Treated Timber Waste Minimisation Project

Milestone 3.2

Timber Identification Tool Development

August 2013

Environment

Canterbury

Report No. R13/71

ISBN:
978-1-927257-83-8 (Hard copy)
978-1-927257-84-5 (Web)
978-1-927257-85-2 (CD)

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1. EXECUTIVE SUMMARY

This report provides an overview of international research related to waste treated timber identification onsite, and a specification and rationale for a decision making process, or “toolkit”, suitable for Christchurch. This specification has considered a multi method approach including:

- Identification through component usage and age of house knowledge
- Simple visual inspection options, particularly for copper based treatments
- Chemical identification techniques

Target users are demolition workers, builders and surveyors. The methodology will enable them to separate timbers that are most likely to be treated (contain copper, arsenic and chromium, etc.) from those that are not treated, which opens up re-use, recycling and recovery options. Primarily, it is expected that this process will be used on the deconstruction site, but could also be used at a processing site to sort stockpiles.

Overall, it is expected that untreated native timbers will dominate the timber waste in Christchurch resulting from the demolition of residential houses. However, copper chrome arsenate (CCA) treated, and other arsenic-containing Pinus radiata will inevitably be present in any amalgamated timber stock pile at the various processing and storage sites if no effort is made to segregate the timber from any of the houses during the deconstruction process. More CCA treated Pinus radiata will also be added to these stock piles once the removal of fencing and landscaping timbers increases.

For these reasons, a recommended decision making process for use during the deconstruction process is detailed overleaf in Figure 1. A pilot tool utilising this process is included in Appendix D of this report. This tool will enable separation of treated from untreated timber, even at a relatively coarse level.

The pilot tool enables an assessment of the likelihood of treated Pinus radiata (radiata) being present in the building before any deconstruction or demolition commences. All houses should also be examined for the presence of later additions or alterations using radiata.

Surface colour and appearance of timber is a simple way to differentiate between native timbers and radiata. Radiata treated with preservatives that contain copper can also be separated from untreated radiata, or radiata treated with other preservatives, if treatment class colour coding is still present.

As a precaution, all radiata should be considered as treated until confirmed to be untreated using the decision making process given in Figure 1. If radiata is present within the interior framing of house constructed in the 1970s or 1980s, then it should be assumed to contain arsenic.

An assessment of the original use of timber is also very important for visual identification of treated timber. Radiata components for load-bearing structures that were exposed to the atmosphere or ground are most likely treated.

A chemical indicator solution can also be used to test for the copper component within CCA treatment. Chemical indicators are simple to use with reasonably clean timbers. Rubeanic acid is the preferred reagent for testing for the presence of copper (i.e. CCA)

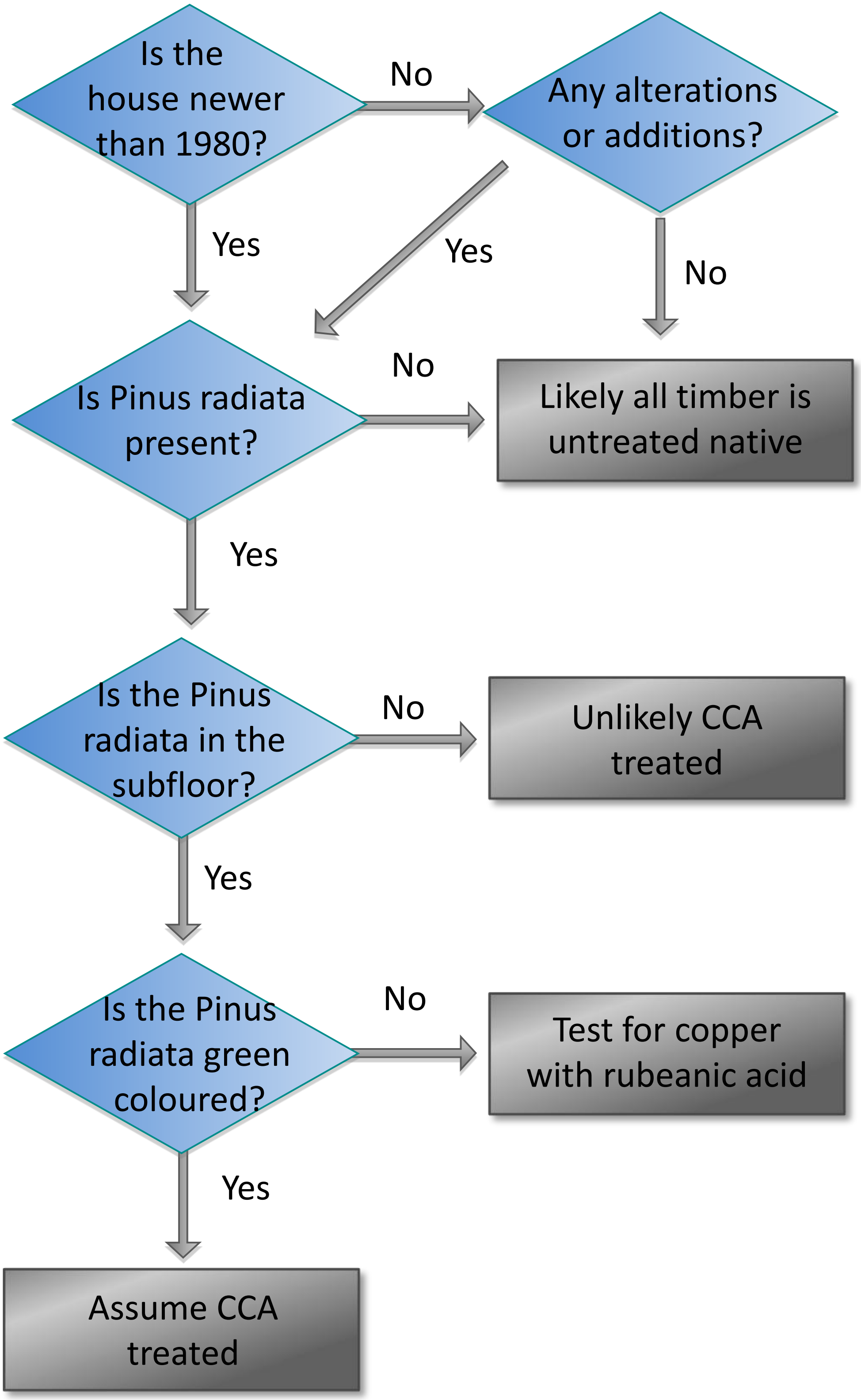


Figure 1: Recommended generalised decision making process for use during the deconstruction process

in radiata. The preparation, use and interpretation of colours obtained when using the rubeanic acid indicator [Anon] are also described in Appendix D.

This research also shows that visual assessments and chemical tests are unlikely to be cost-effective for identifying and sorting large quantities of mixed, stockpiled timber waste. Techniques using X-ray fluorescence spectrometry, laser induced breakdown spectroscopy, and/or near infrared spectroscopy can characterise the treatment components present in timber qualitatively or quantitatively, even at very low concentration levels. Overseas, they are believed to show promise for fast, cost-effective, online sorting of mixed timber waste. Progress has been made in small-scale trials using relatively simple timber mixes, particularly in the USA. However, automated identification and sorting of mixed timber waste using these techniques on an industrial scale still requires significant improvements in accuracy and is therefore not applicable in New Zealand.

2. INTRODUCTION

The Treated Timber Waste Minimisation project was launched on 4 March, 2013, with its overall goal being "to test the feasibility of, and subsequently develop a sustainable business model for the large scale collection and reuse, recycling and/or recovery of hazardous treated timber waste, with a particular focus on earthquake-related building and demolition waste."

This Environment Canterbury led project has received Ministry for the Environment funding of $144,900 towards the project's overall cost of $190,900, with the remainder coming from the project's governance group, consisting of:

- Environment Canterbury (ECAN) – Project owner
- Christchurch City Council (on behalf of the Canterbury Waste Joint Committee)
- BRANZ Limited
- Scion

The feasibility study has three key objectives:

- Identify and/or create a business case, supply chain and financial model, and end use for the collection, reuse, recycling and recovery of up to 20% (5,000 tonnes) of waste treated timber in Canterbury, in such a way that it presents compelling economic and/or brand benefits to all participants in the supply chain (waste owners, processors, logistics providers and end users).
- Identify an appropriate, effective, easy to use and low-cost tool to be used by demolition companies and/or waste processors for identifying treated timber on demolition and/or waste processing sites.
- Increase collaboration between timber waste minimisation stakeholders including demolition, timber and waste industries, Environment Canterbury, Canterbury territorial authorities, construction interest groups and the wider community, to improve waste minimisation management of treated timber over its lifecycle.

Overall, the project is aimed at creating a sustainable and economically viable process or processes for the productive use of waste treated timber.

The project has been split into five key milestones:

1. Industry Overview (completed 10 May, 2013)

A situation analysis and overview of the current waste treated timber industry and potential applications for treated timber waste.

2. International Industry Trends (due 14 June, 2013)

An overview of key international trends and technological developments in the waste treated timber industry internationally and how the application of different elements of these might work in New Zealand.

3. Part 1 – Potential Scenarios (due 16 August, 2013)

A report detailing potential new waste treated timber collection and reuse, recycling and/or recovery systems for application in New Zealand, and the risks, financial implications and potential benefits of each scenario.

Part 2 - Timber Identification Tool Development (due 16 August, 2013)

A report providing an overview of international research related to waste treated timber identification on demolition and/or waste processing sites and undertake a feasibility study on the application of this research to create a tool or toolkit suitable for use in New Zealand.

4. Detailed Business Cases and Stakeholder Collaboration (due 4 October, 2013)

Detailed business cases for each preferred scenario, including pilot trial plans.

5. Pilot Trials (due 20 December, 2013)

A final report will be produced detailing pilot processes and outcomes, and scenario details and implementation plan for the preferred option or options.

3. TIMBER IDENTIFICATION OPTIONS

Mixed timbers sourced from construction sites, or from the demolition of buildings, can be very complex in their content. Techniques for identification and sorting of waste timber during the deconstruction process are discussed in this Section.

These techniques, and other methodologies more suited to automation that are discussed in Appendix C, could also be applied to any amalgamated timber stock pile at the various processing and storage sites.

3.1 Visual Identification

Visual identification is the first option and is the simplest method for sorting timber from construction and demolition sites. Its success is based upon many factors, including knowledge / experience of the person conducting the job.

Native timbers are distinctly different in appearance from douglas-fir and radiata. Heart rimu varies in colour from a dark reddish to yellowish brown, with irregular streaks. Rimu sapwood is a uniform pale brown. The heartwood of totara is an even reddish brown and the sapwood a pale brown. Douglas-fir displays prominent growth-ring bands between the earlywood and latewood. The heartwood is a pale-pinkish colour and the sapwood is near white. Meanwhile, the heartwood of radiata is generally an even light brown to chestnut brown in colour, the sapwood is creamy white. [NZwood]

A judgment concerning the original intended use of timber is also very important for visual identification. Radiata components for load-bearing structures that were exposed to the atmosphere or ground are most likely treated. These might include piles, bearers, joists, framing, rafters, posts, decks and claddings.

Treated timbers can be characterised by their distinct colours, green or olive, while untreated timbers typically have a creamy white colour. In New Zealand, H1.2 boron treated timber, typically for wall framing, has a pink colour. Timbers treated with TBTO (Bis-(tri-n-butyltin) oxide), TBTN (Bis-(tri-n-butyltin) naphthenate) or IPBC / permethrin (Iodo propynyl butyl carbamate) to H1.2 level have a blue colour. However, if weathered, the colour will fade so that the treated timber would be almost indistinguishable from weathered untreated timber. This is particularly the case for timber treated at low retention levels. Consequently, identification or sorting based on colour could be problematic.

Tags, listing type and level of preservative, are normally attached to the end of treated timber lengths (Figure 1). If present, these can be used as identifiers. However, it is likely that most of them would be lost during or after construction

Figure 2. Visual identifiers on treated timbers: end tags [Solo-Gabriele et al., 2006]

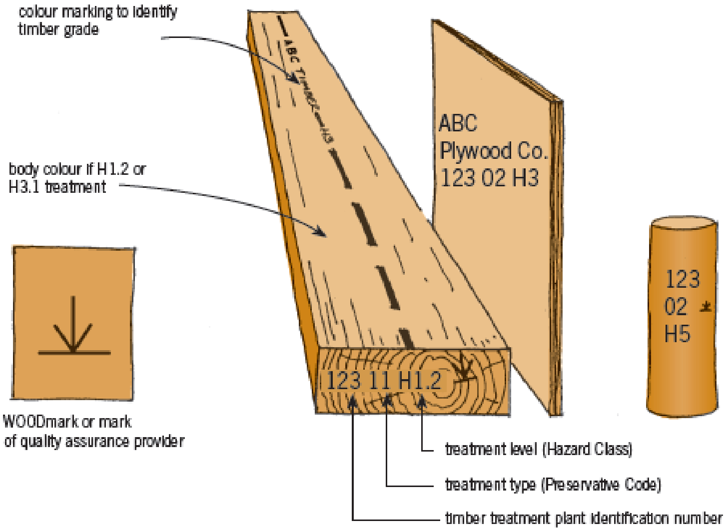


Figure 3. Identifying timber using end brandings [Pringle 2012]

In New Zealand, timber and wood based products to be used in different locations of a residential building have to be treated to different levels, according to New Zealand Standards. Branding, colouring and identification of preservative treated timbers have also been detailed in New Zealand Standards. The end brands have the information of treatment plant number, preservative type code number (see Table 1) and hazard class (see Figure 2). Therefore, visual identification and sorting (i.e. treated or untreated, type of preservative treatment) of construction and demolition timber waste could be effective with the use of branding, depending on the age of the house and with the information of where the timber was in the building.

Table 1. Code numbers of typical preservatives used in New Zealand

Preservative	*Code Number*
Copper Chrome Arsenate (CCA) - Oxide	01
Copper Chrome Arsenate (CCA) - Salt	02
Boron	11
Bis-(tri-n-butyltin) oxide (TBTO)	56
Copper Azole (CuAz)	58
Bis-(tri-n-butyltin naphthenate (TBTN)	62
Iodo propynyl butyl carbamate (IPBC)	63
Copper Naphthenate (CuN)	57
Propiconazole + Tebuconazole	64
Permethrin	70
Alkaline Copper Quaternary (ACQ)	90

Although better than 50% sorting efficiencies were noted during overseas research [Blassino et al], visual sorting of large amounts of timber waste, particularly contaminated and collected from mixed sources, would not be accurate nor cost-effective [Jacobi et al., 2007]. In addition, there are a number of occupational health and safety (OHS) issues associated with manual sorting such as skin irritation and allergic contact dermatitis [Reed, 2003].

Overall, the surface colour of timber can be used effectively during deconstruction or demolition to segregate timbers treated with preservatives that contain copper from untreated timber or timber treated with other preservatives. This technique fits with where copper-containing timber is used within Christchurch properties, as it is particularly suited to sorting timbers after short weathering periods or timber not exposed to the atmosphere. Fortunately, most copper containing timber will be used in subfloor spaces where it is sheltered from the elements.

3.2 Chemical Colour Indicators

Chemical staining or spot testing is commonly used in laboratories to assess penetration and distribution of specific chemicals. The active ingredients in these indicators are chelating agents, specifically designed chemicals that can be applied directly to treated wood and that show the presence of a particular chemical by changing colour. The most relevant colour indicators are discussed in Appendix A.

3.3 Treatment Identification Instruments

Internationally, a variety of instrumented methods for the identification of timber treatments have been developed and researched. These are described in Appendix B.

Overseas, comparative testing of some of these instruments has been completed to assess their applicability and performance in sorting mixed timber waste. Details of this testing are given in Appendix C.

4. HISTORY OF WOOD PRESERVATION IN NEW ZEALAND

Timber preservation in NZ started at the end of the 19^{th} century, when the Railways Department built a pressure creosoting plant in Invercargill for the treatment of kahikatea railway sleepers. This plant did not operate for long because the cost of treatment made the operation uneconomical when compared with the cost of imported Australian hardwoods. There was little further in the way of preservation until the early 1930's, when scientists from the Forest Service commenced experimental treatments of fence posts and poles of various species with creosote, by the hot and cold bath method. The Forest Service established three of these plants in Rotorua, Hanmer and Tapanui.

The preservation of building timbers in NZ began in the late 1930's. After World War II, the number of timber treating organisations increased considerably. The much expanded use of radiata and other NZ grown exotic softwood, necessitated by the shortage of native timber, raised the subject of timber treatment to a level of national importance. In 1938, an organisation known as the Timber Protection Research Committee was set up, for the purpose of testing and approving preservatives for building timber use. Through to the early 1950's, the suitability of boron as a wood preservative was assessed and it was subsequently approved. It was initially used for tawa flooring, but from 1955 was used for treating framing timber and this continued until today. CCA treatment started in NZ in the late 1950s, but was, initially, mainly for fencing and poles. Use of CCA treated timber in building started to expand in the late 1960s, mainly for sub-floor components. Although copper and arsenic are 'fixed' in wood after treatment, there is still some (but very low) leaching of copper, arsenic and free chromium salts, and this has been perceived to be a potential health and environmental hazard. Consequently, other copper water-based preservatives, such as alkaline copper quaternary (ACQ) and Cu Azole, have been developed and commercialised in recent decades.

