NEW PRESERVATIVES - THE CHALLENGE OF RESEARCH

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INTRODUCTION

Wood preservation offers a constant challenge for research because it aims to prevent the fundamental process of biodeterioration. It must always be remembered that the ultimate fate of wood, along with other dead organic materials, is to be degraded by a variety of bacteria, fungi, and insects. Preservation aims to stop, or at least slow down, this process by application of chemicals toxic to the potential wood-destroying organisms. The widespread use of such preservatives as copper-chrome-arsenate, pentachlorophenol, and creosote has been so successful that wood preservation enjoys a high reputation, but possibly the excellent performance of treated timber on which this is based has also led to a degree of complacency. These so-called second-generation preservatives are characterised by being chemically and physically robust, but above all possess broad-spectrum biological activity. Unfortunately, such broad-spectrum activity is no longer considered a desirable characteristic when accompanied by a total lack of specificity towards target organisms. Similarly, physical and chemical robustness are difficult to accommodate when a basic requirement is low environmental impact.

Thus, we now approach the era of the third-generation preservatives which attempt to combine permanence in wood, and toxicity to a plethora of wood-destroying organisms, with complete safety in use and total absence of environmental impact. At present this is an unachievable goal, but it has been accepted that a partial solution is readily achievable - namely, chemicals with all the required properties of a preservative coupled with "acceptably" low mammalian toxicity and little environmental impact.

This paper outlines some of the recent research experiences at the Forest Research Institute (FRI) Rotorua which are pertinent to the search for alternative wood-treatment chemicals. In particular, it will discuss some of the limitations of "third-generation" preservatives and comment on some of the practical implications of their commercial introduction.

ANTISAPSTAIN CHEMICALS

The chlorinated phenols, particularly sodium tetrachlorophenoxide and sodium pentachlorophenoxide, have been the mainstay of antisapstain control world-wide for many years. They have a well-proven record of performance and are very cost-effective, but are under considerable pressure for replacement.

Theoretically, an acceptable antisapstain chemical should be a readily achievable goal. Biocidal activity is sought for a relatively short period of time, as far as wood preservation is concerned, and the broad-spectrum, low mammalian toxicity fungicides used in agriculture and industry should be readily transferable to the protection of wood. Unfortunately this has not been borne out by experience. The FRI, along with many other governmental and industrial research organisations, has had little success in finding a fully acceptable alternative to the chlorinated phenols. One of the major problems is that an antisapstain chemical must be toxic to a very complex and dynamic fungal flora including Fungi Imperfecti, Ascomycetes, and Basidiomycetes. Agricultural chemicals are designed to combine low phytotoxicity to the host plant with specific fungicidal activity towards its pathogens and thus are unlikely to be the basis for extremely broad-spectrum activity. Industrial chemicals offer more scope but because these chemicals are often designed for use in very specific applications (e.g., paint mildewicides), target organisms rarely span the complete spectrum of fungi.

Research at FRI commenced in the early 1970s and from our studies (1,2,3,4,5,6) four chemicals were eventually adopted for commercial use - namely, captafol, folpet, copper-8-quinolinolate, and 2-(thiocyanomethylthio) benzothiazole + methylene bis-thiocyanate. Parallel industrial research and development in New Zealand led to the introduction of methyl thiophanate + chlorothalonil and carbendazim. Although each of the above formulations has established a niche in the New Zealand market, experience has shown that any gain in safety in use and reduced environmental risk has been achieved at the expense of biocidal performance, ease and versatility of application, or chemical behaviour (e.g., lack of corrosivity), amongst other desirable characteristics. Possibly more disturbing has been the fact that performance of these alternative chemicals has not necessarily been constant between countries, wood species, or even wood-handling procedures (7,8,9).

From this experience it is now considered unlikely that any alternative antisapstain chemical will gain the universal acceptance enjoyed by the chlorinated phenols unless greatly increased costs can be accepted. It is therefore very important to recognise any weaknesses in biological or chemical activity of new chemicals and ensure that these limitations are not exceeded in application or use which implies considered judgement on the part of the supplier or user to select chemicals and application procedures particularly suited to the location, the wood supply, and the individual mill requirements. This will lead to a degree of complexity in the market not previously encountered.

