Oregon State University Utility Pole Research Cooperative (UPRC)

Oregon State University College of Forestry

UTILITY POLE RESEARCH COOPERATIVE

Department of Wood Science & Engineering
38th Annual Report
2018

By:
Jed Cappellazzi and Matt Konkler

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COOPERATORS

American Transmission Company

Bonneville Power Administration

Brooks Manufacturing Inc.

Clark Public Utilities

Copper Care Wood Preservatives Inc.

BASF Wolman, GMBH

Fortis Alberta

Genics Inc.

Idaho Power

Intec Services Inc. (Pole Care Inc.)

Lonza

Nisus

Osmose Utilities Services, Inc.

Pacific Gas and Electric

PacifiCorp

Poles Inc.

Portland General Electric Company

Puget Sound Energy Services

Rio Tinto Minerals

Salt River Project

Snohomish County Public Utility District

McFarland-Cascade (Stella-Jones Inc.)

The Pentachlorophenol Working Group

Timber Products Inspection

Western Wood Preservers Institute

Wood Care Systems

Xcel Energy

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Dallin Brooks/Butch Bernhardt	Western Wood Preservers Institute
James Renfroe	Wood Care Systems
Jeff Goodson/Erin Kees	Xcel Energy

RESEARCH

Principle Investigators

Jed Cappellazzi
Matthew J. Konkler
Oregon State University, Department of Wood Science and Engineering

Visiting Scientists
Xiaoping Li
Huadong Xu

Graduate Student
Paola Torres
Hunter Anderson
Shahlinney Lipeh
Leon Rogers

EXECUTIVE SUMMARY

The Cooperative currently operates under five objectives and the progress under each objective will be summarized below.

Objective I primarily examines the performance of the various internal remedial treatments. Over the years, we have established a variety of field and laboratory tests to develop new internal remedial treatments and evaluate their properties. This objective was formerly the most intensively studied part of the Coop, however, most of the treatments are mature. We continue to evaluate several field tests. The most important of these is the large-scale evaluation of internal remedial treatments at the Peavy Arboretum test site. The goal of this test was to evaluate all of the available remedial treatments in one location. The results show that metam sodium treatments provided 3 to 5 years of residual chemical protection, while MITC-FUME provided 7 to 10 years of protection, and dazomet-related treatments still continue to provide protection after 10 years. Boron based treatments have also performed well and continue to provide protection 10 years after treatment. Chloropicrin remains substantially above threshold levels and is performing well long-term. However, re-registration of this chemical remains troublesome due to safety concerns. These results illustrate the slight performance differences between the various systems, but indicate that all are compatible with a 10-year inspection cycle.

We have also continued to evaluate new treatment combinations. This year we installed test poles treated with boron rods and metam sodium as well as poles treated with potassium dithiocarbamate. The latter system is more concentrated than the currently used metam sodium. These trials will be assessed for the first time in 2019.

We also continue to examine dazomet performance under dry conditions. Dazomet performance in drier climates has been hampered by the lack of available moisture for decomposition. Limited laboratory trials were performed to develop improved methods for accelerating decomposition. We have also examined methyl isothiocyanate (MITC) levels in dry-climate poles from California and Arizona. In both cases, MITC levels in poles were below the threshold for protection against fungal attack.

Laboratory tests of boron movement through treated wood are also continuing and show that boron diffusion is much slower through an oil treated shell. These results will be used to better understand how boron will perform below ground in poles installed in wetter soils.

Objective II examines methods for limiting internal decay above ground. The primary tests under this objective are two large field trials examining boron pre-treatments followed by an over treatment with either pentachlorophenol, copper naphthenate, or ammoniacal copper zinc arsenate. Boron pre-treatments have been used in railway ties with great success and have markedly extended tie service life. This method may also be useful for limiting the potential for internal decay above ground in poles. Boron is generally distributed across pole cross sections, but the levels remain lower than expected towards the center. These trials will serve as benchmarks for utilities considering the use of boron pre-treatments to limit the potential of internal decay above ground.

Objective III examines a variety of methods to improve wood performance in utility systems including fire retardants, pole top caps, and selection of cross arms. Cap tests continue to show that water shedding caps markedly reduce internal moisture content of poles in service. A much older ancillary test examining capping in marine piling on the Oregon coast showed that capping, coupled with a chemical treatment, provided the best protection over a 34-year test period. Collectively, the results illustrate the benefits of using water shedding caps to reduce internal moisture content and create conditions less conducive to fungal attack.

Fire continues to be a major problem for utilities with lines running through forested areas, particularly in arid or seasonally-dry climates. We have examined long-term performance of a 14 year test of field applied fire retardants. The two systems (FireGuard and an Elastomeric Paint) both continued to provide protection, although the surfaces of both systems had begun to degrade to the e point where reapplication would be necessary. We also continued to develop a novel fire test method as a preliminary screening tool to evaluate potential utility pole fire retardants. The method has been modified to add extra heating elements, while the test parameters have been refined. Over 90 tests were performed on untreated and penta-treated poles. The tests showed that fire retardant coatings reduced both the likelihood of ignition as well as the resulting depth and area of char. These tests indicate the method is nearing suitability as a Standard test method and the procedures will be developed into a proposed ASTM standard.

Crossarms are an important, but often overlooked, part of the overhead electrical transmission and distribution system. Douglas-fir is the primary species used for crossarms and the grading rules used to select arms are quite rigorous. This past year, we examined the properties of 250 arms representing 50 arms that were considered acceptable according to the current grading rules and 200 that had been rejected for various reasons, primarily for knots. The defects on the arms were mapped, and the arms were tested to failure in a specially constructed apparatus designed to simulate an arm heavily loaded by ice. Almost all of the acceptable arms met the minimum ANSI value of 7800 psi (49/50), but a surprising number of reject arms also met the standards. These data are still being evaluated, but the results indicate a large number of arms were much stronger than the minimum values and efforts are underway to determine how these arms might be identified.

The field stake trial examining the effects of solvents on performance of pentachlorophenol and copper naphthenate is continuing. The results show that penta stakes are largely performing well; however, stakes treated with copper naphthenate in biodiesel continue to perform more poorly than those treated with conventional petroleum derived diesel. These results support previous laboratory studies and field reports, and illustrate the need to carefully evaluate solvent/preservative combinations before moving to large scale commercial application.

Additionally, discussion on the wide variety of methods for reusing treated wood at the end of its service life is provided. Most are not feasible because of the resource condition, collection and transport difficulties, or the economics against competing materials. Thus, there remains a continued need for evaluating new technologies to capture value from treated wood at the end of its service life.

Objective IV examines the performance of external barriers applied below ground on poles. A number of our tests have examined the effects of these barriers on wood moisture content inside the barrier. We have not performed any additional studies on this aspect of the barriers, but we have examined the levels of preservative around poles with and without these barriers. No residual penta was found in soil removed from poles with a barrier, while elevated levels were found in soils around poles with no barrier. One potential benefit of barriers is to reduce preservative migration into surrounding soil. This would be particularly useful for poles in sensitive environments such as wetlands or near surface waters.

Objective V examines the performance of copper naphthenate as a preservative for utility poles. The long term fungus-cellar trial shows that copper naphthenate-treated western redcedar stakes continue to perform well under high decay hazard conditions. No additional field evaluations were performed on copper naphthenate treated poles, but evaluations of poles in Washington State will be undertaken in 2019.

Overall, the Coop continues to remain active in a number of areas. Membership includes 16 Full Utility members and 12 Associate members.

OBJECTIVE I

DEVELOP SAFER CHEMICALS FOR CONTROLLING INTERNAL DECAY OF WOOD POLES

Remedial treatments continue to play a major role in extending the service life of wood poles. While the first remedial treatments were broadly toxic, volatile chemicals, they have gradually shifted to more controllable treatments. This shift has resulted in a variety of available internal treatments for arresting fungal attack. Some of these treatments are fungitoxic based upon movement of gases through wood, while others are fungitoxic based upon movement of boron or fluoride in free water. Each system has advantages and disadvantages in terms of safety and efficacy. In this section, we discuss active field tests of the newer formulations as well as additional work to more completely characterize the performance of several older treatments.

A. Develop Improved Fumigants for Controlling Internal Decay of Wood Poles

While a variety of methods are employed to control internal decay, fumigants are most widely used in North America. Initially, two fumigants were registered for wood preservation; metam sodium (33% sodium n-methyldithiocarbamate) and chloropicrin (96% trichloronitromethane). Of these, chloropicrin was most effective, but both were prone to spills and installer health risks. The UPRC identified two alternatives, methyl isothiocyanate (MITC, commercialized as MITC-FUME) and dazomet (commercialized as Super-Fume, UltraFume, and DuraFume). Both are solid at room temperature which reduces spill risk and simplifies cleanup. Products are listed in Table I-1.

An important part of the development process for these treatments is continuing performance evaluations to determine when retreatment is necessary and to identify any factors that might affect performance.

Table I-1. Characteristics of internal remedial treatments used for utility poles in North America.

<table>
<tr><th>Trade Name</th><th>Active Ingredient</th><th>Conc. (%)</th><th>Manufacturer</th></tr>
<tr><td>TimberFume</td><td>trichloronitromethane</td><td>97</td><td>Osmose Utilities Services, Inc.</td></tr>
<tr><td>WoodFume</td><td rowspan="2">sodium n-methyldithiocarbamate</td><td rowspan="2">33</td><td rowspan="2">Osmose Utilities Services, Inc.
Copper Care Wood Preservatives, Inc.</td></tr>
<tr><td>SMDC-Fume</td></tr>
<tr><td>MITC-FUME</td><td>methyl isothiocyanate</td><td>97</td><td>Osmose Utilities Services, Inc.</td></tr>
<tr><td>Super-Fume</td><td rowspan="3">Tetrahydro-3,5-dimethyl-2H-1,3,5-thiodiazine-2-thione</td><td rowspan="3">98-99</td><td rowspan="3">Pole Care Inc.
Copper Care Wood Preservatives, Inc.
Osmose Utilities Services, Inc.</td></tr>
<tr><td>UltraFume</td></tr>
<tr><td>DuraFume II</td></tr>
<tr><td>Impel Rods</td><td rowspan="2">Disodium Octaborate</td><td>100</td><td>Intec, Inc.</td></tr>
<tr><td>Bor8 Rods</td><td>97</td><td>Wood Care Systems</td></tr>
<tr><td>Cobra Rods</td><td>Disodium Octaborate, Copper Hydroxide, Boric Acid</td><td>88-91, 1.5-3, 4-8</td><td>Genics, Inc.</td></tr>
</table>

1. Performance of Dazomet in Powdered and Rod Forms in Douglas-fir Pole Sections

Date Established:	March 2000
Location:	Peavy Arboretum, Corvallis, OR
Pole Species, Treatment, Size	Douglas-fir, penta
Circumference @ GL (avg., max., min.)	84, 104, 65 cm

Dazomet was originally supplied as a powder, intended for agricultural field application where it could be tilled into soil. Once in soil contact, dazomet rapidly reacts to release MITC, killing potential pathogens prior to planting. Drawbacks to powdered formulations for utility pole treatment include increased spill risk during application and potential exposure to inhalable chemical dusts. In our early trials, we produced dazomet pellets by wetting the powder and compressing the mixture, but these were not commercially available. The desire for improved handling characteristics, however, encouraged development of a rod form (BASF Wolman GmbH). These rods simplified application, but we wondered whether decreased wood/chemical contact associated with rods might reduce dazomet decomposition, thereby slowing fungal control.

Pentachlorophenol (penta) treated Douglas-fir pole sections (206-332 mm in diameter by 3 m long) were set to a depth of 0.6 m at the Corvallis, OR test site. Three steeply angled holes were drilled into each pole beginning at groundline and moving upward 150 mm and around 120º. The holes received either 160 g of powdered dazomet, 107 g of dazomet rod plus 100 g of copper naphthenate (2% as Cu), 160 g of dazomet rod alone, 160 g of dazomet rod amended with 100 g of copper naphthenate, 160 g of dazomet rod amended with 100 g of water, or 490 g of metam sodium. Pre-measured aliquots of amendments were placed into treatment holes on top of the fumigants. Each treatment was replicated on five poles.

Chemical distribution was assessed 1, 2, 3, 5, 7, 8, 10, 12, and 15 years after treatment by removing increment cores from three equidistant locations around each pole (0.3, 0.8 or 1.3 m above groundline). The outer treated zone of each core was discarded, and the remaining inner and outer 25 mm was placed into 5 mL of ethyl acetate. Core sections were extracted in ethyl acetate for 48 hours at room temperature, removed, oven dried and weighed. Ethyl acetate extracts were analyzed for residual MITC by gas chromatography. The remainder of each core was placed on 1.5% malt extract agar and observed for fungal growth. Any fungal growth was examined for characteristics typical of basidiomycetes, a class of fungi containing many important wood decayers.

This test has been completed. For details, consult the 2015 Annual Report.

2. Performance of Dazomet With or Without Copper-based Accelerants

Dazomet was originally studied as a potential wood fumigant in the late 1970's, but its ability to decompose to methyl isothiocyanate (MITC) was deemed too slow to be effective against decay fungi. Previous studies by Malcom Corden under the Coop indicated certain bi-valent metals, such as copper, could markedly accelerate dazomet decomposition and further work by Paul Forsyth showed that mixtures of copper sulfate and dazomet produced excellent decomposition to MITC in the lab. Subsequent field trials showed this mixture resulted in effective MITC levels in poles in the field. While the results were promising, copper sulfate was not registered by the EPA for the internal treatment of in-service utility poles and it was deemed to be too costly to register this material for this one small application. One alternative to copper sulfate was copper naphthenate, which is commonly recommended for treatment of field damage to utility poles. There were, however, questions concerning the ability of copper naphthenate, a copper soap, to enhance decomposition in comparison with the copper salt.

Douglas-fir pole sections (283-340 mm in diameter by 3 m long) were pressure treated with pentachlorophenol in P9 Type-A oil before being set to a depth of 0.6 m at our Peavy Arboretum field test site. Three steeply sloping holes were drilled into the poles beginning at groundline and moving upward 150 mm and around the pole 120 degrees. Two hundred grams of dazomet were equally distributed among the three holes. One set of three poles received no additional treatment, three poles received 20 g of copper sulfate powder equally distributed among the three holes, and three received 20 g of liquid copper naphthenate (2% metallic copper) in mineral spirits, also equally distributed among the three holes. Holes were then plugged with wooden dowels.

The EPA product label for commercially available dazomet-based pole fumigants includes the statement, "An accelerant of a 1% solution of copper naphthenate in mineral spirits may be added to treatment holes after [dazomet], and is designed to speed the decomposition and release of active fumigant inside the wood product." The 20 g of copper sulfate and 20 g of copper naphthenate (2% metallic copper) conflict with the label and would violate the law if used for commercial applications. At the time this test was established dazomet was not commercially used.

Chemical distribution was assessed annually after treatment by removing increment cores from three equidistant points around each pole at sites 0.3, 1.3, and 2.3 m above groundline. The outer 25 mm of each core was discarded. The next 25 mm, and the 25 mm section closest to the pith, of each core were placed into vials containing 5 mL of ethyl acetate. The cores were stored at room temperature for 48 hours to extract any MITC in the wood, then the increment core was removed, oven-dried, and weighed. The core weight was later used to calculate chemical content on a wood weight basis. The ethyl acetate extracts were injected into a Shimadzu gas chromatograph equipped with a flame photometric detector with filters specific for sulfur (a component of MITC). MITC levels in the extracts were quantified by comparison with prepared standards and results were expressed on a µg MITC/oven dried g of wood basis.

The remainder of each core was then placed on the surface of a 1.5% malt extract agar petri dish and observed for evidence of fungal growth. Any fungi growing from the cores were examined for characteristics typical of Basidiomycetes, a class of fungi containing important wood decayers.

This test has been completed. Please consult the 2017 Annual Report for final results. This test has also been re-treated and will reported on in subsequent Annual Reports.

3. Effect of Metam Sodium on Boron Rod Performance

There has been discussion about the potential for combining boron rods with metam sodium. Metam sodium provides a relatively short protective period but its major decomposition product, MITC, rapidly moves through wood to kill existing fungi. Boron requires moisture for diffusion and therefore moves more slowly into the wood after treatment, but our tests suggest that it remains in the poles at effective levels for 10-15 years after treatment. Combining these treatments could take advantage of the best properties of each system. The potential for this treatment combination was evaluated in the following trial.

Douglas-fir pole sections (283-340 mm in diameter by 3 m long) were pressure treated with pentachlorophenol in P9 Type-A oil before being set to a depth of 0.6 m at our Peavy Arboretum field test site. Three steeply sloping holes were drilled into the poles beginning at groundline and moving upward 150 mm and around the pole 120 degrees.

The poles were treated with 500 mL of metam sodium alone, 500 mL of metam sodium plus one fused boron rod per treatment hole, or one fused boron rod per treatment hole alone. The holes were plugged with tight fitting plastic plugs. Each treatment was replicated on 5 poles.

These poles will be sampled for both MITC level and boron content annually by removing increment cores from three equidistant points around each pole at groundline, 300 mm, and 600 mm above groundline. These cores will be processed as described earlier to produce inner and outer 25 mm segments that will be extracted in ethyl acetate. The resulting extracts will be analyzed for MITC as described earlier. If possible, these cores will be air-dried and used for boron analysis if it can be shown that ethyl acetate does not remove boron. Otherwise, parallel cores will be removed and hot water extracted. The resulting extract will be analyzed using the Azomethine H method.

These poles will be sampled for the first time in April 2019.

4. Effect of Potassium N-methyldithiocarbamate as an Internal Remedial Treatment

Metam sodium has been used for over 55 years for controlling internal decay in utility poles. One disadvantage of this chemical is that it is mostly water (32.7% NaMDC) and it has poor decomposition. Potassium N-methyldithiocarbamate (KMDC) is available in more concentrated form (~54%), but has not been previously explored for this application. The potential for using KMDC was evaluated in the following trial.

Douglas-fir pole sections (283-340 mm in diameter by 3 m long) were pressure treated with pentachlorophenol in P9 Type-A oil before being set to a depth of 0.6 m at our Peavy Arboretum field test site. Three steeply sloping holes were drilled into the poles beginning at groundline and moving upward 150 mm and around the pole 120 degrees.

The poles were treated with 500 mL of NaMDC or KMDC. The holes were plugged with tight fitting plastic plugs. Each treatment was replicated on 5 poles.

These poles will be sampled for MITC levels annually by removing increment cores from three equidistant points around each pole at groundline, 300 mm above groundline, and 600 mm above groundline. These cores will be processed as described earlier to produce inner and outer 25 mm segments that will be extracted in ethyl acetate. The resulting extracts will be analyzed for MITC as described earlier.

These poles will be evaluated for the first time in April 2019.

B. Performance of Water Diffusible Preservatives as Internal Treatments

While fumigants have long been an important tool for utilities seeking to prolong the service life of wood poles and limit internal decay, some users have expressed concerns about chemical risk. Water diffusible preservatives such as boron and fluoride have been developed as potentially less toxic alternatives to fumigants.

Boron has a long history of use as an initial treatment of freshly sawn lumber to prevent infestations by various species of powder post beetles in both Europe and New Zealand. This chemical has also been used more recently for treatment of lumber in Hawaii to limit attack by the Formosan subterranean termite (*Coptotermes formosanus* Shiraki). Boron is attractive as a preservative because it has exceptionally low toxicity to non-target organisms, especially humans, and because it has the ability to diffuse through wet wood. In principle a decaying utility pole should be wet, particularly near groundline, and moisture can be a vehicle for boron to move from the point of application to points of decay. Boron is available for remedial treatments in a number of forms, but the most popular are fused borate rods which come as pure boron or boron with copper. These rods are produced by heating boron to its molten state, then pouring the molten boron into a mold. The cooled boron rods are easily handled and applied. In theory, boron is released as the rods come in contact with water.

Fluoride has also been used in a variety of preservative formulations going back to the 1930's when fluor-chrome-arsenic-phenol was employed as an initial treatment. Fluoride, in rod form, has long been used to treat the area under tie plates in railroad tracks and has been used as a dip-diffusion treatment in Europe. Fluoride can be corrosive to metals, although this should not be a problem in groundline areas. Sodium fluoride is also formed into rods for application, but are less dense than boron rods.

Both of these chemicals have been available for remedial treatments for several decades, but widespread use has only occurred in the last decade and most of this application has occurred in Europe. As a result, there is considerable performance data on boron and fluoride as remedial treatments on European species, but little performance data exists on U.S. species used for utility poles.

Fluoride has largely been phased out of use as a remedial treatment in North America because its limited use did not justify the costs for the testing required to maintain the EPA registration. Boron, however, remains widely used for both initial treatment of lumber and remedial treatment, primarily in external preservative pastes.

1. Effect of Glycol on Movement of Boron from Fused Borate Rods

Date Established:	March 1995
Location:	Peavy Arboretum, Corvallis, OR
Pole Species, Treatment, Size	Douglas-fir, penta
Circumference @ GL (avg., max., min.)	84, 104, 65 cm

This test has been completed. Please consult the 2015 Annual Report for final data.

2. Performance of Copper Amended Fused Boron Rods

Date Established:	November 2001
Location:	Peavy Arboretum, Corvallis, OR
Pole Species, Treatment, Size	Douglas-fir penta and creosote
Circumference @ GL (avg., max., min.)	78, 102, 66 cm

This test will not be sampled again until 2021, 20 years after initial treatment.

3. Diffusion of Boron Through Preservative Treated Wood

One of the advantages of boron as a remedial treatment is its ability to move with moisture through wood. However, this property can also be a disadvantage since high soil moisture surrounding the pole can accelerate boron loss into the soil. Several years ago, we examined the levels of remedial treatment below groundline in poles at the Peavy test site. Results were surprising because we found relatively little boron in this zone, despite moisture levels that should have encouraged diffusion. One possible reason for this loss would be diffusion through the external preservative treated shell. In earlier studies, we examined the possibility of fumigants, notably MITC, diffusing through a treated shell. These results indicated that MITC strongly sorbed to the treated shell but did not diffuse through it. However, we have not explored the potential movement of boron through a treated shell. Work at Mississippi State University developed diffusion coefficients for boron applied as disodium octaborate tetrahydrate, but these tests did not include any oil-treated materials.

We have previously reported on efforts to determine a mass balance for the amount of remedial treatment applied vs the amount found within wood. The first attempt was made with boron rods and it suggested large amounts of boron were unaccounted for. We then examined boron levels in belowground portions of poles receiving boron rods, but this still did not account for boron levels recovered. One further possibility is that boron is diffusing to and through the preservative treated shell and into the surrounding soil. However, adjacent soil analyses did not show elevated boron levels, but the overall amount of boron moving into the soil was likely to be substantially diluted. While boron diffusion through wood has been well studied, the potential for the preservative treated shell to retain boron has received little attention.

We should note here, the data presented in this section does not address whether boron can or cannot move through a preservative treated shell (as is the case with external pastes). Rather, it attempts to establish a rate at which boron diffuses through a preservative treated shell in a controlled laboratory setting.

In order to assess the potential for boron to diffuse through a preservative treated zone and out of the pole, we undertook the following tests. The goal of this work is to develop a mass balance for the amount of boron applied vs the amounts found within wood over time.

Douglas-fir lumber was used to create 25 mm diameter discs oriented so the wide surface presented either a radial or tangential face. These discs were conditioned to a stable moisture content at 23°C and 65% relative humidity before being pressure treated to a target retention of 112 kg/m^3 with biodiesel oil.

Non-treated and oil treated discs were then inserted in a diffusion apparatus constructed using 100 mm diameter PVC piping with one chamber on either side of the disk. The disc was held in place using a threaded connector that effectively sealed each chamber so that any movement would have to occur through the wood. One chamber contained a 4% boric acid equivalent (BAE) solution, while the other contained distilled water. Each chamber had a sampling port that allowed for solution to be removed for analysis of boron concentration (Figure I-1).

A wood disc was placed into the apparatus and appropriate solutions were added to each side. The assembly was placed on its side and maintained at room temperature (21 to 24°C). At intervals, 2 mL of solution were removed from the distilled water side of each apparatus and tested for boron concentration. Distilled water was added back into the chambers so they remained full. The experiment was monitored until boron concentrations in the receiving side (distilled water side) stabilized.

Figure I-1. Photograph of five of the diffusion apparatuses used to assess boron movement through non-treated or diesel oil-treated Douglas-fir lumber. A 25 mm diameter wood sample is resting on the fourth chamber to provide a measure of scale.

Two years ago, we reported on tests that included radially oriented specimens with and without diesel treatment. The experiment was monitored on a regular basis for over 100 days. Boron movement was initially limited in both treated and control samples, but concentrations in control samples with no oil treatment increased at a much more rapid rate after 40 days of exposure (Figure I-2). Concentrations on the receiving ends of control samples have continued to increase at a much faster rate than treated samples. This trial was discontinued because leaks in several chambers led to concerns about spurious results.