There are some known drawbacks of water based preservatives, including dimensional changes when treating dry final shape and form timber, raised grain and the need for post-treatment kiln drying. These concerns lead to the development of light organic solvent preservatives (LOSP). The advantage of a LOSP treatment is that it can treat finished products in their final machined shape and form, as LOSP does not swell or distort the timber products and there is no secondary drying required. In New Zealand, LOSP treatment of radiata has been an important component of the wood processing industry, particularly in the production of mouldings, fascia, weatherboards, plywood and other engineered wood products components. From about 2002, LOSP treatments were the dominant treatment for timber framing. However, the main disadvantage of using a LOSP based preservative is the evaporation of the hydrocarbon solvent into the atmosphere. Secondly, LOSP treated timber can give off traces of VOC for months or years, which can cause adverse health effects and illness in sensitive people.

In 2011, there was a simplification of the New Zealand Building Code treatment requirements for framing to a single hazard class (H1.2) with no LOSP treatments specifically listed. Timber framing has now largely converted to boron based preservatives (> 95%) and LOSP now has a small market share (< 5%).

Currently, two types of preservatives, CCA for the treatment of radiata used in ground contact or exposed situations, and boron for building timbers protected from weather, retain a central position in the NZ market.

4.1 History of Timber Use in Canterbury Buildings

In early 1900s, there was little indigenous forest in Canterbury. Much of the timber used was brought into the area from the West Coast, Marlborough, Nelson and Southland.

By the 1950s, most buildings were constructed using West Coast rimu and other indigenous species. There were a few sawmills in Canterbury, cutting mainly radiata and other exotic species such as Douglas-fir and Larch, which were planted by early settlers, but these supplied a relatively small proportion of the timber used locally for building. Preservative treatment of native timber was rare, except for flooring and weatherboards. By the mid-1950s, small quantities of Rimu, Matai and Kahikatea sapwood were treated occasionally with boron for flooring. From the late 1950s, CCA was used for weatherboards and exterior trim.

Boron treated radiata was available by 1960 in the Canterbury market. Housing Corporation standards required the treatment of radiata, Matai and Kahikatea sapwood timber if it was, to be used for house framing. There was no similar requirement for Rimu and Totara hence they were used untreated. Furthermore, framing grades of Rimu and Totara were generally cheaper than treated framing. Hence, although boron treated radiata framing was available, it was less commonly used than Rimu in Christchurch during the 1960s and 1970s. Use of CCA treated radiata for sub-flooring, domestic fencing and roundwood (for poles and piles) became common during the late 1960s, as more pressure treatment plants opened in the Canterbury region and elsewhere.

The bulk of native timber produced on the West Coast continued to be sold in Canterbury through the 1970’s and the 1980’s. However, over that period, the availability of native timber declined throughout the country, and its cost, relative to that of pine, continued to increase. In response to that, several mills on the West Coast began sawing radiata from the forest planted there. In 1985/86, the area of native State Forest available for milling was reduced dramatically and more of the local mills were forced to cut radiata. Some logging from the native forests continued through the 1990’s, but was eventually shut down by the 2002 Labour government.

The only other item of note concerning the use of timber treatment in Canterbury homes was the approval and use of arsenic containing treatments for internal timber uses in hazard class H1. This means there is a possibility for houses from the mid-1970s onwards to have low levels of arsenic (about 0.4 kg/tonne, compared to >1.1 kg/tonne for H3 CCA treatments and above) in the internal areas, that might not necessarily be expected.

4.2 Timber Treatment Summary

Overall, CCA-treated radiata is unlikely to be found in the original structure of New Zealand houses built before 1960. From about 1955 onwards, CCA treated radiata began to be used, primarily in exterior situations such as fences and poles. CCA treated radiata was not used extensively in 1960s or 1970s houses, but may be found in exterior uses such as decks, fencing and poles of any era of house. Later in the 1970s and 1980s, H1 arsenic based treatments became available. This means radiata framing containing arsenic may be present in the building interior spaces too. The timeline for these changes in timber usage and treatments are summarised in Table 2.

Years of Construction	Types of Timber Used in Construction	Typical Timber Treatments
1920s - 1930s	Rimu, miro, matai, totara, tawa, kahikatea, beech	Untreated, creosote
1940s - 1960s	Radiata, douglas fir, larch, rimu	Creosote, boron, CCA
1970s – 1980s	Radiata, douglas fir, rimu	CCA, boron, LOSP, arsenic
1990s on	Radiata, douglas fir	CCA, boron, LOSP

Table 2: Summary of timber types and treatments used in Canterbury

5. CHRISTCHURCH HOUSE INFORMATION FROM BRANZ HOUSE CONDITION SURVEYS

The BRANZ *House Condition Survey* (HCS) is the only systematic survey of the structure, type and condition of dwellings in New Zealand. BRANZ carried out *House Condition Surveys* in 1994, 1999, 2005 and recently completed the 2010 survey. The surveys provide an overall picture of the condition of housing in New Zealand. Analysis of the survey data provides information that contributes to the understanding of social and economic change in relation to the national housing stock. This is through identifying and examining the correlations between housing condition, housing quality, sustainability of housing, dampness, insulation, heating and other components that impact on the energy use, comfort and health of the occupants.

In the first three surveys, owner-occupied houses in the Auckland, Wellington and Christchurch regions were inspected, and their owners interviewed on their family circumstances and maintenance practices. The fourth, 2010, HCS was the first nationwide survey, and also the first to include a representative selection of rental properties, which make up approximately 33% of New Zealand's total housing stock. However, difficulty in maintaining the statistical integrity of the sample after the Christchurch earthquakes led to the removal of Christchurch houses from the 2010 sample. Surveyors were working in Christchurch on 4th September, and moved onto other areas in the South Island. The second, more destructive earthquake on 22nd February, meant it would not be possible to collect data from the required number of houses.

In all the surveys, a sample of approximately 500 houses was examined. In each of the first three surveys, 70-150 of these properties were located in Christchurch.

The HCS inspectors identified and assessed materials, defects and overall condition of about 40 components and features. The extent of defects in components was also recorded. Critically, the survey recorded the materials used in the subfloor and roof spaces. As a result, data on materials used for foundations, piles, joist, bearers and rafters was documented for each property in each survey.

5.1 1994 HCS

As part of the 1994 HCS,123 houses in Canterbury were surveyed. Of these, 72 were in Christchurch and 19 were built after 1970.

The survey data indicates that, of the properties surveyed, the majority had concrete pile foundations. Only five used timber piles, and these were present in addition to, or as replacements for, original piles (two pre-1920s properties). Meanwhile, about 21% of properties surveyed were built upon a concrete slab.

While native joists and bearers were used in 50 of the surveyed properties, radiata joists and bearers were present in nine properties. These were properties built after 1970 (five) or where radiata was present in addition to the original building.

Within roof spaces, radiata was found in nine properties, all built after 1970. It was also observed in nine other properties, where it featured alongside native timbers in addition to or, potentially, as a replacement roof structure (in two properties from the 1920s).

5.2 1999 HCS

During the 1999 HCS, 112 properties in Christchurch were surveyed. Of these, 37 were built after 1970.

Of these, one pre-1910 built property had treated timber piles as replacements for original piles. All others had concrete pile (69%), or concrete slab (30%) foundations.

Only seven properties (6%) featured radiata bearers and joists. Two of these were from the 1960s and the others were of later construction. The remainder used native timbers.

Within roof spaces, radiata was found in 24 properties built after 1970. It was also observed in five other properties, where it featured alongside native timbers. Additionally, two properties from the 1960s and one from the 1950s were reported to have radiata roof structures.

5.3 2004 HCS

The 2005 HCS surveyed 150 properties in Christchurch. In total, 73 of these were built after 1970.

One newly built property had treated timber piles. All others had concrete piles (56%), or concrete slabs (44%).

While native joists and bearers were used in most of the surveyed properties, radiata joists / bearers were present in 11 properties. These were properties built after 1970 (6) or where radiata was present in addition to the original building.

Within roof spaces, radiata was found in 59 of the properties built after 1970. It was also observed in seven other properties, where it featured alongside native timbers. Additionally, six properties from the 1960s and one from the 1950s were reported to have radiata roof structures.

5.4 Conclusions from the Surveys

The HCS datasets clearly show that timber pile foundations are not commonly used in Christchurch. Piles are usually made of concrete. This confirms that H4 /H5 CCA treatments were not used extensively in Christchurch houses. That said, they are likely to be found in exterior uses such as decks, retaining walls, fencing and fence poles of any era of house.

Native subfloor joists and bearers are typically used in Christchurch properties constructed before 1970. A small number of 1960s properties may have CCA treated radiata in the subfloor areas, and earlier properties may use CCA treated radiata in later additions or alterations.

Boron treated radiata, or untreated radiata, may be present in roof spaces from the 1950s onwards in Christchurch houses or in earlier properties that have additions or have undergone alterations.

6. RESIDENTIAL RED ZONE PROPERTY DETAILS

The residential red zone lies along the banks of the Avon River and extends from Richmond through Avonside, Avondale and Burwood to Bexley. This is shown in the Canterbury Earthquake Recovery Authority (CERA) map, reproduced in Figure 43. In total, it is estimated that approximately 12,000 earthquake affected residential properties will be demolished [Scott, 2013].

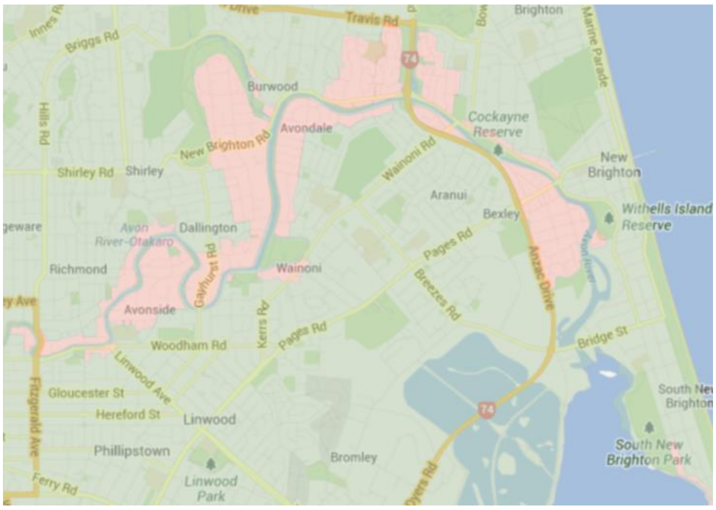


Figure 4: CERA map showing the residential red zone [http://cera.govt.nz/maps/land-status]

Field investigations and desktop analysis utilising the Land Information New Zealand data service, Google Maps, Google Street View and historic District Planning Scheme documents from Christchurch City library digital archives, have yielded an overview of the properties in the residential red zone. It is expected the residential red zone can be employed as an indicator for the mix of timber waste that will result from the demolition of all earthquake affected houses.

Generally, the ages of the residential red-zoned properties decrease with distance from the central city. The majority of these properties were constructed in the 1950s and 1960s, but later infill properties will inevitably be present in all areas of the red zone.

7. TIMBER TYPES IN CHRISTCHURCH RESIDENTIAL PROPERTY ARCHETYPES

BRANZ has previously examined appropriate property archetypes for New Zealand. These formed the basis for the Renovate series of publications and the associated website [www.renovate.org.nz].

The characteristics of Christchurch properties from different decades are detailed in the following sections. Meanwhile, the amount of timber likely to be removed from commercial buildings will largely depend on the design and materials specifications used [Scott, 2013]. That said, there is no reason to believe that the overall mix of timbers from commercial properties will differ substantially from residential properties of similar ages.

7.1 1920s – 1930s Bungalows

By the early 1920s, the bungalow was the predominant style of house being built in New Zealand. Typical bungalow features include a gabled roof sloping about 15 – 25°, bay or bow windows, one or more porches and timber weatherboard cladding. Bungalows are, by definition, single-storey buildings.

Native timbers were still plentiful into the 1930s, and the timber from the planting of radiata forests that had begun in the 1920s was not yet available in large quantities. Rimu was used for framing, joinery and weatherboards, and was the most commonly used timber for general construction.

A schematic giving guidance on the timber used in 1920s - 1930s bungalows is shown in Figure 54.

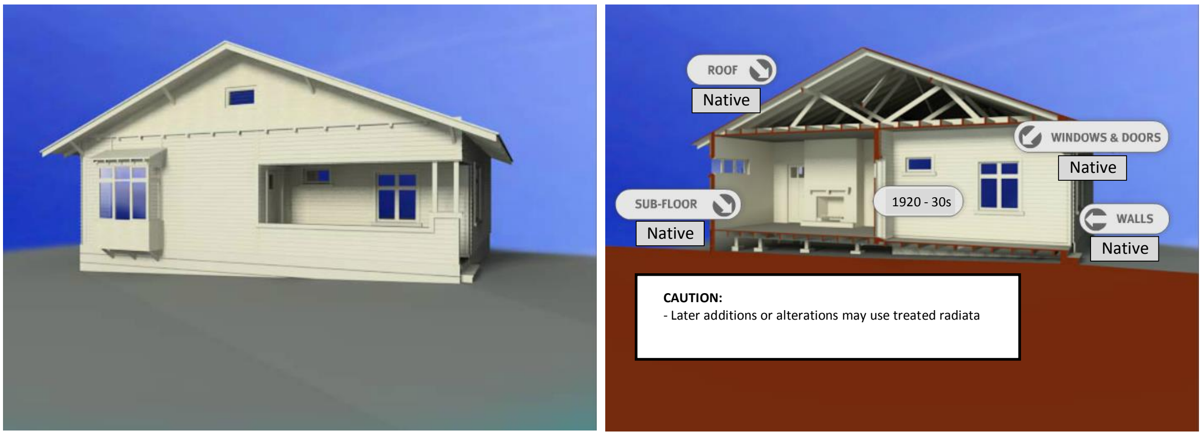


Figure 5: Schematic for 1920s -1930s bungalows

7.2 1940s through 1960s - Timber Weatherboards

Government financing rules meant that most private housing in the 1940s and 1950s was modest and closely resembled state housing. In the early 1960s, houses continued to resemble those of the 1950s in terms of external appearance, roof pitch, and window shape and size.

Boric timber treatment was introduced in 1952, to treat timber for internal use.

CCA treatment was introduced into New Zealand in 1955, to treat timbers for external use. It was initially only used for fencing and poles and is unlikely to be found within the original structure of 1950s houses. It is possible that CCA treated radiata may be present in subfloor spaces of 1960s houses and may also be present in any house as part of any alterations or additions.

Figure 65 shows a schematic giving guidance on the timber used in 1940s - 1960s properties.

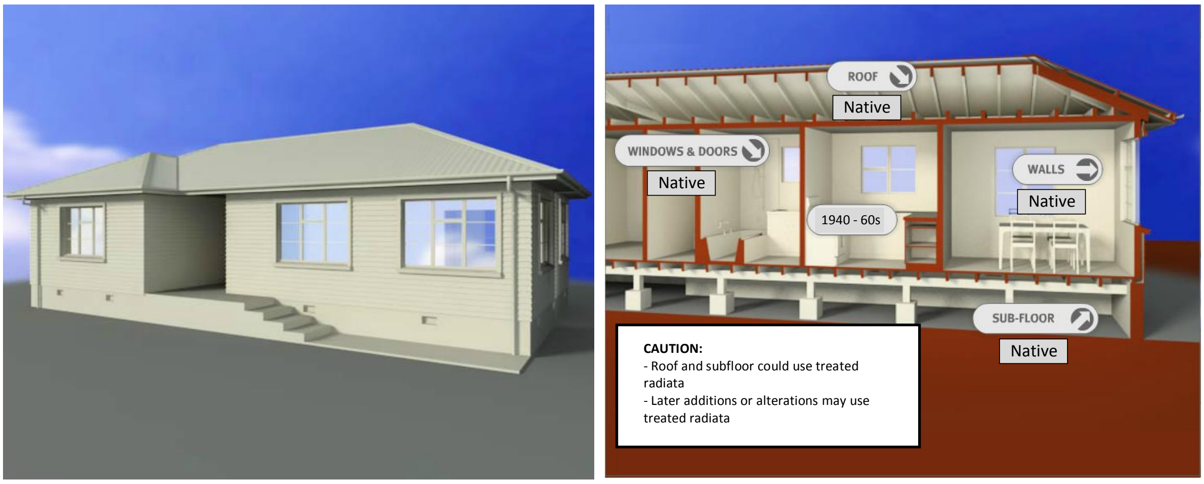


Figure 6: Schematic for 1940s -1960s properties

7.3 1960s Brick and Tile

Brick and tile houses that had minimal or no visible timber were built in large numbers with Government support from the late 1950s and into the early 1960s. There were a number of exceptions, particularly with architecturally designed houses. As the decade progressed, eaves tended to become wider than in earlier houses, and there was some more variation in plan shapes. Windows slowly got bigger and a family space was often included in the plan.

CCA treatment was not used extensively in 1960s houses, but may be found in exterior uses such as decks, fencing and poles. It is also possible that CCA treated radiata may be present in subfloor spaces and as part of any alterations or additions.

A schematic giving guidance on the timber used in 1960s brick and tile properties is shown in Figure 76.

Figure 7: Schematic for 1960s brick and tile properties

7.4 1970s and 1980s

The late 1960s saw a change in house style, with the publication of a number of plan books, such as New Zealand Home Builder by Leighton Carrad, that illustrated new styles, materials and layout that continued through the 1970s.

Over time, architect-designed styles had an increasing influence on the design and appearance of mass housing. By the late 1960s, timber once again achieved popularity in domestic construction – the desire for brick-and-tile construction had passed.

The 1970s was a period of expanding suburban development. Many were built by developers as speculative ('spec') houses, and many others were built from plan books offering styles such as 'colonial', 'ranch', 'Mediterranean' and 'contemporary'.

The spec houses were typically small and plain, rectangular or L-shaped in plan, and built from lower-cost materials. At the same time, houses in the more affluent areas were increasing in size.