To overcome some of these problems much more attention needs to be focussed on formulation and application technology rather than on the search for another "unique" fungicide.

Low biological performance, when clearly identified, can be overcome by addition of specific fungicides (e.g., addition of chlorothalonil to captafol formulations to enhance control of <u>Trichoderma viride</u>). However, the importance of formulation of non-biologically active components can be of equal, if not greater, importance. It has recently been shown (10) that formulations based on highly stable emulsions suffer reduced biological activity because concentrations of chemicals on wood surfaces become greatly reduced as a result of diffusion into wet

timber. Less stable emulsions would obviously overcome this problem, but dip solutions would be rapidly depleted of chemical as it was "stripped" by the emulsion breaking on the surfaces of contaminating sawdust and other debris. New application technology may provide a mechanism for utilising improved formulations by circumventing some of the existing problems.

The aim of efficient application of antisapstain chemicals is to apply the minimum required dosage on wood surfaces. In an attempt to achieve this aim, the FRI has invented a novel foam application system which applies the precise concentration of the chemical on to the wood in ultra-low volume dosage. The foam, generated from applicators applied to each side of the timber, is immediately dissipated on the surfaces of freshly sawn timber. The solution dosage is so low (10 ml/m^2) that evidence of treatment can be determined only by means of UV-fluorescent tracers added to the formulation; there is no detectable change in surface moisture characteristics. The feed rate for timber in the first commercial applicator will be 4 m/sec. The benefits of this system are:

- no run-off of solution from treated timber;
- both solutions and wettable powders can be used;
- no contamination of the system by sawdust and therefore "stripping" of the active ingredient cannot occur;
- premixing of chemicals in plant may not be required because solutions are used at relatively high concentration, thus minimising problems of quality control;
- treatment is more cost-effective because there is no wastage.

Performance in a commercial system has yet to be tested, but experimental trials to date have been extremely encouraging. Similar developments in ultra-low volume application are being pursued elsewhere, for identical reasons, and the introduction of such technology must be regarded as offering great potential to the industry.

At present, the major thrust of FRI research on antisapstain chemicals is to significantly increase the protection of export timber. Of particular interest is the combination of fungicidal action with water repellency. Large field trials have been established with sawn timber, machined posts, and debarked logs at an early stage in our work because a completely suitable laboratory test procedure was not available. The development of a test method which combines weathering and bioassay to stress both the fungicide and the water-repellent simultaneously is urgently required. A research programme involving accelerated weathering tests of potential water repellents is nearing completion and results will be used to decide on formulations for future field trials.

NEW WOOD PRESERVATIVES

The FRI has pursued the development of alternative wood preservatives since 1974. Although most attention was focussed on alkylammonium compounds (11,12) many other chemicals were screened as potential wood preservatives (13). General progress in the search for new preservatives (14) and the requirements and problems of a research and development programme to achieve this goal (15) have recently been discussed and will not be addressed further. More pertinent is a discussion of recent experiences with the commercial application of benzalkonium chloride in New Zealand.

Briefly, the New Zealand Timber Preservation Authority (TPA) approved the commercial use of benzalkonium chloride in 1978. Approvals were restricted to treatment of <u>Pinus radiata</u> by Bethell or Lowry processes. Retention requirements for wood exposed above-ground were originally a mean charge retention of 2.5 kg a.i./m^3 (minimum 0.37% a.i. w/w), but in 1982 they were amended to 3.75 kg a.i./m^3 (minimum 0.55% a.i. w/w) because inadequate field performance has been noted in a limited number of instances. The volume of timber treated increased steadily from 6000 m^3 in 1979 to a peak of some 65 000 m^3 in 1983. In 1985 all approvals were rescinded because of poor performance. These problems did not come to our attention until 1982 and were represented by decay during long-term storage and premature decay of treated wood in service. Benzalkonium chloride was the first of the "third-generation" wood preservatives to be used commercially and the opportunity must not be lost to gain an understanding of the reasons for its unfortunate "demise". A detailed account of the criteria for approvals, and performance in service has been given very recently (12) and thus requires only reference at this juncture.