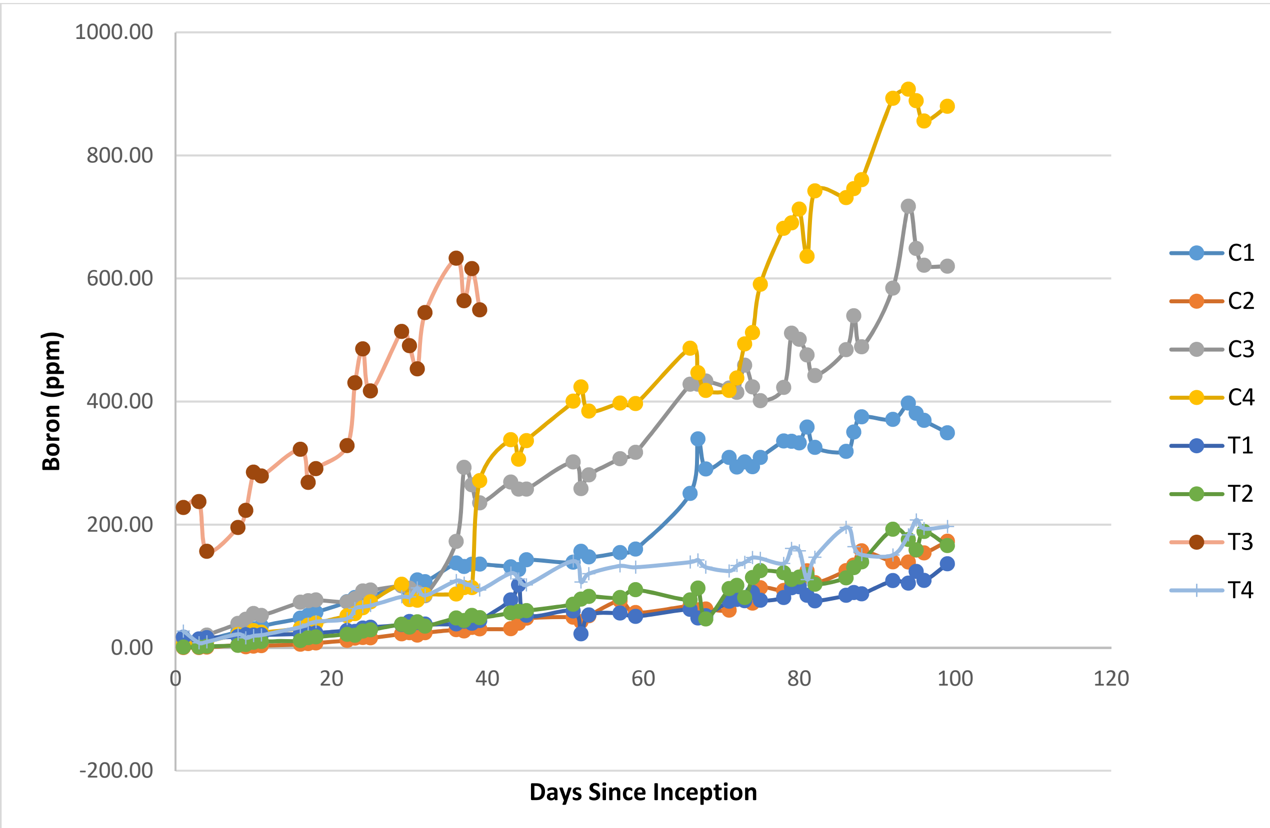

Figure I-2. Boron concentrations on the receiving end of diffusion tests using radially oriented Douglas-fir sapwood with or without a biodiesel treatment where C= no treatment and T= diesel treated samples. The T-3 sample developed a leak and was dropped from the test.

A second test was established last year using a similar set up but with better seals. This test has been monitored for 375 days before leaks developed and the test was terminated (Figure I-3). Boron was detected on the receiving (distilled water) side of the chambers within 25 days in chambers containing either treated or non-treated samples, although levels detected were higher in chambers with untreated samples. Boron levels continued to increase with time in both sets of chambers; however, boron concentrations increased much more rapidly in chambers with untreated wood. Initially, it appeared that boron concentrations in the receiving chamber were reaching an equilibrium state; however, boron levels have continued to gradually increase, suggesting a steady state has not been reached. At this point, boron levels in chambers containing oil-treated wood were 67% of those in chambers containing non-treated wood. These results suggest oil poses an incomplete barrier to boron movement, but boron is still capable of moving through the wood. Thus, low boron levels in poles at the Peavy site may be a function of the extremely high winter water table, which leads to boron leaching into the surrounding soil.

Previous studies of railroad ties dipped in boron prior to air-seasoning and creosote over-treatment have shown creosote helps retain boron in railroad tie interiors for decades after treatment, even when ties are installed in track. Our test site is far wetter than the conditions a tie would be exposed to in a track on a well-drained ballast. This diffusion test suggests boron losses are slowed by preservative treated shells, even when continuously exposed to liquid water. The data can then be used to model boron movement from poles and, hopefully, help explain the results obtained from sampling below-ground boron treated poles in the large scale internal remedial treatment test.

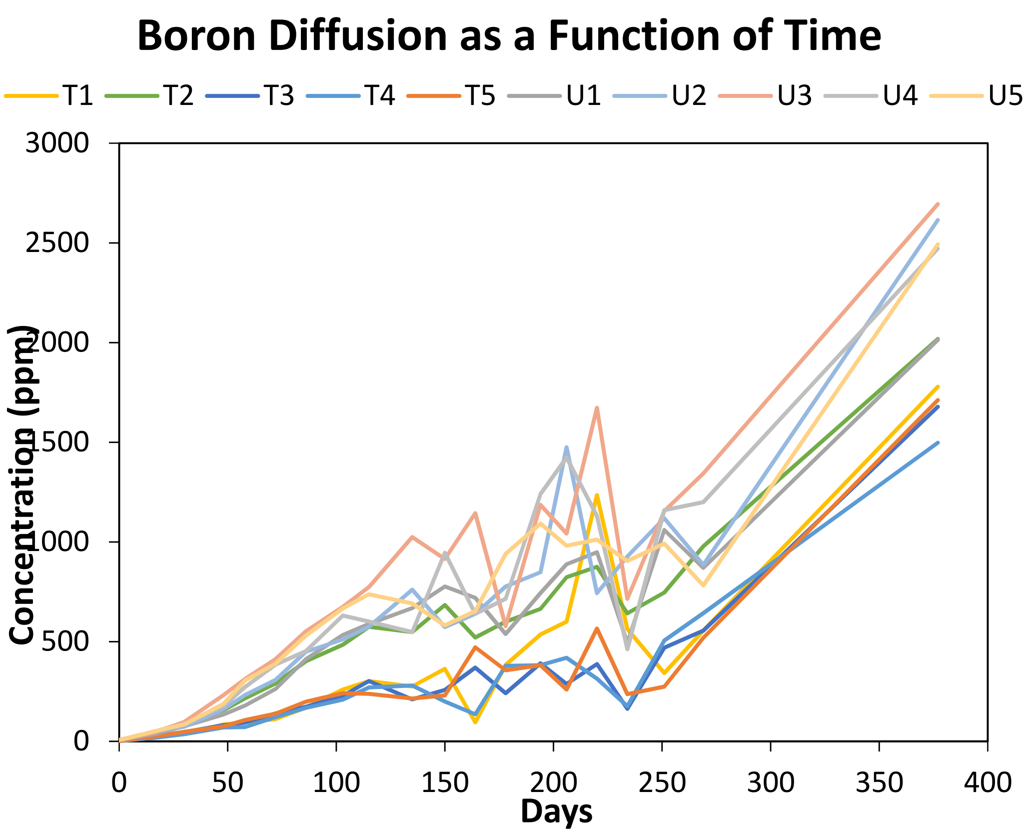

Figure I-3. Boron concentrations vs time on the receiving end of diffusion tests using radially oriented Douglas-fir sapwood with (T samples) or without a biodiesel treatment (U samples).

C. Tests Including Both Fumigants and Diffusibles

1. Full Scale Field Trial of All Internal Remedial Treatments

Date Established:	March 2008
Location:	Peavy Arboretum, Corvallis, OR
Pole Species, Treatment	Douglas-fir, penta
Size: Circumference @ GL (avg., max., min.)	102, 117, 86 cm

We have established numerous field trials to assess the efficacy of internal remedial treatments. Initially, these tests were designed to assess liquid fumigants, but over time, we have also established a variety of tests of solid fumigants and water diffusible pastes and rods. The methodologies in these tests have often varied in terms of the treatment and sampling patterns employed to assess chemical movement. While these differences seem minor, they can make it difficult to compare data from different trials.

We addressed this issue by establishing a single large scale test of all the EPA registered internal remedial treatments at our Corvallis test site (Table I-2).

Table I-2. Internal remedial treatments evaluated on Douglas-fir poles at the Peavy Arboretum test site.

Product Name	Dosage/pole	Additive	Common name	Active Ingredient
DuraFume	280 g	CuNaph	dazomet	Tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2-thione
SUPER-FUME	280 g	CuNaph	dazomet	Tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2-thione
UltraFume	280 g	CuNaph	dazomet	Tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2-thione
Basamid	280 g	CuNaph	dazomet	Tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2-thione
Basamid rods	264 g	CuNaph	dazomet	Tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2-thione
MITC-FUME	120 g	none	methylisothiocyanate	methylisothiocyanate
WoodFume	475 ml	none	metam sodium	Sodium N-methyldithiocarbamate
SMDC-Fume	475 ml	none	metam sodium	Sodium N-methyldithiocarbamate
Pol Fume	475 ml	none	metam sodium	Sodium N-methyldithiocarbamate
Chloropicrin	475 ml	none	chloropicrin	trichloronitromethane
Impel rods	238 g (345 g BAE)	none	boron rod	Anhydrous disodium octaborate
FLURODS	180 g	none	fluoride rod	sodium fluoride
PoleSaver rods	134 g	none	fluoride rod	disodium octaborate tetrahydrate, sodium fluoride

Penta-treated Douglas-fir pole stubs (280-300 mm in diameter by 2.1 m long) were set to a depth of 0.6 m. Three (for poles treated with diffusible rods) and four (for poles treated with fumigants) steeply sloping treatment holes (19 mm x 350 mm long) were drilled into the poles beginning at groundline and moving upward 150 mm and around the pole 120 degrees. The various remedial treatments were added to the holes at the recommended dosage for a pole of this diameter. The treatment holes were then plugged with removable plastic plugs. Copper naphthenate (2% Cu in diesel oil) was added to all dazomet treatments since this compound is known to accelerate dazomet decomposition. The accelerant was poured onto the top of the dazomet in the treatment holes until the visible fumigant appeared to be saturated. The addition of copper naphthenate at concentrations higher than 1% is a violation of the product label and not allowed for commercial applications. No attempt was made to quantify the amount of copper naphthenate added to each treatment hole.

Chemical movement in the poles was assessed 18, 30, 42, 54, 89, and 125 months after treatment by removing increment cores from three equidistant sites beginning 150 mm belowground, then 0, 300, 450, and 600 mm above groundline. An additional height of 900 mm above groundline was sampled for fumigant treated poles in recognition that these chemicals have a greater ability to diffuse upward. The outer, preservative-treated shell was removed, and then the outer and inner 25 mm of each core was retained for chemical analysis using treatment appropriate methodology. The fumigants were analyzed by gas chromatography. Chloropicrin was detected using an electron capture detector while MITC based systems were analyzed using a flame-photometric detector. The remainder of each core was plated on malt extract agar and observed for fungal growth. Boron based systems were analyzed using the Azomethine-H method. Fluoride based systems were analyzed using neutron activation analysis.

Chemical levels in most poles were elevated 18 months after treatment, and gradually declined over the 125 months test (Table I-3). This time interval is a typical remedial treatment cycle for inspection and treatment of poles in North America. Fumigant levels tended to be highest toward the center of the poles at a given height, reflecting the tendency for the sloping holes to direct chemical toward the center. Chemical levels were also highest at or below groundline and then typically declined with distance upward. This is also consistent with the application of the chemicals near groundline. Based upon previous field and laboratory studies, we have used a level of 20 µg of active/oven dried g of wood as a protective threshold for fumigants. This level is based upon extensive chemical analysis of cores removed from poles coupled with culturing of adjacent wood for the presence of decay fungi. Although the properties of the two primary active ingredients in all currently registered fumigants differ dramatically, the threshold for both chloropicrin and methyl isothiocyanate (MITC) is the same.
Wood samples removed from the sodium n-methyldithiocarbamate based (NaMDC) treatments (Pol-Fume, SMDC-Fume, and WoodFume) contained MITC levels that were

Table I-3. Residual MITC levels in Douglas-fir poles 18 to 125 months after application of selected remedial treatments. [a]

Treatment	Cu Naph	months after treatment	Chemical Level (μg/g), Height above groundline (mm): -150		0		300	
			inner	outer	inner	outer	inner	outer
Control	-	18	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		30	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		42	11 (16)	5 (8)	8 (13)	4 (6)	5 (8)	4 (7)
		54	1 (1)	0 (1)	6 (13)	1 (2)	1 (1)	1 (1)
		89	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		125	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Dazomet	+	18	**337** (266)	**158** (196)	**289** (322)	**102** (105)	**163** (112)	**151** (119)
		30	**253** (257)	**78** (73)	**366** (278)	**78** (60)	**201** (139)	**109** (77)
		42	**270** (297)	**165** (146)	**299** (281)	**196** (176)	**181** (212)	**121** (69)
		54	**102** (86)	**63** (45)	**472** (662)	**76** (74)	**123** (116)	**57** (36)
		89	**139** (126)	**55** (35)	**279** (237)	**62** (57)	**100** (65)	**35** (19)
		125	**138** (365)	**38** (41)	**61** (66)	**47** (59)	**76** (128)	**22** (27)
Dazomet rods	+	18	**283** (260)	**181** (347)	**254** (166)	**51** (73)	**159** (66)	**95** (115)
		30	**348** (292)	**149** (169)	**391** (394)	**115** (122)	**220** (90)	**134** (201)
		42	**315** (198)	**171** (145)	**691** (1128)	**176** (129)	**253** (139)	**118** (74)
		54	**233** (256)	**107** (104)	**413** (564)	**107** (95)	**201** (311)	**66** (50)
		89	**113** (62)	**66** (64)	**238** (192)	**61** (77)	**120** (67)	**46** (39)
		125	**27** (28)	6 (11)	**40** (43)	15 (27)	**24** (30)	12 (18)
DuraFume	+	18	**255** (164)	**126** (118)	**160** (87)	**83** (95)	**131** (81)	**82** (79)
		30	**297** (232)	**106** (88)	**333** (359)	**79** (55)	**212** (201)	**72** (44)
		42	**256** (199)	**152** (171)	**243** (150)	**143** (117)	**329** (536)	**87** (43)
		54	**116** (122)	**60** (59)	**134** (131)	**55** (32)	**158** (209)	**54** (44)
		89	**185** (198)	**48** (36)	**146** (104)	**47** (33)	**98** (61)	**41** (39)
		125	**145** (136)	**23** (33)	**130** (108)	**40** (70)	**60** (74)	12 (11)
Super-Fume Tubes	+	18	**173** (152)	**50** (77)	**121** (85)	**46** (46)	**91** (72)	**54** (47)
		30	**138** (160)	**42** (42)	**135** (104)	**58** (73)	**83** (40)	**38** (26)
		42	**132** (150)	**72** (60)	**157** (244)	**50** (38)	**68** (23)	**39** (26)
		54	**120** (211)	**63** (84)	**61** (44)	**36** (18)	**43** (20)	**42** (32)
		89	**87** (100)	**33** (33)	**57** (46)	**25** (40)	**53** (59)	18 (25)
		125	**27** (28)	**21** (27)	**62** (65)	**25** (29)	**39** (49)	**21** (24)
UltraFume	+	18	**174** (92)	**239** (324)	**175** (115)	**136** (183)	**168** (83)	**151** (208)
		30	**229** (188)	**318** (821)	**300** (198)	**136** (162)	**195** (85)	**170** (204)
		42	**246** (267)	**206** (163)	**283** (236)	**194** (187)	**246** (152)	**166** (105)
		54	**158** (116)	**131** (126)	**179** (81)	**97** (59)	**119** (89)	**113** (150)
		89	**91** (62)	**59** (57)	**163** (131)	**50** (38)	**102** (102)	**47** (42)
		125	**54** (44)	**21** (25)	**111** (112)	**34** (42)	**41** (33)	19 (22)
MITC-FUME	-	18	**1868** (1682)	**207** (219)	**24710** (88693)	**560** (1335)	**2085** (1906)	**372** (430)
		30	**1773** (1871)	**565** (435)	**2328** (1945)	**535** (461)	**1318** (1176)	**412** (323)
		42	**1210** (1243)	**712** (1569)	**794** (617)	**334** (187)	**491** (311)	**246** (136)
		54	**612** (1472)	**155** (115)	**180** (123)	**150** (155)	**115** (83)	**78** (61)
		89	**66** (75)	**20** (18)	**37** (35)	20 (23)	18 (21)	9 (10)
		125	13 (19)	4 (10)	7 (8)	3 (7)	4 (7)	1 (4)
Pol Fume	-	18	**132** (74)	**63** (56)	**661** (1539)	**69** (36)	**149** (104)	**120** (168)
		30	**53** (30)	**47** (49)	**52** (36)	**40** (37)	**50** (23)	**47** (24)
		42	**38** (28)	**21** (14)	**27** (17)	**24** (21)	**34** (24)	16 (7)
		54	14 (20)	8 (12)	18 (22)	11 (18)	8 (15)	3 (1)
		89	1 (2)	0 (0)	1 (2)	0 (0)	0 (1)	0 (0)
		125	1 (2)	0 0	0 0	0 0	0 0	0 0
SMDC-Fume	-	18	**152** (75)	**74** (55)	**168** (132)	**50** (22)	**135** (75)	**90** (77)
		30	**76** (50)	**48** (27)	**75** (41)	**40** (19)	**64** (28)	**45** (24)
		42	**39** (28)	20 (9)	**36** (21)	**20** (10)	**25** (8)	14 (3)
		54	11 (8)	6 (6)	11 (13)	4 (3)	10 (18)	5 (4)
		89	0 (1)	0 (1)	0 (1)	0 (0)	0 (0)	0 (0)
		125	0 0	0 0	0 0	0 0	0 0	0 0
WoodFume	-	18	**187** (125)	**91** (120)	**157** (106)	**74** (54)	**156** (107)	**103** (99)
		30	**68** (52)	**38** (32)	**75** (61)	**45** (45)	**57** (40)	**37** (24)
		42	**53** (24)	20 (22)	**33** (21)	17 (19)	**24** (21)	15 (16)
		54	16 (13)	6 (5)	15 (11)	5 (5)	9 (8)	8 (9)
		89	2 (7)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)
		125	0 0	0 0	1 (2)	0 0	0 0	0 0
Chloropicrin	-	18	**37096** (134096)	**6052** (11848)	**16347** (24851)	**18001** (25506)	**22498** (27167)	**12951** (16512)
		30	**12749** (22396)	**4900** (8571)	**1149** (2837)	**1071** (1895)	**6516** (6511)	**1585** (1853)
		42	**6488** (6654)	**2904** (3671)	**4606** (3245)	**1257** (2437)	**3438** (2753)	**4059** (5007)
		54	**2317** (1768)	**267** (413)	**1808** (1503)	**331** (375)	**1023** (1088)	**226** (295)
		89						
		125	**3492** (3965)	**3243** (6665)	**1335** (1210)	**889** (2074)	**723** (749)	**337** (507)

[a] Numbers in parentheses represent one standard deviation around the mean of 15 replicates. Numbers in bold type are above the toxic threshold, 20µg MITC/g dry wood, 20µg chloropicrin/g dry wood.

Table I-3 cont. Residual MITC levels in Douglas-fir poles 18 to 125 months after application of selected remedial treatments. [a]

Treatment	Cu Naph	months after treatment	Chemical Level (µg/g)					
			Height above groundline (mm)					
			450		600		900	
			inner	outer	inner	outer	inner	outer
Control	-	18	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		30	0 (0)	0 (0)	0 (0)	0 (0)	1 (4)	0 (0)
		42	8 (13)	5 (8)	5 (8)	5 (7)	7 (10)	5 (7)
		54	3 (5)	2 (4)	1 (1)	1 (1)	1 (1)	0 (1)
		89	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		125	0 0	0 0	0 0	0 0	0 0	0 0
Dazomet	+	18	**148** (112)	**167** (205)	**107** (99)	**123** (206)	**47** (30)	19 (12)
		30	**165** (102)	**93** (55)	**142** (110)	**106** (95)	**75** (38)	**48** (46)
		42	**128** (66)	**125** (108)	**114** (58)	**106** (103)	**99** (63)	**96** (144)
		54	**90** (70)	**49** (26)	**87** (67)	**51** (39)	**65** (48)	**42** (56)
		89	**54** (28)	**27** (15)	**34** (21)	**25** (28)	**31** (23)	10 (8)
		125	**32** (44)	14 (24)	18 (17)	9 (9)	12 (12)	9 (12)
Dazomet rods	+	18	**147** (55)	**118** (168)	**97** (53)	**53** (69)	**49** (36)	9 (21)
		30	**153** (55)	**84** (64)	**114** (52)	**72** (82)	**79** (37)	**29** (23)
		42	**170** (53)	**118** (98)	**138** (79)	**85** (71)	**77** (32)	**35** (21)
		54	**105** (96)	**59** (47)	**83** (58)	**80** (82)	**49** (39)	**89** (99)
		89	**77** (51)	**42** (58)	**51** (31)	**24** (24)	**34** (11)	7 (9)
		125	10 (9)	7 (10)	7 (10)	**21** (37)	8 (18)	11 (23)
DuraFume	+	18	**132** (59)	**105** (109)	**99** (86)	**90** (134)	**45** (22)	**27** (37)
		30	**120** (73)	**57** (37)	**92** (51)	**49** (23)	**58** (34)	**32** (18)
		42	**111** (52)	**88** (73)	**76** (38)	**56** (44)	**46** (26)	**36** (29)
		54	**60** (32)	**67** (64)	**68** (54)	**64** (88)	**60** (53)	**68** (97)
		89	**46** (33)	**26** (31)	**21** (20)	17 (18)	16 (12)	3 (5)
		125	**36** (29)	13 (12)	13 (16)	8 (12)	10 (14)	3 (6)
Super-Fume Tubes	+	18	**60** (22)	**60** (44)	**39** (17)	**38** (30)	**35** (72)	16 (19)
		30	**54** (21)	**31** (15)	**37** (19)	**24** (22)	**25** (10)	12 (11)
		42	**53** (33)	**40** (32)	**44** (21)	**23** (10)	**24** (13)	11 (8)
		54	**30** (12)	**26** (21)	**37** (29)	**40** (67)	**27** (31)	**33** (54)
		89	**28** (26)	13 (18)	16 (19)	9 (14)	13 (19)	4 (7)
		125	**26** (18)	19 (19)	17 (11)	14 (26)	14 (23)	9 (16)
UltraFume	+	18	**112** (51)	**113** (134)	**98** (72)	**77** (65)	**59** (69)	**26** (20)
		30	**156** (79)	**103** (112)	**127** (74)	**87** (64)	**76** (47)	**39** (24)
		42	**150** (63)	**125** (81)	**143** (57)	**175** (187)	**78** (47)	**82** (80)
		54	**69** (36)	**211** (530)	**55** (24)	**52** (31)	**39** (19)	**30** (29)
		89	**44** (23)	**42** (37)	**37** (20)	**30** (40)	**20** (15)	10 (10)
		125	**20** (14)	13 (12)	11 (9)	8 (8)	2 (4)	0 (1)
MITC-FUME	-	18	**1574** (2239)	**360** (332)	**840** (673)	**283** (214)	**848** (764)	**235** (208)
		30	**882** (932)	**292** (236)	**904** (1066)	**330** (279)	**662** (589)	**261** (250)
		42	**389** (281)	**184** (107)	**350** (284)	**189** (106)	**369** (250)	**165** (117)
		54	**107** (70)	**77** (50)	**85** (41)	**68** (51)	**73** (50)	**98** (104)
		89	13 (13)	7 (7)	14 (13)	5 (7)	15 (14)	9 (11)
		125	1 (4)	1 (3)	1 (2)	1 (2)	1 (3)	1 (3)
Pol Fume	-	18	**136** (76)	**123** (111)	**118** (61)	**78** (58)	**65** (29)	**35** (26)
		30	**51** (26)	**39** (20)	**53** (26)	**45** (23)	**41** (22)	**23** (19)
		42	**25** (18)	15 (7)	**24** (17)	16 (8)	**20** (9)	14 (7)
		54	3 (2)	3 (2)	3 (1)	4 (2)	8 (13)	4 (2)
		89	0 (0)	0 (0)	1 (3)	0 (0)	0 (0)	0 (0)
		125	0 0	0 0	0 0	0 0	0 0	0 0
SMDC-Fume	-	18	**144** (112)	**71** (52)	**114** (89)	**61** (47)	**72** (51)	**24** (23)
		30	**56** (26)	**37** (19)	**49** (20)	**31** (16)	**52** (37)	**25** (15)
		42	**26** (12)	13 (4)	**24** (10)	13 (5)	**27** (15)	13 (13)
		54	4 (2)	4 (2)	5 (3)	3 (2)	9 (19)	3 (3)
		89	1 (2)	0 (1)	1 (3)	0 (0)	0 (0)	0 (0)
		125	0 0	0 0	0 0	0 0	0 0	0 0
WoodFume	-	18	**127** (79)	**85** (112)	**129** (62)	**100** (112)	**95** (48)	**46** (60)
		30	**53** (34)	**35** (21)	**48** (25)	**33** (26)	**55** (28)	**32** (30)
		42	20 (15)	14 (16)	**25** (24)	13 (13)	**26** (17)	12 (12)
		54	6 (5)	8 (13)	5 (5)	4 (3)	6 (4)	4 (4)
		89	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		125	1 (5)	0 0	0 0	0 0	0 0	0 0
Chloropicrin	-	18	**9263** (14788)	**6772** (13209)	**3429** (6239)	**606** (853)	**795** (780)	**86** (181)
		30	**424** (1009)	**2307** (5072)	**3582** (4241)	**1129** (1819)	**3691** (11390)	**278** (339)
		42	**1546** (1472)	**1363** (1131)	**1720** (1489)	**678** (837)	**1639** (1990)	**310** (560)
		54	**867** (931)	**276** (376)	**984** (1040)	**381** (621)	**387** (509)	**604** (1219)
		89						
		125	**1324** (2516)	**369** (619)	**613** (780)	**345** (393)	**202** (219)	**451** (411)

[a] Numbers in parentheses represent one standard deviation around the mean of 15 replicates. Numbers in bold type are above the toxic threshold, 20µg MITC/g dry wood, 20µg chloropicrin/g dry wood.

3 to 5 times the 20 µg of MITC/oven dried g of wood threshold 18 months after treatment. These levels then declined steadily over the next 24 months but were still over threshold at most sampling locations 42 months after treatment. MITC levels have continued to decline and were all uniformly below the threshold level 54 months after treatment (Figure I-4). MITC is virtually non-detectable in these same poles after 125 months. These findings are consistent with previous tests of this chemical. These formulations contain 33% NaMDC in water. The NaMDC decomposes in the presence of organic matter (e.g. wood) to produce a range of sulfur containing compounds including carbon disulfide, carbonyl sulfide, and, most importantly, MITC.