The 1970s generic style of housing continued into the mid to late 1980s, when there was a distinct change with the adoption of monolithic claddings, style changes such as parapets and membrane roof decks, and the use of sealants.

Timber framed walk-on waterproof and timber slat decks at first floor level became a common feature with 1970s houses. Timber slatted decks were either cantilevered out from the wall below or supported off ledgers or stringers and posts/beams.

Use of CCA for building timbers started to expand in the late 1960s, but the treatment was not used extensively in 1970s houses. That said, CCA treated radiata may be found in exterior uses such as decks, piles, fencing and poles, or as part of any alterations or additions.

The 1970s saw the introduction of kiln dried H1 LOSP treatment, which was an insecticide treatment only. This led to a reduction in the use of wet boric treated timbers. In the 1970s and 1980s, arsenic based H1 treatments for radiata framing were also available in Canterbury.

A schematic giving guidance on the timber used in 1970s and 1980s properties is shown in Figure 87.

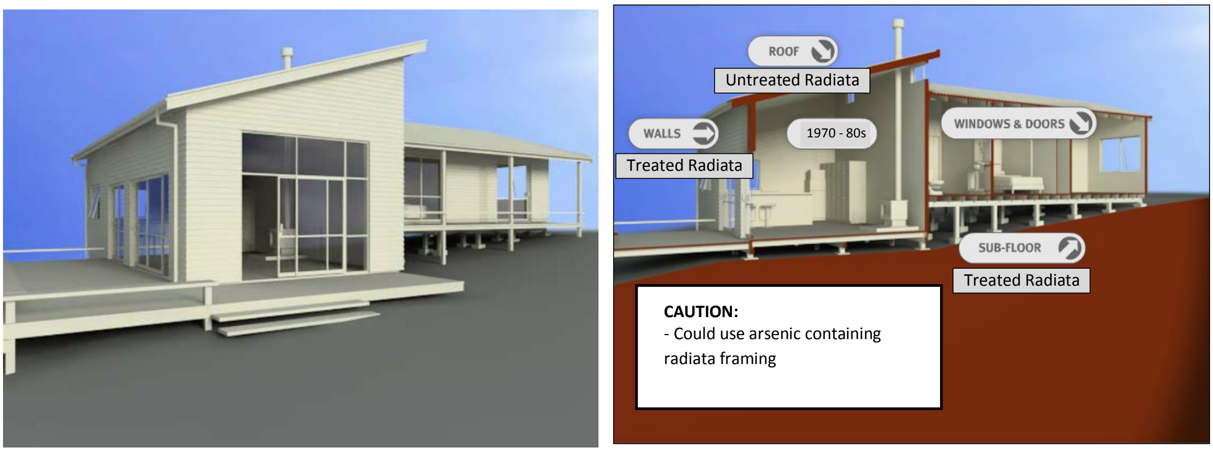


Figure 8: Schematic for 1970s and 1980s properties

7.5 1990s onward

The 1990s saw a distinct change with the adoption of monolithic claddings, style changes such as parapets and membrane roof decks, and the use of sealants.

In the new millennium, concrete slab foundations found increasing favour, as did concrete tile roofs and brick veneer cladding.

Roof framing in houses constructed during the last couple of decades will generally be untreated radiata. Boron treated radiata wall framing replaced the untreated radiata which was used during the 1990s. Suspended floor structures will use CCA treated and boron treated radiata. CCA treated radiata will also be present in decks, balconies, retaining walls and fencing.

Figure 98 shows a schematic giving guidance on the timber used in post 1990 properties.

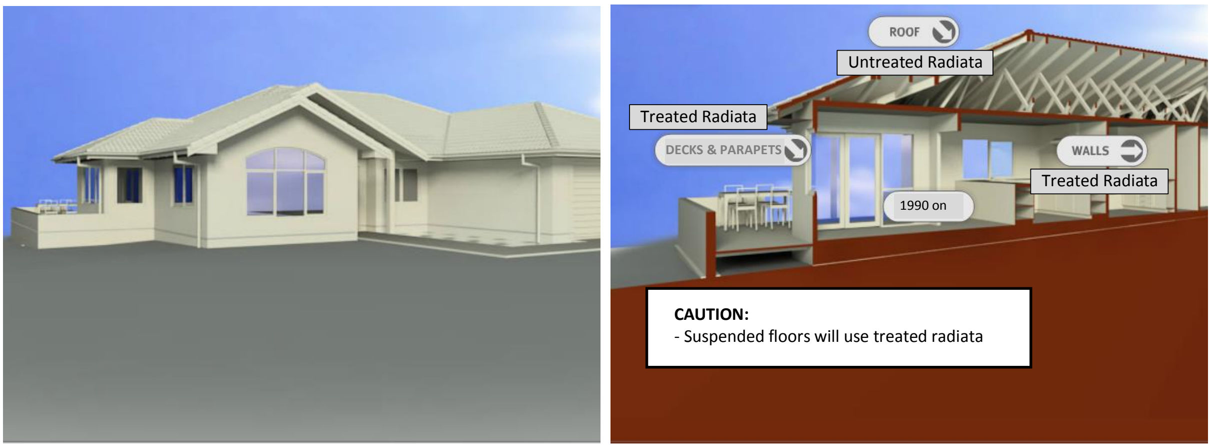


Figure 9: Schematic for post 1990s properties

8. CONCLUSIONS

8.1 Treated Timber from Earthquake Affected Houses

Generally, the ages of the residential red zoned houses decreases with distance from the central city. The majority of these properties were constructed in the 1950s and 1960s, but later infill properties will inevitably be present in all areas of the red zone.

Meanwhile, native timber produced on the West Coast continued to be sold in Canterbury through the 1970's and the 1980's. As a result, CCA-treated radiata is relatively unlikely to be found in Christchurch houses built before about 1980, but may be found in exterior uses such as decks, fencing and poles of any era of house. H1 arsenic treated radiata may be found in 1970s and 1980s houses and in additions to earlier houses . This means timber containing arsenic may be present in timber in the building interior spaces too.

Overall, using the residential red zone as an indicator, it is expected that untreated native timbers will dominate the timber waste resulting from the demolition of earthquake affected houses. However, CCA treated, and other arsenic containing radiata, will inevitably be present in any amalgamated stock pile if no effort is made to segregate the timber from any of the houses during the demolition process. More CCA treated timber will also be added to the stock pile once the removal of fencing and landscaping timbers increases.

8.2 Tool Definition

The approach that BRANZ recommends begins with an assessment of the likelihood of treated radiata being present in the building before any deconstruction or demolition commences. As detailed earlier in this report, the use of untreated native timbers continued in Canterbury well into the 1980s, and so a logical first step is to consider the age of the house. This can also be assisted by the knowledge of typical timber use within Christchurch properties developed within this research, and the schematics in Figure 54 through Figure 98 present this information in a simple and accessible way. That said, all houses should also be examined for the presence of later additions or alterations using radiata. If present, all radiata should be considered as treated until confirmed to be untreated, as described in the following paragraphs.

A judgment concerning the original intended use of timber is also very important for visual identification. Radiata components for load-bearing structures that were exposed to the atmosphere or ground are most likely treated. These might include piles, bearers, joists, framing, rafters, posts, decks and claddings.

The surface colour of timber should be examined to differentiate between native timbers and radiata treated with preservatives that contain copper from untreated radiata, or radiata treated with other preservatives. Fortunately, most CCA containing radiata will be used in subfloor spaces where it is sheltered from the elements, and the green colouration should be readily apparent. All internal radiata framing in 1970s and 1980s houses should be assumed, as a precaution, to contain arsenic.

A chemical indicator solution can also be used to test for the copper component within the CCA treatment. Chemical indicators are simple to use with reasonably clean timbers and, as such, should be viable to be applied during deconstruction / demolition. Details of the different indicators for copper and arsenic containing treatments are given in Table 3. Further details of each of these indicators is contained in Appendix A. Rubeanic acid is the preferred reagent for testing for the presence of copper (i.e. CCA) in radiata that has been in service for some time. This is because it is fast acting (as detailed in Table 3) and is also reliable in indicating the presence of copper in timber that has been in ground contact. The preparation, use and interpretation of colours obtained when using this indicator are described in Appendix A.3 and in Appendix D.

Test	Indicates Presence of	Time to Indicate
PAN	Copper	10 – 15 seconds
Chromazurol S	Copper	5 – 45 seconds
Rubeanic Acid	Copper	1 – 5 seconds
Arsine Gas Method	Arsenic	10 - 15 minutes
Ammonium Molybdate/ Potassium Antimonyl Tartrate	Arsenic	1 hour
Stannous Chloride	Arsenic	30 -45 minutes

Table 3: Summary of indicator tests for treated timber

Overall, it is expected that well trained staff will be able to identify and sort waste timbers from known sources (at the demolition site) using visual inspection together with chemical stains, with reasonably high efficiency and accuracy. However, this is considered unlikely to be feasible due to time and resource requirements. That said, a ‘coarse’ sort may be possible using the tool, i.e. segregation of subfloor and wall timbers in post 1990 houses. To further assist with this, a flow chart for use on the deconstruction site is included in Figure 1. In summary, manual sorting is labour-intensive and, in particular, will not work well for processing the large amounts of waste timbers already stock piled at various sites.

8.3 Instrumented Timber Treatment Identification Tools

Due to the increasing amount of waste timber produced from construction, demolition and renovation sites, and stricter regulations on the disposal of preservative treated timber waste in many countries, instrumented, cost-effective, fast and reliable identification and sorting of waste timber has been researched internationally. This has been aimed at minimising environmental risks and supporting timber materials reuse or recycling. Many techniques have been developed, based on either chemical or physical principles, to detect the presence of certain elements within the timber. These have been tested overseas to assess their viability in sorting / separating waste timber. These techniques each have their own strengths and weaknesses. A brief summary of these is given in Table 42.

Current results obtained from overseas lab tests and small-scale field trials indicate that NIR, XRF and LIBS have the capability of detecting inorganic and/or organic components in timber qualitatively or quantitatively. However, identification and/or sorting with satisfactory accuracy using these techniques has not been attempted during field tests examining large quantities of waste containing mixed timbers from complex sources. A significant effort is still required to improve the capability and reliability essential to commercialisation so they are unlikely to be feasible for Christchurch. Further, the capital investment for these techniques would still need to be evaluated to determine their economic feasibility for different sizes of timber waste recyclers.

Table 4. Summary of identification technology for timber waste

Technique	Capability	Sample Preparation	Automation	Drawbacks	Likely Capital Cost
Visual	Treated and untreated timber	None	No	Highly dependent on training, experience of staff and knowledge of timber waste source. Unsuitable for commingled timber waste.	~$30-115 per tonne
Colour Indicator	Copper or arsenic	Little or None	No	Qualitative with reasonably clean timber waste. Staff training and experience needed for accurate sorting. Arsenic indicators take 10+ minutes to give a result.	~$0.05-1.25 per sample
Biosensor	Organic and inorganic components	High	No	Qualitative. Ground material needed. Takes minutes to give a result.	Low
IMS	Accurate detection of low-level organic components	Little or None	No	Qualitative analysis only. Extensive staff training required for accurate result analysis.	Moderate-High
NIR	Organic and inorganic; good accuracy; preservative level determination possible	Little or None	Possible	Extensive calibration needed for quantitative analysis. Surface preparation needed. Difficult with high moisture content timber.	Moderate; Handheld Unit: ~$37,500
LIBS	Rapid and non-destructive detection of organic and inorganic components	Little or None	Possible	Quantitative analysis not very successful. Detection limits not as good as colour indicators. OHS issues with high energy laser.	High; Online System: > $125,000
XRF	Rapid, non-destructive detection of inorganic components	None	Possible	Quantitative analysis only possible with robust calibration. Regular maintenance of radioactive source required. OHS issues.	Moderate to High; Handheld Unit: $25,000- 45,000; Online System: > $200,000

9. FURTHER WORK

This research has identified a practical rationale to allow the effective segregation of treated timber from other timber on the deconstruction site. The component parts, comprising the decision making process (Figure 1) and appropriate property archetypes for Christchurch, have been developed into a prototype tool which is included in Appendix D.

Some issues remain unresolved within this definition of a prototype tool, for example the reliable assessment of painted timber components has not been completely or explicitly addressed.

It is believed that tool optimisation can be further explored and resolved during field testing of the proposed approach with a representative user group, during Milestone 5 of this research programme. This testing would also serve to more fully confirm the timber types used in Christchurch construction and to double check the property archetypes. Ultimately, it is envisaged that the tool can be developed into a small laminated booklet containing information on each house type and wood type for quick comparisons on site.

Overseas lab tests and small-scale field trials indicate that NIR, XRF and LIBS have the capability of detecting inorganic and/or organic components in timber, qualitatively or quantitatively. International work also indicates that the use of these instruments has the potential to offer automated timber sorting at high through-puts. Budget price for online systems have also been estimated. These technologies could be further investigated in the next phases of the programme, if appropriate.

APPENDIX A CHEMICAL INDICATOR TESTS FOR TIMBER TREATMENTS

A.1 PAN Indicator

PAN (1-(2-pyridylazo)-2-naphthol) is an orange-red solid with a molecular formula $C_{15}H_{11}N_3O$ and was originally used to determine the presence of almost all metals, except alkali metals. The reaction between its active chelating agents and copper in timber treated with copper-bearing preservatives produces a magenta to red colour, normally within 10 - 15 seconds (Figure 109). Untreated timber turns orange. Since this indicator reacts with the copper, timber treated with any copper-based preservative will test positive using this stain [Blassino et al., 2002].

The American Wood Preservation Association (AWPA) developed the PAN indicator. It is produced by dissolving PAN into methanol at 0.05% by weight, to create a reagent that can be sprayed over the timber surface [AWPA A3-91]. The formulation given in a guide issued by the Waste and Resources Action Programme, (WRAP) UK, contains the chemicals listed in Table 53 [Sawyer and Irle 2005a].

Table 5. Formula of optimised PAN indicator

Component	***Quantity***
PAN	0.1 g
Methanol	40 mL
n-propanol	40 mL
Mono-ethylene glycol	10 mL
Distilled or deionised water	10 mL

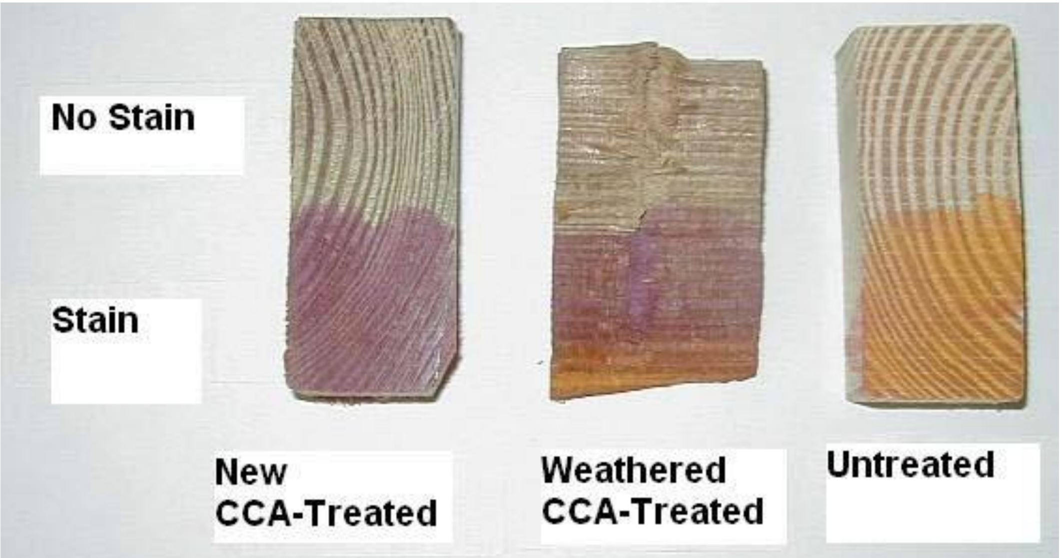


Figure 10. PAN stain performance on untreated and CCA treated timbers [Solo-Gabriele et al., 2006]

Figure 11. Interferences from nails and paint [Solo-Gabriele and Townsend, 2005]

The PAN indicator solution can be purchased as a pre-mixed solution that is convenient for field application. If large quantities of the stain are needed, the economical option would be to purchase the basic chemical ingredients and mix these ingredients in the laboratory.

The typical procedure for use of PAN colour indicator is described as follows [Solo-Gabriele et al., 2006]:

- Using a dropper bottle, apply the stain to a clean, dry area of the timber surface.
- Wait for colour development (about 15 seconds). Colour development is fastest if applied to the transverse direction of the timber instead of the radial direction.
- If the sample turns a magenta colour, then the timber is positive for copper. If an orange colour is observed, the timber is copper-free.

PAN indicator will not work properly on coloured mulches or mulches that are heavily soiled. It will sometimes react positively with paint and nails on timber, even though the timber may be untreated (Figure 1110). Thus, the PAN indicator could be useful for separating untreated waste timber from reasonably clean, uniform CCA treated timber in-situ. It is probably not a good method for sorting mixed, dirty or wet timber waste.

A.2 Chromazurol S Indicator

The active ingredients in chromazurol S (CS, $C_{23}H_{16}Cl_2O_9S$) can react with copper, aluminium, beryllium and uranium. Its reaction with copper produces a blue colour and, therefore, can be used to detect copper based preservatives [Solo-Gabriele et al., 1999; Irle et al., 2004]. The formula published by the AWPA contains 1 g/L CS and 10 g/L sodium acetate in distilled water. Sodium acetate acts as a pH buffer [AWPA A3-

91]. The original formulation of the CS indicator needed about one minute to soak into timber to cause a colour change. Research has been conducted to modify the formulation to achieve an instantaneous blue colour appearance (Figure 1211) [Sawyer and Irle 2005b]. The optimal formulation for the CS indicator, in terms of reaction time and splash resistance, consists of the components detailed in Table 4 [Sawyer and Irle 2005b & c].