The large majority of instances of decay during storage, and failure during service, brought to our attention have been associated with sub-standard treatment. However, it must be clearly stated that FRI has not examined all examples of decayed timber, nor is the magnitude of the problem known at this stage. Some additional instances of decay may be attributed to extreme abuse of timber treated for above-ground use, such as packets of timber being left on the ground and close to hedgerows for 2-3 years, or fence palings and decking timbers which were in continual ground-contact. Despite this abuse, the rapid onset of decay does suggest a lack of robustness in performance of benzalkonium chloride; timber treated with CCA preservatives for the same commodity use and similarly abused does not suffer the same fate.

Of special concern are those examples of decay in wood treated up to specification. In the last 18 months there have been several instances of decay of well-treated timber during storage in block stack, even when the wood has been stored under cover and not in ground contact. The cause of decay was a <u>Coniophora</u> sp. An additional problem, of which there have been few examples, is associated with establishment of decay fungi in surface zones of the wood which have previously been totally depleted of benzalkonium chloride. Detailed examination of these chemically-depleted zones, before colonization by decay fungi, show them to be totally devoid of fungi or bacteria and thus tends to eliminate the possibility of biological breakdown. As yet, no explanation is available for this phenomenon. Qualitative analyses of depleted surface zones for possible chemical breakdown products of benzalkonium chloride have so far been unsuccessful.

Some examples of decay of well-treated wood in service have also been encountered, but the situation is somewhat complicated by evidence that some infection may have been carried over from long-term storage in many instances. It is too early to judge the performance of benzalkonium chloride in service, but present indications are that if the wood was free of decay at time of installation the preservative should perform satisfactorily in the vast majority of cases.

Poor standard of treatment has been diagnosed as a major reason for lack of performance both in storage and in service. This does not imply a criticism of the preservation industry, because if this was common practice similar problems would be experienced with CCA and this is certainly not the case. Thus, the problem is thought more likely to emanate from the preservative.

Although benzalkonium chloride, along with most other alkylammonium compounds, is very substantive to wood, comprehensive trials on <u>P. radiata</u> have given no indication that "stripping" and resultant poor preservative distribution would be a problem (16,17). We now know that "stripping" can occur in commercial treatment when insufficient pressure pump capacity results in a slow build-up of pressure, and presumably a slower penetration of the preservative into the wood. Problems of poor distribution will obviously be exaggerated if treated wood is gauged or profiled after treatment which is common practice in production of decking timbers, for example. In addition, poor preservative penetration and distribution can result from treatment of partially wet material. This is a problem sometimes encountered with "custom-treatment" where the responsibility for wood preparation is primarily the responsibility of the customer rather than the treatment plant. It is possibly significant that many examples of sub-standard treatments have been associated with "custom-treated" material.

Monitoring the standard of commercial treatment by random sampling has obviously proved inadequate to detect poor treatments. In retrospect it was unfortunate that a "piece by piece" examination was not undertaken for a series of successive commercial charges, but this was not considered necessary on the basis of results from experimental charges. It must be concluded that benzalkonium chloride is sensitive to deficiencies in treatment plant performance and a laboratory programme to establish treatability cannot reproduce the realities of commercial practice.

The problem of decay in benzalkonium-chloride-treated wood during storage caused by a <u>Coniophora</u> sp. also deserves close examination. The 1982 revised retentions of benzalkonium chloride (3.75 kg a.i./m^3) were based on toxic thresholds generated for 16 basidiomycetes in high-hazard decay tests and for 10 basidiomycetes in moderate-hazard decay tests simulating ground-contact and above-ground exposure respectively (12). The mean toxic threshold of 4 kg a.i./m^3 established in severe decay tests was exceeded by only one fungus which occurred in New Zealand, <u>Coniophora puteana</u> (toxic threshold <u>c</u>. 6 kg a.i./m^3). In moderate decay test, the highest toxic threshold for any fungus was 2.0- 2.5 kg a.i./m^3 which equates to the minimum retention level of 0.55% a.i. w/w for individual pieces within a charge.