The theoretical decomposition rate of NaMDC to MITC is 40% of the original 32.1%, but numerous tests suggest that the rate in wood is actually nearer to 20% of the original treatment. As a result, NaMDC-based treatments should produce much lower levels of chemical in the wood than any of the other MITC based systems and their retention in the pole should be relatively short. Some users of these treatments have raised concerns about the potential for this shorter protective period to allow decay fungi to re-colonize the poles and cause renewed damage before the next treatment cycle (which should be 10 years). However, there is evidence that decay fungi do not re-colonize the poles very quickly and, in some cases, they never reach levels at which they were present prior to treatment. For this reason, there is a substantial time lag between loss of chemical protection and re-colonization that permits the use of this treatment.

MITC-FUME treated poles contained the highest MITC levels of any product 18-months after treatment, approaching 100 times the threshold 150 mm below and 300 mm above groundline. MITC levels have declined steadily since that time, but were still well above the threshold for protection against fungal attack 54 months after treatment (Figure I-5). For example, MITC levels in the inner zones of cores removed 150 mm below groundline averaged 612 µg/g of wood, over 30 times the threshold at 54 months. MITC levels at other locations are somewhat lower, but are still three to nine times threshold. MITC levels in poles 89 months after treatment had declined sharply from those at 54 months. While the levels were above the threshold at or below groundline, MITC levels above ground were no longer protective. MITC levels after 125 months were mostly below threshold for fungal protection, indicating retreatment would be advisable. These results illustrate the excellent properties of this treatment and are consistent with the original field trials showing protective levels remained in Douglas-fir poles 7 years after treatment. These results indicate MITC-FUME would easily provide protection against renewed fungal attack for 10 years based upon the time required for fungi to begin reinvading fumigant-treated poles.

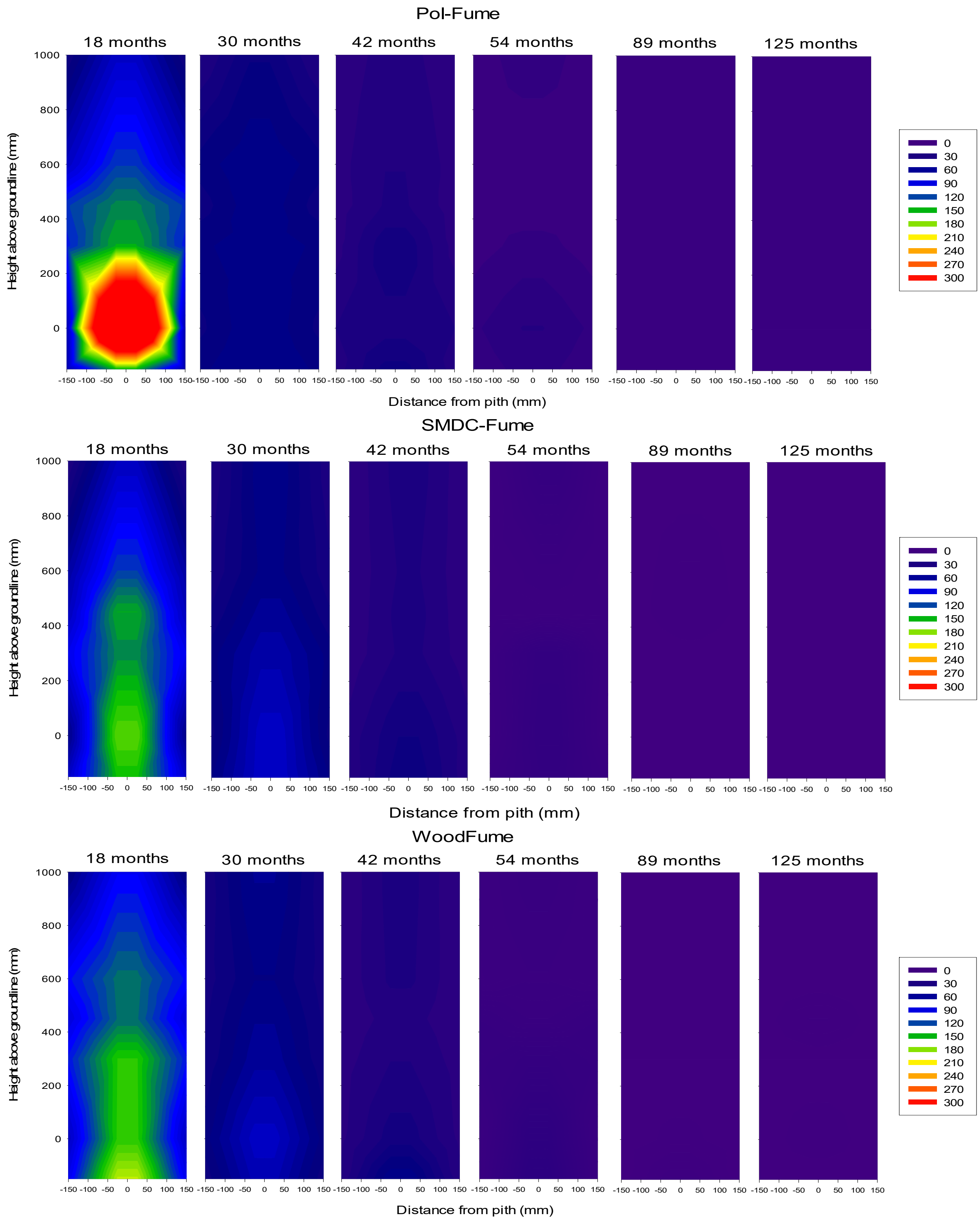

Figure I-4. Distribution of MITC in Douglas-fir pole sections 18 to 125 months after treatment with Pole Fume, SMDC Fume or Wood-Fume. Dark blue signifies little or no chemical while increasingly light blue to green or yellow signifies MITC levels above the threshold. Charts are extrapolated from individual MITC analyses at assay locations described in Table I-3.

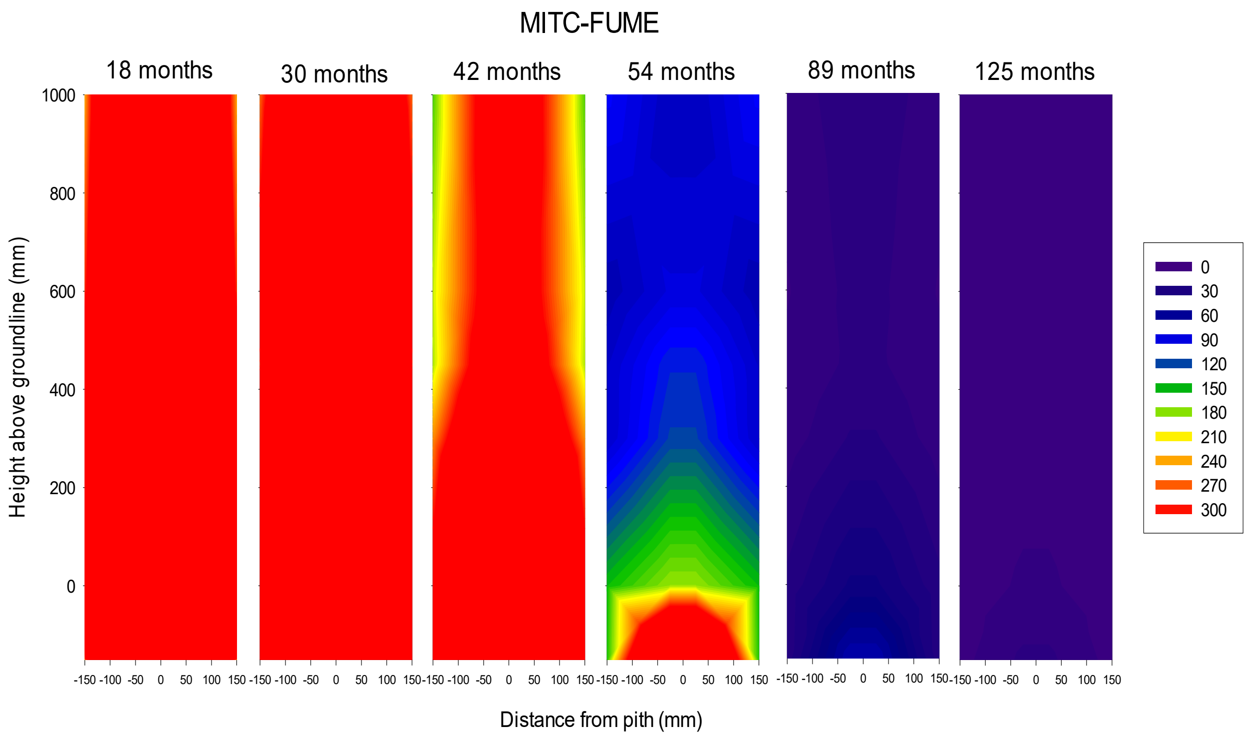

Figure I-5. Distribution of MITC in Douglas-fir pole sections 18 to 125 months after treatment with MITC-Fume. Dark blue signifies little or no chemical while increasingly light blue to green or yellow signifies MITC levels above the threshold. Charts are extrapolated from individual MITC analyses at assay locations described in Table I-3.

Like NaMDC, dazomet decomposes to produce a range of sulfur-containing compounds. The most important of these decomposition products is MITC. Unlike NaMDC, dazomet is a powder, which sharply reduces the risk of worker contact or spilling. Originally, dazomet decomposition in wood was viewed as too slow for this chemical to be of use as a remedial pole treatment, but extensive research indicated that the process could be improved by adding copper compounds to the powder at the time of application to accelerate decomposition to MITC. At present, dazomet is commonly applied with a small dosage of oil-borne copper naphthenate.

Dazomet was applied to the test poles as a powder, in rod form, or in tubes. All holes received copper naphthenate at the time of treatment to accelerate decomposition. MITC levels 150 mm below groundline in poles receiving dazomet powder (dazomet, DuraFume, or UltraFume) 18 months earlier ranged from 8-11 times threshold in UltraFume-treated poles, to 7 to 16 times threshold in the dazomet-treated poles. In general, MITC levels were well over the threshold in all dazomet treatments although the levels 900 mm above groundline were sometimes below threshold. MITC levels were all above threshold 30 and 42 months after treatment, reflecting the ability of this treatment to continue to decompose to produce MITC over time. MITC levels 54 months after treatment were still above the threshold at all sampling locations, but the overall levels had declined by 30 to 50% over the 12 month interval (Figure I-6). MITC levels after 54 months were still 3 to 11 times above the minimum threshold, and, as in previous trials, we have observed periodic surges in MITC levels in dazomet-treated poles. We have attributed these increases to periods of elevated rainfall that increased wood moisture content, thereby enhancing residual dazomet decomposition in the treatment holes. It is impossible to predict whether this will occur during our testing, but MITC levels do remain adequate to provide protection against fungal attack in all dazomet treatments. MITC levels 89 months after application of the three dazomet systems were above threshold from below groundline to 600 mm above groundline. Overall levels continued to decline but MITC concentrations remained 3 to 6 times threshold at many locations. MITC levels in poles 125 months after treatment remain above threshold 300 mm below ground to 300 mm above the zone. MITC levels were more variable above that level, but many areas still contained protective levels of chemical. These results are also consistent with previous field trials and indicate this system will provide at least the 10 year protective period used by most utilities in their inspection and treatment cycles. There also appeared to be little difference in performance between dazomet treatments.

MITC levels in poles receiving either dazomet in rod form or in tubes (Super-Fume tubes) tended to be lower than levels found in poles receiving powdered treatments, but were still above the threshold at all sampling points below groundline and up to the 900 mm above groundline. Chemical levels near the surface at 900 mm were more variable than in the powdered treatments (Figure I-7). The rods and tubes both may restrict contact between the wood and the chemical, creating the potential for reduced decomposition. There were negligible differences in MITC levels between poles receiving powdered or rod dazomet for most of the test. The tubes appeared to have a greater effect on MITC levels, with consistently lower MITC levels than the other dazomet based systems; however, levels remained 1.5 to 6 times threshold at 54 months at all sampling locations. These results indicate that, while the tubes slow MITC release, this does not result in chemical levels below threshold at 54 months. The results at 89 months indicated MITC levels continued to decline in poles treated with either the rod or the tube system. MITC levels were still above the threshold up to 300 mm above groundline, then declined below threshold higher up the poles. As in previous inspections, MITC levels were slightly lower in poles receiving tubes than rods. Dazomet rods produced MITC levels that were similar to those found with powder for the first 54 months. MITC levels after that time were slightly lower in poles receiving either rods or tubes and were approaching threshold at 125 months. Results indicate dazomet rod or tube systems would provide 10 year inspection cycle protection.

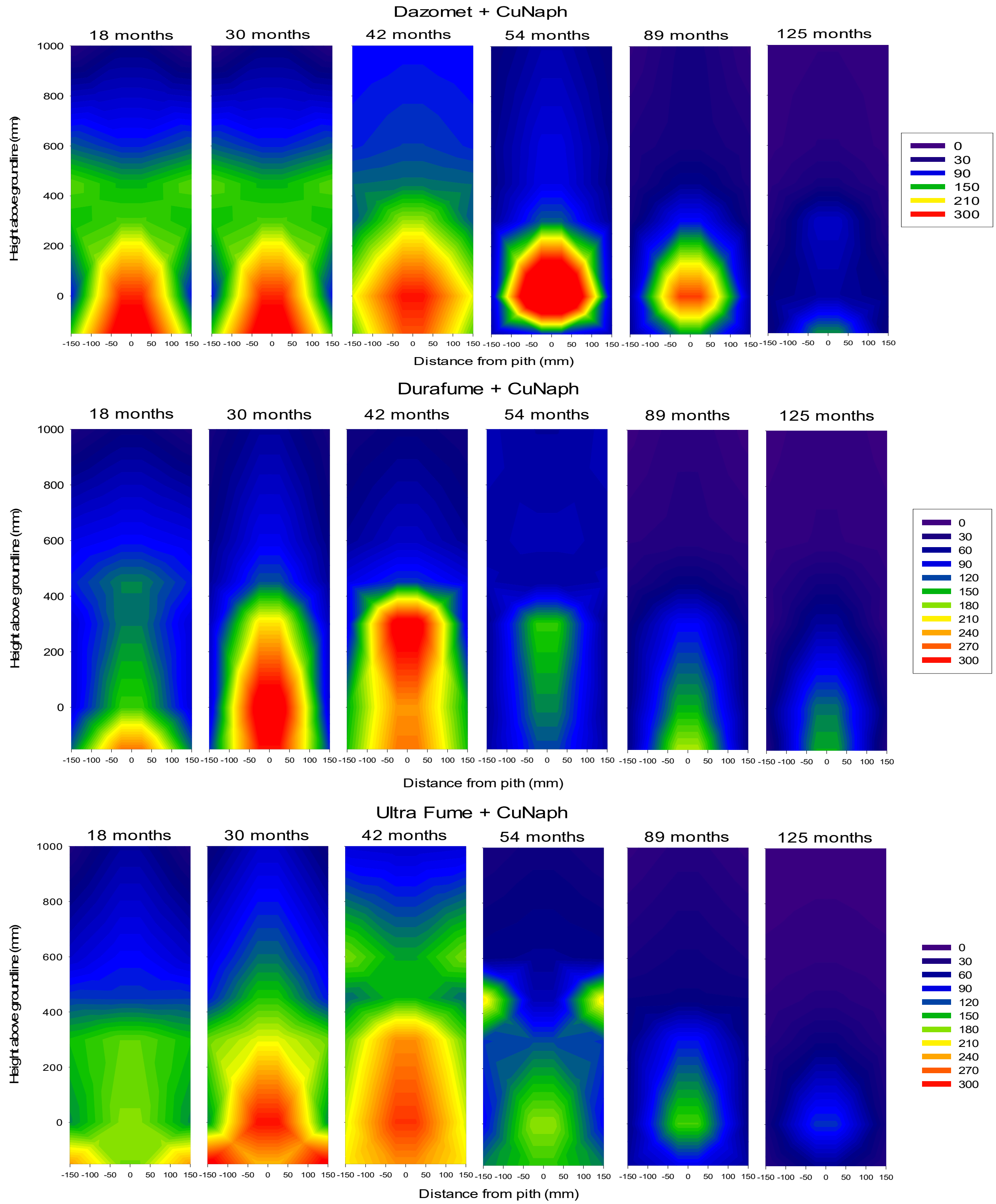

Figure I-6. Distribution of MITC in Douglas-fir pole sections 18 to 125 months after treatment with dazomet, DuraFume, or UltraFume plus copper naphthenate. Dark blue signifies little or no chemical while increasingly light blue to green or yellow signifies MITC levels above threshold. Charts are extrapolated from individual MITC analyses at assay locations described in Table I-3.

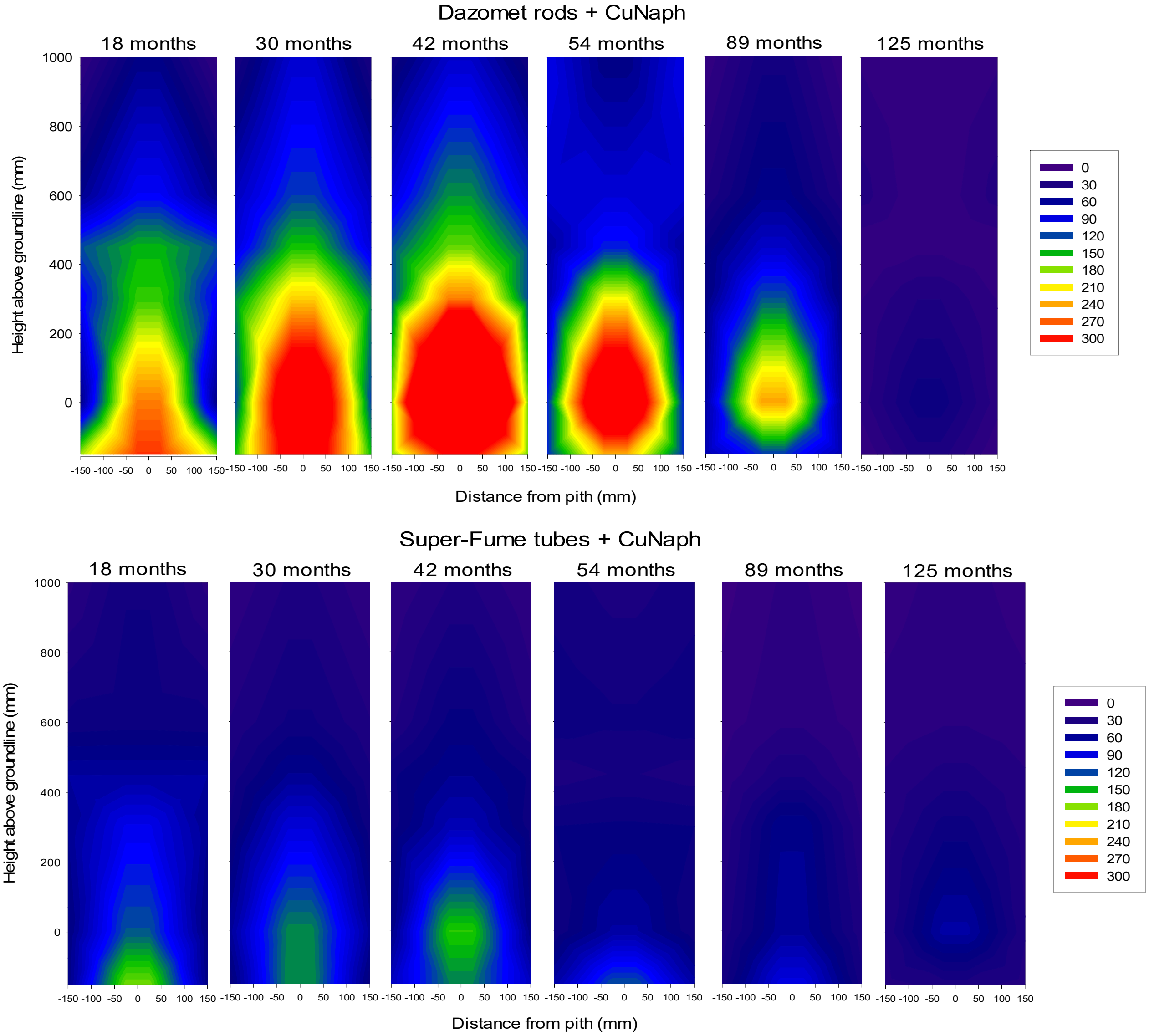

Figure I-7. Distribution of MITC in Douglas-fir pole sections 18 to 125 months after treatment with dazomet rods or Super-Fume tubes plus copper naphthenate. Dark blue signifies little or no chemical while increasingly light blue to green or yellow signifies MITC levels above the threshold. Charts are extrapolated from individual MITC analyses at assay locations described in Table I-3.

The results of all treatments support previous tests done on individual systems as they were developed. In general, the results show metam sodium provides the shortest protective period, while MITC-FUME and the dazomet treatments provide longer-term protection consistent with the typical pole retreatment cycle.

Chloropicrin levels in the poles were more than 2000 times the 20 µg/oven dried g of wood threshold in the inner zone of poles belowground 18 months after treatment.

Levels declined marginally 30 months after treatment, but remained extremely high. Chloropicrin levels appeared to increase at the 42 month evaluation, but a re-examination of the data revealed that the levels reported in the 2012 annual report were approximately double the actual value. The revised values continue to show a steady decline at the 42 month point, but chloropicrin levels remained 17 to 350 times threshold. Chloropicrin retentions 54 months after treatment declined further, but remained 13 to 100 times threshold (Figure I-8). Chloropicrin was not analyzed in the 89 month sampling, but was analyzed after 125 months. Chemical levels were 10 to 150 times threshold, with lower levels further above groundline. Most levels were 50 to 100 times threshold. Unlike MITC, chloropicrin has strong chemical interactions with wood which results in much longer residual times. We have found detectable chloropicrin in poles 20 years after treatment and the results in the current study are consistent with a long residual protective period for this fumigant.

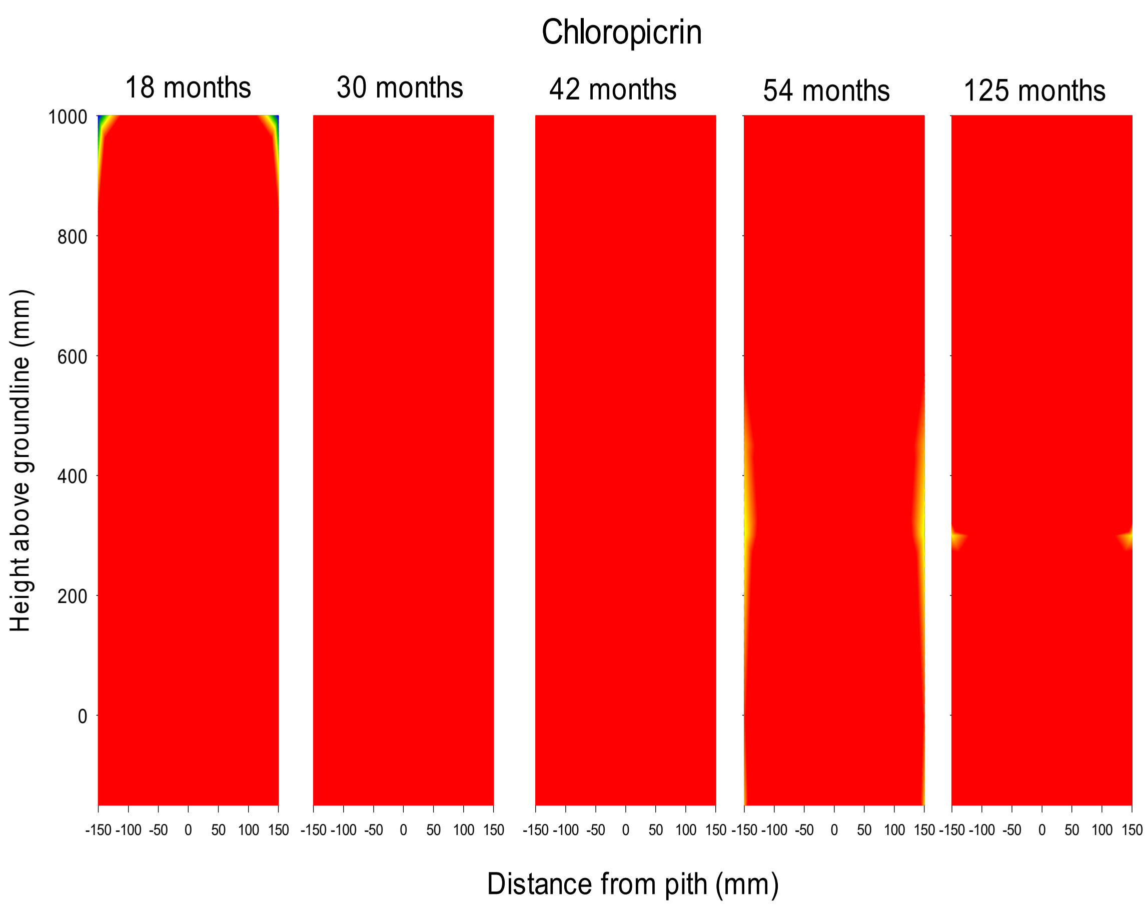

Figure I-8. Distribution of chloropicrin in Douglas-fir pole sections 18 to 54 months after treatment with TimberFume. Red indicates chloropicrin levels multiple times over threshold. Charts are extrapolated from individual chloropicrin analyses at assay locations described in Table I-3.

Boron-based internal remedial treatments have been available in Europe since the late 1970's, but were not introduced into the US until much later. Unlike fumigants, which diffuse as gases, boron moves with moisture. Generally, wood moisture levels must be above the point where free water is present or the fiber saturation point for diffusion to occur. Elevated moisture levels should be present at groundline in most poles, except under drier conditions where moisture tends to be deeper in the soil.

The threshold for boron for protection against internal decay has been calculated at 0.6 kg/m^3 (Freitag and Morrell 2005). This value is based upon carefully controlled trials of wafers treated to specific levels with boron.