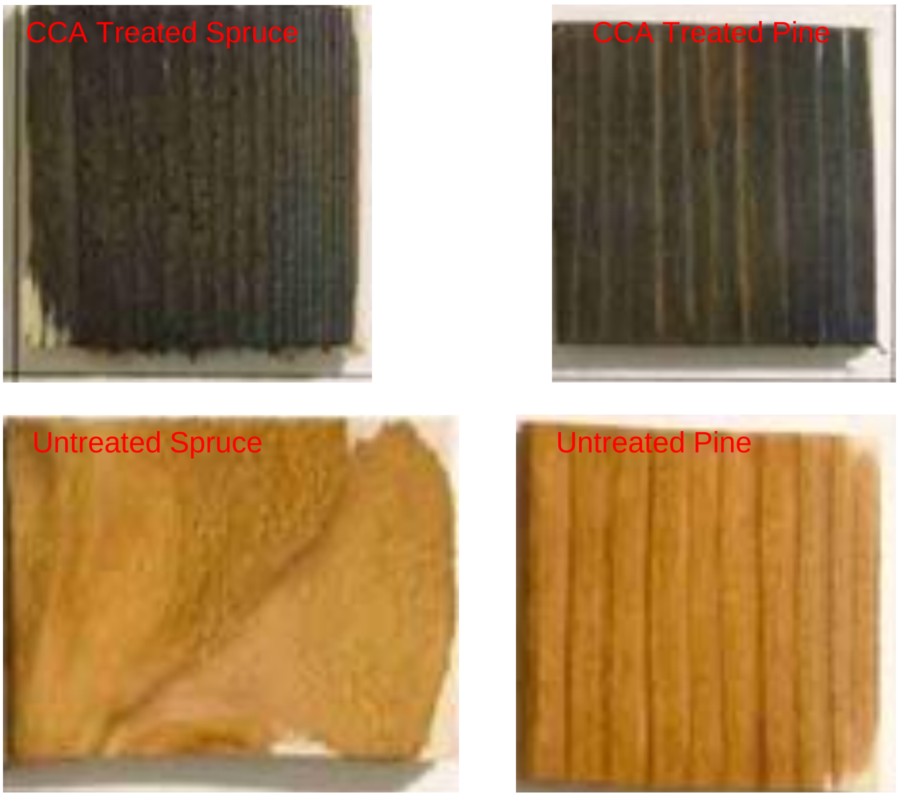


Figure 12. CS stain performance on different timbers [Sawyer and Irle 2005b]

Table 6. Formulation of chromazurol S colour indicator

Component	***Quantity***
Chromazurol S	0.5 g
Distilled or deionised water	26 mL
Sodium acetate	10.0 g
Ethanol	40 mL
Mono-ethylene glycol	33 mL

The indicator can be made as follows:

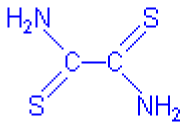
- add the CS to the water,
- warm gently and stir until fully dissolved,
- slowly add the sodium acetate and stir until dissolved,
- add the ethanol and mono-ethylene glycol, stir, and allow to cool,
- store in a sealed container in a cool, dark place.

Field testing by Sawyer and Irle showed that the improved formulations of CS and PAN can give results in 5-45 seconds. It appeared that CS was more reliable. Therefore, they suggested that the PAN indicator could be used first, because it is fast, and then the CS could be used to cross check on any positive PAN results.

A.3 Rubeanic Acid Indicator

Rubeanic acid has a molecular formula of $C_2H_4N_2S_2$. It is widely used to test the penetration of copper in CCA treated timbers [FAO 1986]. Rubeanic acid is also known as ethanedithioamide, dithiooxamide or dithiooxalic diamide, and the chemical structure is shown below. It is theorised that it works because the copper is chelated between the sulphur and nitrogen (see Kiernan).

$H_2NCSCSNH_2$



It reacts with copper to produce an olive green colour (Figure 1312) and can also be used to identify timbers treated with copper-bearing preservatives [Anon; Solo-Gabriele et al., 1999].

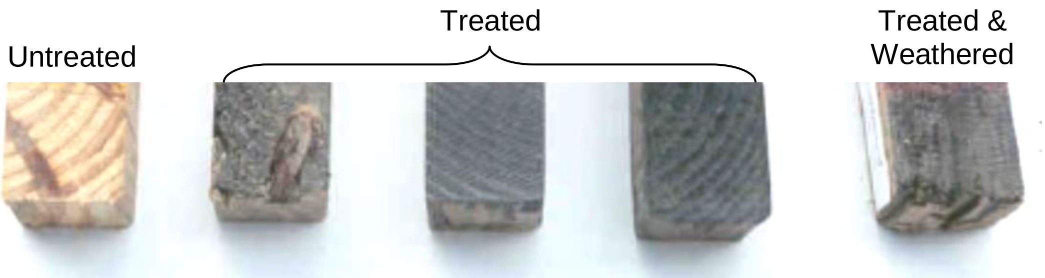


Figure 13. Rubeanic acid indicator performance on different timbers [Solo-Gabriele and Townsend, 2005]

To carry out the test, two solutions need to be sprayed onto the timber surface separately. The first is the rubeanic acid solution, which is made by dissolving 0.5 g of rubeanic acid in 100 mL of ethanol. The second is the sodium acetate solution, which is made by dissolving 5.0 g of sodium acetate in 100 mL distilled water, and this acts as a buffer.

In practice, the application of two separate solutions is a significant disadvantage. Furthermore, some researchers worry that the green colour could be mistaken for other materials [Blassion et al]. However, rubeanic acid is very sensitive to copper and has approximately the same sensitivity as Chromazurol S at ca. 25 ppm copper. Chromazurol S is the preferred reagent for freshly treated wood because of its stronger reaction. Rubeanic acid is, however, more specific to copper and is less subjected to interference reactions.

As a result rubeanic acid is the preferred reagent for testing for the presence of CCA in wood that has been in service for some time. It is also reliable in indicating the presence of copper in timber that has been in ground contact.

A.4 Chemical stain for identifying timber treated with arsenic containing preservatives

There are several preservative formulations that contain arsenic, i.e., chromated copper arsenate (CCA) and sodium arsenate. In recent years, preservatives without arsenic have received more attention due to increasing environmental concerns. These typically include waterborne, copper containing chemicals, such as ammoniacal copper quaternary (ACQ) and copper azoles (CuAz).

A.5 Conventional arsenic test kit

Methods used to detect arsenic in drinking water have been modified for the detection of arsenic in treated timber. In this test, timber sawdust was collected and then immersed into water to which a series of chemicals (mainly zinc and hydrochloric acid) were added. Arsenic in the treated timber was then chemically converted into arsine gas, which then reacts with a test strip to produce a distinctive colour change. A commercially available arsenic-containing timber test kit is shown in Figure 1413.

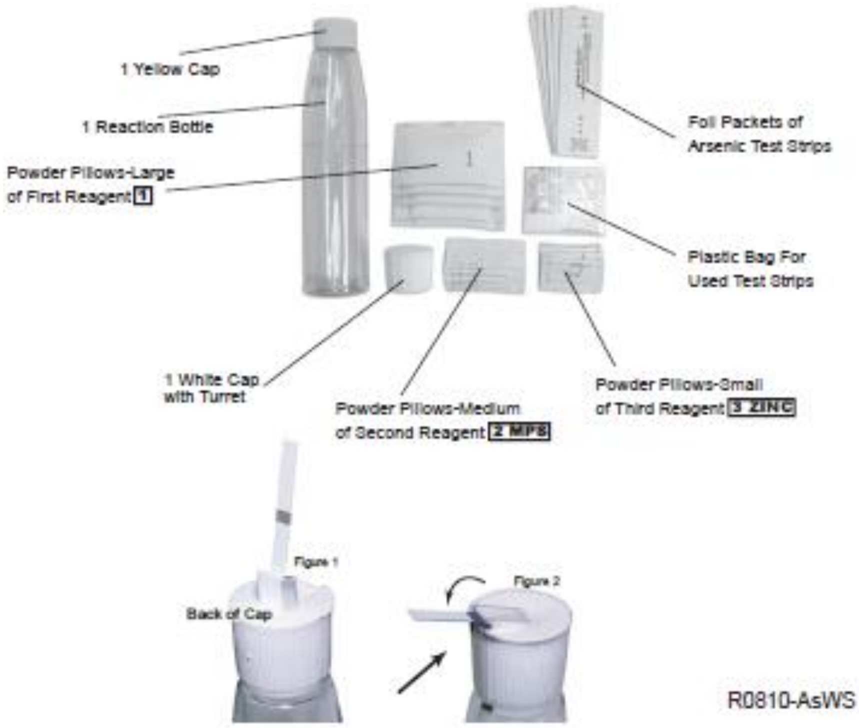


Figure 14. A commercially available test kit used for identifying timber treated with arsenic containing preservatives [Industrial Test Systems, Inc]

The operating procedure for this test kit is as follows:

- add wood chips to the reaction bottle,
- add 50 mL of tap water to the reaction bottle,
- add 1 Powder Pillow of First Reagent to the reaction bottle,
- add 1 Powder Pillow of second Reagent to the reaction bottle,
- cap bottle and shake vigorously for 15 seconds,
- let the solution sit for 2 minutes,
- add 2 Powder Pillows of Third Reagent to the reaction bottle,
- cap securely and shake vigorously for 5 seconds,
- remove yellow mixing cap and recap bottle securely using the white cap with turret up,
- insert test strip into the turret and position the strip so that the test pad and red line are facing the back of the white cap,

- insert the strip into the turret until the red line is even with the top of the turret, and close the turret,
- allow the reaction to occur in an undisturbed, well ventilated area for 5 minutes,
- pull up the turret and carefully remove the test strip,
- observe the colour of the test strip and determine arsenic concentration:
    - White: absence of arsenic
    - Yellow: moderate amount of arsenic present
    - Brown: high amount of arsenic present.

This method requires sample processing and is time consuming. Furthermore, the method involves the formation of hazardous arsine gas, which makes its use a safety concern and it is not recommended for use by those who are inexperienced with handling of strong chemicals and/or toxic gases.

A.6 Modified arsenic test formula

The main arsenic ingredient or component in CCA treated timber is arsenate (AsO_4^{3-}) which is quite similar to phosphate (PO_4^{3-}) in structure and chemical behaviour. There are several colorimetric methods for detecting phosphate that rely on the formation of a colour complex involving molybdenum. These phosphate detection methods result in either molybdenum blue or molybdenum yellow, which, when reduced further, results in molybdenum blue. The most well-known phosphate colorimetric identification stains include stannous chloride, ascorbic acid, and vanadomolybdophosphoric acid. The stannous chloride and ascorbic acid methods result in the formation of molybdenum blue, which is directly related to the concentration of phosphate present.

Based on this mechanism, two types of solution have been developed by Solo-Gabriele et al. [Solo-Gabriele and Townsend 2005; Omae et al., 2006; Solo-Gabriele et al., 2011]. The first one is based upon the reaction of ammonium molybdate and potassium antimonyl tartrate with arsenate to form a heteropoly acid-phosphomolybdic acid, which is blue in colour. This formula contains the following reagents:

- Sulphuric acid: dilute 70 mL concentrate H_2SO_4 to 500 mL with distilled water
- Potassium antimonyl tartrate solution: Dissolve 1.3715 g $K(SbO)C_4O_6 \cdot 1/2\ H_2O$ in 400 mL distilled water in a 500 mL volumetric flask and dilute to volume; Store in a glass-stoppered bottle
- Ammonium molybdate solution: Dissolve 20 g $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$ in 500 mL distilled water; Store in a glass-stoppered bottle
- Ascorbic acid: Dissolve 1.76 g ascorbic acid in 100 mL distilled water
- Combined reagent: Mix the above reagents in the following proportions for 100 mL of the combined reagent: 50 mL 5N H_2SO_4, 5 mL potassium antimonyl tartrate solution, 15 mL ammonium molybdite solution, and 30 mL ascorbic acid solution.

Testing of treated timber using the above solution should follow the procedures described below:

- scrape away a small area of the timber surface using a sanding block to get a clean area,
- use a dropper bottle to apply the combined reagent onto the timber surface,
- wait 1 hour for colour to develop,

- observe the colour. If the sample turns an intense blue, then the timber is positive for arsenic (Figure 1514).

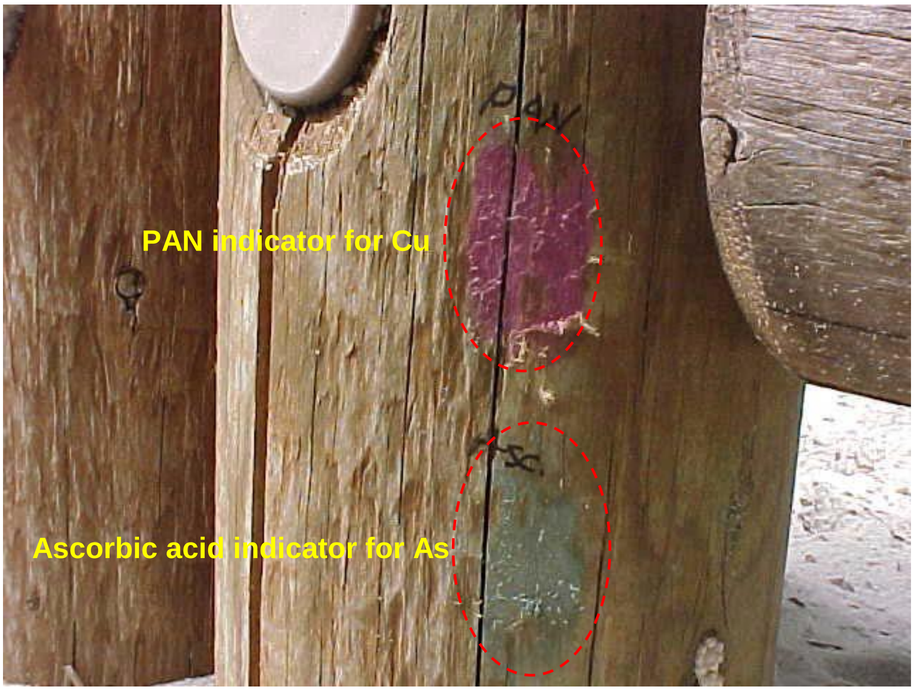


Figure 15. Performance of ascorbic acid based chemical stain indicator with CCA treated timber [Solo-Gabriele and Townsend, 2005]

The major disadvantages of the ascorbic acid colour indicator is that it requires 1 hour for colour development and, on occasions, untreated timber samples show a faint blue colour which may be confused with the more intense blue colour associated with CCA-treated wood.

Figure 16. Performance of PAN indicator and diluted stannous chloride stain on different timbers [Omae et al., 2006]

To solve this problem, a diluted stannous chloride stain has been developed. It comprises two reagents: ammonium molybdate reagent and stannous chloride reagent.

- Ammonium molybdate reagent: Dissolve 25 g $(NH_4)_6Mo_7O_{24}\cdot4H_2O$ in 175 mL distilled water. Add 280 mL concentrated H_2SO_4 to 400 mL distilled water. Cool, add molybdate solution, and dilute to 1 L.

- Stannous chloride reagent: Dissolve 2.5 g fresh $SnCl_2 \cdot 2H_2O$ in 100 mL glycerol. Heat in a water bath and stir with a glass rod to hasten dissolution.

These reagents are combined to form the stannous chloride stain, using eight parts ammonium molybdate reagent and one part stannous chloride reagent, immediately prior to testing. The stain radiates a noticeable blue colour in 30 to 45 minutes and an intense blue forms in approximately 5 hours (Figure 1615). However, the intensity of blue colour depends on the concentration of arsenate (Omae et al.2006).

Wiping kits are another type of arsenic test kit (Maas et al. 2004), but they do not provide results on-site and are time-consuming because the wipe sample must be sent to a lab where the wipe is processed and the resultant extract from the wipe is then analysed by an AA (Atomic Absorbance) spectrometer.

In general, techniques based on colour changes could be useful and effective for sorting clean and uniform timber waste from known sites or separating untreated from CCA treated timbers on a small scale. Sorting on large scales would be time consuming and economically impractical.

APPENDIX B INSTRUMENTED TESTS FOR TIMBER TREATMENTS

B.1 Liquid Phase Biosensor

Liquid phase biosensors use bioluminescent bacteria to detect the presence of preservatives in waste timber. This technique has been used for the detection of heavy metals, such as mercury, lead and cadmium [Vasilenko 2012]. The preservation chemical is extracted from the timber by grinding and added to a kit containing the bioluminescent bacteria. The light output, or luminescence, is linked to metabolic activity and is measured using a luminometer and, then, compared to appropriate controls. This technique detects the level of toxicity of the compounds; the more toxic the test compound, the less flow from the bacteria. Analysis can be performed quickly and is able to detect at a dilution level of 0.01% of the extracted preservative. This technique is, however, not able to differentiate between the individual types of preservatives.

Equipment is available as a hand-held device that is simple to use and minimal training is required to operate. This technology is a batch process with ground material that takes minutes to give a result. It is useable for quality control purposes with homogenous samples with known treatments. It is not feasible as a method for online or large-scale identification of waste timber.