This raises the obvious question of what weight should be given to the toxic thresholds of highly tolerant fungi when setting retention levels. Essentially this involves the calculation of a risk factor. Firstly, Coniophora puteana is usually associated with decay of sub-floor timbers in houses with poor ventilation and was not considered to be a potential problem for timber in above-ground use. This has been borne out in practice, since Coniophora spp. have yet to be implicated in the decay of benzalkonium-chloride-treated timber in service; most decay is associated with Gloeophyllum trabeum. Secondly, although the extremely high tolerance of many strains of Poria vaillantii to CCA preservatives is well known (18), this information is not taken into account when setting commercial retentions. Practical experience over many years has shown that, although rapid failure of wood well-treated with CCA can be attributed to this fungus, the instances are so few and the economic impact so slight that a dramatic rise in retentions is unwarranted. The incidence of decay in timber treated to specification with benzalkonium chloride is certainly greater than would have been expected from the above experience, but it represents only a small proportion of the total storage decay problem. Certainly, problems of decay in block-stacked, treated timber stored under cover was not anticipated, and experience with untreated timber would not have indicated that Coniophora sp. would be a problem; fungal species such as Phlebia gigantea and Stereum purpurum would have been considered more likely candidates. Finally, it must be stated that the evaluation programme was designed to protect timber in use and the potential problems associated with long-term storage of timber under adverse conditions was not a factor taken into account.

The depletion of benzalkonium chloride from surface zones of the wood represents a new phenomenon which could not have been predicted and which has yet to be explained, even on technical grounds. Its occurrence was so rare that it played little part in the demise of benzalkonium chloride apart from representing another potential problem.

As stated previously, decay of well-treated timber in service is difficult to assess since infection may well have commenced during long-term adverse storage. However, a few examples brought to notice cannot be explained in this way. In a few instances, a depletion of benzalkonium chloride has been detected but this is by no means the norm. The only positive observation that can be made is that treated timber, possibly because of the surfactant properties of benzalkonium chloride, takes up moisture more rapidly and remains wet for longer periods than CCA-treated or even untreated wood. Thus, benzalkonium-chloride-treated wood is likely to have a moisture content conducive to decay establishment for extended periods of time.

It will be noted that the data base used for setting commercial retention levels was generated exclusively in the laboratory. The question needs to be asked whether results of field trials would have substantially modified retention levels. A series of field trials has been established over the last 8 years and sufficient information is now available to address this question.

Results may be summarised as follows:

- after 3 years of exposure, treated wood in tests of rail units, shingles, and L-joints, was performing up to expectation;

- after 4.5 years one L-joint treated to 1.8 kg a.i./m^3 was rated as 70% sound and one treated at 2.5 kg a.i./m^3 was noted as having a trace of decay. At retentions of 1.3 kg a.i./m^3 no basidiomycete decay was detected but there was evidence of surface softening through action of soft-rot fungi. At the highest retention of 3.75 kg a.i./m^3 all joints were noted as being in good condition;

- after 7 years all shingles, which were treated to retentions of about 5 kg a.i./m^3 were free from decay;

- after 6 years some rail units (also treated to approximately 5 kg a.i./m^3) were noted as having decay and mean condition was assessed as 95% sound. Re-examination after 8 years' exposure showed the mean condition of rails to be 92% sound, but 10 rails were rated as 70% sound and one as 40% sound out of a total of 63 units. Decay is progressing, albeit slowly, but the post and rail fence still remains totally serviceable;

- after 2.5 years, battens stored under very poor conditions were all regarded as being fully acceptable for use. Battens in direct soil contact showed some superficial softening (up to 2 mm depth) whilst the remainder were totally free of fungal infection. They were treated at FRI to mean charge retentions of 2.5 kg a.i./m^3 and 3.75 kg a.i./m^3 but retentions in some individual pieces were as low as 1.3 kg a.i./m^3.