Boron levels in poles receiving Impel rods or Pole Saver rods tended to be below threshold 300 or more mm above the groundline, regardless of sampling time or core position (Table 1-4). While boron is water diffusible, it has a limited ability to diffuse upward. Boron levels 150 mm below groundline and at groundline were above threshold in the inner zone for both Impel Rod and Post Saver rod-treated poles 18 months after treatment, but below threshold in the outer zone. The difference again reflects the tendency of the sloping treatment holes to direct chemical downward toward the center of the pole. Boron levels were above threshold for both inner and outer zones 30 months after treatment with either rod system, but still below threshold in the outer zone 150 mm below groundline. Boron levels were all well above threshold both below and at groundline 42 and 54 months after treatment (Figure I-9). Boron levels in pole sections treated with either rod system remained above threshold in the inner zones at or below groundline 89 and 125 months after treatment, but had declined below that level in the outer zones of poles receiving PolSaver rods.

Boron achieved threshold levels 300 mm above groundline at only one point in the inner zone of poles receiving Impel Rods. These results are consistent with previous tests showing uniform boron movement requires several years. If these trends continue, we would expect to find elevated boron levels in the poles for 5 to 7 more years. This would be consistent with our long-term boron rod trials. Boron levels in Impel Rods and Post Saver rods appear to be similar near groundline while boron levels are higher in Impel Rod-treated poles in the inner zone belowground. An alternative approach to examining boron distribution would be to look at the inner zones at groundline or belowground over the test period (Figure I-9). The inner zone is likely to present a more stable environment for moisture that would facilitate boron movement over time. As we view these data, we can begin to see distribution patterns. Boron levels belowground in the inner zones of poles treated with PolSaver rods remained low for the entire exposure period, while they were at very high levels early in the exposure period then declined over time at groundline. Boron is not the only chemical in these rods (which contain fluoride as well), but previous studies have indicated that fluoride levels remain very low. Soil moisture levels at this test site are high in winter which should facilitate boron loss from poles over time, especially belowground. Boron levels in poles treated with Impel rods rose between 18 and 30 months, 150 mm below groundline, then steadily declined over time. However, boron levels were more than two times higher than those found in PolSaver poles. Boron levels at groundline in Impel rod-treated poles varied more widely during the test. Impel rods represent a highly densified boron delivery system, while PolSaver rods are less dense and therefore have less material to deliver. Our results closely follow those differences, although it is important to note that boron levels in poles treated with both systems are well over the protective level 89 months after treatment. Overall trends indicate boron-based systems are producing protective levels within the groundline zone, but diffusion above this zone is very limited.

In the past, we often have not included fungal colonization rates in our discussion; however, we have completed these analyses during each sampling period (Table I-5). The incidence of decay fungi were fairly high in the non-remedially treated control poles, especially at or below groundline. Isolation levels were also somewhat higher in poles treated with the metam sodium systems (Pole Fume, SMDS Fume, or Wood -Fume), reflecting the short-term protection afforded by this fumigant. Isolations were highest in poles treated with Pole Fume in the zone 300 mm to 1 m above groundline. This zone would be consistent with the area where the fumigant was likely to dissipate fastest after treatment. Decay fungi were also isolated sporadically from poles treated with Super-Fume tubes or Dura-Fume, but levels were low and showed no evidence of a colonization pattern. One decay fungus was isolated from a chloropicrin-treated pole which was interesting given the extraordinarily high levels of residual fumigant.

Decay fungi were also isolated from cores removed from Impel rod, Post-Saver rod, or FluRod-treated poles; however, the levels were extremely low with FluRod and Post Saver rods. Decay fungi were present at higher levels beginning 300 mm above groundline in Impel rod poles. Water diffusible systems tend to remain relatively close to the point of application and should not move upward for appreciable distances. Isolation of decay fungi above the application point is consistent with these tendencies and illustrates the need to reconsider application patterns for water diffusible treatments because chemicals do not move upward for substantial distances.

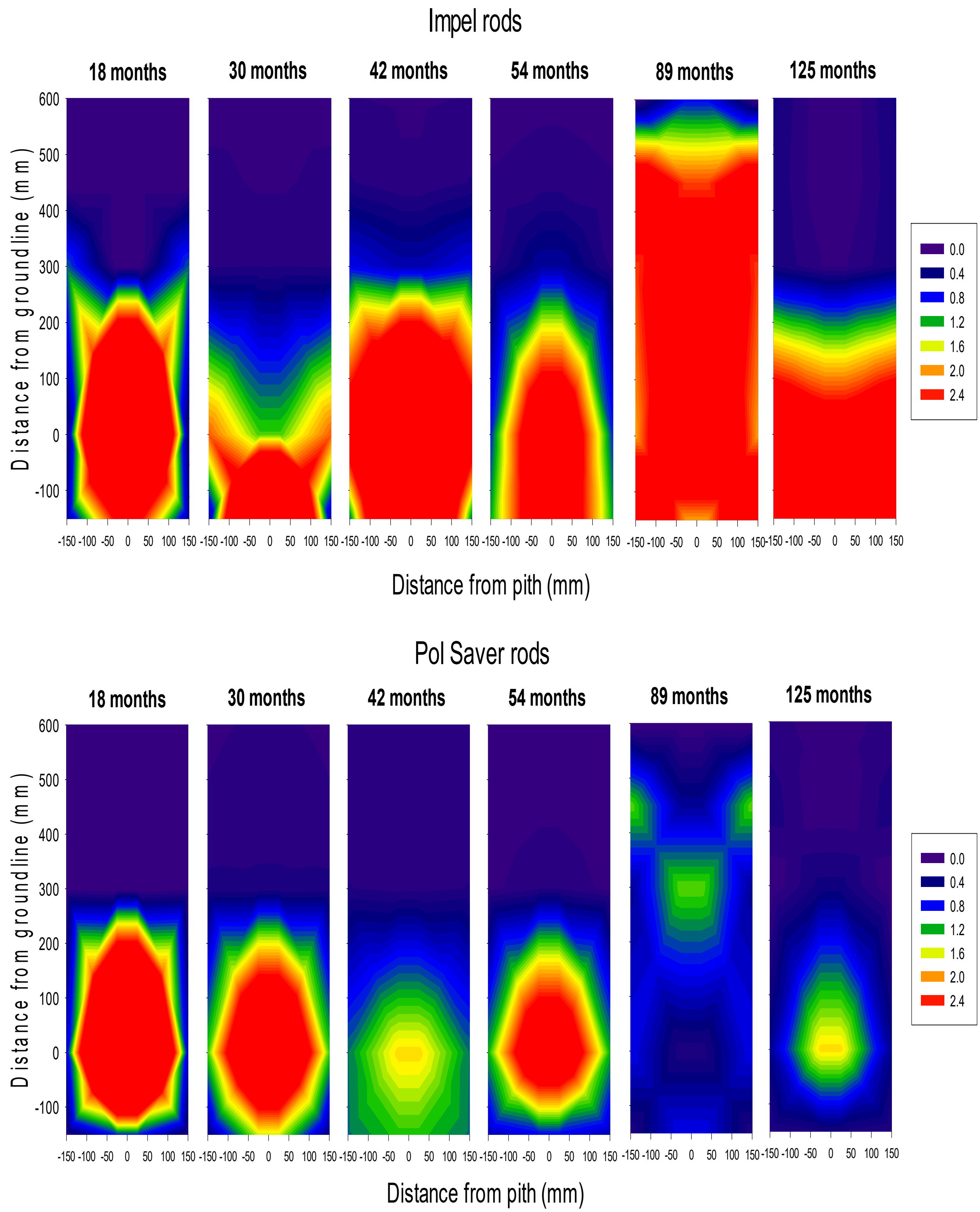

Figure I-9. Distribution of boron in Douglas-fir pole sections 18 to 125 months after treatment with Impel or PolSaver Rods. Dark blue signifies little or no chemical while increasingly light blue to green or yellow signifies boron levels above the threshold. Charts are extrapolated from individual boron analyses at assay locations described in Table I-3.

Table I-4. Boron levels at various distances above and below the groundline in Douglas-fir poles 18 to 125 months after application of Impel or Pole Saver rods.

Treatment	Time (Mo)	Residual Boron Content (kg/m^3 B_2O_3)[a]									
		150 mm below GL		Groundline		+300 mm		+450 mm		+600 mm	
		inner	outer	inner	outer	inner	outer	inner	outer	inner	outer
None	18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.07	0.07	0.07	0.06	0.08	0.08	0.10	0.06	0.08	0.07
	42	0.18	0.19	0.21	0.18	0.21	0.20	0.19	0.21	0.21	0.08
	54	0.00	0.04	0.03	0.01	0.00	0.00	0.00	0.01	0.00	0.03
	89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	125	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Impel Rods	18	**2.59**	0.37	**7.68**	0.16	0.02	**0.97**	0.02	0.02	0.02	0.00
	30	**6.67**	0.39	**1.30**	**2.14**	0.16	0.15	0.07	0.10	0.07	0.05
	42	**5.49**	**0.98**	**6.30**	**3.09**	**0.53**	**0.72**	0.09	0.17	0.07	0.08
	54	**3.34**	**1.12**	**3.57**	**0.84**	0.47	0.13	0.12	0.09	0.06	0.04
	89	**1.91**	**3.95**	**3.16**	**2.25**	**0.76**	0.00	0.06	0.00	0.00	0.00
	125	**4.00**	**3.13**	**2.99**	**3.50**	**0.07**	0.24	0.00	0.23	0.00	0.25
Pol Saver	18	**0.84**	0.14	**7.50**	**0.61**	0.00	0.04	0.02	0.06	0.02	0.03
	30	**1.54**	0.31	**4.44**	**1.28**	0.18	0.18	0.12	0.09	0.09	0.07
	42	**1.24**	**1.02**	**1.73**	**1.03**	0.13	0.16	0.11	0.11	0.13	0.11
	54	**0.74**	**0.53**	**3.56**	**1.17**	0.15	0.05	0.06	0.00	0.05	0.00
	89	**0.72**	0.18	**1.34**	0.44	0.01	0.00	0.08	0.00	0.00	0.07
	125	0.23	0.14	**1.72**	0.41	0.27	0.00	0.00	0.22	0.05	0.10

[a] Values represent means of 3 samples per height from each of 5 poles per treatment. Figures in bold are above the threshold for protection against internal fungal attack. Inner represents the innermost 25 mm of the core, while outer represents the 25 mm inside the preservative treated zone.

Table I-5. Degree of fungal colonization (%) in Douglas-fir poles 18 to 125 months after internal remedial treatment with water diffusible rods or fumigants. [a]

Treatment	Cu Naph	Months After Treatment	Height above groundline (mm)						Pole
			-150	0	300	450	600	1000	
Fumigant Control	-	18	33 [17]	17 [0]	0 [0]	0 [0]	0 [0]	0 [0]	8 [3]
		30	33 [50]	33 [50]	17 [17]	0 [17]	0 [17]	0 [0]	14 [25]
		42	50 [50]	50 [50]	50 [50]	33 [50]	33 [17]	0 [50]	36 [44]
		54	22 [11]	33 [0]	11 [0]	33 [0]	33 [0]	22 [0]	26 [2]
		89	33 [56]	56 [56]	56 [33]	56 [11]	44 [22]	22 [44]	44 [37]
		125	67 [100]	67 [89]	56 [22]	44 [56]	44 [78]	0 [56]	46 [67]
Dazomet	+	18	0 [7]	0 [0]	7 [13]	0 [7]	0 [7]	0 [7]	1 [7]
		30	0 [0]	0 [0]	0 [0]	0 [7]	0 [0]	0 [0]	0 [1]
		42	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]
		54	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]
		89	0 [0]	0 [7]	0 [0]	0 [0]	0 [0]	0 [7]	0 [2]
		125	0 [20]	7 [20]	7 [0]	0 [0]	0 [13]	0 [13]	2 [11]
Dazomet rods	+	18	0 [0]	0 [7]	0 [0]	0 [0]	0 [0]	0 [7]	0 [2]
		30	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]
		42	0 [0]	0 [7]	0 [0]	0 [0]	0 [0]	0 [0]	0 [1]
		54	0 [0]	0 [0]	0 [0]	0 [0]	0 [7]	0 [0]	0 [1]
		89	0 [7]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [1]
		125	0 [33]	0 [13]	0 [0]	0 [0]	0 [7]	0 [7]	0 [10]
DuraFume	+	18	0 [7]	0 [7]	0 [0]	0 [0]	0 [7]	0 [7]	0 [4]
		30	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]
		42	0 [0]	0 [7]	0 [0]	0 [7]	0 [0]	0 [0]	0 [2]
		54	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]
		89	0 [0]	0 [7]	0 [7]	7 [7]	0 [0]	0 [0]	1 [3]
		125	13 [33]	0 [7]	0 [20]	0 [0]	0 [13]	0 [0]	2 [12]
MITC-FUME	-	18	0 [0]	0 [13]	0 [0]	0 [0]	0 [0]	0 [0]	0 [2]
		30	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]
		42	0 [0]	0 [7]	0 [0]	0 [0]	0 [0]	0 [0]	0 [1]
		54	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]
		89	0 [7]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [1]
		125	7 [40]	0 [33]	0 [33]	7 [40]	7 [33]	0 [7]	3 [31]
Pol Fume	-	18	0 [0]	0 [7]	0 [7]	0 [13]	0 [0]	0 [20]	0 [8]
		30	0 [0]	0 [13]	0 [0]	0 [0]	0 [0]	0 [7]	0 [3]
		42	7 [7]	0 [0]	7 [7]	0 [7]	7 [7]	0 [0]	3 [4]
		54	0 [7]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [1]
		89	0 [60]	0 [87]	27 [27]	40 [27]	27 [7]	0 [40]	16 [41]
		125	33 [47]	40 [47]	33 [33]	33 [53]	33 [40]	33 [60]	34 [47]
SMDS-Fume	-	18	0 [0]	0 [13]	0 [7]	0 [7]	0 [13]	0 [7]	0 [8]
		30	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]
		42	0 [0]	0 [0]	0 [7]	0 [0]	0 [0]	0 [0]	0 [1]
		54	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]	0 [0]
		89	0 [67]	7 [73]	0 [13]	0 [27]	0 [40]	0 [20]	1 [40]
		125	0 [87]	7 [73]	20 [53]	7 [47]	0 [40]	0 [73]	6 [62]

Table I-5 cont. Degree of fungal colonization (%) in Douglas-fir poles 18 to 125 months after internal remedial treatment with water diffusible rods or fumigants. [a]

Treatment	Cu Naph	Months After Treatment	Height above groundline (mm) -150	0	300	450	600	1000	Pole
Super-Fume Tubes	+	18	0^{0}	0^{0}	0^{13}	0^{7}	0^{0}	0^{7}	0^{4}
		30	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		42	0^{7}	0^{0}	0^{7}	0^{7}	0^{7}	0^{0}	0^{4}
		54	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		89	7^{0}	0^{0}	0^{20}	0^{13}	0^{0}	0^{0}	1^{6}
		125	0^{20}	0^{20}	0^{13}	0^{0}	7^{0}	0^{7}	1^{10}
UltraFume	+	18	0^{0}	0^{0}	0^{20}	0^{7}	0^{7}	0^{0}	0^{6}
		30	0^{0}	0^{0}	0^{0}	0^{7}	0^{0}	0^{7}	0^{2}
		42	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		54	0^{0}	0^{0}	0^{0}	0^{7}	0^{0}	0^{0}	0^{1}
		89	0^{13}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{2}
		125	0^{7}	0^{7}	0^{13}	0^{7}	0^{7}	0^{20}	0^{10}
WoodFume	-	18	0^{0}	0^{0}	0^{0}	0^{0}	0^{20}	0^{7}	0^{4}
		30	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		42	0^{0}	0^{0}	0^{0}	0^{20}	0^{7}	0^{0}	0^{4}
		54	0^{0}	0^{7}	0^{0}	0^{0}	0^{0}	0^{0}	0^{1}
		89	0^{47}	0^{33}	7^{27}	13^{13}	0^{27}	7^{7}	4^{26}
		125	13^{67}	7^{67}	13^{73}	33^{60}	7^{60}	7^{47}	13^{62}
Chloropicrin		18	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		30	0^{7}	7^{0}	0^{0}	0^{0}	0^{0}	7^{0}	2^{1}
		42	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}
		54	0^{27}	0^{7}	0^{7}	0^{0}	0^{0}	0^{0}	0^{7}
		89	0^{13}	0^{13}	0^{0}	0^{0}	0^{7}	0^{13}	0^{8}
		125	0^{60}	0^{33}	7^{33}	0^{40}	0^{20}	0^{33}	1^{37}
Diffusible Control		18	0^{0}	14^{0}	0^{0}	0^{0}	0^{0}		3^{0}
		30	22^{56}	33^{11}	0^{22}	0^{0}	0^{22}		11^{22}
		42	33^{67}	33^{67}	33^{33}	22^{44}	0^{44}	n/a	24^{51}
		54	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}		0^{0}
		89	0^{67}	0^{56}	11^{22}	0^{56}	11^{56}		4^{51}
		125	17^{67}	33^{50}	0^{33}	0^{50}	0^{17}		10^{36}
Impel rods		18	0^{7}	0^{8}	0^{18}	0^{8}	0^{7}		0^{10}
		30	7^{47}	0^{7}	0^{27}	7^{33}	0^{47}		3^{32}
		42	0^{67}	0^{27}	7^{60}	13^{60}	7^{60}	n/a	5^{55}
		54	0^{0}	0^{0}	7^{0}	0^{0}	0^{0}		1^{0}
		89	0^{60}	0^{27}	20^{67}	40^{40}	7^{53}		13^{49}
		125	0^{40}	0^{20}	33^{47}	27^{47}	13^{53}		15^{41}
Pol Saver rods		18	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}		0^{0}
		30	0^{67}	0^{0}	0^{33}	0^{44}	0^{44}		0^{38}
		42	0^{78}	0^{56}	0^{78}	0^{78}	0^{78}	n/a	0^{73}
		54	0^{0}	0^{0}	0^{0}	0^{0}	0^{0}		0^{0}
		89	0^{44}	0^{56}	0^{22}	0^{44}	11^{33}		2^{40}
		125	0^{22}	0^{22}	0^{56}	0^{67}	0^{56}		0^{44}
FLUROD		18	0^{0}	0^{0}	0^{20}	0^{40}	0^{13}		0^{15}
		30	0^{13}	0^{0}	0^{47}	0^{60}	0^{60}		0^{36}
		42	0^{20}	0^{20}	0^{33}	0^{20}	0^{53}	n/a	0^{29}
		54	0^{0}	0^{0}	0^{0}	0^{7}	0^{0}		0^{1}
		89	0^{47}	0^{20}	0^{27}	0^{13}	7^{20}		1^{25}
		125	7^{60}	0^{60}	0^{53}	0^{53}	7^{40}		3^{53}

[a] Values represent percentage of cores containing decay fungi. Superscript values represent percent of cores containing non-decay fungi.

2. Performance of Internal Remedial Treatments in Arid Climates

Methyl Isothiocyanate Levels in the Below Ground Zones of Pole Stubs Removed from Service in Arizona - Salt River Project System (SRP)

Remedial treatments with fumigants are normally used to arrest and prevent internal decay in thin sapwood species such as Douglas-fir. These treatments move as gases through wood that normally resists treatment and, more importantly, remain at effective levels 3 to 10 years after treatment. Fumigants were largely developed to control decay in regions that receive reasonable amounts of rainfall (> 0.5 m per year), creating conditions near groundline conducive to decay. Fumigant application in drier climates poses a challenge since decay is generally present further beneath the ground, often at the limit of current intrusive inspection systems. This is less of an issue for liquid fumigants such as metam sodium or solid chemicals that sublime such as methyl isothiocyanate (MITC), but it poses a much greater challenge for chemicals that require moisture to decompose to become effective. Dazomet is one such chemical and evidence is emerging that moisture levels in poles in drier climates are insufficient for decomposition. As a result, much of the applied dazomet remains in treatment holes, while decay continues to progress further down the pole.

The first step in assessing this problem is to determine the actual levels of fumigant in poles in drier climates at various times after remedial treatment. These results can then be used to more accurately assess the problem.

In a previous test, Salt River Project (SRP) personnel removed increment cores from various locations below groundline and sent these to OSU for analysis. Results indicated fumigant levels (as methyl isothiocyanate) were low and their presence was inconsistent across the system. These tests, however, were limited to cores removed within 600 mm of groundline because of the logistics of removing cores further down the pole. As an alternative, SRP removed the butts of several poles that were scheduled for removal from service and sent them to OSU for analysis. This report details results of those tests.

Pole sections were palletized and shipped to Oregon State for assessment. Once there, increment cores were removed from 6 equidistant sites around each pole beginning 300 mm below the butt and moving upward towards the original groundline (Table I-6). The outer, preservative treated zone of each core was discarded and the outer, middle, and inner 25 mm of the remainder of each core was collected and placed into a tube containing 5 mL of ethyl acetate. The cores were incubated for 48 hours at room temperature and the ethyl acetate extract was analyzed for methyl isothiocyanate (MITC) on a Shimadzu Gas Chromatograph equipped with a flame photometric detector. MITC levels were quantified by comparison with similar analyses of known standards. The increment cores were oven dried at 104°C and weighed so that MITC content could be expressed on a µg of MITC per oven dried g/wood basis. The established threshold for protection against fungal attack with MITC is 20 µg/g of wood.

Only six out of eleven poles sampled had been internally treated at any point during their service life (Table I-6). One pole had been treated with MITC-FUME, four had been treated with dazomet and the final pole had treatment holes but it was not possible to determine the treatment employed. Possible treatments for this pole could include dazomet or metam sodium.

Table I-6. Condition of the poles received for MITC analysis.

Pole #	Prior Treatment	Residual in Holes
1	None	-
2	Dazomet	Yes
3	None	-
4	None	-
5	Unknown	-
6	None	-
7	MITC-Fume	Tubes
8	Dazomet	Yes
9	Dazomet	Yes
10	Dazomet	Yes
11	None	-

MITC was only detected in 3/6 poles and was only present at substantial levels in the dazomet-treated Pole #9 (Table I-7; Figure I-10). Almost all cores removed from Pole # 9 contained MITC (76/80). The incidence of MITC in the other two poles was far more sporadic, with detections in 7 of 78 samples from Pole #2 and 3 of 63 detections in Pole #8 (Table I-8). Interestingly, MITC was detected at the butt of Pole #8. Results for Poles #2 and #8; however, indicate that there is little remaining protective effect of remedial treatment. MITC levels in Pole #9 clearly remain above the threshold level required to limit the risk of fungal attack (Figure I-11).

While it is unfortunate that almost half of the poles had received no prior remedial treatment, the results from those that did indicate that most of the poles, which had been treated 7 to 9 years earlier, retained little or no MITC and would require some form of re-treatment to provide continued protection.

Table I-7. Frequency of MITC detected at various distances from the pole butt in the inner, middle, and outer zones of increment cores removed at each distance from the butt.

Distance from Butt (mm)	Core Position	Number of Cores Per Pole with MITC		
		Pole # 2	Pole # 8	Pole # 9
300	Inner	0/6	1/6	6/6
	Middle	0/3	1/3	3/3
	Outer	0/1	0/1	1/1
610	Inner	0/6	0/5	6/6
	Middle	0/2	0/1	2/2
	Outer	0/2	0/1	1/2
915	Inner	0/6	0/6	5/6
	Middle	0/4	0/4	3/4
	Outer	-	-	-
1070	Inner	0/4	0/4	4/4
	Middle	0/4	0/3	5/5
	Outer	0/2	0/2	2/2
1220	Inner	1/6	0/5	6/6
	Middle	0/3	0/3	4/4
	Outer	-	-	-
1370	Inner	1/6	0/5	6/6
	Middle	1/3	0/2	3/3
	Outer	0/3	1/2	2/3
1520	Inner	1/5	0/3	5/5
	Middle	3/4	0/2	3/4
	Outer	0/1	0/1	1/1
1680	Inner	0/4	0/2	4/4
	Middle	0/2	0/1	2/2
	Outer	0/1	0/1	1/1
1830	Inner	-	1/2	4/4
	Middle	-	0/1	2/2
	Outer	-	0/2	2/3

"-" Denotes no samples removed from that zone

Table I-8. Average MITC content in increment cores removed from selected distances away from the butt

Distance from Butt (mm)	Average MITC Content (ug/g wood)		
	Pole # 2	Pole # 8	Pole # 9
300	-	10.4	26.3
610	-	-	22.2
915	-	-	18.2
1070	-	-	21.2
1220	0.7	-	26.0
1370	1.3	1.3	25.8
1520	2.9	-	30.5
1680	-	-	30.6
1830	-	5.4	44.7

"-" Denotes no MITC detected in any cores at that location

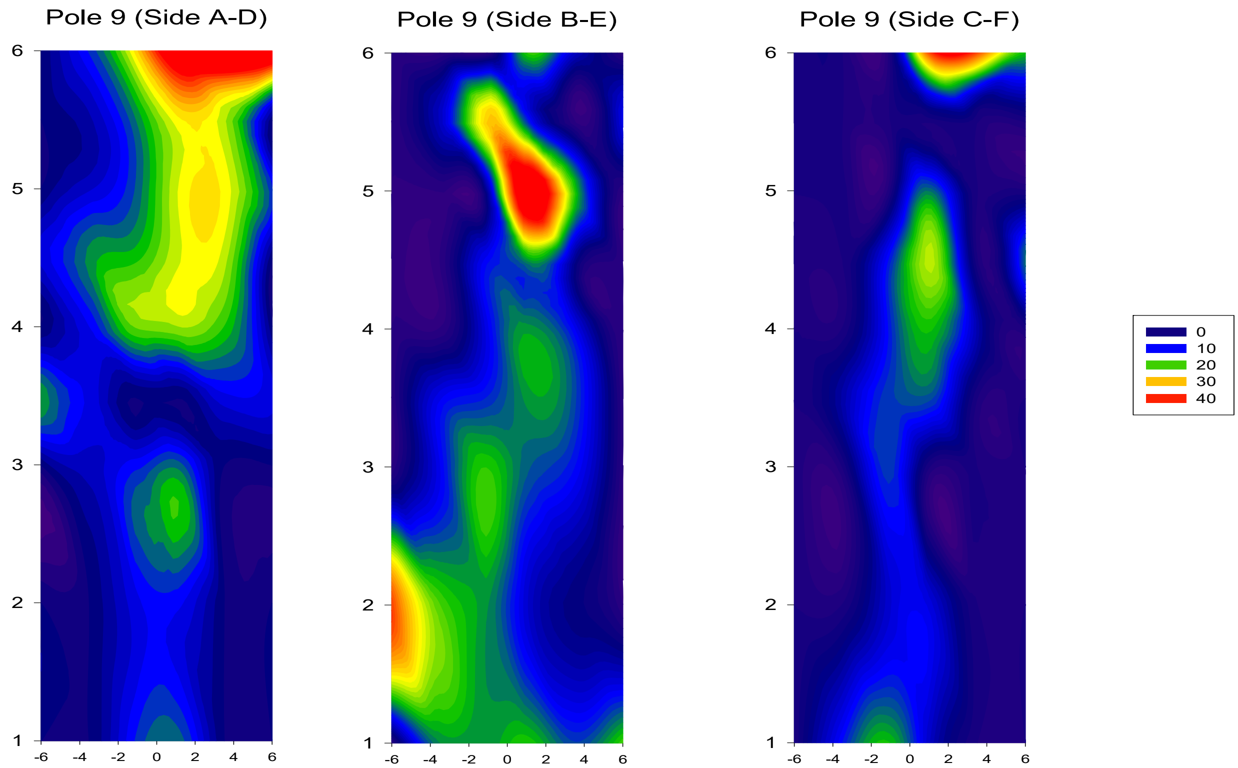

Figure I-11. Diagrams illustrating the distribution of MITC in Pole # 9 from different sides of the pole at various distances from the butt (where "1" is close to the butt and "6" is approaching groundline). Green to red colors indicate MITC levels that would be above the threshold for fungal protection.