B.2 Ion Mobility Spectrometry

Ion mobility spectrometry (IMS) involves ionising a gas phase anolyte by means of a small radioactive source. The ionised sample drifts through the cell under the influence of a uniform weak electric field and the ion drifting speed is used to determine the chemical composition of the sample [Röck et al., 2008]. This method can be very accurate, with a detection level down to ~0.001 mg/kg.

A battery-powered IMS device has been developed with a thermal desorption chamber for the analysis of small pieces of preservative treated timber samples. The results obtained with this instrument were compared to those of a mobile GC/MS system and a portable, multicapillary GC-ECD instrument, both equipped with direct thermal desorption injection devices. Compound identification with a short analysis time of less than 1 minute without sample treatment, low cost per analysis and good portability of the equipment are the advantages of IMS [Schröoder et al., 1998].

B.3 X-ray Fluorescence Spectrometry

X-ray fluorescence spectrometry (XRF) uses a high-energy X-ray beam to knock electrons out of the innermost orbital of atoms. An energetic electron from another orbital will move into this newly generated vacant space, to reach the lowest stable energy state. During this process, any extra energy will be emitted and this energy is a characteristic of the X-ray fluorescence of the elements inside the sample. The spectrometer measures this energy to determine the nature and concentration of atoms that are present within the sample.

X-ray fluorescence technology can rapidly identify a wide range of elements (from sodium to uranium) and has been used for multiple field applications, such as analysis of metals in soil and sediment (particularly contaminated land), metals in aerosols collected on a filter, lead dust, archaeological artefacts, and the classification of hazardous wastes [Sterling et al., 2000; Kalnicky and Singhvi 2001; Caruso and Love; Hou et al., 2004; Kuznetsova et al., 2004; Vanhoof et al., 2004; Rossini and Bernardes 2005; Humar 2010]. XRF has also been used traditionally by wood treatment plants as a rapid, non-destructive method for the determination of the retention of preservatives within pressure-treated timber [AWPA Method A9-01 2005].

Handheld XRF analysers have been used in the field to identify CCA treated timber waste and to quantify arsenic concentration [Block et al., 2007]. However, XRF results were 1.5 - 2.3 times higher than measurements from traditional laboratory analysis. Its quantitative identification of treated timber containing arsenic depends heavily on analysis time and concentration of preservative in the timber. Therefore, it requires precise calibration using treated timber standards. In another study, the applicability of XRF as a method for rapidly assessing metals in waste wood chips derived from construction and demolition processes was examined [Watanabe et al., 2005]. Metal concentrations in waste wood chip samples determined by XRF, based on cellulose powder calibration standards, were close to those determined by atomic absorption spectrometry, inductively coupled plasma-atomic emission spectrometry, or inductively coupled plasma-mass spectrometry.

Recent research on XRF has focused on its potential as an online technique, to sort large quantities of CCA treated timber from untreated timber at full-scale recycling facilities, by using arsenic as the characteristic metal for analysis [Blassion et al., 2002; Solo-Gabriele et al., 2004; Fattah et al., 2009; Hasan et al., 2011a & b]. Automated XRF sorting equipment tested at the Florida Wood Recycling in Medley, Florida, consisted of an in-feed motorised belt-conveyor and an inclined conveyor. The XRF detection unit installed 0.4 m above the in-feed conveyor, at a 45-degree angle from the horizonta,l consisted of an X-ray tube operated at 44 kV and 1 mA. The detector was connected to a digital pulse processing unit that was linked to a control panel. A schematic of this XRF online sorting system is shown in Figure 1716.

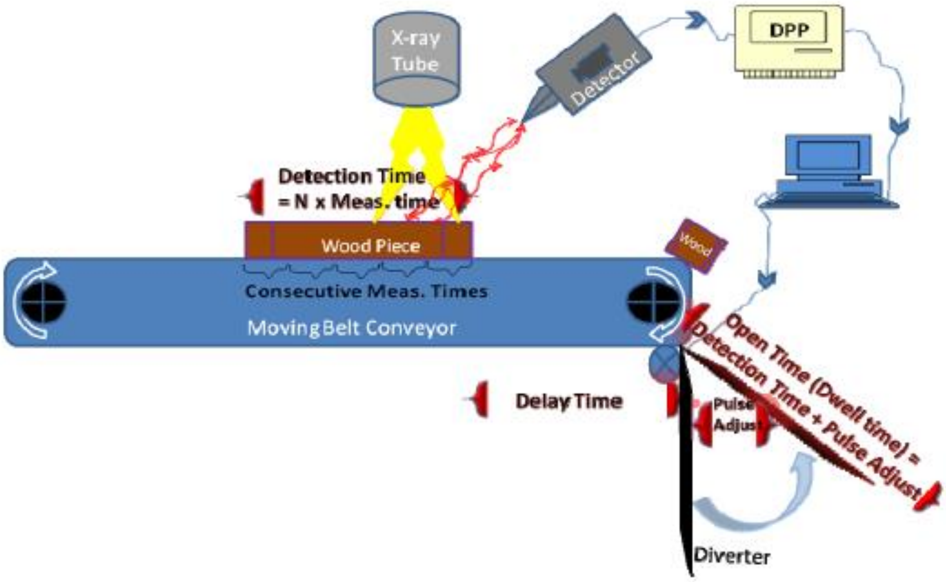


Figure 17. Schematic diagram for treated timber detection by online XRF system [Hasan et al., 2009]

Results showed that online sorting using XRF could be achieved when the motorised belt conveyor speeds ranged from 15 to 30 metre per minute. Typical analysis time was less than 2 seconds per sample. Sorting efficiencies of a 50:50 in-feed (50% untreated timber and 50% treated timber) were found to be between 92% and 99% for removal of As, between 90% and 97% for removal of Cr, and between 75% and 92% for removal of Cu. Efficiencies for a 95:05 in-feed (95% untreated timber and 5% treated timber; most likely representing the in-feed at recycling facilities that practice visual sorting of construction and demolition timber waste) were reported to be 81% to 96% As, 80% to 96% for Cr, and 72% to 91% for Cu [Solo-Gabriele et al., 2009]. Similar efficiencies were reported by these researchers in their recent tests [Hasan et al., 2011a & b]. The researchers believed that XRF technology could potentially fulfil the need for cost-effective processing at large facilities (>30 tons per day) which require the removal of As-based preservatives from the waste timber stream.

The XRF technique has the potential to differentiate between CCA and other preservatives, such as ACQ and CuAz, treated timber waste. Overseas research also indicates that it can be used for the sorting of weathered, rotted or dirty timber waste. Moisture, coating/painting, or defects in timber would not, in general, interfere with the XRF analysis. Thus, with further development, it could offer a highly efficient, online technique for field sorting of treated timber waste.

B.4 Laser-Induced Breakdown Spectroscopy

Laser-induced breakdown spectroscopy (LIBS) uses a laser pulse as an effective excitation source. When a laser beam is focused onto the sample, a nearly totally ionised gas, i.e. plasma, will be formed through dielectric breakdown on the surface. This plasma envelops part of the sample surface. Immediately after plasma initiation, continuum radiation, primarily recombination and Bremsstrahlung emissions, will dominate. At longer timescales, ions and neutral species begin to relax back to their ground state, resulting in atomic emissions at discrete wavelengths that are unique to each element. Observation of the resulting plasma emission is the basis of LIBS as an analytical technique [Moskal and Hahn 2002].

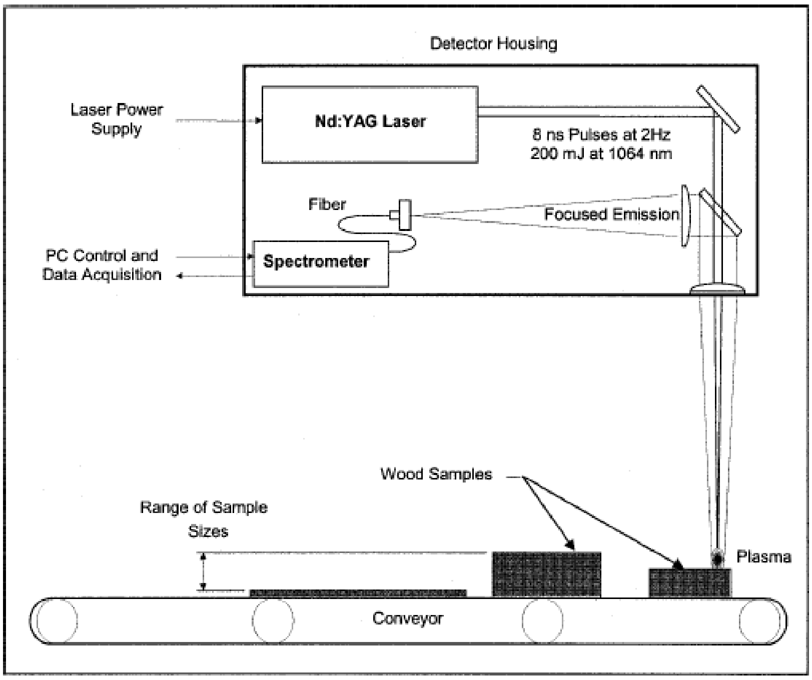


Figure 18. Schematic of LIBS system for online sorting of timber waste [Moskal and Hahn 2002]

A LIBS system for online sorting of waste timber is shown schematically in Figure 1817. The laser beam (Nd:YAG laser with an output pulse energy of 200 mJ per pulse and a pulse repetition rate of 2 pulses per second) was directed vertically downward using a set of mirrors and lenses. The long focal length enabled the timber samples to pass underneath the detector housing, while the gradual focus provided an energy density in excess of the breakdown threshold over a relatively broad sample range. The plasma emission was collected axially and collimated for analysis.

CCA treated timber samples were found to yield a marked increase in the peak-to-base ratio corresponding to the chromium emission spectral region, as compared to the untreated timber samples (Figure 1918). Analysis of chromium and calcium peaks from the signal could then be used to best determine CCA treated waste timber. LIBS quantitative analysis of inorganic preservatives in treated timbers (containing, e.g. Cu, Cr, B, As, Pb, or Hg) has been performed by using carbon as a reference element. It was shown that the commercial system developed for mobile laser-plasma-analysis as well as for industrial sorting plants could detect heavy metals in the ppm-range and organic contaminants by their specific functional groups in timbers [Uhl et al., 2001].

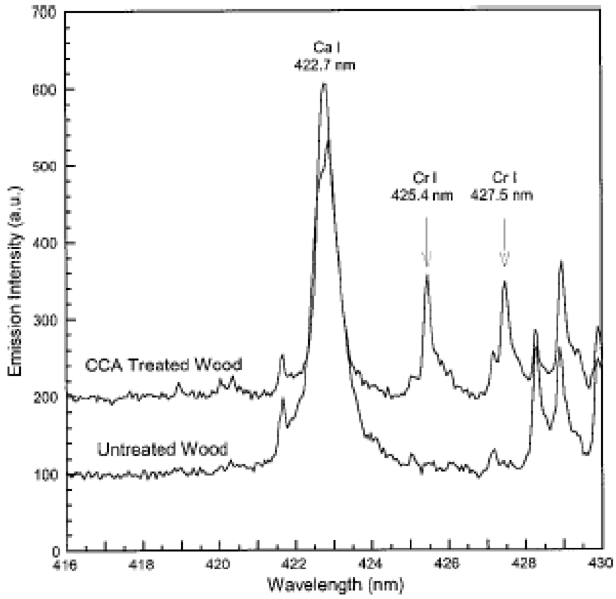


Figure 19. Single-shot emission spectra corresponding to a CCA treated timber sample and an untreated timber sample from a construction and demolition debris waste stream [Moskal and Hahn 2002]

Identification of CCA treated timber has been tested at a construction and demolition timber waste recycling facility [Solo-Gabriele et al., 2001; Moskal and Hahn 2002]. Separation?? between CCA treated and untreated timbers with accuracies of 92 and 100% has been demonstrated in an industrial setting.

Its capability for determining the level of residual CCA preservative in reclaimed timber waste has also been assessed [Gething et al., 2006; Gething et al., 2009]. The remaining amount of preservative in the three reclaimed deck boards (aged from 10, 18 and 25 years) were investigated and then compared with XRF. Results showed that current LIBS could not quantify residual CCA-preservative in reclaimed decking with acceptable certainty. The large variation in measurement results is mainly the result of heterogeneity in the wood matrix, preservative concentration profile, and of small excitation region / depth of laser. However, researchers still believe that the current LIBS technique exhibits the potential to be used as a method for identifying threshold values of residual preservative in reclaimed CCA-treated decking.

Other results also indicate that LIBS could be an effective technique for fast online sorting of construction and demolition timber waste [Yasuda et al., 2006]. However, the operation parameters must be fine-tuned to improve efficiency and accuracy for timber waste with either variable thicknesses, coated with stains and paints, rotted or wet.

B.5 Near Infrared Spectroscopy

Near infrared spectroscopy (NIR) is a spectroscopic method based on molecular overtones and combination vibrations of C-H, O-H and N-H. Transition from the ground state to the first excited state absorbs light strongly in NIR region (750-3000 nm) (Figure 2019). As a result, intense bands, i.e. fundamental bands, are produced. Transition from the ground state to the second excited state with the absorption of NIR gives rise to weak bands called 1st overtone. Transition from the ground state to the third excited state gives rise to 2nd overtone. Similarly, 3rd and 4th overtone bands will occur as a result of the transition to the 4th and 5th excited states due to absorption of NIR. Atoms or molecules absorb characteristically within a definite range to change states. The shift in position of absorption for a particular group may change due to any changes in the molecular structure. Measuring the frequency of light absorbed or emitted can then be quite useful to predict the presence of functional groups and to identify the compounds [Aenugu et al., 2011].

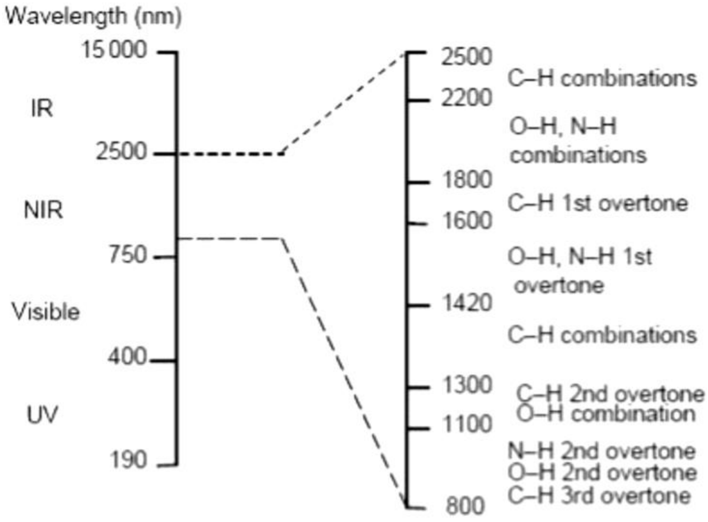


Figure 20. Absorption of characteristic groups in near infrared region [Aenugu et al., 2011]

NIR has been used for the non-destructive measurement of organic materials such as agricultural products or foods. It has also been successfully applied in the timber, pulp and paper industries to monitor moisture content, mechanical performance, basic weight or to non-destructively evaluate timber quality [Tsuchikawa 2007; Haartveit and Flæte 2008; Watanabe et al., 2010; Fujimoto et al., 2010].

The use of NIR to detect the presence of inorganic preservatives in timber has been briefly reported by Feldhoff et al [Feldhoff et al., 1998]. So et al developed a technique using near infrared spectroscopy (Nexus model 670 FTIR spectrometer; ASD FieldSpec Pro FR spectrometer) together with multivariate analysis (MVA) to detect and distinguish between a variety of treated timber with or without organic or inorganic preservatives [So et al., 2003, 2004, 2007]. In this technique, principal component analysis (PCA) was used to differentiate between various preservative treatments applied to timber specimens. As shown in Figure 2120, clusters are clearly evident to differentiate the CCA, ACQ and ACZA preservative treatments. Partial least squares (PLS) regression was undertaken to predict preservative retention levels. It appears that a relatively strong relationship exists between the experimentally determined concentration (CuO, CrO_3 and As_2O_5) and that predicted by NIR (Figure 2221).