Results after 3 years' exposure would clearly have endorsed the adequacy of commercial retention levels, and certainly would have given no indication of problems of premature failure. Even the long-term (2.5 year) storage trial under poor conditions gave no evidence of the problems being experienced by the industry. For the L-joint trial, wood samples were cross-cut after treatment and joints formed at their mid-point. Thus the trial should have readily identified problems of poor distribution. Performance after 4.5 years was generally very good with only one joint being identified with significant decay, but the retention level was well below the minimum set for commercial treatment. A trace of decay was also detected in one of 10 joints treated at the minimum retention level of 2.5 kg a.i./m^3 but this could have been attributed to a slight preservative distribution problem. Shingles were completely free from decay although exhibiting losses of up to 35% of benzalkonium chloride over the 7-year exposure period which would have lowered retentions to at least 3.5 kg a.i./m^3. Decay in rail units was not detected until after 6 years of exposure, and even after 8 years mean condition was assessed as 92% sound. The presence of advanced decay in some units after this time would certainly have raised doubts about long-term performance. However, it is unlikely that field trials would have been extended beyond 5 years and at that stage the overall performance of benzalkonium-chloride-treated wood would have vindicated the approved retention levels. If any deficiencies existed in this reasonably comprehensive series of field trials, they were that no test reflected the realities of commercial treatment, most simulated exposure of wood in use rather than abuse, and in no trial was the tolerant Coniophora sp. encountered. This was because field trials followed well-proven and established procedures. It is now considered that performance in ground contact, by field stake trial or fungus cellar exposure, should also be taken into account when setting retentions for above-ground use.

The overall experience with benzalkonium chloride leads to conclusions that closely parallel those for alternative antisapstain chemicals. Namely, that a gain in safety and reduced environmental impact is obtained at the sacrifice of robustness in use. The important lesson to learn from our experiences with benzalkonium chloride is that the problems encountered during commercial use could not be anticipated from a very comprehensive evaluation programme. Alkylammonium compounds are still regarded as offering considerable potential as "third-generation" wood preservatives, and the commercial failure of one chemical (benzalkonium chloride) should not negate this potential. A greatly expanded data base is now available and the deficiencies of commercial treatment and use have been clearly identified. Again, it is necessary to make comparisons with alternative antisapstain chemicals and emphasise the need for developments in formulation which could assist improvement in treatability and extend fungicidal effectiveness.

PROBLEMS WITH CCA-TREATED TIMBER IN GROUND CONTACT

Much attention has been given to the sensitivity of "third-generation" preservatives when compared with such preservatives as CCA which are highlighted as being chemically and physically robust and of very broad-spectrum activity. Recent experience in New Zealand has shown that even the limits of performance of CCA can be exceeded in certain circumstances, which underlines the constant challenge of wood preservation in general, and the extreme challenge of finding acceptable alternatives.

Pinus radiata posts treated with CCA have been widely used in New Zealand as horticultural support systems on the understanding that they would remain in service for at least 30 years. In 1982 FRI attention was drawn to problems of premature decay in some posts in vineyards and kiwifruit orchards. The problem was considered of such potential importance that it prompted a comprehensive research programme encompassing a national survey (19), intensive surveys in selected horticultural properties examining both biological (20,21) and chemical aspects (22,23), and laboratory studies of chemical stability and biological activity of CCA formulations (24). An overview of the general problem was presented recently (25).

The problem was manifested by decay becoming established in CCA-treated *P. radiata* posts after exposure in horticultural soils for 8-12 years. In extreme cases decay was sufficiently advanced to cause post failure, and on certain properties was detected after only 4 years of exposure. The particular CCA formulation used was a B-type CCA, and even after 12-18 years' exposure chemical analysis showed posts to comply with the required specifications of the TPA, namely a minimum retention of 0.66% total elements (Cu + Cr + As)/m^3. Thus, poor standard of

treatment was not implicated. In general terms the problem was worst on properties with heavy, poor-draining soils and least severe on those with light, free-draining soils.