Methyl Isothiocyanate Levels in Poles in California Treated with Dazomet - Southern California Edison System (SCE)

As noted earlier, fumigant application in drier climates poses more of a challenge since decay is generally present further beneath the ground, often at the limit of current intrusive inspection systems. Evidence is emerging that pole moisture levels in drier climates are insufficient for dazomet decomposition. As a result, much of the applied dazomet remains in the treatment holes, while decay continues to progress further down the pole.

This problem appears to be widespread in many areas of the desert Southwest U.S.; however, it is unclear how big the problem is in other areas of the arid west, notably California. This past year, Southern California Edison (SCE) began a project to survey MITC levels in dazomet-treated poles throughout their system. SCE personnel removed increment cores at groundline and 300 mm above ground. The outer preservative-treated zone of each core was discarded and the outer and inner 25 mm of the remainder of each core was collected and placed into a tube containing 5 mL of ethyl acetate. Cores were incubated for 48 hours at room temperature after which the ethyl acetate extract was analyzed for methyl isothiocyanate (MITC) on a Shimadzu Gas Chromatograph equipped with a flame photometric detector. MITC levels were quantified by comparison with similar analyses of known standards. Increment cores were oven dried at 104°C and weighed so MITC content could be expressed on a µg of MITC per oven dried gram of wood basis. The established threshold for protection against fungal attack with MITC is 20 µg/g of wood. A total of 193 poles have been inspected to date.

Results suggest that average MITC levels in the inner zones of the poles are almost uniformly above the minimum levels for protection, while those nearer the surface are much lower and far more variable (Table I-9). Averages; however, can provide a false sense of security. MITC levels are far lower and more variable when the individual results are examined (Table I-10) and many cores contain no detectable MITC.

The data can be examined a number of ways, but the simplest measures would be the number of poles with no measurable MITC, as well as the number of sites where MITC levels were above the protective threshold. Seventy one of the 193 poles did not contain MITC at the threshold level at any of the four analysis points, representing 36.8% of samples. The percentage of samples that contained no detectable MITC varied from 40.9 to 50.8% depending on the sample location, with the most non-detects in the outer zone of poles 150 mm below groundline (Table I-11). The percentage of core samples that contained threshold MITC levels ranged from 23.8% in the outer zone 300 mm above groundline to 33.2% in the inner zone at this same location. Overall percentages ranged from 23.8 to 33.2%, indicating MITC was only present at effective levels in 29.7% of collected samples.

The results suggest dazomet decomposition remains variable, even when copper naphthenate is applied as a decomposition accelerant. These data are extremely preliminary and represent only a small fraction of the total sample, but they illustrate the potential issues associated with dazomet use in drier climates.

Table I-9. Average MITC content of increment cores removed from Douglas-fir poles at various times after dazomet treatment.

Climate	Irrigated	Average MITC (ug/g wood)[a]			
		150 mm below GL		300 mm above GL	
		Inner 25 mm	Outer 25 mm	Inner 25 mm	Outer 25 mm
Coastal	No	**26.3** (28.2)	14.9 (23.5)	**27.0** (31.8)	6.7 (11.8)
Coastal	Yes	**51.8** (119.9)	14.2 (27.3)	**55.1** (71.0)	**38.5** (87.7)
Desert	No	**36.8** (38.8)	15.4 (24.2)	**22.9** (44.7)	5.3 (14.3)
Unknown	No	9.5 (0.0)	0	**26.7** (0.00)	0
Unknown	Yes	**55.0** (46.2)	13.0 (18.4)	**51.6** (55.6)	**45.4** (64.2)
Unknown	Unknown	**21.6** (65.7)	**42.5**(200.9)	**26.8** (51.9)	**22.3** (50.2)

[a]Values represent averages while figures in parentheses represent one standard deviation. Values in bold are above the threshold for fungal protection (20 µg/g wood).

Table I-10. MITC content of increment cores removed from individual Douglas-fir poles at various times after dazomet treatment.

Pole ID	MITC (µg/g wood)			
	GL		300 mm above GL	
	Inner 25 mm	Outer 25 mm	Inner 25 mm	Outer 25 mm
X0150	14.31	0.00	0.00	0.00
X0151	10.71	**26.51**	0.00	0.00
X0152	0.00	0.00	0.00	0.00
X0153	14.90	**63.26**	2.86	0.00
X0154	0.00	0.00	0.00	0.00
X0155	**24.03**	0.00	0.00	0.00
X0156	2.34	0.00	0.52	0.91
X0157	0.00	0.00	0.00	**30.14**
X0158	0.00	0.00	0.00	0.00
X0159	0.00	0.00	0.00	0.00
X0160	0.00	0.00	0.00	0.00
X0161	0.00	0.00	5.24	0.00
X0162	0.00	**64.09**	3.01	0.00
X0163	0.00	0.00	0.00	0.00
X0164	0.00	0.00	4.58	0.00
X0167	0.00	0.00	0.00	0.00
X0168	0.00	0.00	0.00	0.00
X0169	**26.52**	0.00	0.00	**52.02**
X0170	2.33	0.00	0.00	0.00
X0171	6.85	15.26	6.45	0.00
X0172	**88.45**	**42.04**	1.12	0.00
X0173	0.00	7.68	0.00	0.00
X0174	0.00	**22.36**	**63.09**	0.00
X0175	0.00	0.00	**29.48**	1.15
X0176	0.00	0.00	10.15	0.00
X0177	0.00	0.00	0.00	0.00
X0178	**25.09**	0.00	18.04	2.97
X0179	**81.73**	**30.21**	**33.51**	0.00
X0180	0.00	0.00	**21.27**	0.00
X0181	0.00	**57.29**	0.00	0.00
X0182	15.73	0.00	7.12	0.00
X0183	0.00	0.00	**274.84**	0.00
X0184	**28.54**	0.00	**26.18**	7.37
X0185	0.00	0.00	15.34	12.12
X0186	**145.94**	**71.00**	18.43	6.80
X0187	**84.25**	**39.81**	**63.79**	**73.18**
X0188	**101.37**	**55.59**	**53.80**	19.44
X0189	**111.00**	**90.93**	**173.34**	**50.38**
X0190	**711.27**	3.54	**66.49**	7.06
X0191	19.10	0.00	0.00	0.43
X0192	1.99	19.63	**53.27**	0.00
X0193	0.00	0.00	0.00	0.00
X0194	0.00	0.00	1.84	0.00

Table I-10 cont. MITC content of increment cores removed from individual Douglas-fir poles at various times after dazomet treatment.

Pole ID	MITC (µg/g wood)			
	150 mm below GL		300 mm above GL	
	Inner 25 mm	Outer 25 mm	Inner 25 mm	Outer 25 mm
X0195	0.00	0.00	0.00	0.00
X0196	0.00	0.00	0.00	0.00
X0197	7.68	4.44	**26.72**	0.00
X0198	5.90	9.81	**34.38**	0.00
X0324	**35.65**	13.57	**47.82**	**42.17**
X0327	2.69	0.00	0.00	0.00
X0328	**30.98**	2.38	16.48	0.00
X0331	0.00	0.00	0.00	0.00
X0332	**33.68**	10.37	11.40	14.13
X0333	**76.36**	18.86	0.00	0.00
X0334	0.00	0.00	0.00	0.00
X0335	19.16	7.65	6.91	4.14
X0336	17.44	**25.34**	**38.64**	0.00
X0337	**83.42**	**22.52**	**75.01**	0.00
X0338	0.00	4.75	14.95	0.00
X0339	**21.53**	0.00	15.13	0.00
X0340	**47.38**	**20.76**	0.00	**28.96**
X0341	0.00	0.00	**56.71**	0.00
X0342	7.02	0.00	0.00	0.00
X0343	**27.30**	0.00	2.13	0.00
X0344	**35.60**	0.00	**161.90**	4.78
X0345	0.00	0.00	**40.85**	0.00
X0346	12.76	0.00	0.00	0.00
X0347	2.85	4.19	9.18	33.12
X0348	0.00	0.00	19.27	0.00
X0349	0.00	0.00	0.00	0.00
X0350	14.44	9.13	4.23	0.00
X0351	**63.76**	0.00	**22.63**	0.00
X0352	48.37	**25.18**	**64.02**	0.00
X0353	**91.95**	0.00	**138.58**	0.00
X0354	**23.45**	0.00	18.89	0.00
X0355	0.00	0.00	0.00	0.00
X0356	0.00	0.00	**28.41**	0.00
X0357	**39.18**	0.00	13.69	0.00
X0358	**120.53**	0.00	0.00	0.00
X0359	**39.41**	0.00	**93.45**	0.00
X0360	**36.54**	**34.48**	**22.89**	0.00
X0361	0.00	17.82	0.00	19.65
X0362	0.00	0.00	12.71	0.00
X0363	**41.21**	0.00	**43.65**	15.32
X0364	0.00	0.00	**55.22**	0.00
X0365	**33.35**	0.00	0.00	**60.66**
X0366	0.00	0.00	0.00	**77.94**

Table I-10 cont. MITC content of increment cores removed from individual Douglas-fir poles at various times after dazomet treatment.

Pole ID	MITC (µg/g wood)			
	150 mm below GL		300 mm above GL	
	Inner 25 mm	Outer 25 mm	Inner 25 mm	Outer 25 mm
X0367	0.00	11.43	10.74	**303.95**
X0368	**48.89**	15.67	0.00	**56.54**
X0369	**110.37**	**61.01**	0.00	0.00
X0370	0.00	0.00	0.00	0.00
X0371	0.00	**34.28**	15.29	**63.38**
X0372	0.00	0.00	0.00	**46.73**
X0373	**48.05**	**148.80**	0.00	**79.94**
X0374	0.00	0.00	**203.66**	**41.37**
X0375	12.69	0.00	**180.47**	0.00
X0376	**87.62**	**25.95**	12.26	0.00
X0377	12.15	0.00	**51.57**	**28.08**
X0378	**22.36**	0.00	**90.88**	**90.76**
X0379	0.00	18.70	0.00	**64.58**
X0380	**29.41**	**28.25**	13.99	**27.41**
X0381	**47.69**	0.00	**31.74**	0.00
X0382	9.53	0.00	**26.65**	0.00
X0383	**110.07**	**34.36**	**32.21**	17.39
X0384	9.67	**83.76**	0.00	23.62
X0385	18.20	0.00	**39.40**	14.99
X0386	0.00	0.00	**104.88**	**49.94**
X0387	12.16	0.00	0.00	**102.31**
X0388	0.00	13.18	15.78	0.00
X0389	**36.93**	0.00	0.00	4.04
X0391	**57.12**	0.00	3.90	0.00
X0392	**56.82**	**21.20**	10.82	14.91
X0393	**94.12**	**68.70**	**65.15**	0.00
X0394	**473.02**	**100.69**	14.76	**62.28**
X0395	0.00	**57.62**	13.23	**25.38**
X0396	17.01	15.70	0.00	0.00
X0397	0.00	13.66	**25.00**	**21.41**
X0398	0.00	17.80	15.10	**165.51**
X0399	6.63	17.30	**179.32**	**347.10**
X0400	**55.16**	**25.95**	**20.90**	0.00
X1065	0.00	**42.25**	0.00	**48.61**
X1066	0.00	0.00	0.00	**89.97**
X1501	9.64	0.00	7.93	0.00
X1502	**54.63**	**25.14**	**237.24**	**25.62**
X1503	**97.02**	**54.92**	**109.48**	**45.40**
X1504	0.00	0.00	**22.56**	0.00
X1505	12.61	0.00	9.15	0.00
X1506	**145.71**	**47.27**	**148.03**	**40.05**
X1507	**22.19**	**25.73**		
X1508	7.80	11.39	**98.90**	0.00

Table I-10 cont. MITC content of increment cores removed from individual Douglas-fir poles at various times after dazomet treatment.

Pole ID	MITC (µg/g wood)			
	150 mm below GL		300 mm above GL	
	Inner 25 mm	Outer 25 mm	Inner 25 mm	Outer 25 mm
X1509	15.93	0.00	3.06	13.03
X1510	0.00	0.00	17.57	0.00
X1511	0.00	0.00	0.00	0.00
X1512	0.00	0.00	0.00	0.00
X1513	17.22	**28.55**	0.00	**32.02**
X1514	0.00	**64.72**	**28.65**	0.00
X1515	0.00	0.00	0.00	0.00
X1516	11.79	**42.04**	**23.92**	12.54
X1517	0.00	10.51	0.00	0.00
X1518	**32.22**	11.35	0.00	0.00
X1519	0.00	0.00	0.00	0.00
X1520	0.00	**29.03**	7.85	2.19
X1521	**23.07**	0.00	19.53	0.00
X1522	0.00	0.00	17.74	0.00
X1523	0.00	0.00	0.00	0.00
X1524	14.37	**1467.17**	11.02	**54.90**
X1525	19.31	**23.34**	**21.02**	0.00
X1526	0.00	**36.74**	0.00	**29.17**
X1527	0.00	6.27	0.00	0.00
X1528	0.00	0.00	0.00	0.00
X1529	0.00	0.00	0.00	**30.55**
X1530	0.00	**89.26**	0.00	0.00
X1531	0.00	**23.46**	**32.56**	1.61
X1532	0.00	14.70	0.00	0.00
X1533	3.50	**41.87**	2.07	18.82
X1534	0.00	11.92	0.00	0.00
X1535	0.00	7.25	0.00	0.00
X1536	**97.29**	**171.26**	0.00	0.00
X1537	0.00	0.00	0.00	0.00
X1538	0.00	0.00	0.00	0.00
X1539	0.00	16.68	0.00	0.00
X1540	0.00	**1890.62**	0.00	8.29
X1541	**46.96**	**95.53**	**149.62**	**36.99**
X1542	**59.59**	**61.16**	**70.66**	**37.65**
X1543	**27.73**	**101.06**	**56.72**	**105.53**
X1544	**74.38**	**55.40**	**37.79**	**91.38**
X1545	**28.14**	**90.23**	**24.72**	**161.71**
X1546	**44.35**	**91.69**	**51.88**	19.80
X1547	11.90	**37.12**	**62.69**	18.98
X1548	0.00	0.00	0.00	0.00
X1549	**21.78**	0.00	**39.11**	**60.19**
X1550	**47.94**	0.00	0.00	**126.98**
X1551	18.63	1.42	0.00	13.76

Table I-10 cont. MITC content of increment cores removed from individual Douglas-fir poles at various times after dazomet treatment.

Pole ID	MITC (µg/g wood)			
	150 mm below GL		300 mm above GL	
	Inner 25 mm	Outer 25 mm	Inner 25 mm	Outer 25 mm
X1627	2.24	0.00	0.00	0.00
X1630	0.00	**39.51**	**75.06**	**33.92**
X1638	0.00	0.00	7.23	7.54
X1649	0.00	**31.99**	**260.74**	0.00
X1654	0.00	8.79	5.14	0.00
X1655	0.00	0.00	**51.56**	0.00
X1657	0.00	**38.98**	**238.78**	**381.92**
X1677	0.00	15.01	0.00	1.20
X1681	0.00	16.27	2.25	0.00
X1682	0.00	1.08	0.00	13.77
X1841	0.00	13.84	0.00	**22.57**
X1843	0.00	0.00	4.24	15.01
X1844	10.85	0.00	0.00	15.44
X1845	4.78	15.21	4.81	**51.44**
X1846	0.00	**41.36**	12.79	10.15
X1847	**22.73**	**47.68**	**28.77**	13.13
X1848	2.61	0.00	12.96	0.00
X1849	4.65	0.00	0.00	**21.63**
X1850	**30.35**	0.00	0.00	11.91
X1852	0.00	0.00	**115.82**	5.36
X1923	**127.20**	**67.86**	**173.67**	0.00

[a]Values in bold are above the threshold for fungal protection (20 µg/g wood).

Table I-11. Relative distribution of MITC in increment cores removed from selected locations of Douglas-fir poles at various times after dazomet treatment

MITC Content	Percentage of samples in a category[a]			
	-150 mm below GL		300 mm above GL	
	Inner 25 mm	Outer 25 mm	Inner 25 mm	Outer 25 mm
None	46.1	50.8	40.9	56.0
>20 µg/g	31.6	30.1	33.2	23.8

[a]Values represent percentages of samples from 193 poles

Literature Cited

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OBJECTIVE II

IDENTIFY CHEMICALS FOR PROTECTING EXPOSED WOOD SURFACES IN POLES

Preservative treatment of utility poles prior to installation provides an excellent barrier against fungal, insect, and marine borer attack; however, this barrier remains effective only while intact. Deep checks that form after treatment, field drilling holes for attachments including guy wires and communications equipment, cutting poles to height after setting, and heavy handling of poles resulting in fractures or shelling between the treated and non-treated zones can all expose non-treated wood to possible biological attack. Most utility standards recommend that all field damage to treated wood should have supplemental protection with copper naphthenate solutions. While this treatment will never be as good as the initial pressure treatment, it provides a thin barrier that can be effective aboveground. Despite their merits, these recommendations are often ignored by field crews who dislike the liquid nature of the treatment and know it is highly unlikely that anyone will later check to confirm proper treatment application. In 1980, the Coop initiated a series of trials to assess the efficacy of various treatments for protecting field drilled bolt holes, non-treated western redcedar sapwood and non-treated Douglas-fir timbers above groundline. Many of these trials have been completed and have led to further tests assessing decay levels present in aboveground zones of poles in this region and efforts to develop accelerated test methods for assessing chemical efficacy.

Despite the length of time this objective has been underway, aboveground decay and its prevention remain problematic for many utilities as they encounter increased restrictions on chemical use. The problem of aboveground decay facilitated by field drilling promises to grow in importance as utilities find a diverse array of entities operating under the energized phases of their poles with cable, telecommunications and other services that require field drilling for attachments. Developing effective, easily applied treatments as damage is done, when these systems are attached, can result in substantial long-term savings and is the primary focus of this objective.

A. Effect of Boron Pretreatment on Performance of Preservative Treated Douglas-fir Poles

Douglas-fir heartwood has a well-deserved reputation for being difficult to impregnate with preservatives. Through-boring, radial drilling, and deep incising can all improve treatment, but their application is generally limited to groundline. While this represents the area with greatest risk of internal decay, fungi can attack non-treated heartwood above this zone. Aboveground decay poses great future risk. Entities attaching equipment to poles are almost all field-drilling attachment holes. Non-treated, field-drilled holes represent decay fungal access paths into non-treated heartwood. While progression of fungal attack and decay is slower aboveground, these field drilled holes eventually become decay sites. Under Objective II, we have examined simple methods for treating holes with boron compounds and evaluated the potential for using preservative-coated bolts. None of these practices have been adopted or have led to changes in practices.

Another approach to reduce decay risk in non-treated heartwood might be to initially treat poles with water diffusible chemicals such as boron or fluoride prior to seasoning and treatment. Diffusible chemicals could move into the heartwood as poles dry, and be over-treated with conventional oil-borne preservatives such as copper naphthenate, penta, or creosote to help retain boron.

We explored this possibility in the 1980s to reduce the risk of fungal colonization during air-seasoning, first with ammonium bifluoride (fluoride) and later with disodium octaborate tetrahydrate (DOT). Results with fluoride were initially promising. Poles were flooded with a 20% solution of ammonium bifluoride and exposed at four sites in the Pacific Northwest and California. Fungal colonization was assessed over a three year period by removing increment cores for culturing. Initially, the percentage of cores containing basidiomycetes was low at all sites, but steadily increased at the wetter sites (Table II-1). Results indicated fluoride could initially limit fungal colonization, but eventually a more weather-resistant treatment would be required.

Table II-1. Basidiomycete isolations from Douglas-fir pole sections with or without an ammonium bifluoride treatment after 1 to 3 years of exposure in various locations in the Pacific Northwest (from Morrell et al., 1989).

Seasoning Location	Cores Containing Basidiomycetes (%)					
	Non-Treated			Fluoride Treated		
	1 Yr	2 Yr	3 Yr	1 Yr	2 Yr	3 Yr
Arlington, WA	39	74	71	14	38	69
Scappoose, OR	27	56	76	14	36	45
Eugene, OR	36	52	72	12	19	35
Oroville, CA	29	39	37	8	11	12

In a follow-up study near Corvallis, OR, Douglas-fir pole sections were either dipped for 3 minutes in a 20% BAE solution of DOT or sprayed at 6-month intervals with a 10% solution of DOT and exposed for 1 to 3 years. Dip-treated pole sections contained much lower basidiomycete levels 1-year after treatment than non-treated controls, while isolation levels were similar after 2-years of exposure (Table II-2). Spray treatments followed similar patterns, even when sprays were applied at 6-month intervals. Results indicate boron and fluoride inhibit fungal attack, but their protection was limited and needs to be followed by over-treatment with traditional non-diffusible wood preservatives.

The potential for boron as a pre-treatment has also been explored on railroad ties in the southern U.S. Extensive studies at Mississippi State University have clearly demonstrated that dip or pressure treatment with boron followed by air seasoning and creosote treatment markedly improved performance of ties; this approach is now widely used by mainline railroads. Boron may also have value as a pre-treatment for utility poles. In order to assess this potential, we have undertaken the following test

Table II-2. Basidiomycete isolations from Douglas-fir pole sections with or without a disodium octaborate tetrahydrate treatment after 1 to 3 years of exposure in various locations in the Pacific Northwest (from Morrell et al., 1991).

Treatment	Cores Containing Basidiomycetes (%)		
	Year 1	Year 2	Year 3
Control	23	59	87
Dip	9	47	30
Sprayed (0/6 mo.)	19	43	61

1. Boron Pre-treatment Followed by Copper Naphthenate Pressure Treatment of Douglas-fir Poles

Freshly peeled Douglas-fir pole sections (2.4 m long by 250-300 mm in diameter) were pressure treated with a 7% solution (BAE) of DOT, then six increment cores were removed from two sides near the middle of each pole. Cores were divided into 25 mm segments from surface to pith and combined by depth for each pole. Combined cores were ground to pass a 20 mesh screen before extraction in hot water and boron analysis according to AWPA Standard A2, Method 16. No AWPA borate retention is specified for utility pole pre-treatment. The current AWPA Standard for borate pre-treatment of ties specifies 2.7 kg/m^3 of boron (as B_2O_3, equal to 4.9 kg/m^3 BAE); however, our data suggest the boron threshold for protecting Douglas-fir from internal decay is far lower (0.6 kg/m^3). Clearly, a proper treatment level will need to be determined. For the purposes of this discussion the tie level will be used, although it is probably much higher than necessary.

Five poles not subjected to further treatment were set aside to air-dry. Five of the remaining ten poles were kiln dried to 25% MC 50 mm from the surface, and pressure treated with copper naphthenate to the AWPA U1 UC4B target retention of 0.095 pcf (as Cu). The remaining five poles were pressure treated with copper naphthenate to the same retention, but the poles were seasoned in the cylinder using the Boulton process. Following treatment, all poles were returned to OSU, sampled and analyzed for boron content as described above. Eight additional cores were taken from each copper naphthenate-treated pole so the outer 6 to 25 mm could be assayed for copper by x-ray fluorescence spectroscopy.

Boron retentions (as kg/m^3 BAE) were highest in the outer 25 mm of each pole, ranging from 4.56 to 15.17 kg/m^3 immediately after treatment but before drying (Table II-3). With the exception of one pole, retentions were extremely low in the next 25 mm inward and remained low toward the pole center. These results are typical of any short term pressure treatment of Douglas-fir poles.

If all boron in pole sections immediately after treatment was considered, poles would contain an average of 2.36 kg/m^3 BAE, or half the required level. These values are skewed by one pole that had extremely high boron levels in 4/6 assay zones. The remaining poles had much lower boron levels. Boron was largely confined to the outer 25 mm.

After kiln drying, boron levels were elevated in the outer 25 mm of pole sections, but declined sharply inward (Table II-4). Boron levels, if averaged across the entire pole cross section, would average 1.02 kg/m^3 BAE, far below the specified level. Boron levels in the outer 25 mm were lower after drying in nine of the ten pole sections and, in some cases, the differences were substantial (Table II-5). Some of these reductions may be attributed to differences in sampling locations at different time points as well as to movement of boron into the next 25 mm from the surface, but the levels of loss also suggest some of the boron was lost from the wood during drying. The results suggest that drying schedules will have to be adjusted to reduce boron loss.