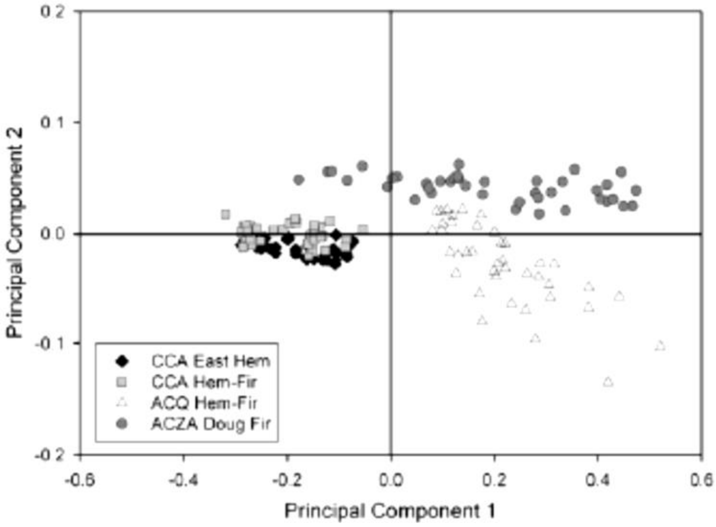


Figure 21. PCA scores plot from NIR spectra collected from different timber samples [So et al., 2007]

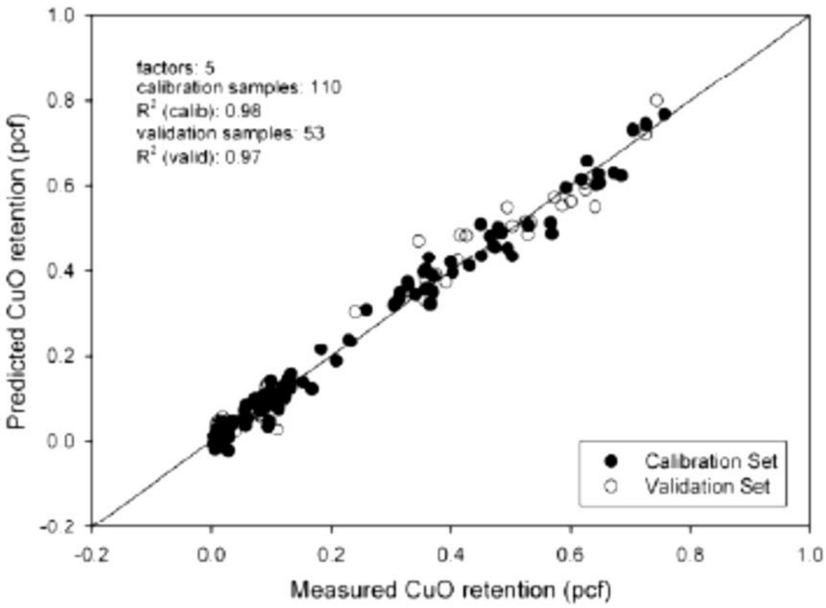


Figure 22. Relationship between measured and NIR predicted concentrations of CuO in CCA treated timber [So et al., 2007]

Taylor and Lioyd also used NIR combined with MVA to detect the presence of boron based preservative (0.01-15.0% disodium octaborate tetrahydrate) in treated timbers. Their results suggested that NIR has the potential to quantify borate concentrations, though a more robust predictive model is needed to determine the influences of wood species, preservative formulation and moisture content [Taylor and Lioyd 2007].

Although very limited lab or field trials have been performed with NIR for automated identification and sorting of treated waste timber, current results indicate that a NIR scanning system has the potential to be installed online at a waste timber sorting facility or used in the field with a hand-held spectrometer for rapid, non-destructive identification of timbers treated with both inorganic and organic preservatives. However, its economic feasibility still needs to be verified on different scales.

APPENDIX C COMPARATIVE TESTING OF TECHNOLOGIES

Three technologies, XRF, NIR, and LIBS, that appear promising for automated identification and sorting of treated timber waste, have been trialled by the WRAP (Waste & Resources Action Programme), UK [Pöyry Forest Industry Consulting Ltd 2009].

In this trial, 1.4 m^3 of timber samples (a mixture of timber treated with CCA, CuAz and creosote, MDF, particleboard and clean softwood) were collected from various sources. These were cut to similar sizes and exposed to the same climatic conditions for 10 days. Handheld XRF and NIR analysers that needed direct contact with timber samples were used for tests under dynamic conditions (the specifications for XRF and NIR analysers and the LIBS system are shown in Tables 4-6). In these experiments, 20-30 timber samples were placed on a conveyor belt and analysed one after another.

C.1 XRF

A Thermo Scientific Niton XL3t handheld X-ray fluorescence analyser was used in this comparative trial. The specifications and an image of this instrument are shown in Table 75 and Figure 2322, respectively.

Figure 23. Thermo Scientific Niton XL3t handheld x-ray fluorescence (XRF) analyser [http://www.niton.com/en/niton-analyzers-products/xl3/xl3t]

Table 7. Specifications of the XRF analyser

Brand	Thermo Scientific Niton XL3t XRF Handheld Analyser with GOLDD technology
Manufacture	Thermo Fisher Scientific Inc., USA
Dimensions	24 × 23 × 10 cm; 1.3 Kg
X-ray Source	Electronic X-ray Tube (Ag or Au target)
Analytical Range	>25 elements from Mg to U
Detector	Geometrically Optimised Large Drift Detector (GOLDD) Proprietary Silicon Drift Detector (SDD) with 180,000 throughput cps, <170 eV resolution
Measuring Period	1-30 seconds

All of the 21 CuAz treated timber samples placed on the conveyor belt tested positively and also failed the test, since their copper concentrations exceeded the European Panels Federation (EPF) limit of 40 ppm. Under realistic conditions all CuAz treated samples would, therefore, have been removed from the waste stream. The average measurement time was less than 3 seconds. Analysis with CCA treated timber showed that only 33% of the samples failed the test because concentrations exceeded the EPF limits. The majority of the samples were categorised as inconclusive.

This ambiguous sorting result was believed to be related to the large variation in the actual copper concentrations of the timber samples. Neither arsenic nor chromium was detected in significant concentrations. CCA concentrations in these samples might be too low to achieve reliable detection. The average measurement time with CCA treated timber samples was 6.2 seconds. A much longer measurement time, 15 - 30 seconds, was needed to analyse clean timber samples. The WRAP researchers believe this period was too long to allow any conclusions under dynamic conditions. Therefore, most of the clean wood samples tested on the conveyor belt gave an inconclusive result.

C.2 NIR

A Phazir handheld NIR material analyser was used in the WRAP comparative trial. The specification and an image of this instrument are shown in Table 86 and Figure 2423, respectively.

Figure 24. Phazir Handheld NIR Material Analyser [http://www.engineerdir.com/product/catalog/12415/]

Table 8. Specifications of the NIR analyser

Brand	***PhazIR NIR handheld analyser***
Manufacture	Polychromix, MA 01887, USA
Dimensions	25.4 × 29 × 15 cm
Light Source	Tungsten light bulb
Spectral Range	1600-2400 nm
Spectral Resolution	12 nm
Measuring Period	1-2 seconds

Identification was based on qualitative measurement since actual threshold levels could not be set with NIR analysis. An accuracy of around 90% was achieved with most timbers (Figure 2524).

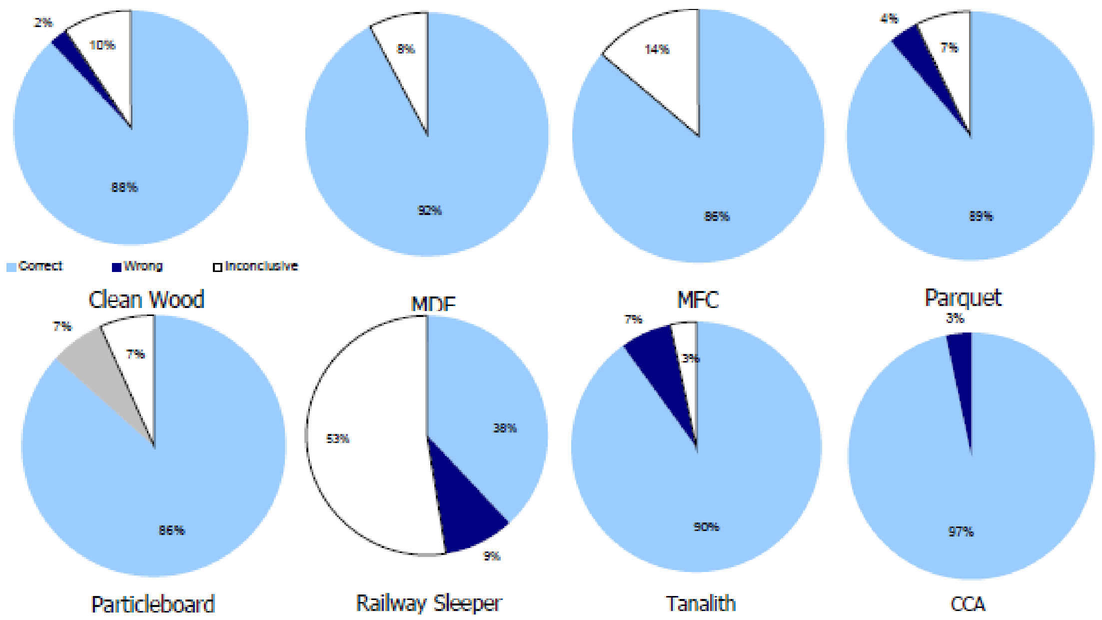


Figure 25. Sorting accuracy of NIR under dynamic conditions [Pöyry Forest Industry Consulting Ltd, 2009]

Although a satisfactory detection accuracy was achieved with NIR in this trial under relatively simple conditions, more robust identification using NIR still requires extensive calibration using large quantities of timber of different dimensions, colours, species, moisture contents and different preservative treatments, to accommodate large variations in waste timber.

C.3 LIBS

In the WRAP test, a high-intensity, 10 nanosecond-wide laser pulse beam was focused onto the timber sample placed inside a sample chamber. Various elemental emission lines were automatically labelled by comparing those emission lines with pre-defined intensity levels for element detection. The specification in Table 97 and the image in Figure 2625 give an indication of commercially available LIBS systems.

Figure 26. LIBS2000+ LIBS system [http://www.speciation.net/Database/Instruments/Ocean-Optics/LIBS-2000-;i2306]

Table 9. Specifications of the LIBS system

Brand	***LIBS2000+ spectrometer***
Manufacture	Ocean Optics, FL 34698, USA
Laser	200mJ Nd:YAG
Spectral Range	200-980 nm
Spectral Resolution	0.1 nm
Measuring Period	15.8 µsec

No testing under dynamic conditions was conducted with LIBS. Some differences between the materials were identified, with copper being the most obvious differentiator for the two preservatives, CuAz and CCA. However, it is not known whether the differences found in elemental analysis could be used to reliably differentiate timbers of different treatment. LIBS capability still needs to be explored using samples with large variations.

C.4 Comparative Testing Conclusions

Based on the results of the trial and the cost-benefit analysis, WRAP researchers concluded that an automated sorting system is not currently economically feasible, since capital investment would be very high for these potential techniques. Although sorting results from the WRAP study are summarised in Table 108, more research and development work is still needed to improve instrument capability to allow fast and reliable identification of timber wastes under varied conditions and from complex sources.

Table 10. Sorting capability of NIR, XRF and LIBS

Timber Sample	***NIR***	***XRF***	***LIBS***
Clean Wood	✓	(✓)	?
CCA Treated Timber	✓	✓	(✓)
Tanalith Treated Timber (CuAz)	✓	✓	(✓)
Sleeper (Creosote)	(✓)	?	?
Parquet	✓	×	?
Medium Density Fibreboard (MDF)	✓	×	?
Raw Particleboard	✓	×	?
Melamine Faced Chipboard (MFC Particleboard)	✓	?	?

Note:

✓: Material / Treatment can be sorted by system

(✓): Theoretically sortable, but ambiguous trial results

×: Material / Treatment cannot be sorted by system

?: Sorting capability unknown, but possible

It seems that the conclusion drawn by the WRAP researchers is somewhat different from that obtained by the researchers in the USA, particularly, Solo-Gabriele and Townsend, on the capability and efficiency of XRF and/or LIBS for automated identification and sorting. This might be due to these researchers using equipment with different detection capabilities (handheld equipment for WRAP compared to a large and heavy detector mounted on top of motorised conveyor for Solo-Gabriele et al).

However, this also indicates that online sorting systems for recovering timber waste are in an early development stage and that a limited number of purpose-built systems are being trialled in laboratories and/or at small scale industrial sites. Accurate and fast identification as a full scale industrial operation using XRF, NIR or LIBS is still some way off.

APPENDIX D PILOT TIMBER IDENTIFICATION TOOL

This tool helps the separation of treated and untreated timber during the deconstruction of residential properties in Christchurch. This tool enables an assessment of the likelihood of treated Pinus radiata being present in the building before any deconstruction or demolition commences. All houses should also be examined for the presence of later additions or alterations using radiata. This guide will enable separation of treated from untreated timber, even at a relatively coarse level.

Surface colour and appearance of timber is a simple way to differentiate between native timbers and radiata. Radiata treated with preservatives that contain copper can also be separated from untreated radiata, or radiata treated with other preservatives, if treatment class colour coding is still present.

As a precaution, all radiata should be considered as treated until confirmed to be untreated using the decision making process given in the flow diagrams.

An assessment of the original use of timber is also very important for visual identification of treated timber. Radiata components for load-bearing structures that were exposed to the atmosphere or ground are most likely treated.

A chemical indicator solution can also be used to test for the copper component within the Copper Chrome Arsenate (CCA) treatment. Chemical indicators are simple to use with reasonably clean timbers. Rubeanic acid is the preferred reagent for testing for the presence of copper (i.e. CCA) in radiata. The preparation, use and interpretation of colours obtained when using this indicator are described on the last page.

Ket Points

- All houses should be examined for the presence of later additions or alterations using Pinus radiata
- Surface colour of timber should be examined to differentiate between other timbers and radiata
- All radiata should be considered as treated until confirmed to be untreated by examining surface colour or chemical indicator testing
- Radiata components for load-bearing structures that are exposed to the atmosphere or ground are most likely treated
- Treated radiata components might include piles, bearers, joists, framing, rafters, posts and claddings
- Most CCA containing radiata will be used in subfloor spaces
- Rubeanic acid is the preferred reagent for testing for the presence of copper (i.e. CCA) in radiata
- All internal radiata framing in 1970s and 1980s houses should be assumed to contain arsenic as a precaution
- Decks and fences are likely to use CCA treated timber

Common Timber Types

Pinus Radiata

Douglas fir

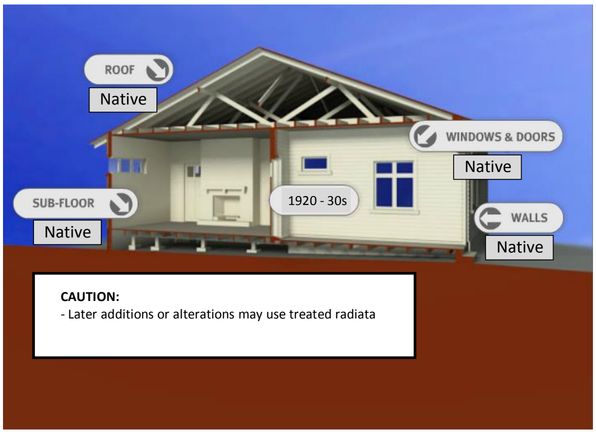
Rimu

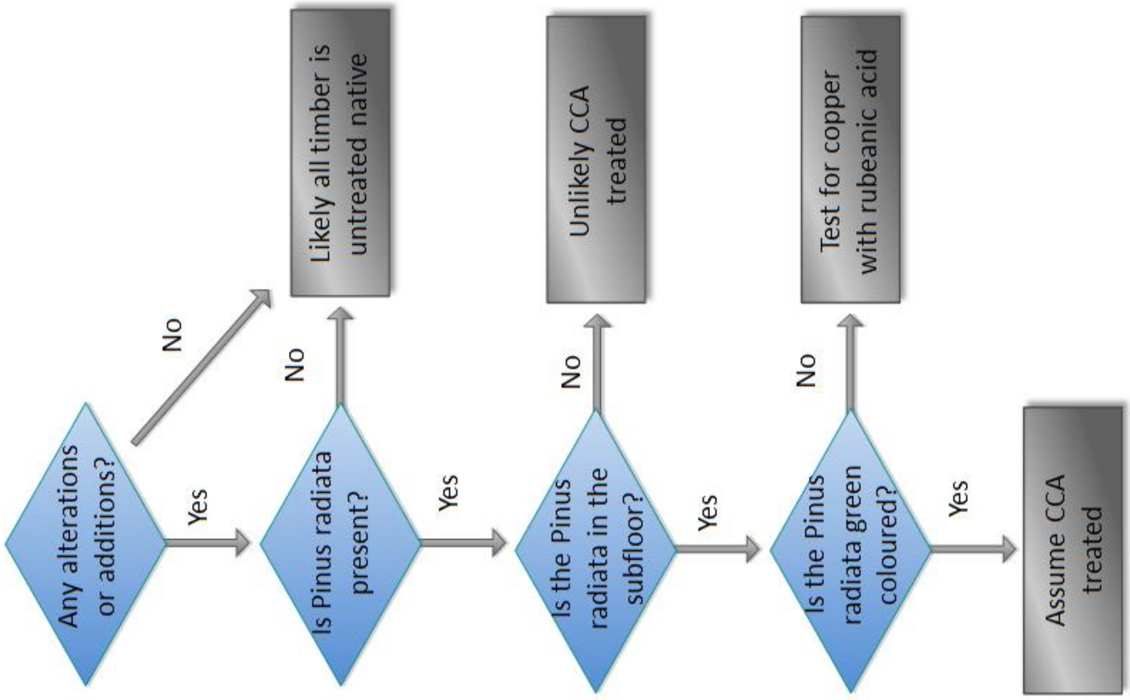
Totara

Kauri

1920s – 1930s Bungalows

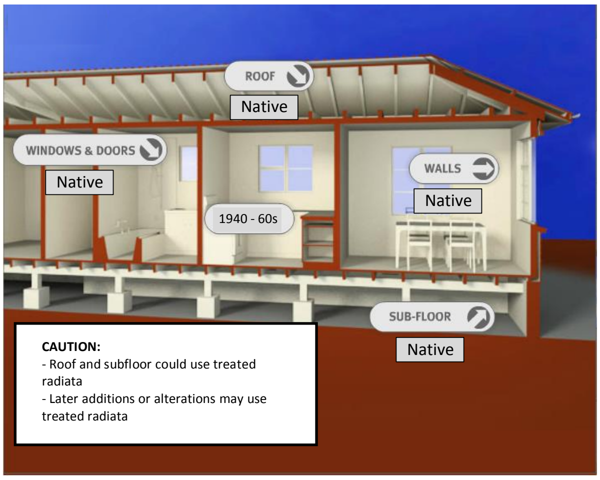
- Later additions or alterations may use treated timber
- Decks and fences are likely to use treated timber