A wide range of wood-destroying organisms was associated with decay. Basidiomycete decay (brown rot and white rot) was least common, but brown-rot fungi were the major cause of post failure where failure occurred. The most common cause of decay were soft-rot fungi, but bacteria were also of major importance in the worst affected regions. Studies of edaphic factors suggests that the high ionic status of horticultural soils could represent a major leaching hazard for CCA, and laboratory leaching experiments with a variety of ionic solutions supported this view (26), but field observation did not confirm this as a possibility. However, it is not known whether high levels of elements such as calcium may interfere with preservative availability. Constant fertiliser application and frequent mulching were indicated as influencing preservative performance by generally raising biological activity in soils and thus increasing inoculum potential. Although no definite conclusions could be reached on the basis of these studies it was surmised that the extreme fertility of horticultural soils provided conditions highly favourable for a broad range of wood-destroying organisms. The fungal and bacterial flora, which were represented by a wide range of species, therefore had the capacity to absorb change in environmental conditions and this was manifested by different organisms becoming important as causes of decay where local soil conditions particularly favoured their establishment. Regular fungicide and insecticide application to the crops, and herbicide application to control ground vegetation, are a feature of horticultural practice. Chemical residues of these biocides in the soil may also have influenced composition of the microflora. However, over the many years that CCA preservatives have been used it is likely that the whole range of environmental and edaphic conditions would have been met singly, if not in combination, and other factors were therefore implicated.

The range of fungal species encountered, and particularly those of the soft-rot category, were not uncommon in soils, and although some species were tolerant of CCA the levels of tolerance were not high enough to explain the rapid onset of decay in well-treated material. The situation with wood-destroying bacteria was different. Three main types of bacteria were associated with decay, namely the tunnelling, cavitation, and erosion bacteria (21), so-called in respect to the type of damage they cause to cell walls. Their widespread occurrence in CCA-treated wood exposed in ground contact is regarded as a new phenomenon, especially as they were recorded as being the principal cause of decay (and very occasionally failure) of posts on certain properties. All of these bacterial types have been the subject of recent intensive study (27,28,29,30) and the role of bacteria in decay of CCA-treated wood has recently been reviewed (31). Of particular interest has been the very high tolerance to CCA exhibited by these bacteria (attack being demonstrated in wood at retention levels of 26 kg/m^3 of CCA type C and >33 kg/m^3 of CCA type B when exposed in infected soils for 6 months) and the effect of high soil moisture contents in accelerating the rate of decay (31). It has been concluded (21) that these bacteria are responsible for the initial degrade of CCA-treated posts predisposing them to secondary infection by soft-rot fungi which ultimately will be the cause of post failure in most circumstances.

A practical solution to premature decay of CCA-treated horticultural posts was found by increasing retention levels and recommending a change from B-type to C-type formulations of CCA. The mean charge retentions now recommended (16 kg/m^3, CCA type C) will obviously not eliminate the chance of bacterial infection, but should extend service life close to that previously expected. Retentions of the order of 30 kg/m^3, which would have been required to control bacterial infection, were not considered warranted since instances of severe infection were not widespread.

Three major conclusions can be drawn from this experience. Firstly, that even highly robust preservatives such as CCA can have their limits of performance exceeded. Secondly, that despite many years of research and practical experience of commercial use a new problem can emerge with near disastrous consequences. Thirdly, that present laboratory, field, and service test procedures are inadequate to predict all likely deficiencies in performance. The implications for the successful introduction of "third-generation" preservatives are considerable, especially as most candidate chemicals do not have any history of use in such demanding areas of application.

A PROTOCOL FOR PRESERVATIVE APPROVAL

Recent experience with both new and established wood preservatives has highlighted the need for improving the procedures, particularly in test methodology and interpretation, that lead to approvals for commercial use. The rationale for such a requirement was recently summarised as: "If any philosophy of testing is apparent, it is the need for greater complexity and versatility to establish a range of toxic thresholds in relation to exposure conditions and hazards from which the limits of preservative action can be defined. Essentially the target of the programme should be to identify both the strengths and the weaknesses of the new preservative and use such data for predicting the limits of preservative action and its suitability for particular products and end use" (15).