Boron should become more uniformly distributed over time as it diffuses inward from the pole surface. Boron levels in poles 2 months after treatment averaged 2.14 kg/m^3 BAE, and levels were slightly higher in the 25 to 50 mm zone (Figure II-1). However, boron levels in four of the five poles in this treatment group remained very low 50 mm or further inward. The overall shape of the preservative gradient changed only slightly (Figure II-1). This suggests that the majority of boron remained in the outer pole zones.

Treated poles were set to a 0.6 m depth at Peavy Arboretum, Corvallis OR. Five Boulton seasoned and copper naphthenate treated poles, and five kiln dried and copper naphthenate poles were installed. Boron content was assessed one, two, and three years after treatment by removing increment core pairs from three equidistant points around each pole at groundline and 1.2 m. Coring holes were plugged with tight-fitting wooden dowels. Increment cores were divided into 25 mm segments from the outside

Table II-3. Boron levels in Douglas-fir poles immediately after pressure treatment with disodium octaborate tetrahydrate and prior to drying/treatment. Bold values are above threshold.

Pole #	Boron Retention (kg/m^3 BAE)					
	0-25 mm	25-50 mm	50-75 mm	75-100 mm	100-125 mm	125-150 mm
758	**15.17**	**8.85**	0.36	0.30	**5.85**	**7.95**
759	**10.30**	0.21	0.16	0.08	0.73	0.11
760	**7.22**	0.09	0.12	0.06	0.11	0.02
761	**10.29**	0.10	0.03	0.03	0.08	0.03
762	**7.47**	0.11	0.11	0.07	0.09	0.05
763	**10.24**	0.23	0.06	0.08	0.05	0.08
764	**4.56**	0.12	0.05	0.04	0.08	0.06
765	**7.23**	0.11	0.08	0.08	0.08	0.31
766	**10.57**	0.14	0.07	0.05	0.02	0.03
767	**11.66**	0.19	0.08	0.00	0.16	0.11
770	**8.42**	0.15	0.02	0.02	0.00	0.05
786	**5.90**	0.05	0.00	0.03	0.00	0.05
787	**7.16**	0.16	0.00	0.07	0.00	0.35
788	**14.21**	0.24	0.16	0.08	0.07	0.00
789	**9.71**	0.11	0.04	0.10	0.00	0.03
Average	**9.34**	0.72	0.09	0.07	0.49	0.61
Standard deviation	2.93	2.25	0.09	0.07	1.49	2.03

Table II-4. Boron levels in Douglas-fir poles immediately after pressure treatment with disodium octaborate tetrahydrate and drying/treatment. Bold values are above threshold.

Pole #	Boron Retention (kg/m^3 BAE)					
	0-50 mm	25-50 mm	50-75 mm	75-100 mm	100-125 mm	125-150 mm
759	3.21	0.42	0.01	0.02	0.12	**1.80**
760	4.22	**0.60**	0.06	0.00	0.01	0.05
762	**6.60**	0.14	0.03	0.00	0.00	0.06
763	4.04	0.12	0.01	0.01	0.02	0.03
764	3.37	0.26	0.02	0.03	0.08	0.07
766	3.50	0.07	0.01	0.01	0.00	0.01
767	3.74	0.15	0.08	0.03	0.01	0.02
770	4.30	**1.06**	0.12	0.06	0.31	0.13
788	**14.82**	**0.63**	0.03	0.01	0.00	0.00
789	**6.17**	0.45	0.04	0.00	0.02	0.02
Average Std. Dev.	**5.40** (3.50)	0.39 (0.31)	0.04 (0.03)	0.02 (0.02)	0.06 (0.10)	0.22 (0.56)

towards the center. Core segments from a given height and zone were combined and ground to pass a 20 mesh screen. Ground wood was analyzed for boron.

Table II-5. Differences in boron retentions in the outer 25 mm of poles immediately after treatment and after kiln drying. Bold values are above threshold.

Pole #	Boron Retention (kg/m^3) in the outer 25 mm		
	Pre-Drying	Post-Drying	Difference
759	**10.30**	3.21	7.09
760	**7.22**	4.22	3.00
762	**7.47**	**6.60**	0.87
763	**10.24**	4.04	6.20
764	4.56	3.37	1.19
766	**10.57**	3.50	7.07
767	**11.66**	3.74	7.92
770	**8.42**	4.30	4.12
788	**14.21**	**14.82**	-0.61
789	**9.71**	**6.17**	3.54

Boron levels in the outer 25 mm of poles one year after treatment had declined (Figure II-2; Tables II-6, II-7). The field site receives ~1200 mm of rainfall per year and tends to be extremely wet during the winter. Previous tests revealed that interior pole moisture content at groundline tends to be above 30% most of the year, but only reaches that level above groundline near the end of winter. Elevated moisture contents are expected to help boron diffuse and distribute evenly. Declines suggest boron is moving out of poles and into surrounding soil. Boron levels in the outer 25 mm of wood 1.2 m above groundline were higher than at groundline, suggesting boron moved at the same rate out of soil contact. Boron levels were similar or slightly lower in the inner 25 to 150 mm at both heights, suggesting there had been relatively little inward movement after installation. It is important to remember that the initial boron application levels could be increased by using a stronger treatment solution. Pole sections were treated with a process typically used on lumber for the Hawaiian market and solution concentrations might have been somewhat lower than needed. Lack of substantial boron redistribution suggests that other methods may be needed to ensure boron movement beyond the surface to protect the non-treated interior once the pole is placed in service.

Boron levels in poles 2 years after installation had declined in the outer 25 mm of the poles at both groundline and 1.2 m above that level (Figure II-2; Tables II-6, II-7). Boron levels in the outer zone tended to be much higher 1.2 m above the groundline, suggesting some boron was leaching from poles in soil contact (Figure II-2). Levels further inward remained similar to those found after one year. These results suggest boron lost from the outer 25 mm zone is not moving to a substantial extent inward to help increase boron levels in those zones.

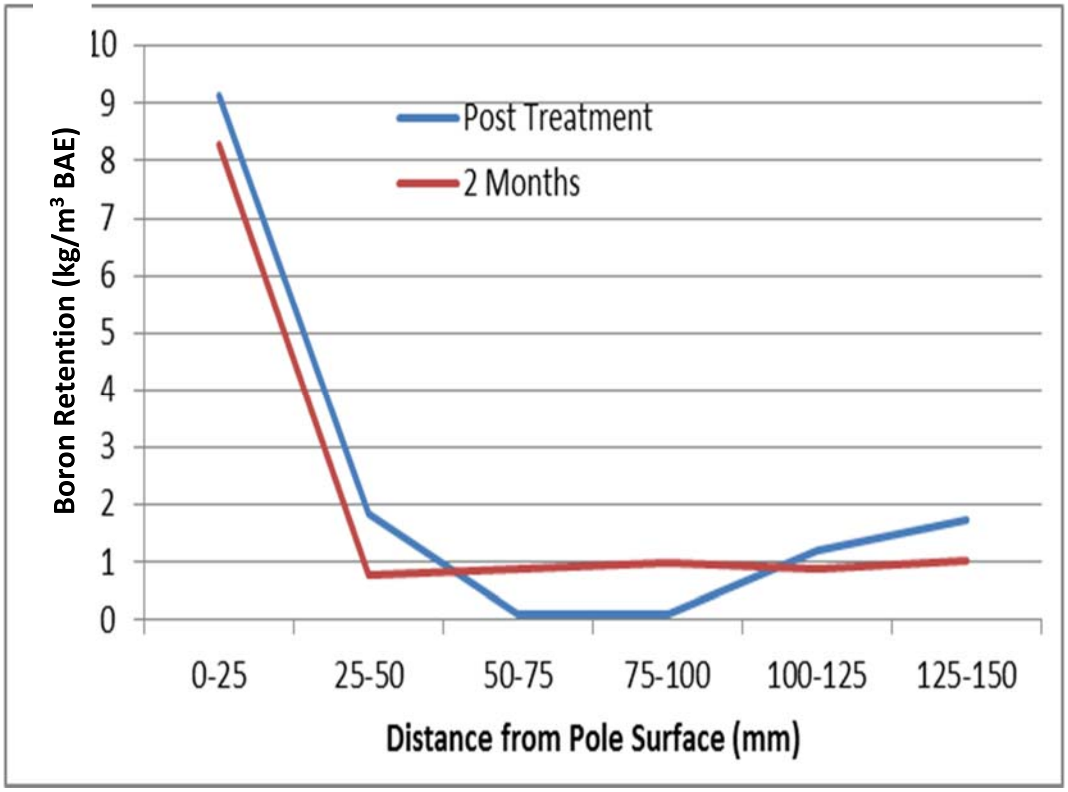

Figure II-1. Boron retentions in 25 mm increments inward from the surface in Douglas-fir poles immediately after pressure treatment with disodium octaborate tetrahydrate and again 2 months later.

Boron levels in poles 3 years after treatment continue to remain elevated near the surface but are much lower further inward (Figure II-2). Boron levels more than 75 mm from the surface tended to vary widely and were often below threshold. The failure of boron to become more evenly distributed is perplexing, especially near groundline where moisture levels should be more than adequate for diffusion to occur.

Boron levels in poles 4 years after treatment continue to remain above the threshold in the outer 75 mm of the poles that were Boulton seasoned during treatment, but more variable deeper in the pole. Boron was detectable at the innermost sampling point, albeit at low levels. Boron levels in poles that were air-seasoned prior to treatment were above the threshold in the outer 50 mm. Boron was again detected further inward, but at levels that would not be protective.

The results five years after installation remain similar. Boron levels are at or near the threshold in the outer pole zones but slightly below in the pole interior. There appeared to be little to no difference in boron levels in poles that had been Boulton seasoned vs those that had been kiln dried prior to treatment (Tables II-6, II-7). Lower boron levels deeper in poles might suggest treatment failure; however, it is unclear how much boron is required for protection against spore germination, particularly in moderately durable heartwood. The results do illustrate an inherent difficulty in using conventional water-born solutions of boron to deliver a sufficient load in the outer sapwood to allow continued diffusion inward at levels capable of preventing fungal attack. This problem will increase with pole diameter. There are other systems that allow for higher boron concentration that might be suitable for this treatment approach.

These results differ from those found with railroad ties, where boron remains at elevated levels for many years after initial treatment followed by a creosote over-treatment. However, there are several important differences in this test. First, ties are typically installed over well-drained ballast which should reduce the potential for excessive wetting that leads to boron loss. In addition, overall boron levels in these poles were much lower than those typically placed into an air-seasoning tie. This occurred because the poles were pressure treated with a treatment solution that was intended for lumber. Thus, initial loadings were somewhat lower than desired given the larger volume of wood that needs to be protected. The lower loadings, however, should not have affected overall diffusion as evidenced by the absence of gradually increasing boron levels further away from the outer 25 mm zone. The results suggest higher loadings alone may not be sufficient to produce the desired internal boron concentrations. Wood species may also have affected the results. The railroad tie research was performed on hardwoods. Boron movement through Douglas-fir tends to be much slower than in other species, although it also appeared to remain in the wood for longer periods of time.

The results from this study led us to undertake a more comprehensive study of boron treatment that is described in the next section.

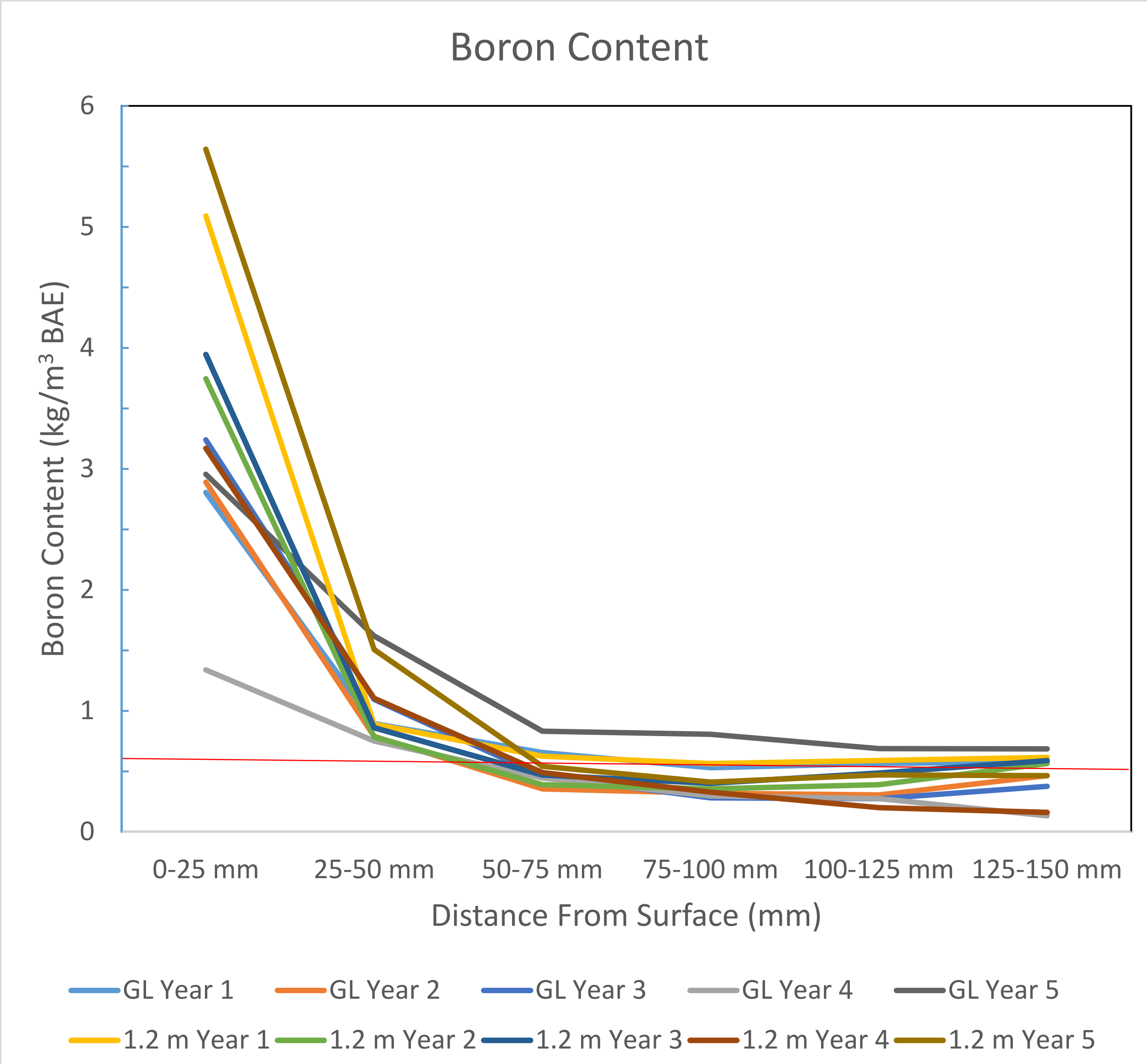

Figure II-2. Boron content at 25 mm increments from Douglas-fir pole surface 1-5 years after pre-treatment with disodium octaborate tetrahydrate followed by either kiln drying or Boulton seasoning and copper naphthenate treatment. Red line indicates 0.6 kg/m³ BAE.

Table II-6. Boron content in increment cores removed from groundline or 1.2 m above groundline of Douglas-fir poles 1-5 years after pre-treatment with disodium octaborate tetrahydrate followed by Boulton seasoning and pressure treatment with copper naphthenate.

Pole #	Kiln/ Boulton	Boron Retention (kg/m^3 BAE)[a]											
		0-25 mm		25-50 mm		50-75 mm		75-100 mm		100-125 mm		125-150 mm	
		gl	1.2 m	gl	1.2 m	gl	1.2 m	gl	1.2 m	gl	1.2 m	gl	1.2 m
759	Boulton Year 1	2.37	4.57	**1.12**	**1.12**	**0.67**	**0.72**	0.58	**0.72**	0.54	**0.72**	0.58	**0.72**
760		2.51	3.09	**1.66**	**1.39**	**1.12**	**0.99**	0.67	**0.72**	**0.63**	0.58	**0.63**	0.49
762		3.00	4.52	**0.81**	**0.76**	0.49	0.54	0.45	0.49	0.49	0.58	0.54	**0.72**
763		3.63	**4.97**	0.58	**0.67**	0.54	0.49	0.54	0.45	0.58	0.54	0.54	0.49
764		2.60	3.23	**1.61**	**1.16**	**1.12**	**0.63**	0.00	**0.63**	**1.08**	0.54	**1.16**	0.54
Mean (SD)		2.82 (0.51)	4.08 (0.86)	**1.16** (0.48)	**1.02** (0.27)	**0.79** (0.28)	**0.67** (0.17)	0.56 (0.26)	**0.60** (0.13)	**0.66** (0.24)	0.59 (0.07)	**0.69** (0.27)	0.59 (0.12)
759	Boulton Year 2	3.22	4.48	**1.34**	**1.12**	0.49	0.36	0.40	0.40	0.31	0.40	0.22	0.36
760		2.87	2.91	**1.75**	**1.57**	**0.81**	**0.94**	**0.67**	0.72	**0.67**	0.45	0.31	0.72
762		3.27	3.72	0.45	**0.85**	0.45	0.13	0.45	0.54	0.09	0.49	0.09	0.72
763		0.36	3.18	0.13	0.58	0.05	0.27	0.27	0.00	0.27	0.58	0.05	-
764		2.78	2.51	**1.30**	**1.08**	**0.76**	0.54	0.72	0.19	0.36	0.19	**0.81**	0.49
Mean (SD)		2.50 (1.22)	3.36 (0.77)	**0.99** (0.68)	**1.04** **(0.37)**	0.51 (0.30)	0.45 (0.31)	0.50 (0.19)	0.37 (0.28)	0.34 (0.21)	0.42 (0.15)	0.42 (0.28)	0.57 (0.18)
759	Boulton Year 3	1.91	**6.05**	**1.56**	**2.28**	0.53	**0.89**	0.27	0.41	0.45	**1.27**	0.25	**0.86**
760		3.12	2.22	**1.53**	**1.82**	0.55	**0.99**	0.30	0.79	0.13	0.47	**0.74**	0.49
762		3.13	2.68	0.34	**0.89**	0.11	0.23	0.12	0.18	0.20	0.21	0.10	0.39
763		2.93	4.38	0.56	0.23	0.50	0.48	**0.62**	0.02	0.32	0.01	**0.60**	0.08
764		**5.44**	2.91	**1.88**	**0.63**	**1.26**	0.31	0.51	0.40	0.57	0.23	-	-
Mean (SD)		3.30 (1.16)	3.65 (1.40)	**1.18** (0.61)	**1.17** (0.76)	0.59 (0.37)	0.58 (0.31)	0.36 (0.18)	0.36 (0.26)	0.33 (0.16)	0.44 (0.44)	0.34 (0.29)	0.37 (0.31)
759	Boulton Year 4	0.82	3.63	**0.86**	**1.60**	**0.83**	0.53	0.46	0.18	0.48	0.21	0.31	0.07
760		0.80	2.18	**0.63**	**1.41**	0.58	**1.03**	0.50	0.64	0.43	0.31	0.35	0.09
762		0.31	3.71	0.21	**0.61**	0.00	0.06	0.00	0.03	0.00	0.00	0.00	0.00
763		2.67	3.52	**0.78**	**3.55**	0.03	0.40	0.06	0.23	0.09	0.16	0.00	0.58
764		1.68	2.51	**1.17**	**1.27**	**0.71**	**1.13**	**0.80**	0.50	**0.89**	0.34	0.16	0.22
Mean (SD)		1.26 (0.82)	3.11 (0.64)	**0.73** (0.31)	**1.69** (0.99)	0.43 (0.35)	**0.63** (0.40)	0.36 (0.30)	0.32 (0.22)	0.38 (0.32)	0.20 (0.12)	0.17 (0.15)	0.19 (0.21)
759	Boulton Year 5	1.89	**6.29**	**1.84**	**2.63**	**0.98**	**0.64**	**1.35**	0.24	**0.98**	0.38	0.58	0.32
760		1.81	**6.30**	**1.76**	**3.17**	**1.50**	**0.97**	**1.46**	0.69	**1.20**	0.36	**1.32**	0.58
762		1.60	**6.69**	**1.12**	**1.15**	0.31	0.26	0.17	0.35	0.04	0.22	0.05	0.16
763		3.27	**6.18**	**1.74**	**1.28**	**0.63**	0.06	0.46	0.00	0.31	0.05	0.20	0.00
764		3.12	3.61	**2.38**	**1.23**	**1.59**	0.58	**1.36**	0.70	**1.20**	**0.78**	**1.52**	**0.86**
Mean (SD)		2.34 (0.71)	**5.81** (1.12)	**1.77** (0.40)	**1.89** (0.84)	**1.00** (0.49)	0.50 (0.32)	**0.96** (0.54)	0.39 (0.27)	**0.75** (0.48)	0.36 (0.24)	**0.73** (0.59)	0.38 (0.30)

[a] Values in bold type signify boron retentions above the threshold for protection against internal fungal attack. SD= Standard deviation

Table II-7. Boron content in increment cores removed from groundline or 1.2 m above groundline of Douglas-fir poles 1-5 years after pre-treatment with disodium octaborate tetrahydrate followed by kiln drying and pressure treatment with copper naphthenate.

Pole #	Kiln/ Boulton	Boron Retention (kg/m^3 BAE)[a]											
		0-25 mm		25-50 mm		50-75 mm		75-100 mm		100-125 mm		125-150 mm	
		gl	1.2 m	gl	1.2 m	gl	1.2 m	gl	1.2 m	gl	1.2 m	gl	1.2 m
766	Kiln Year 1	2.20	3.58	0.54	0.58	0.54	0.54	0.45	0.49	0.49	0.54	0.49	0.54
767		2.28	4.12	**0.63**	**0.63**	0.54	0.49	0.49	0.54	0.45	0.49	0.4	0.45
770		3.00	3.63	**0.63**	**0.85**	0.54	**0.81**	**0.63**	**0.67**	0.49	**0.90**	0.49	**1.25**
788		3.81	**9.27**	**0.72**	**0.85**	0.54	0.45	0.49	0.45	0.40	0.54	0.49	0.40
789		2.64	**9.90**	**0.63**	**0.90**	0.45	**0.63**	0.45	0.49	0.54	0.49	0.49	0.54
Mean (SD)		2.79 (0.65)	**6.10** (3.20)	**0.63** (0.06)	**0.76** (0.15)	0.52 (0.04)	0.58 (0.14)	0.50 (0.07)	0.53 (0.09)	0.47 (0.05)	0.59 (0.17)	0.47 (0.04)	**0.64** (0.35)
766	Kiln Year 2	1.84	2.87	0.13	0.40	0.31	0.36	0.09	0.31	0.05	0.36	0.54	0.13
767		2.96	3.72	0.58	0.22	0.31	0.09	0.05	0.09	0.31	0.22	0.27	0.22
770		**5.51**	3.67	**1.52**	**1.03**	0.13	**0.72**	0.27	0.40	0.22	0.36	0.32	**1.30**
788		3.62	**5.96**	0.36	0.36	0.05	0.27	0.05	0.67	0.05	0.54	0.09	-
789		2.46	4.44	0.36	**0.63**	0.22	0.22	0.22	0.22	0.31	0.31	**1.12**	0.58
Mean (SD)		3.28 (1.41)	4.13 (1.16)	0.59 (0.54)	0.53 (0.32)	0.20 (0.11)	0.33 (0.24)	0.14 (0.10)	0.34 (0.22)	0.27 (0.15)	0.36 (0.12)	0.51 (0.43)	0.56 (0.53)
766	Kiln Year 3	0.86	1.25	0.27	0.31	0.27	**0.63**	0.08	0.28	0.12	0.07	0.60	0.03
767		2.19	**4.93**	0.58	0.29	0.26	0.13	0.15	0.07	0.04	0.04	0.15	0.09
770		**5.60**	1.85	**2.96**	**0.78**	**0.71**	**0.66**	0.28	**0.85**	0.59	0.59	**0.76**	**1.21**
788		4.28	**7.47**	**0.91**	0.57	0.11	0.26	0.27	0.58	0.05	**1.86**	0.38	**2.57**
789		2.95	**5.71**	0.35	**0.81**	0.30	0.12	0.24	0.44	0.27	0.13	0.18	0.15
Mean (SD)		3.17 (1.64)	4.24 (2.36)	**1.01** (1.00)	0.55 (0.55)	0.33 (0.20)	0.36 (0.24)	0.20 (0.08)	0.44 (0.27)	0.21 (0.21)	0.54 (0.69)	0.41 (0.24)	**0.81** (0.81)
766	Kiln Year 4	0.66	1.79	**0.62**	0.27	0.35	0.19	0.17	0.17	0.03	0.00	0.00	0.00
767		1.33	2.66	0.30	0.34	0.23	0.17	0.12	0.08	0.08	0.04	0.07	0.01
770		2.03	3.25	**1.56**	**1.01**	**0.94**	**0.95**	0.52	**0.91**	0.48	**0.61**	0.39	0.56
788		1.10	3.85	**0.69**	0.39	0.17	0.24	0.08	0.38	0.05	0.19	0.05	0.06
789		1.97	4.60	**0.70**	0.58	**0.61**	0.21	0.26	0.16	0.20	0.14	0.00	0.00
Mean (SD)		1.42 (0.52)	3.23 (0.96)	**0.77** (0.42)	0.52 (0.27)	0.46 (0.28)	0.35 (0.30)	0.23 (0.16)	0.34 (0.30)	0.17 (0.17)	0.20 (0.22)	0.10 (0.15)	0.13 (0.22)
766	Kiln Year 5	1.22	3.15	**0.86**	**1.12**	0.39	0.48	0.27	0.44	0.20	0.21	0.37	0.32
767		4.40	**5.36**	**0.91**	0.30	0.29	0.22	0.32	0.13	0.45	0.10	**0.72**	0.08
770		3.16	3.88	**2.31**	**2.10**	**1.28**	**1.43**	**1.54**	**1.08**	**1.45**	**2.15**	-	**1.58**
788		**5.68**	**6.80**	**1.97**	**1.01**	**0.81**	0.59	0.56	0.33	0.53	0.41	**0.86**	**0.74**
789		3.38	**8.16**	**1.29**	**1.06**	0.53	0.18	0.56	0.17	0.51	0.04	**0.61**	0.00
Mean (SD)		3.57 (1.47)	**5.47** (1.84)	**1.47** (0.58)	**1.12** (0.57)	**0.66** (0.35)	0.58 (0.45)	**0.65** (0.46)	0.43 (0.34)	**0.63** (0.43)	0.58 (0.79)	**0.64** (0.18)	0.55 (0.58)

[a] Values in bold type signify boron retentions above the threshold for protection against internal fungal attack. SD= Standard deviation

2. Effect of Boron Pre-treatment on Performance of Douglas-fir Poles Treated with Pentachlorophenol, Copper Naphthenate, or Ammoniacal Copper Zinc Arsenate

As noted, the initial trial to evaluate the potential for pre-treatment with borates produced somewhat anomalous results. There were several delays in processing that might have affected the outcome. In order to develop better data, additional poles were obtained for a larger trial.