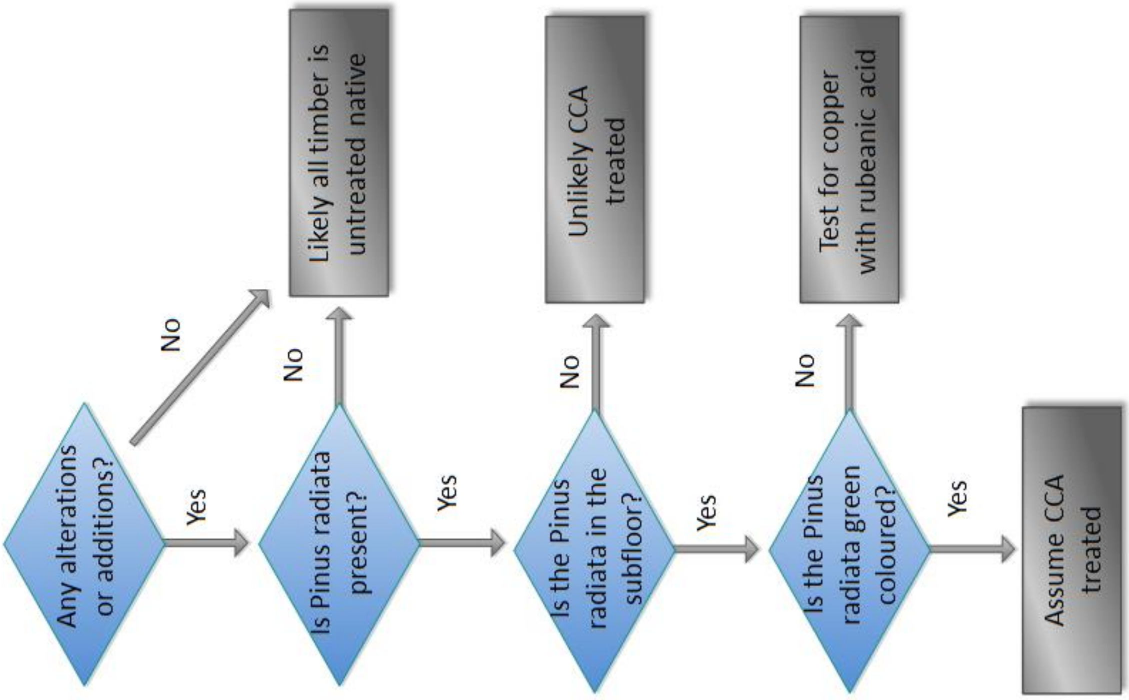




1940s – 1960s Timber Weatherboard

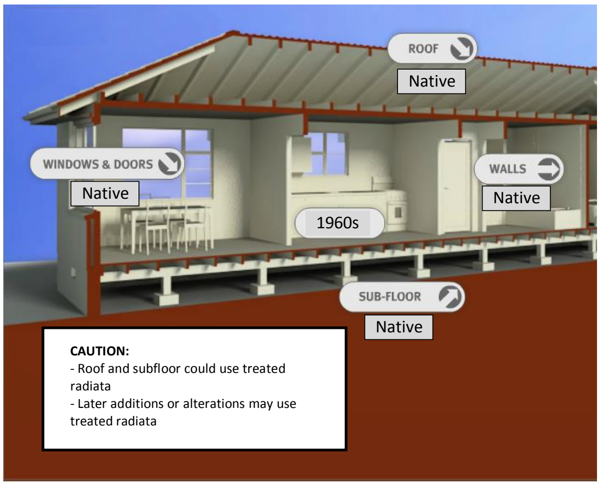
- Weatherboards and exterior trim may use treated timber
- Later additions or alterations may use treated timber
- Decks and fences are likely to use treated timber

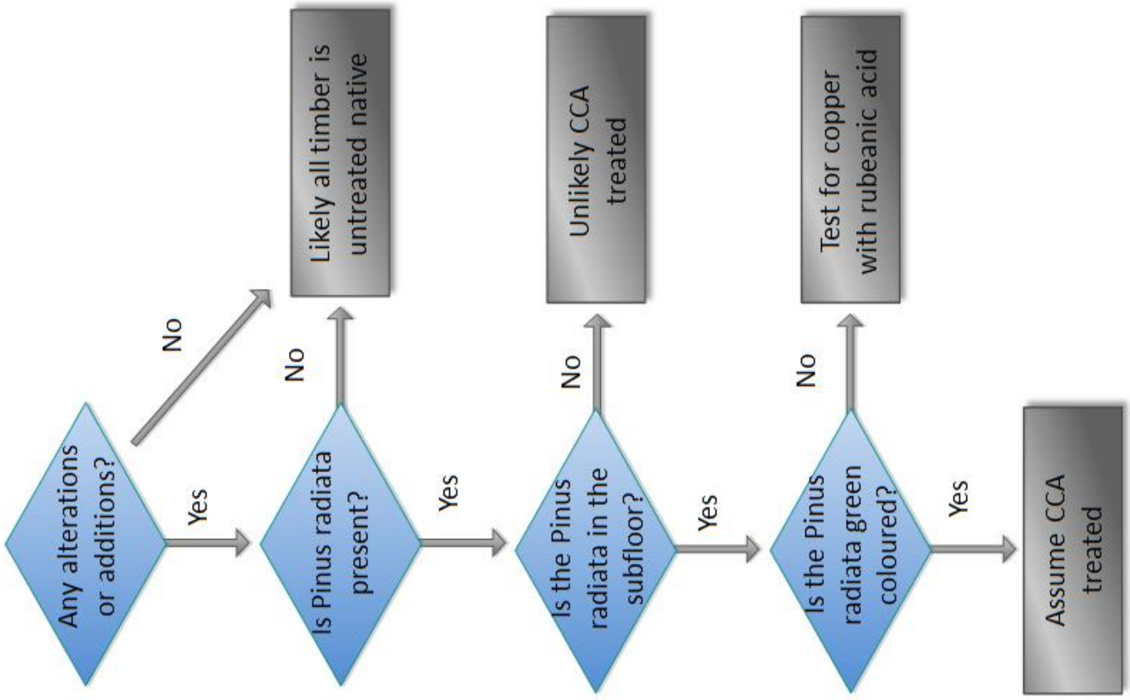




1960s Brick and Tile

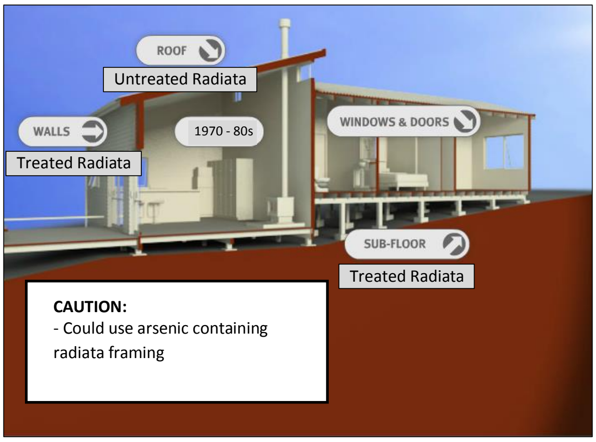
- Later additions or alterations may use treated timber
- Decks and fences are likely to use treated timber

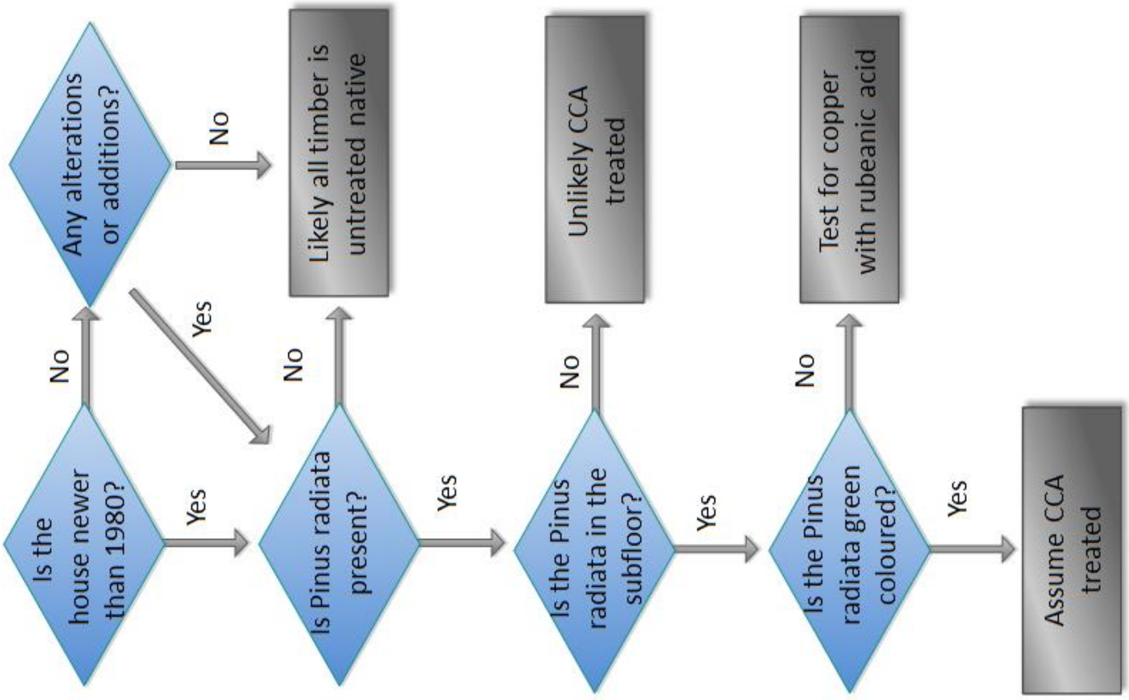




1970s – 1980s

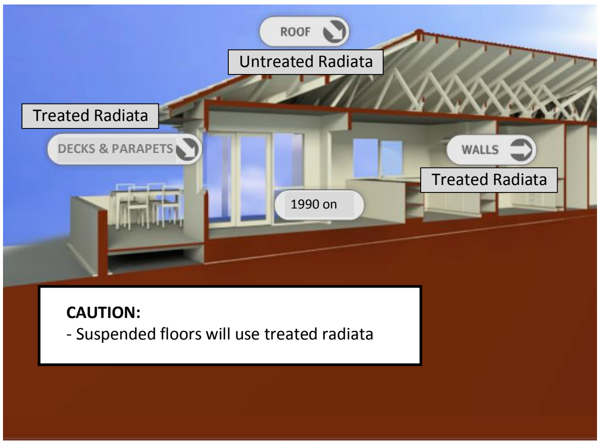
- Worst case is most timber is treated
- Post 1980 houses more likely to have treated timber
- Arsenic may be present in framing timber
- Decks and fences are likely to use treated timber

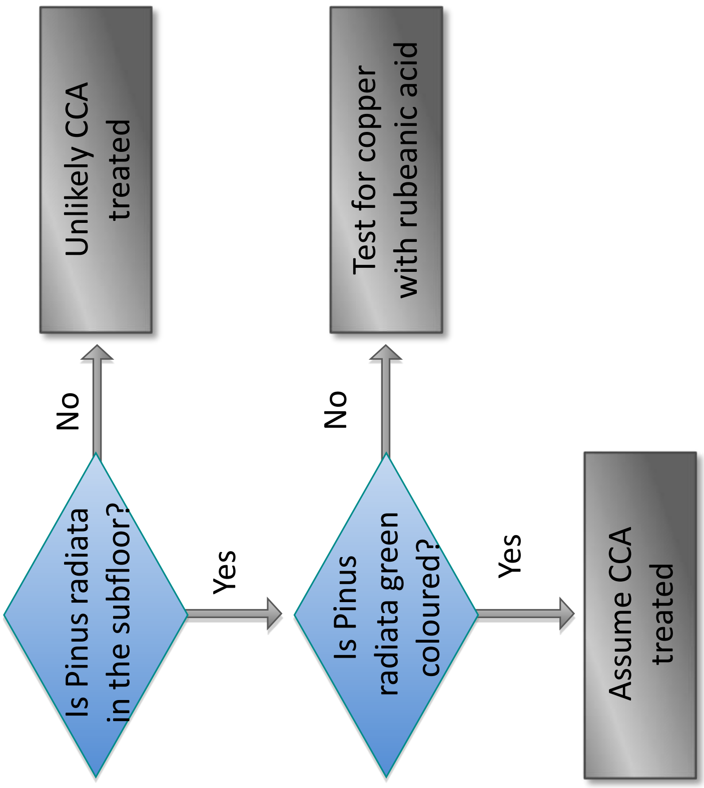




1990 on

- Likely most timber is treated
- Decks and fences are likely to use treated timber





Rubeanic Acid Test for Copper in CCA treated timber

Test Solutions

(1) 5 % ammonia solution
(2) 0.5 % rubeanic acid in alcohol

Ammonia Solution

Dilute 1 part of 0.880SG ammonia with 6 parts of distilled water or 1 part of 0.91 ammonia solution with four parts of distilled water.

Rubeanic Acid Solution

5 g of rubeanic acid dissolved in a litre of a mixture of 90 parts ethanol and 10 parts acetone. Iso-propyl alcohol may be substituted for ethanol if required.

Spray timber with solution (1) followed by solution (2). Copper containing timber goes greenish black to almost black, untreated areas stay natural wood colour.

APPENDIX E REFERENCES

Aenugu HPR at al. 2011. Near Infra Red Spectroscopy – An Overview. International Journal of ChemTech Research 3(2):825-836

Anon. CCA Timber Treatment – Manual for Timber Treaters and Testing. www.fiapng.com

Anon. 2006. Appendix B. Operating Manual [http://www.ccaresearch.org/final_medley_appendixB_March31_2006.pdf]

AWPA. A3-91: Standard Methods for Determining Penetration of Preservatives and Fire Retardants. American Wood-Preservers' Association Standard

AWPA. A9-01: Standard Method for Analysis of Treated Wood and Treating Solutions by X-Ray Spectroscopy. American Wood-Preservers' Association Standard

Bailey DS. 2003. The Feasibility of Recycling CCA Treated Wood from Spent Residential Decks. Master's Thesis, Virginia Polytechnic Institute and State University at Blacksburg, Virginia, USA

Blassino M, Solo-Gabriele H and Townsend T. 2002. Pilot Scale Evaluation of Sorting Technologies for CCA-treated Wood Waste. Waste Management and Research 20:290-301

Blassino M, Solo-Gabriele H and Townsend T. Methods to Control Fuel Quality at Wood Burning Facilities. http://www.nrbp.org/papers/054.pdf

Block CN, Shibata T, Solo-Gabriele HM and Townsend TG. 2007. Use of Handheld X-ray Fluorescence Spectrometry Units for Identification of Arsenic in Treated Wood. Environmental Pollution 148(2):627-633

BRANZ Renovate. [http://www.renovate.org.nz]

BRANZ Renovate. Bungalow. Wall Framing. [http://www.renovate.org.nz/bungalow/walls-and-claddings/use-of-timber/]

BRANZ Renovate. Art Deco. Wall Framing. [http://www.renovate.org.nz/art-deco/walls-and-cladding/use-of-timber/]

BRANZ Renovate. 1940s – 1960s Wall Framing. [http://www.renovate.org.nz/1940-60s/walls-and-cladding/use-of-timber/]

BRANZ Renovate. 1970s. Wall Framing. [http://www.renovate.org.nz/1970s/walls-and-cladding/use-of-timber/]

BRANZ Study Report SR062. 1995. New Zealand House Condition Survey 1994.

BRANZ Study Report SR091. 2000. BRANZ house condition survey (2000).

BRANZ Study Report SR142. 2005 . New Zealand 2005 House Condition Survey.

BRANZ Study Report SR240. 2011. Preliminary BRANZ 2010 House Condition Survey Report – Second Edition.

BRANZ Study Report SR264. 2011. BRANZ 2010 House Condition Survey – Condition Comparison by Tenure.

