they were nearing unserviceable condition. (Fig. 5). The tin retention of 0.16% m/m tin has not been tested, but the usual dose response reaction would lead to the expectation that 0.16% m/m tin will perform better than 0.08% and 0.12% m/m tin. A recent statistical analysis of the results performed for this review, suggests that increasing the tin retention will provide a useful extension to the service life of treated decking (Fig. 5). It shows that the best fit was obtained using a non-parametric curve on a logit scale. The curve recognizes that the maximum score is ten, and that untreated decking would have had a zero index of condition after fifteen years.

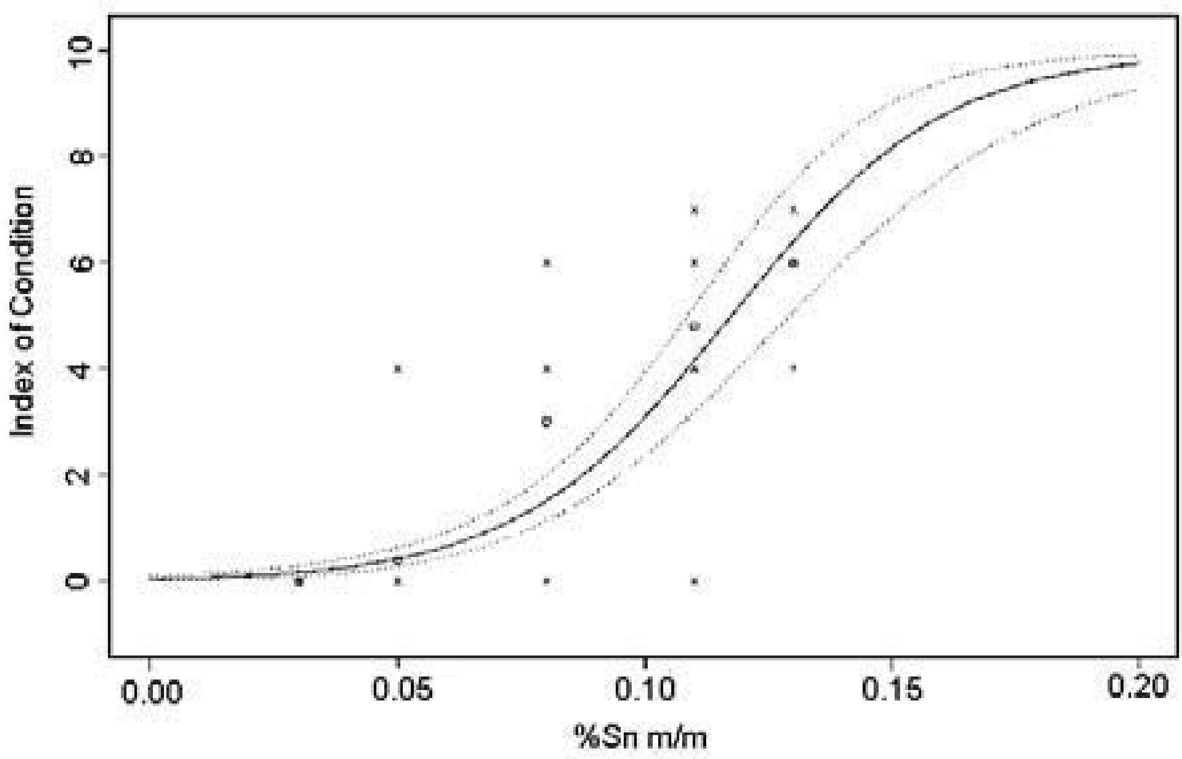

Figure 5. Plot of relationship between tin content (% Sn m/m) and Index of Condition after fifteen years in a decking trial near Rotorua, NZ. Non-parametric curve on a logit scale. The circles are mean values, X are individual values (10 for each mean), and dotted lines are the 95% confidence limits.

It is anticipated that LOSP formulations with fungicides based on a 1:1 mixture of propiconazole and tebuconazole will soon become registered and approved in Australia, and that these formulations will replace TBTN. The azoles have performed better than TBTN in field tests.

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Disclaimer

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