Class 3, 40 foot long Douglas-fir poles were cut into twenty four, 2.4 m long sections and allocated to one of three treatments. Twelve poles were tagged and sent to be commercially treated with a 10% solution of disodium octaborate tetrahydrate (DOT) as part of a lumber charge. After treatment, the poles were commercially treated to the AWPA UC4 retention with copper naphthenate (1.44 kg/m^3) or pentachlorophenol (9.6 kg/m^3). The remaining six pole sections were impregnated with a DOT/ammoniacal copper zinc arsenate solution. Following treatment, increment cores were taken at 300 mm increments along the length of the poles. These cores were divided into 25 mm long segments and the 8 segments from a given depth were combined for each pole. These segments were oven dried, ground to pass a 20 mesh screen, and hot water extracted. The hot water extract was analyzed for boron using the Azomethine H method. Initial preservative retention was determined by taking additional cores. The outer 6 mm of each core was discarded, then the next 19 mm of increment core was retained. These segments were ground to pass a 20 mesh screen and analyzed by x-ray fluorescence. We experienced some interference with the ACZA samples in our XRF unit. Instead, these samples were microwave digested and analyzed by ion-coupled plasma spectroscopy for copper, zinc, arsenic, and boron.

Average boron levels were elevated at all depths in the ACZA treated poles, although there was some variation in distribution within each pole (Table II-8). For example, boron levels ranged from the limit of detection (0.04 kg/m^3 BAE) to 7.64 kg/m^3 BAE in the second 25 mm inward from the surface. Variations in chemical distribution are to be expected in wood, but the range suggests that further work will be needed in the process to deliver more consistent treatment.

Average boron levels in copper naphthenate treated poles were fairly low in the outer 3 zones and then were very high in two inner most sampling zones. These high levels reflected one pole with extremely high boron concentrations. Boron levels were only above the protective threshold in 7 of 30 assays. Similarly, boron levels in penta-treated poles ranged from below the detection limit to 7.34 kg/m^3 BAE. Boron levels were again only above the protective threshold in 7 of 30 assays. Boron pre-treatment is not intended to provide initial protection against fungi. Rather, it is used to protect untreated heartwood that is exposed as the poles season in service and develop checks. As a result, the presence of sub-threshold levels at this point is not as important, although it is important to have a sufficient total loading in the pole so subsequent diffusion creates a well-protected core. We would expect boron to continue to distribute more evenly as the poles wet and dry.

Table II-8. Boron levels at 25 mm increments inward from the surface of Douglas-fir poles dual-treated with DOT and copper naphthenate, pentachlorophenol, or ACZA measured shortly after pressure treatment..

Treatment	Rep	Boron retention (kg/m³ BAE)				
		0-25 mm	25-50 mm	50-75 mm	75-100 mm	100-125 mm
ACZA	1	-----	**6.80**	**1.07**	**6.88**	**2.03**
	2	-----	0.54	0.22	0.16	0.00
	3	-----	0.04	0.03	0.21	**1.36**
	4	-----	**0.64**	0.13	0.37	0.31
	5	-----	**7.64**	0.50	**0.92**	**4.25**
	6	-----	**3.69**	**4.25**	XXX	**6.13**
Mean (SD)		-----	**3.22** (3.07)	**1.03** (1.48)	**1.71** (2.60)	**2.35** (2.19)
CuNaph	1	0.00	0.29	0.42	**1.72**	0.26
	2	0.00	0.00	0.00	**0.90**	0.42
	3	0.00	0.09	0.52	0.31	0.44
	4	1.12	0.49	0.00	0.52	0.27
	5	0.00	0.53	0.00	0.10	0.24
	6	0.00	0.16	**1.22**	**5.68**	**3.14**
Mean (SD)		0.26 (0.42)	0.26 (0.20)	0.36 (0.44)	**1.54** (1.92)	**0.85** (1.05)
Penta	1	0.00	0.47	0.34	0.23	0.09
	2	0.34	0.00	0.00	0.01	0.01
	3	0.00	**0.85**	**7.34**	**2.08**	**5.52**
	4	1.76	0.23	0.00	0.00	0.05
	5	1.66	**0.86**	0.09	0.21	0.00
	6	0.13	0.04	0.00	0.08	0.22
Mean (SD)		0.65 (0.76)	0.41 (0.35)	**1.29** (2.71)	0.44 (0.74)	**0.98** (2.03)
*Numbers in bold text represent values above the threshold to prevent fungal attack.						

The poles were sampled one and two years after installation by removing increment cores from three locations around each pole at groundline and 1.2 m above groundline. Each core was divided into 25 mm long segments. Core segments from a given location on each pole were combined and ground to pass a 20 mesh screen. The resulting ground wood was hot water extracted and analyzed for boron via the azomethine H method. Results were expressed on a kg/m³ boric acid equivalent (BAE) where the threshold for fungal protection is considered to be equal to, or greater than 0.6 kg/m³ BAE.

Boron levels at groundline and 1.2 m above groundline did not differ markedly from each other one year after treatment (Table II-9). The 1.2 m height was selected to determine if proximity to the soil resulted in accelerated boron loss near the surface. This did not appear to be the case. Boron levels in the poles were above the threshold in the outer 50 mm at both groundline and 1.2 m above groundline, but levels declined sharply further inward. There was a slight gradient with distance inward beyond the outer 50 mm, but the differences were slight and there was little evidence of substantial movement inward from the surface (Figure II-3). The results would appear to differ substantially from the results immediately after treatment; however, these results must be interpreted carefully. Boron levels were generally low in the freshly treated poles except in a few poles per treatment. These outliers tended to push the averages upward so that the poles looked better treated. It is important to stress that the results do not necessarily mean that boron is not performing a function. Research on railroad ties showed trace amounts of boron protected the wood for over 20-years after treatment, and we would expect the results to be similar in utility poles. While higher boron loadings would be preferable, it does not take much boron to inhibit the germination of fungal spores. We will continue to monitor these poles to determine how boron redistributes in the interior of the poles.

Boron levels tended to be slightly higher in many poles sampled 2 years after installation; however, it is difficult to detect specific boron level trends (Figure II-3). There were some treatments (ACZA at GL, CuNaph at GL and 1.2 m) that were above threshold at all depths from the surface, but there was considerable variation in the other treatments. If all of the results for the different treatments are combined; however, boron levels at the groundline are clearly at or above the threshold level through the entire cross section, while they are slightly below those levels above groundline (Figure II-4). These results would be consistent with moisture-mediated redistribution of boron in zones where moisture contents would be expected to be highest.

While there is still considerable variation in boron levels among individual poles, the results in these tests appear to show more consistent boron movement. These poles will continue to be monitored for boron movement and eventual depletion

Table II-9. Boron levels at 25 mm increments inward from the surface at groundline and 1.2 m above groundline in Douglas-fir poles one and two years after dual treatment with boron plus ACZA, copper naphthenate, or pentachlorophenol.

Primary Treatment	Depth (in)	GL		1.2 m	
		(kg/m^3 BAE)	Std. Dev.	(kg/m^3 BAE)	Std. Dev.
ACZA (2017)	0-1	**3.74**	(2.33)	**2.83**	(1.47)
	1-2	**0.65**	(0.39)	**0.63**	(0.61)
	2-3	0.50	(0.43)	0.23	(0.22)
	3-4	0.42	(0.27)	0.35	(0.31)
	4-5	0.45	(0.25)	0.46	(0.45)
	5-6	0.51	(0.52)	0.47	(0.42)
ACZA (2018)	0-1	**3.30**	(2.13)	**4.36**	(3.30)
	1-2	**1.48**	(1.47)	0.40	(0.24)
	2-3	**1.45**	(2.16)	0.47	(0.24)
	3-4	**1.53**	(1.77)	0.64	(0.38)
	4-5	**1.21**	(0.76)	0.60	(0.33)
	5-6	**1.03**	(0.86)	**1.04**	(0.96)
CuNaph (2017)	0-1	**2.27**	(1.61)	**4.47**	(2.62)
	1-2	0.41	(0.32)	**0.75**	(0.47)
	2-3	0.24	(0.18)	0.48	(0.33)
	3-4	0.30	(0.30)	0.20	(0.10)
	4-5	0.37	(0.38)	0.23	(0.13)
	5-6	0.31	(0.41)	0.16	(0.12)
CuNaph (2018)	0-1	**3.06**	(3.01)	**3.11**	(1.02)
	1-2	**1.28**	(1.77)	**0.63**	(0.61)
	2-3	**0.70**	(0.63)	0.59	(0.36)
	3-4	**0.78**	(0.89)	**0.64**	(0.60)
	4-5	**0.75**	(0.74)	**0.79**	(0.96)
	5-6	**0.72**	(0.78)	0.41	(0.54)
Penta (2017)	0-1	**3.81**	(2.91)	**2.38**	(0.97)
	1-2	**1.11**	(1.04)	**0.90**	(0.46)
	2-3	0.53	(0.55)	0.55	(0.35)
	3-4	0.41	(0.43)	0.39	(0.17)
	4-5	0.48	(0.45)	0.42	(0.25)
	5-6	0.29	(0.20)	0.25	(0.20)
Penta (2018)	0-1	**2.92**	(2.63)	**3.97**	(2.91)
	1-2	**1.00**	(0.63)	0.33	(0.34)
	2-3	0.31	(0.19)	0.39	(0.20)
	3-4	0.35	(0.28)	**0.72**	(0.57)
	4-5	**0.61**	(0.60)	**0.69**	(0.66)
	5-6	0.38	(0.43)	0.51	(0.50)

[a]Values represent means of samples from 6 poles per treatment, while numbers in parentheses represent one standard deviation. Values in bold are above the threshold for protection against internal fungal attack (0.6 kg/m^3).

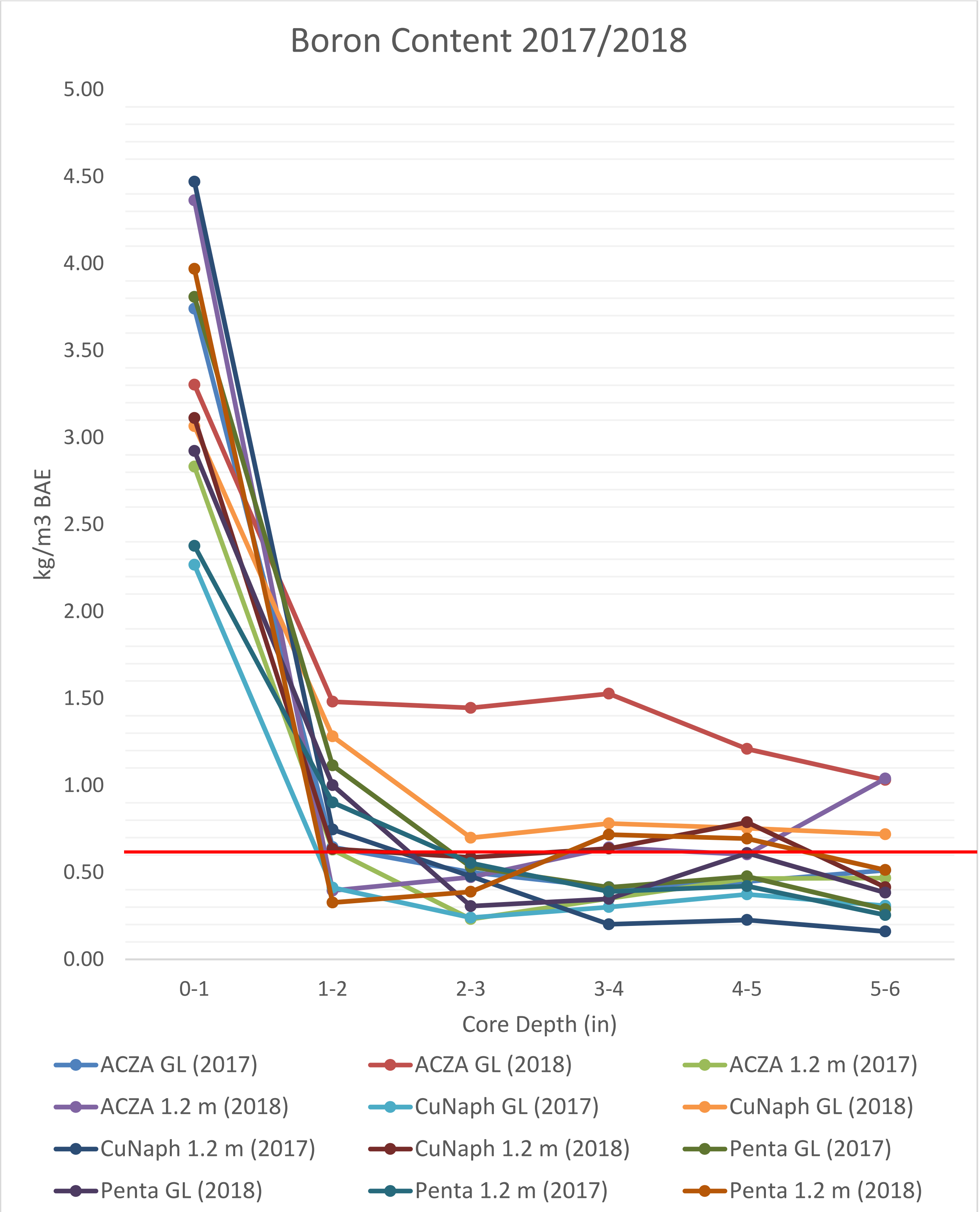

Figure II-3. Boron levels in Douglas-fir poles subjected to either a boron pre-treatment followed by over-treatment with copper naphthenate or pentachlorophenol, or an ACZA/boron pressure treatment. Red line indicates 0.6 kg/m³ BAE.

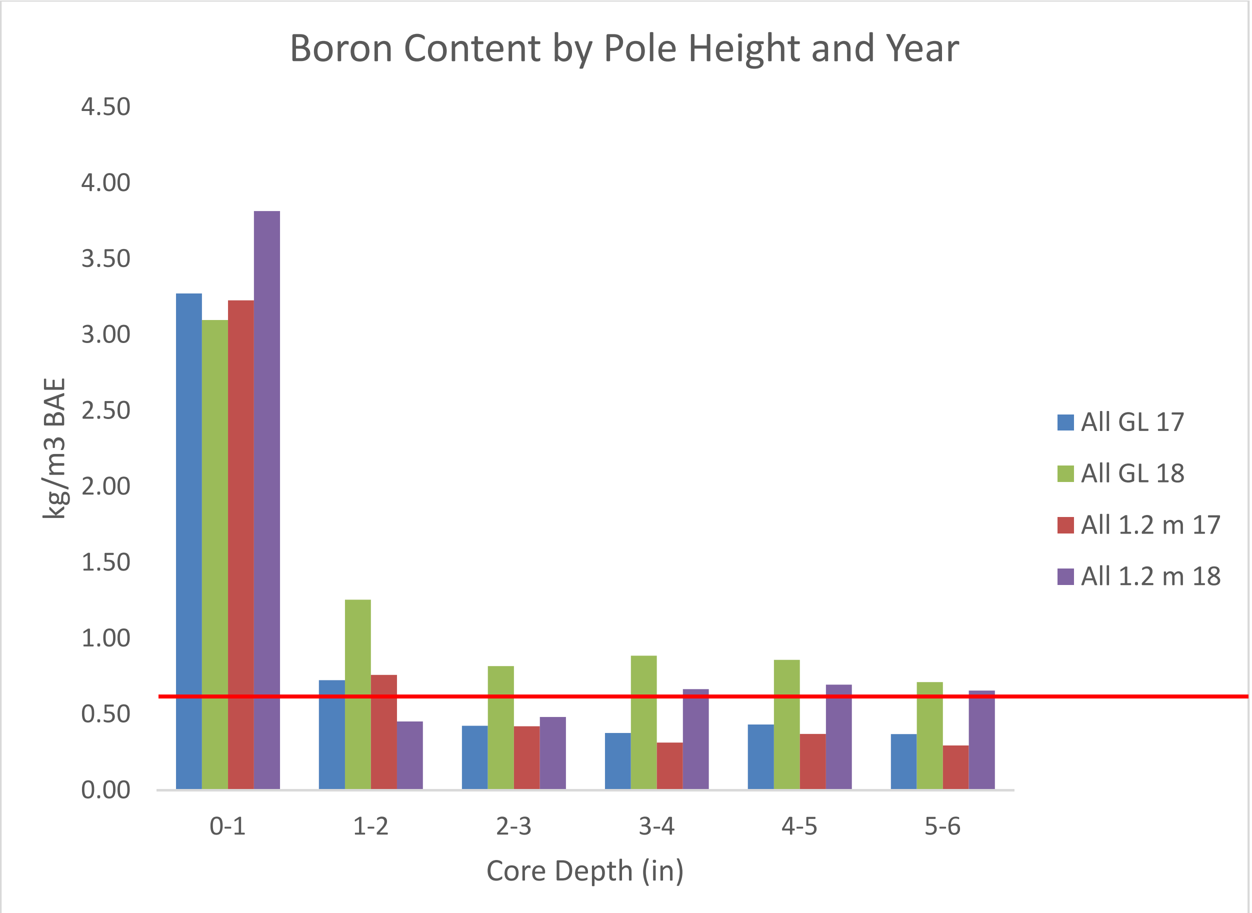

Figure II-4. Combined boron levels in Douglas-fir poles subjected to a boron pre-treatment followed by over-treatment with copper naphthenate or pentachlorophenol, or an ACZA/boron pressure treatment. Red line indicates 0.6 kg/m^3 BAE.

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OBJECTIVE III

EVALUATE PROPERTIES AND DEVELOP IMPROVED SPECIFICATIONS FOR WOOD POLES

A well-treated pole will provide exceptional performance under most conditions, but even a properly treated structure can experience decay in-service. While most of our efforts have concentrated on developing systems for arresting in-service decay, developing methods for preventing this damage through improved initial specifications and identifying better methods for assessing in-service poles would produce even greater investment savings for utilities. The goals of Objective III are to develop new primary treatment methods, explore the potential for new wood species, assess various inspection tools, and explore methods to produce more durable wood poles.

A. Effect of Capping on Pole Moisture Content

Remedial treatments at groundline have markedly improved the service life of wood poles across North America. Controlling decay at groundline, however, has little influence on fungal activity further up the pole. The risk of fungal attack above ground is much lower and the rates of decay are much slower above ground, but fungi will eventually affect pole performance above groundline. One area where this becomes evident in older poles is at the top. Some utility specifications call for a water shedding cap to be applied to the top of poles, while others leave pole tops without a cover.

Preservative treatment tends to penetrate through the end of the pole for distances ranging from 150 to 450 mm depending on the species. Logic would suggest that this degree of preservative penetration should prevent fungi from entering the untreated wood beneath; however, checks and splits that develop during seasoning can extend deeper into the wood allowing fungi and moisture to enter. This results in decay that extends downward into regions where the cross arms and other pole hardware are attached, necessitating early replacement. Remedial treatment of this type of damage is difficult, with the best approach being prevention using a water shedding cap.

We have long advocated for utilities to use water shedding caps to protect the tops of utility poles. However, there were insufficient data showing the effects of capping on pole condition. In this section, we will present data on three tests examining the effects of capping as well as pole top shape on moisture content. Moisture content has been used as an indirect indicator of decay risk because poles that become wet are likely to be attacked by decay fungi.

1. Effect of Conventional Capping on Pole Moisture Content:

Ten Douglas-fir poles that had been removed from service were cut into 2.5 m lengths and set in the ground to a depth of 0.6 m. The poles were cut so that the top was at least 150 mm away from any pre-existing bolt hole. The original bolt holes were plugged with tight-fitting wood or plastic plugs to impede moisture entry. Five of the poles were left without caps while the remainder received Osmose pole caps.

Initial moisture contents for each pole were determined during installation from increment cores taken 150 mm below the top of the pole. The outer treated zone was discarded, and the inner and outer 25 mm of the remainder of the core were weighed, oven-dried, and re-weighed to determine wood MC.

Cap effect on MC was assessed 4 to 126 months after installation by removing increment cores from just beneath the pole cap or at an equivalent location on the non-capped poles (Table III-1). The cores were processed as described above.

Moisture contents were initially higher in capped poles, slowly dried to levels less than 20%, and have since declined to an average of 7 to 8% over the 126 months since installation. The moisture level generally considered necessary for fungal attack is 28-30%. Thus, wood in the area beneath the caps is well below the level required for fungal growth.

Moisture contents of poles without caps were initially lower than the capped poles, but levels have steadily increased over each wet season. Moisture contents were very high after 90 months of exposure and there was some decay evident in cores. Sampling of poles at 113 months showed moisture levels near pole centers averaged 29.5% while those closer to the surface averaged 21.5%. The higher moisture levels in the center are consistent with previous results. Moisture levels after 126 months were below 20% but still higher than those with caps. The last two samplings have taken place at the end of the dry summer. These poles will be sampled this coming winter to provide a better indication of the effects of capping on moisture content.

One concern about the caps is their expected service life. The caps are exposed to severe ultraviolet light radiation and many plastics are susceptible to UV damage. However, the caps remained sound and free of damage that might allow moisture to intrude into the wood (Figure III-1). The results clearly show the benefits of capping in terms of reducing internal moisture content. Ultimately, reducing the time when conditions are suitable for fungal growth should translate into improved performance.

Table III-1. Moisture contents in Douglas-fir poles with or without water shedding caps as determined over 126 months.

Exposure Time (Months)	Sampling Month	Moisture Content (%)			
		No Cap		Capped	
		Inner	Outer	Inner	Outer
0	February	20.1	16.8	28.4	19.7
4	June	25.2	18.9	19.0	18.3
12	February	37.5	26.1	14.2	16.4
28	June	60.7	27.4	15.5	15.9
32	October	29.3	17.4	13.6	13.5
40	June	99.3	35.5	13.6	16.1
44	October	53.1	21.5	14.7	14.1
52	June	85.1	22.0	-	-
56	October	41.7	23.3	9.8	9.4
64	June	48.4	13.0	8.8	8.3
90	August	83.6	28.2	13.3	11.0
113	July	29.5	21.5	18.1	16.3
126	August	17.9	10.4	7.7	7.0

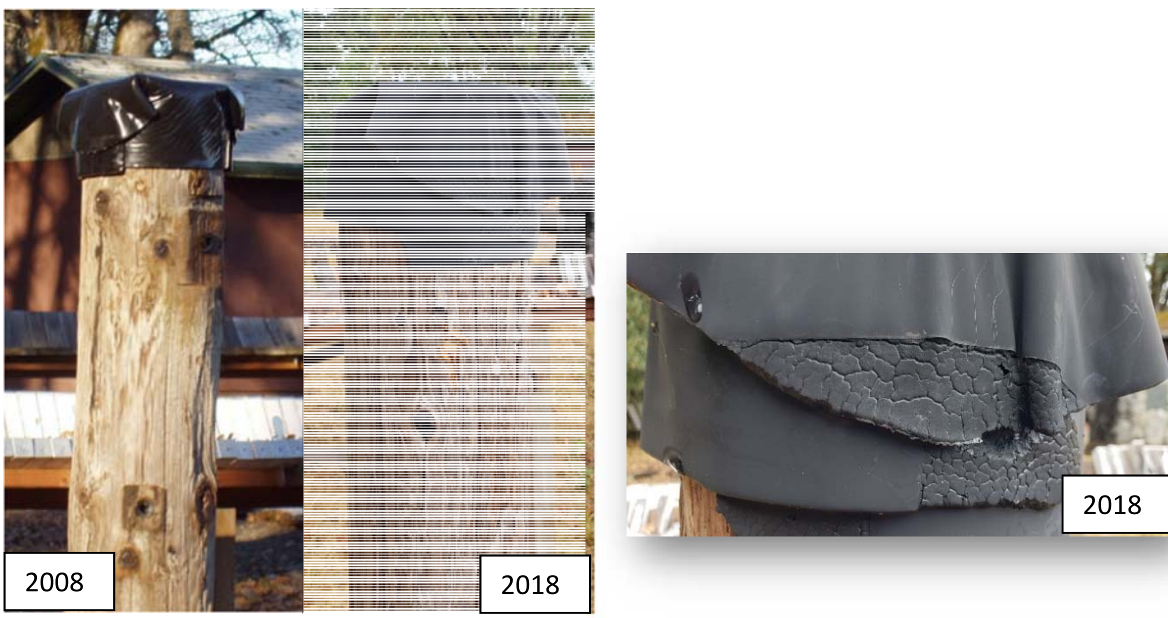


Figure III-1. Example of the condition of water-shedding caps at the start of exposure and after 126 months of exposure in Corvallis, OR.

2. Use of Polyurea Caps for Limiting Moisture Intrusion on Douglas-fir Pole Tops:

Polyurea barriers have proven to be durable on crossarm sections in sub-tropical exposures in Hilo, Hawaii. However, decay fungi have been able to penetrate the film on untreated Douglas-fir cross arms under extreme sub-tropical conditions.