Caruso N and Love B. Use of X-Ray Fluorescence Spectrometer (XRF) for Remediation of a Copper Chromium Arsenic (CCA) Contaminated Site. http://www.wasteminz.org.nz/wp-content/uploads/Brendon-Love.pdf

Castro AM, Pico FA, Ribeiro AB, Mateus EP and Oliveira AV. Electrodialytic Removal of Heavy Metals from Treated Timber Waste. http://cnea.no.sapo.pt/papers/poster_11.pdf

Clausen CA. 2003. Reusing Remediated CCA-Treated Wood. Proceedings of Managing the Treated Wood Resource – II. American Wood-Preservers' Association Utility Solid Waste Activities Group. May 1, 2003. Boston Marriott Copley Place, Boston, Massachusetts

Clausen CA and Smith RL. 1998. CCA Removal from Treated Wood by Chemical, Mechanical, and Microbial Processing. Proceedings of the 4th International Wood Preservation Symposium - The Challenge-Safety and Environment. 2-3 February 1998. Cannes-Mandelieu, France

Clausen CA and Kenealy WR. 2004. Scale-up Remediation of CCA-Treated Wood. Proceedings of Environmental Impacts of Preservative-Treated Wood, February 8 - 11, 2004. Orlando, Florida, USA. Florida Center for Environmental Solutions Gainesville, Florida, USA

Cooper PA. Future of Wood Preservation in Canada - Disposal Issues. 1999. Proceedings of the 20th Annual Canadian Wood Preservation Association Conference. October 25-26, 1999, Vancouver BC, Canada

Fattah HA, Solo-Gabriele H, Townsend T and Zhang JY. 2009. Online Sorting of Recovered Wood Waste Using Automated X-Ray Technology. Final Report Prepared for Town of Medley for Submission to the FDEP Innovative Recycling Grants Program

Feldhoff R, Huth-Fehre T and Cammann K. 1998. Detection of Inorganic Wood Preservatives on Timber by Near Infrared Spectroscopy. Journal of Near Infrared Spectroscopy 6:171-173

Felton CC and De Groot RC. 1996. The Recycling Potential of Preservative-Treated Wood. Forest Product Journal 46(7/8):37-46

Fujimoto T, Matsumoto K, Kurata Y and Tsuchikawa S. 2010. Enhanced On-line Stress Grading of Sawn Lumber Using Near Infrared Spectroscopy. World Conference on Timber Engineering. 20-24 June 2010. Riva del Garda, Italy

Food and Agriculture Organisation of the United Nations. 1986. FAO Forestry Paper 76 – Wood Preservation Manual. Rome, Italy

Gething BA, Janowiak JJ and Falk RH. 2006. Quantification of Metals in Preservatively-treated Lumber Using Laser Induced Breakdown Spectroscopy (LIBS). In: Ecowood 2006 - 2nd International Conference on Environmentally-Compatible Forest Products Fernando Pessoa University, Oporto, Portugal, 20-22 September 2006; pp. 427-432

Gething BA, Janowiak JJ and Falk RH. 2009. Assessment of Laser Induced Breakdown Spectroscopy (LIBS) for Classification of Preservative in CCA-treated Lumber. Forest Products Journal 59(3):67-74

Gifford P. 2007. Bioenergy Options for New Zealand: A situation analysis of biomass resources and conversion technologies. ISBN 0-478-11019-7. Scion, Energy Group, New Zealand

Haartveit EY and Flæte PO. 2008. Near Infrared Spectroscopy (NIRS) as a Tool for Effective Classification of Wood. Proceedings of the 51st International Convention of Society of Wood Science and Technology. 10-12 November 2008. Concepción, Chile

Hasan AR, Schindler J, Solo-Gabriele HM and Townsend TG. 2011a. Online Sorting of Recovered Wood Waste by Automated XRF-technology: Part 1. Detection of preservative-treated wood waste. Waste Management 31(4):688-694

Hasan AR, Solo-Gabriele HM and Townsend TG. 2011b. Online Sorting of Recovered Wood Waste by Automated XRF-technology: Part 2. Sorting efficiencies. Waste Management 31(4):695-704

Helsen L, Van den Bulck E and Hery JS. 1998. Total Recycling of CCA Treated Wood Waste by Low-temperature Pyrolysis. Waste Management 18:571-578

Helsen L and Van den Bulck E. 2005. Review of Disposal Technologies for Chromated Copper Arsenate (CCA) Treated Wood Waste, with Detailed Analysis of Thermochemical Conversion Processes. Environmental Pollution 134(2):301-314

Hery JS. A Complete Industrial Process to Recycle CCA-Treated Wood. Environmental Impacts of Preservative-Treated Wood. Florida Center for Environmental Solutions Gainesville, Florida. 8-11 February 2004, Orlando, Florida, USA

Hou X, He Y and Jones BT. 2004. Recent Advances in Portable X-ray Fluorescence Spectrometry. Applied Spectroscopy Reviews 39(1):1-25

Huang A and Cooper PA. 2000. Cement-bonded Particleboards Using CCA Treated Wood Removed from Service. Forest Products Journal 50(6):49-56

Humar M. 2010. Inorganic Pollutants in Recovered Wood from Slovenia and Boards Made of Disintegrated Wood. The Open Environmental Engineering Journal 3:49-54

Illman BL and Yang VW. 2010. Mycoremediation of Waste Wood Treated with CCA and ACQ. In: 7th International Conference Remediation of Chlorinated and Recalcitrant Compounds Preliminary Program. March 24-27, 2010. Monterey, CA. Battelle 7th International Conference Program and Abstract Book, Monterey, CA. 5p

Industrial Test Systems, Inc., USA. http://www.sensafe.com/PDF/481396-W%20Quick%20Arsenic%20In%20Wood%20Instruction%20Sheet%2008-10-10.pdf

Irle M, Maher K, Fru C and Sawyer G. 2004. Development of Methods and Sampling Protocols for Measuring Contaminants in Recycled Wood for Use in the Panelboard Sector. Project code: W003-007. The Waste & Resources Action Programme (WRAP), The Old Academy, 21 Horse Fair, Banbury, Oxon OX16 0AH. www.wrap.org.uk

Jacobi G, Solo-Gabriele H, Townsend T and Dubey B. 2007. Evaluation of Methods for Sorting CCA-treated Wood. Waste Management 27:1617-1625

Jambeck JR. 2004. The Disposal of CCA-Treated Wood in Simulated Landfills: Potential Impacts. PhD Thesis. University of Florida, USA

Jambeck J, Weitz K, Solo-Gabriele H, Townsend T and Thorneloe S. 2007. CCA-Treated Wood Disposed in Landfills and Life-cycle Trade-offs with Waste-to-energy and MSW Landfill Disposal. Waste Management 27:S21–S28

Kabir MJ, Rasul MG, Ashwath N and Chowdhury AA. 2012. A Review on Green Wastes Pyrolysis for Energy Recovery. In Recent Researches in Environmental and Geological Sciences, edited by N. Altawell, K. Volkov C. Matos and PF de Arroyabe. WSEAS Press, www.wseas.org. 14-17 July 2012. Kos Island, Greece

Kalnicky D and Singhvi R. 2001. Field Portable XRF Analysis of Environmental Samples. Journal of Hazardous Materials 83:93-122

Kangas E. 2002. Consultation on Suggested European Community Legislation on the Use of Arsenic in the Preservation of Wood. The Finnish Wood Preserving Association

Kazi FKM and Cooper PA. 1999. Recovery and Reuse of Chromated Copper Arsenate (CCA) Wood Preservative from CCA Treated Wastes. Proceedings of the 20th Annual Canadian Wood Preservation Association Conference, 25-26 October 1999, Vancouver BC, Canada

Kuznetsova OV, Korzhova EN, Smagunova AN, Mukhetdinova AV, Tomilova OA and Sizykh YI. 2004. Comparison of the Results of Atomic Absorption and X-ray Fluorescence Analysis of Metals in Atmospheric Aerosols. Journal of Analytical Chemistry 59(1):46-51

Love S. 2007. Extended Producer Responsibility of Treated Timber Waste. SB07 NZ Conference, Transforming Our Built Environment. 14-16 November 2007. Auckland, New Zealand. http://www.branz.co.nz/cms_show_download.php?id=93dd1fb212135dd2247edab26e73bc23f22ecd79

Maas, R., Patch, S., and Berkowitz, J., 2004. Integrated Studies of the Dynamics of Arsenic Release and Exposure from CCA-Treated Lumber, in *Post-Conference Proc. of the "Environmental Impacts of Preservative-Treated Wood" Conference*, Florida Center for EnvironmentalSolutions, Orlando, Florida, 17-31. (www.ccaconference.org)
Ministry for the Environment. 2009. Environmental Report Card - Solid Waste Composition. Wellington, New Zealand. http://www.mfe.govt.nz/environmental-reporting/report-cards/waste-composition/2009/

Moskal TM and Hahn DW. 2002. On-Line Sorting of Wood Treated with Chromated Copper Arsenate Using Laser-Induced Breakdown Spectroscopy. Applied Spectroscopy 56(10):1337-1344

Munson JM and Kamdem DP. 1998. Reconstituted Particleboards from CCA Treated Red Pine Utility Poles. Forest Products Journal 48(3):55-62

NZwood. Timber species. (www.nzwood.co.nz/what-wood/timber-species).

Omae A, Solo-Gabriele H and Townsend T. 2006. A Chemical Stain for Identifying Arsenic-Treated Wood. Report #05-0432025. Florida Centre for Solid and Hazardous Waste Management, 2207 NW 13 Street, Suite D, Gainesville, FL 32609

Pöyry Forest Industry Consulting Ltd. 2009. Automated Sorting of Treated Wood Waste, MDD015. Waste & Resources Action Programme. The Old Academy, 21 Horse Fair, Banbury, Oxon, OX16 0AH, UK. www.wrap.org.uk/recyclingindustry

Pringle T. 2012. Timber Treatment. BUILD 128:19-20

Qi D and Cooper PA. 2000. Leaching of Chromium and Other CCA Components from Wood-cement Composites Made with Spent CCA Treated Wood. IRG/WP 00-50153. Internatioal Research Group on Wood Preservation. Stockholm, Sweden

Reed D. 2003. Report on Copper, Chromium and Arsenic (CCA) Treated Timber. ERMA, New Zealand

Rhodes S and Dolan L. Recovery and Disposal Options for Treated Timber. http://www.wasteminz.org.nz/wp-content/uploads/Scott-Rhodes.pdf

Ribeiro AB, Mateus EP, Ottosen LM and Bech-Nielsen G. 2000. Electrodialytic Removal of Cu, Cr, and As from Chromated Copper Arsenate-Treated Timber Waste. Environmental Science and Technology 34(5):784-788

Röck F, Barsan N and Weimar U. 2008. Electronic Nose: Current Status and Future Trends. Chemical Reviews 108:705-725

Rossini G and Bernardes AM. 2005. Galvanic Sludge Metals Recovery by Pyrometallurgical and Hydrometallurgical Treatment. Journal of Hazardous Materials 131(13):210-216

Sabo R, Winandy JE, Clausen CA and Basta A. 2008. Remediation and Recycling of WBP-treated Lumber for use as Flakeboard. Proceedings of 104th Annual Meeting of the American Wood Protection Association. Portland, Oregon, May 18-20, 2008

Sawyer G and Irle M. 2005a. The PAN Colour Indicator Technique to Detect Copper Contamination in Wood Waste for Recycling – A Guide for Use. WOO0034. The Waste & Resources Action Programme. The Old Academy, 21 Horse Fair, Banbury, Oxon OX16 0AH. http://www.wrap.org.uk

Sawyer G and Irle M. 2005b. Development of Colour Indicator Techniques to Detect Chemical Contamination in Wood Wate for Recycling. WOO0034. The Waste & Resources Action Programme The Old Academy, 21 Horse Fair, Banbury, Oxon OX16 0AH. http://www.wrap.org.uk

Sawyer G and Irle M. 2005c. The Chromazurol S Colour Indicator Technique to Detect Copper Contamination in Wood Waste for Recycling - A Guide for Use. WOO0034. The Waste & Resources Action Programme The Old Academy, 21 Horse Fair, Banbury, Oxon OX16 0AH. http://www.wrap.org.uk

Schröoder W, Matz G and Kübler J. 1998. Fast Detection of Preservatives on Waste Wood with GC/MS, GC-ECD and Ion Mobility Spectrometry. Field Analytical Chemistry & Technology 2(5):287-297

Scott F. 2013. Treated Timber Waste Minimisation Project. Milestone 1: Industry Overview. http://ecan.govt.nz/publications/Reports/treated-timber-waste-minimisation-project-report.pdf

Sipilä J, Zevenhoven M and Zevenhoven R. 2007. Combined Thermal Treatment of CCA-wood Saste and Municipal Sewage Sludge for Arsenic Emissions Control. Åbo Akademi University, Turku, Finland

Smith R, Bailey D and Araman P. 2003. Evaluating Spent CCA Residential Decks for Second-life Products. Managing the Treated Wood Resource – II, Special Seminar sponsored by American Wood-Preservers' Association and the Utility Solid Waste Activities Group. 1 May 2003. Boston Marriott Copley Place, Boston, Massachusetts, USA

Smith R, Bailey D, Alderman D and Araman P. 2006. Chapter 19 - The Reuse of Treated Wood. In Environmental Impacts of Treated Wood. Edited by TG Townsend and H Solo-Gabriele. Taylor & Francis Group, Boca Raton

So CL, Lebow ST, Eberhardt TL, Groom LH and Shupe TF. An Evaluation of the Use of Near Infrared (NIR) Spectroscopy to Identify Water and Oil-borne Preservatives. In Managing the Treated Wood Resource – II, Special Seminar sponsored by American Wood-Preservers' Association Utility Solid Waste Activities Group. 1 May 2003, Boston Marriott Copley Place, Boston, Massachusetts, USA

So CL, Lebow ST, Eberhardt TL, Groom LH and Rials TG. 2004. The Application of Near Infrared (NIR) Spectroscopy to Inorganic Preservative-treated Wood. Wood and Fiber Science 36(3):329-336

So CL, Lebow ST, Eberhardt TL, Groom LH and Shupe TF. 2007. Application of Near Infrared Spectroscopy to Preservative-Treated Wood. In Advanced Biomass Science and Technology for Bio-Based Products, edited by CY Hse, ZH Jiang, ML Kuo, F Fu and PY Burns. May 23-25, 2007, Beijing, China

Solo-Gabriele H, Calitu V, Kormienko M, Townsend T and Messick B. 1999. Disposal of CCA-treated Wood: An Evaluation of Existing and Alternative Management Options. Florida Center for Solid and Hazardous Waste Management, 2207 NW 13 Street, Suite D, Gainesville, FL 32609, USA

Solo-Gabriele H, Hosein N, Jacobi G, Townsend T, Jambeck J, Hahn D, Moskal T, and Iida K. 2001. On-line Sorting Technologies for CCA Treated Wood. http://www.dep.state.fl.us/waste/quick_topics/publications/shw/recycling/InnovativeGrants/IGyear3/finalreports/sarasota.pdf

Solo-Gabriele HM, Townsend TG, Hahn DW, Moskal TM, Hosein N, Jambeck J and Jacobi G. 2004. Evaluation of XRF and LIBS Technologies for On-line Sorting of CCA-treated Wood Waste. Waste Management 24(4):413-424

Solo-Gabriele H and Townsend T. 2005. Educational Outreach and Stain Distribution Project for Identifying Copper-Treated Wood. Report # 0232003-05. Florida Centre for Solid and Hazardous Waste Management, 2207 NW 13 Street, Suite D, Gainesville, FL 32609, USA

Solo-Gabriele H, Jacobi G, Lam E, Townsend T and Dubey B. 2006. Augmented Sorting of Recovered Wood Waste Using Stain and X-ray Technologies. Report prepared for Town of Medley for submission to the FDEP Innovative Recycling Grants Program

Solo-Gabriele HM, Townsend TG and Fattah HA. 2009. Knock on Wood. Recource Recycling. May 2009

Solo-Gabriele HM, Omae AL and Townsend TG. 2011. Arsenic-specific Stain for Identification Arsenic-treated Wood. US Patent, US 8053241 B2, 8 November 2011

Standards New Zealand. 2003. NZS 3602 – Timber and Wood-based Products for Use in Building. SNZ, Wellington 6140, New Zealand

Standards New Zealand. 2003. NZS 3640 – Chemical Preservation of Round and Sawn Timber. SNZ, Wellington 6140, New Zealand

Sterling DA, Lewis RD, Luke DA and Shadel BN. 2000. A Portable X-ray Fluorescence Instrument for Analyzing Dust Wipe Samples for Lead: Evaluation with field samples. Environmental Research 83:174-179

Taylor A and Lioyd J. 2007. Potential of Near Infrared Spectroscopy to Quantity Boron Concentration in Treated Wood. Forest Product Journal 57(1/2):116-117

Townsend TG and Solo-Gabriele HM. 2003. Potential Concerns and Impacts of CCA-Treated Wood for the Waste-to-Energy Industry. Proceedings of 11th North American Waste to Energy Conference. April 28-30, 2003, Tampa, Florida

TRADA Technology & Enviros Consulting Ltd. 2005. Options and Risk Assessment for Treated Wood Waste. WRAP Reference No: 09WOO. Published by: The Waste & Resources Action Programme (WRAP), The Old Academy, 21 Horse Fair, Banbury, Oxon OX16 0AH. www.wrap.org.uk

Tsuchikawa S. 2007. A Review of Recent Near Infrared Research for Wood and Paper. Applied Spectroscopy Reviews 42(1):43-71

Uhl A, Loebe K and Kreuchwig L. 2001. Fast Analysis of Wood Preservers Using Laser Induced Breakdown Spectroscopy. Spectrochimica Acta Part B: Atomic Spectroscopy 56(6):795-806

Vanhoof C, Corthouts V and Tirez K. 2004. Energy-dispersive X-ray Fluorescence Systems as Analytical Tool for Assessment of Contaminated Soils. Journal of Environmental Monitoring 6(4):344-350

Vasilenko M. 2012. Feasibility of Using Biosensors for Heavy Metal Detection in Complex Matrices such as Bio-slurries. Master of Science Thesis, Tampere University of Technology, 33720 Tampere, Finland

Vick CB, Geimer RL and Wood JE. 1996. Flakeboards from Recycled CCA Treated Southern Pine Lumber. Forest Products Journal 46(11-12):89-91

Watanabe K, Hart JF, Mansfield SD and Avramidis S. 2010. Near-infrared Technology Applications for Quality Control in Wood Processing. The Future of Quality Control for Wood & Wood Products, The Final Conference of COST Action E53. 4-7th May 2010, Edinburgh

Watanabe Y, Kurata Y, Ono Y, Takada M, Nakai S and Hosomi M. 2005. An X-ray Fluorescence Method for Rapid Screening of As, Cr, Cu and Pb Concentration in

Waste Wood from Construction and Demolition Processes. Journal of Environmental Chemistry 15(1):145-152

Wood C. Waste Minimisation in New Zealand. Waste Minimisation Best Practice: Design, Specification and Construction. New Zealand Green Building Council. www.nzgbc.org.nz/images/.../Waste_Minimisation_Best_Practice.pdf

Yasuda K, Tanaka M and Deguchi Y. 2006. Basic Evaluation of Sorting Technologies for CCA Treated Wood Waste. WIT Transactions on Biomedicine and Health, Vol 10, Environmental Toxicology, 319-327