This philosophy has now been expanded and a document put forward for comment and criticism (32). It considers the benefits of a highly systematic approach to the evaluation of preservatives, and particularly addresses the interpretation of test data. In the past, simplicity of testing and the generation of reproducible toxic thresholds have been given more importance than an acceptance of the dynamic nature of toxic thresholds and what the data mean in practical terms. The proposal is not concerned with the applicability of any individual test method, but rather with a broad protocol which encompasses several test procedures and follows a step-wise approach to evaluation.

The protocol encompasses:

- laboratory evaluation by several test procedures to establish a broad reference point for further evaluation and to provide preliminary data on permanence and distribution in treated wood;

- fungus cellar tests to provide performance data from which suitability for above-ground and ground-contact use can be judged, and a series of preservative retentions can be derived for field testing;

- field tests which encompass a variety of commodity tests for above-ground use as well as ground-contact tests from which likely service performance can be predicted. The concept of "weighting" tests in recognition of varying exposure hazard is introduced;

- chemical, weathering, and treatment trials to examine permanence of the preservative (resistance to weathering) and acceptability of treatment processes. Chemical analysis will be an integral part of determining performance in field tests in addition to biological observations;

- introduction of a concept of provisional approvals to allow commercial use at an earlier stage (after 2.5 years' and 5 years' field testing for above-ground and groundline use, respectively) than is presently deemed necessary for full approval. This would be given after 5 or 8.5 years for above-ground use, depending on the particular commodity, and after 10 years for ground contact. Approvals would be given only after the appropriate health and safety clearances had been obtained;

- the strict monitoring of standard of treatment during commercial application.

However, this proposed and detailed evaluation programme may still be insufficient to adequately predict field performance under all conditions. For example, highly tolerant organisms may not be encountered and field test sites may not represent the full range of exposure hazard. Thus a parallel series of specifically designed "extreme hazard" tests may need to be introduced to test the limits of preservative performance.

In laboratory tests a serial-exposure method (33) may be of value in that it generates a series of toxic thresholds with progressive exposure periods and allows some measure of the lag phase before decay becomes established. For field trials of above-ground commodities the procedures which involve inoculation of test pieces by infected dowels before exposure (34), are worthy of strong consideration; preservative performance can be measured against a wide range of fungi rather than established on the basis of chance infection by one or more decay fungi.

The fungus cellar offers a very powerful tool for assisting evaluation of the performance of treated wood in ground contact. For example, by bringing selected horticultural soils into the fungus cellar, together with soil from our major field test site, it was possible to establish that horticultural soils provided the highest hazard for CCA-treated wood whereas soil from the test site was shown to display the highest hazard for untreated wood (35). Thus, the fungus cellar can help distinguish the decay potential of different soil types. It has also been used extensively for examining the effect of fertiliser amendment of soils on rates of decay.

Of extreme interest is that this facility allows close reproduction of field exposure problems. Before laboratory test procedures were established, fungus cellar tests with unsterile, infected soils were the only mechanism for promoting bacterial decay of treated wood. The fungus cellar also allowed a complete reproduction of the spread of infection in horticultural soils from small loci of infection which closely mirrored the apparently variable attack between posts which had been observed from detailed field examinations.

CONCLUSIONS

The challenge of finding acceptable alternatives to established preservation chemicals is considerable. To date it has not been possible to move away from the highly robust, highly toxic, broad-spectrum chemicals without considerable sacrifice of versatility in application and use or of biological activity. Recognition of this fact must lead to greater attention being focussed on test methodology so that the limitations in performance can be clearly defined. Some limitations can possibly be overcome by improvements in applications or formulation technology, but in general the wood preservation industry may have to accept a move away from chemicals suitable for protection of all commodities by simple variation in retention, towards use of specific chemicals targeted towards protection of specific commodities against specific hazards. Experience to date has clearly highlighted the complexities of the quest for new preservatives, but considerable progress has been made. It will not be an easy task, but it is an achievable goal if we build constructively on that experience.

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