We wondered if these materials would also be effective for protecting the tops of newly installed utility poles. To investigate this possibility, six penta-treated Douglas-fir pole sections (3 m long) were coated with polyurea from the tip to approximately 0.9 m below that zone (Figure III-2). The poles were set to a depth of 0.6 m at a test site on the OSU campus. Increment cores were removed from the non-coated section of the pole and divided into inner and outer 25 mm sections as described above. Each core section was weighed immediately after removal from the pole, oven-dried, and re-weighed. The difference was used to determine MC. The sampling hole was covered with a patch of seal-fast tape (Mule-Hide Products, Beloit, WI). Moisture contents at the time of installation ranged from 16.0 to 31.8%. The averages for the inner and outer zones were 23.8% and 19.0%, respectively (Table III-2). The poles, installed in the spring of 2011, were sampled after 4, 12, 16, 24, 38, 61, and 74 months of exposure to assess the effect of the polyurea coating on internal moisture. Increment cores were removed in the same manner as previously described for the first capping test and MC was determined for each pole by weighing, then oven drying and weighing the cores again. Non-coated, non-capped poles from the previously-installed moisture shedding pole cap study served as controls. The condition of the surface coating was also visually monitored for evidence of adhesion with the wood as well as the development of surface degradation.

Figure III-2. Example of a polyurea capped pole top.

The caps remain sound and free of damage ~6 years after installation (Figure III-3). Moisture contents of non-coated poles varied with season and were consistently above 30% during the winter months. Moisture contents were often above 30% during the dryer summer months suggesting that the wood in these poles was wet enough for decay to progress continually throughout the year.

Moisture contents in polyurea capped poles were initially around 20%, declining over additional sampling times. Moisture contents were at or below 20% for all sampling points after 4 months. These results are similar to those found with the traditionally capped poles and, again, illustrate the benefits of capping for moisture exclusion.

Table III-2. Moisture content beneath the tops of Douglas-fir poles with and without a water-shedding polyurea coating as determined over 74 months.

Exposure Time (Months)	Sampling Month	Moisture Content (%)[a]			
		No Cap		Polyurea Coated	
		Inner	Outer	Inner	Outer
0	June	99.3	35.5	23.8	19.0
4	October	5.1	21.5	21.6	13.2
12	June	85.1	22.0	4.6	8.3
16	October	41.7	23.3	17.9	16.2
24	June	48.4	13.0	17.8	14.0
38	August	83.6	28.2	17.3	18.3
61	July	29.5	21.5	20.4	14.7
74	August	17.9	10.4	15.0	16.0

[a]Values for the non-capped control were from the Osmose test and are presented for relative comparison.

Figure III-3. Condition of polyurea coatings on the tops of Douglas-fir pole sections after 61 months of exposure in Corvallis, OR.

B. Effect of Pole Top Configuration on Moisture Uptake in Poles

In previous tests, we have explored the benefits of capping poles at the time of installation to retard moisture uptake and limit the potential for pole top decay. These tests have shown dramatic differences in moisture content between poles with and without caps. One other aspect of a pole specification is variation in the shape of the pole top. Some utilities specify a flat top, while others require sloping or roofed tops. The presumption is that the slope encourages water to run off the wood more quickly, thereby reducing the risk of water uptake that creates conditions conducive to fungal attack. However, it has been our assertion that these sloping surfaces actually expose a greater wood surface area to wetting. This becomes especially important as poles season and check in service. Preservative treatment imparts some moisture resistance to wood, but continuous wetting will eventually lead to moisture uptake. This increased moisture content swells the wood. Stresses develop as the wood dries which lead to the development of micro-checks on the upper surface that act as conduits for moisture to penetrate into the wood, potentially beyond the original depth of preservative treatment.

There are, however, no data examining differences in moisture uptake on pole tops with differing roofing patterns. Over the past two years, we had the opportunity to establish such a test

Douglas-fir poles were cut into twenty-four, 0.9 m long sections which were allocated to four different treatment groups. Two groups were left with their tops cut perpendicular to the length. The tops of one set of pole sections were cut at 30 degree angles while the final set was cut with two sloping sides coming to a point (Figure III-4).

Poles were then pressure treated with penta in P9 Type-A oil in a commercial cylinder. Half of the poles with their tops cut perpendicular to the longitudinal direction received a commercial water shedding cap, while the remaining pole sections received no cap. In our previous capping tests, we removed increment cores from poles at varying intervals. These cores were weighed, oven dried, and re-weighed. Differences were used to determine wood moisture content. This process, while accurate, was time consuming and created a tremendous number of holes in each section that could become pathways for moisture ingress. In the current test, we will use weight gain of each section as an indirect measure of moisture change. Each section was weighed to provide a starting weight, then placed upright on a rack. The rack was exposed outside and samples were periodically weighed to assess effects of pole top configuration on moisture uptake.

Sample moisture contents varied somewhat at the time of installation and the resulting changes in mass as the samples dried made it difficult to delineate differences associated with roofing style. In order to deal with this issue, the mass of the samples at the end of the summer was used as the initial starting point for assessing future moisture changes. This time was chosen because the pole sections had ample time to dry during the hot, rain-free summer months. As a result, differences measured by weight changes do not reflect absolute moisture content, but relative changes to our selected start time.

Figure III-4. Examples of the different pole top roofing patterns assessed for their ability to resist moisture ingress.

The results over the first year showed that mass changes were greatest during the December to April period, then declined over the next 5 months (Table III-3). Pole sections with a flat top and cap had the lowest mass gains over the test period, while mass changes in the other pole sections were similar to one another. The initial results show little noticeable difference among the various roofing designs. We would expect this to change as the poles continue to wet and dry over time. This process should create internal stresses that lead to checking and provide pathways for moisture entry into pole sections. We will continue to monitor these sections to determine if pole top configuration ultimately affects moisture uptake.

Table III-3. Mass changes of Douglas-fir pole sections with different top configurations as determined by weighing over a 12 month exposure period in Western Oregon.

Date	Average mass change (%)			
	Double pitch	Flat Top	Flat top/cap	Single slope
9/20/2017	0.0 (0.0)	1.8 (1.8)	1.2 (1.4)	1.5 (1.8)
10/25/2017	2.2 (1.5)	3.3 (0.9)	0.7 (1.3)	2.3 (1.6)
12/21/2017	6.8 (2.1)	7.5 (1.1)	3.3 (2.7)	6.2 (1.3)
4/2/2018	5.2 (1.6)	6.2 (1.4)	3.3 (1.4)	4.7 (2.0)
5/7/2018	3.9 (2.2)	4.2 (1.6)	1.2 (1.4)	3.1 (0.3)
8/14/2018	0.0 (0.0)	0.9 (1.3)	1.4 (1.6)	0.0 (0.0)
9/19/2018	2.7 (1.0)	2.6 (0.9)	2.6 (0.3)	4.4 (2.9)

[a]Values represent averages of 4 or 5 replicates per roof style. Figures in parentheses represent one standard deviation.

C. Effect of Capping and Supplemental Chemical Treatment on Marine Pile Decay

Capping clearly reduces the risk of moisture entry into pole tops, creating conditions that are less conducive to fungal attack. However, we have largely limited our assessments to moisture measurements beneath caps as an indirect measure of decay risk. We have a separate trial that examined the benefits of capping on marine pilings. While marine pilings clearly have different exposures in soil or water, the tops experience much of the same decay risk.

The South Beach Marina is located in Newport Oregon along the Yaquina River. The marina was built in 1979, using creosote-treated Douglas-fir pilings. Marina specifications included cutting pile tops at a 45 degree angles after driving. While pile tops are supposed to be covered with a bitumen coating to retard moisture entry, this was not included in the process. Two-years after installation, a limited inspection revealed 27% of increment cores removed from the piles contained viable decay fungi. These results suggested that the pilings would eventually have substantial decay problems. All of the piles were sampled 5-years after installation by removing increment cores from 15 mm below the top of each pile. The cores were cultured on malt extract agar and any fungi were examined for characteristics typical of decay fungi. Twenty-one percent of cores contained one or more decay fungi. The pilings were subsequently allocated into groups of five to receive a number of chemical and capping treatment combinations (Table III-4).

Four, eight, and thirteen years after treatment, the incidence of decay fungi in the piles was assessed by removing increments cores from sites 150 and 450 mm below the top. The piles were recently sampled 34-years after treatment by removing increment cores from sites 150 mm below the cap. Cores were cultured on 1.5% malt extract agar and observed for decay fungal growth as described earlier.

ABF, FCAP, and NAF all rapidly eliminated decay fungi from the piling (Table III-5). Boron rods with copper were initially more effective than boron rods alone, but this difference disappeared at the 8-year assessment. ABF, NaF, Boron, Boron plus CuO, and FCAP continued to protect the piles 8 years after treatment. Capping produced more variable results with decay fungi isolated from piles receiving no cap, as well as those capped with fiberglass or metal, but not from those capped with a coal-tar fiberglass mesh or roofing paper. Neither of the latter treatments is likely to move into the wood to any extent. Patox, pentachlorophenol, and Pole Topper all failed to completely eliminate decay fungi. Capping was generally associated with reduced incidence of decay fungi.

Table III-4. Treatments applied to Douglas-fir piles tops exposed at Newport, Oregon[a]

Treatment designation, by type	Dosage	Description of Chemicals
A	200 ml	Methylisothiocyanate (MITC) applied to holes drilled in pile top; holes were than plugged with tight-fitting dowels.
B	200 ml	Vorlex® (20% MITC in chlorinated C_3 hydrocarbons) applied as in Treatment A.
C	200 ml	Chloropicrin (trichloronitromethane) applied as in Treatment A.
D		Timber-gard® (water soluble rod containing sodium fluoride, potassium bifluoride, sodium dichromate, and 2,4-dinitrophenol); five inserted in holes drilled in pile top.
E	454 g	Ammonium bifluoride (ABF) applied in semipermeable bags nailed to pile top.
F	454 g	Sodium fluoride (NAF) applied as in Treatment E.
G	454 g	Fluor-chrome-arsenic-fluoride (FCAP) applied as in Treatment E.
H	–	Patox® discs (absorbent pads commercially soaked with combinations of sodium fluoride, potassium dichromate, sodium pentachlorophenate, and coal tar creosote) applied to pile top, one disk/top.
I	350ml	Pole topper fluid® (10% pentachlorophenol) applied by pouring solution into five holes 30 cm into pile top and then plugging holes with tight-fitting dowels.
J	350 ml	Pentachlorophenol (5%) applied as in Treatment I.
K	200 g	Boric oxide rods inserted in holes drilled in pile top.
L	200 g	Boric oxide + cupric oxide (3%) applied as in Treatment K.
M	200 g	Timbor® (Sodium octaborate tetrahydrate) applied as in Treatment K.
N	200 g	Timbor® + cupric oxide (3%) applied as in Treatment K.
Caps		
O	–	Coal tar creosote with two layers of fiberglass mesh.
P	–	Fiberglass roofing cut 2.5 cm larger than pile diameter; wooden spacers (1/4 × 1 × 6 in.) inserted between cap and pile top to allow airflow; caps then nailed down.
Q	–	Plywood dip-treated with ammoniacal copper arsenate; cut, spaced, and nailed as in Treatment P.
R	–	Metal cones (galvanized sheet metal riveted into cone shape) approximately 2.5 cm larger than pile diameter.
S	–	Roofing felt (50 lb.) cut and nailed to pile top.

[a]Each treatment was applied to five piles

The most recent evaluation showed that decay fungi were still prevalent in piles that were not capped and received no supplemental chemical treatment, but there were decay fungi scattered throughout a number of treatments including borate rods with copper (Table III-5). Fungal isolation levels were low in all treatments receiving a chemical and cap combination. While these results were produced on marine piling, the top of a pole and the top of a marine pile present very similar decay environments. The performance of these treatments on the coast of Oregon is also impressive because this site receives considerable rainfall (> 2 m year) and most of it is wind-driven. The results illustrate the benefits of capping.

Table III-5. Incidence of decay fungi in Douglas-fir piling 0, 4, 8, and 34-years after application of various chemical treatments to the tops with or without water shedding caps.

Chem.	Cores with Decay Fungi (%)																													
	No Cap					Coal Tar					Fiberglass					Plywood					Metal Cone					Roofing Felt				
	0 yr.	4 yr.	8 yr.	13 yr.	34 yr.	0 yr.	4 yr.	8 yr.	13 yr.	34 yr	0 yr.	4 yr.	8 yr.	13 yr.	34 yr.	0 yr.	4 yr.	8 yr.	13 yr.	34 yr.	0 yr.	4 yr.	8 yr.	13 yr.	34 yr	0 yr.	4 yr.	8 yr.	13 yr	34 yr
A	20	0	0	0	0	40	0	0	0	0	40	0	60	20	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B	20	20	0	20	0	60	0	0	0	0	0	0	40	40	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C	20	0	0	0	0	60	0	0	0	0	20	0	0	0	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D	17	0	0	0	0	25	0	0	0	0	0	0	0	0	0	40	0	20	0	0	-	-	-	-	-	-	-	-	-	-
E	40	10	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F	0	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
G	27	0	0	0	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	40	0	20	0	20	-	-	-	-	-	-	-	-	-	-
I	-	-	-	-	-	20	0	0	0	0	25	0	0	0	0	50	40	20	20	0	60	20	0	20	0	-	-	-	-	-
J	-	-	-	-	-	20	0	0	0	0	20	0	0	0	0	29	0	0	0	0	40	0	0	0	0	-	-	-	-	-
K	25	20	20	0	0	-	-	-	-	-	-	-	-	-	-	40	20	20	0	20	-	-	-	-	-	-	-	-	-	-
L	20	0	0	0	20	-	-	-	-	-	-	-	-	-	-	67	25	0	0	0	-	-	-	-	-	-	-	-	-	-
M	20	20	0	0	0	-	-	-	-	-	-	-	-	-	-	33	17	0	0	0	-	-	-	-	-	-	-	-	-	-
N	20	0	0	0	0	-	-	-	-	-	-	-	-	-	-	60	25	20	0	0	-	-	-	-	-	-	-	-	-	-
UTC	21	38	17	13	44	20	20	0	20	0	13	44	6	6	13	41	35	17	10	9	36	36	10	7	0	27	31	7	0	0

D. Developing Data on the Ability of Various Systems to Protect Poles from Wildfire

Changing climatic conditions in North America are predicted to result in hotter, drier summers with increased risk of wildfire. At the same time, decades of fire suppression, failure to otherwise manage large sections of publically owned forests, and regional bark beetle outbreaks have created unprecedented fuel loadings in many forests. These conditions create the risk of major conflagrations, especially across the western parts of the United States and Canada. Increased fire risks have raised major concerns among electric utilities whose distribution and transmission lines run through at-risk areas, where lines are largely supported by either wood or steel poles.

At first glance, replacement of wood with steel seems like a logical approach; however, it is important to look more closely at the problem (Smith, 2014). The ability of wood to burn is well known; however, little consideration has been paid to the tendency of steel to melt and deform when exposed to elevated temperatures. In essence, both materials are susceptible to failure during wildfires. Calls to place all lines underground would be technically difficult and prohibitively expensive. Going underground would also create other long term maintenance issues that could reduce system reliability and slow outage repairs. As a result, identifying methods to limit the risk of fire damage to poles would be a more practical approach to maintaining system reliability in the face of increasing fire danger. One of the most important aspects of this process is better right of way vegetation management. This is essential regardless of fire prevention mechanisms to ensure the material used to support overhead lines remains in service. It will also be important to develop new treatments that protect poles against fire for the life of the pole, as well as treatments that can be applied to in-service poles to increase fire resistance.

Developing fire retardant treatments for long term exterior exposure is challenging. While there are several exterior fire retardants on the market for wood in houses, wood poles present special challenges. First, they are either treated with petroleum-based solvents that are inherently flammable, or they are treated with metal-based preservatives containing chromium or copper that will slowly combust once ignited (Preston et al., 1993). Furthermore, poles in very dry areas may develop wide, deep checks, which can act as chimneys to accelerate burning. In addition, treatments must last the 60-80 years in which a pole remains in service. Finally, unless a separate process is employed to restrict treatment to the surface, a substantial amount of the intended fire retardant will be delivered to the pole interior where it will serve little purpose, except as a possible long-term reservoir for replenishing surface chemical. An alternative approach would be to develop fire retardant wraps or barriers that could be applied immediately after treatment. This approach is being applied in Western Australia with some success (Powell, personal communication). Developing effective fire retardant systems for new poles should be a research direction for chemical companies and the electric utility industry, but it is a long-term goal. Given the time required to replace all poles already in service (using an estimated 60-80 year pole service life), it will be equally important to address protecting millions of poles already in service.

1. In-Service Pole Protection:

Protecting poles against fire is not a new concern. Utilities have attempted to use various methods to limit pole fire risk. Many utilities have considered placing thin steel sheets around the poles at groundline. These barriers can provide fire resistance; however, they tend to trap moisture and create conditions for development of extensive surface decay between the steel sheet and the wood. They can also make it more difficult to climb a pole (depending on how far up the pole they are placed). In addition, it is unclear whether these sheets would be completely protective against the charring that can occur with copper based preservative systems such as chromated copper arsenate, ammoniacal copper zinc arsenate, or alkaline copper quaternary. The metals in these systems can ignite following relatively short, but intensive fires and will continue to smolder until the pole fails. A metal sheet would protect the wood from direct flame, but would also readily transmit heat to the wood and could ignite the metal, thereby negating any protective value.

Another alternative for fire protection is to apply a protective coating to the pole surface. Fire retardant coatings have long been available for this application; however, interest in these materials has grown as utilities become aware of their increased exposure to fire risk. These materials need to be relatively inexpensive and easy to apply in the field. Given the high cost of driving to a utility structure, they must also be capable of providing protection for 5 to 10 years. There are a second group of protectants that are sprayed on the wood surface shortly before a pole is subjected to a fire. These systems were originally designed for temporary protection of houses and other high value assets and are applied just ahead of an advancing fire. Temporary coatings could also be applied to poles, but systems would be applied every time fire threatened a structure. The wide array of possible fire protection products with varying claims of efficacy have created interest to develop improved methods for evaluating these systems.
There is a critical need to develop a simple, mobile system to assess the effectiveness of both initial and supplemental fire retardants on poles. The system would:

1. Employ standard materials
2. Test small pole sections
3. Enable reproducible heating
4. Have a relatively low cost

We have previously reported on our new method developed by the Utility Pole Research Cooperative to assess the performance of fire-retardant systems. The test method is relatively simple and inexpensive, but reproducible. The device uses a stainless-steel shield to contain the heat as close to the pole as desired (Figure III-5). Two infrared heating elements are placed along the stainless-steel walls. A thermocouple is placed into the pole from the poles backside (non-heated side) to within 6 mm of the pole surface on the heat-exposed face. This thermocouple is connected to a data-logger to record temperature during exposure. In addition, an infrared scanner is used to monitor air temperature between the heating elements and wood. The system allows the pole surface to be heated incrementally with the ability to determine maximum temperatures as well as surface temperatures over the exposure period. In preliminary testing, poles were allowed to burn for 20 minutes after ignition (they could also be run to failure). In order to reduce the potential for smoke complaints, burn time was shortened to 10 minutes in subsequent tests. The degree of protection afforded by a treatment can be assessed by determining depth of char and the area burned. In addition, thermal data can provide clues as to how a given system performed, although characteristics such as time to ignition may not be useful since some treatments may actually begin to react much earlier in order to form a protective char layer.

The device was evaluated on a limited number of poles without supplemental fire protection (Figure III-6). Penta-treated Douglas-fir pole stubs (~150 mm diameter by 1 m long) were conditioned to approximately 6% MC before being tested. The device was placed 150 mm away from the pole and the test was initiated. Infrared readings were taken every 10 seconds until ignition, then the flames were allowed to continue for 20 minutes before being extinguished. The design permits variation of test conditions including heat intensity, proximity to the heating source, and time of heat exposure. Untreated poles rapidly ignited and continued to burn until they were extinguished. The test apparatus was simple and very inexpensive to construct. The total cost for the assembly was less than $200 and provided a system that was easy to move, reproducible, and simple to operate.

The system was subsequently used to evaluate poles receiving two external wraps (Brooks and CopperCare), along with three surface-applied systems (FireSheath, FireGuard, and SunSeeker). The tests were run as previously described. Following the

Figure III-5. Example of the small-scale fire test apparatus showing the heating shield on a tripod and a close up of the heating elements.

tests, the area charred by the fire was estimated, then the depth of char was measured by scraping away the charred wood until sound, non-charred wood was visible (Figure III-7). The depth of the wood removed was then measured to the nearest mm. One other approach would be to use loss in circumference; however, this measure is less useful because the current test apparatus only applies heat to one face of the pole and poles are not allowed to burn to completion. Thus, any loss in cross section is limited by the surface area exposed. These tests are continuing and only one pole treated with each system has been evaluated.

Time to ignition was 10 minutes for the non-protected control and only slightly longer for the SunSeeker (12 minutes) (Table III-4). The remaining systems did not ignite,

Figure III-6. Example of the fire test apparatus being applied to a penta-treated Douglas-fir pole showing initial heating, the beginning of combustion with smoke and finally, the pole on fire.

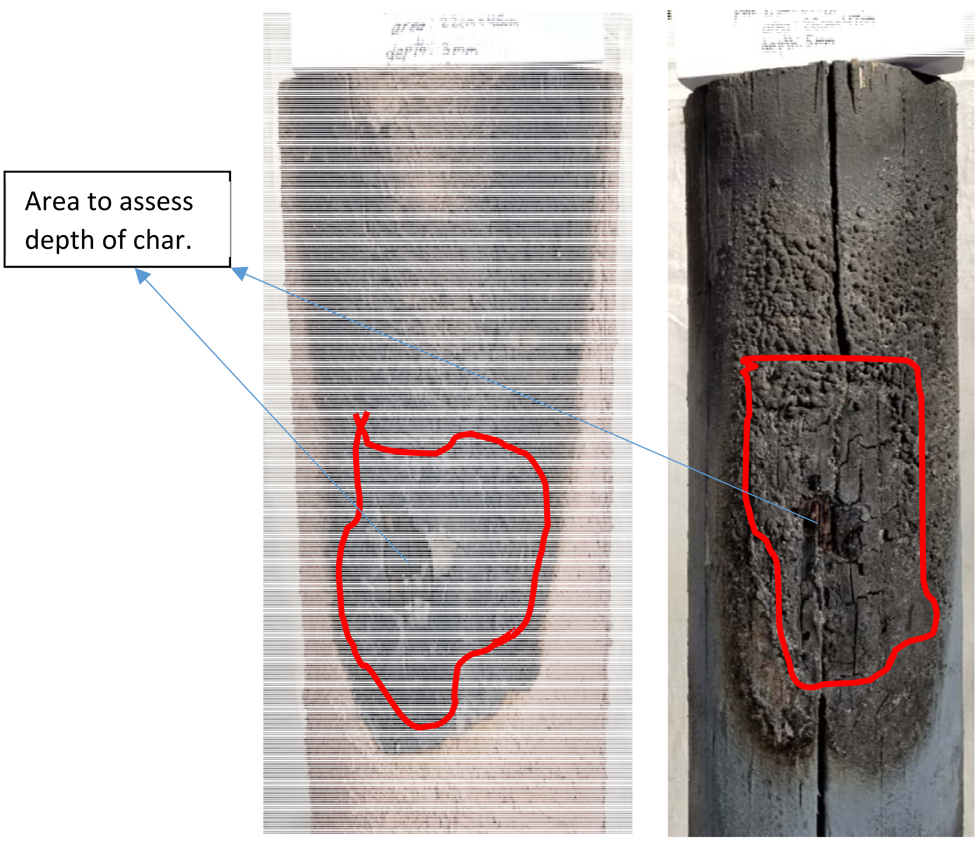


Figure III-7. Example of burned poles showing char, rough char area, and depth of char visualized by scraping surface char away.

although they did experience surface-charring on either the barrier or the applied film (Table III-4). Thus, time to ignition may not be as useful for assessing efficacy. Maximum temperatures measured near the wood surface were 365°C for both the non-protected control and the SunSeeker system. The CuCare barrier reached a temperature of 271°C, while the remaining treatments reached temperatures between 182°C and 197°C. The systems also affected the observed heating pattern.

While the described test method has proven useful, there was considerable discussion at the previous Advisory Committee meeting about modifications to the apparatus to create more uniform heating. Most of the recommendations would have substantially complicated the system, making it more similar to the fixed system that has been proposed as an ASTM Standard. In the end, the apparatus was modified to add a heating ring, but no effort was made to add fans or other devices that might create drafts to accelerate flame spread. The goal of this apparatus remains to produce an inexpensive unit that can be used to rapidly screen a wide array of protective systems to identify those which merit more extensive assessment.

The modified device has been used to assess a number of protective treatments on both untreated, and penta-treated poles. The systems evaluated in these tests were:

1. FireGuard
2. FireSheath
3. Sunfire Defense 3000

Each protective treatment was applied from 3 to 11 poles. The poles were subjected to multiple burns on different portions of the pole. Initial pole temperature was measured, then the poles were subjected to a 10 or 15 minute heat exposure period. The time to pole ignition was recorded. The resulting char area and depth of char were recorded as previously described. A total of ninety five tests were performed.

Exposure of untreated Douglas-fir poles in the test for 10 minutes produced ignition in 5 of the 10 poles; however, poles still experienced considerable char area and depth of char. Increasing exposure time to 15 minutes produced more uniform ignition, but the resulting char area and depth of char were very similar (Table III-6). Tests on penta-treated poles with no supplemental fire protection resulted in a similar time to char, while char area and char depth were both greater. Tests on copper naphthenate-treated poles produced results similar to those found with penta. These increases likely reflect the presence of the solvent as fuel.

A ten-minute exposure of untreated poles with either FireGuard or FireSheath both produced no ignition and a marked reduction in both char area and depth. A ten-minute exposure of untreated poles with SunFire Defense resulted in ignition in 2 of 7 tests, with char depth and area values that were similar to those found with untreated poles without a fire-retardant system. These results suggest that SunFire had little effect on limiting fire damage under the conditions tested.

Tests on treated poles were subsequently increased to 15-minute exposures and only penta poles were tested with fire retardant systems. Four of 10 penta-treated poles with FireGuard ignited, with an average time to ignition for those poles of 5.3 minutes. Depth of char was similar to that found for untreated poles but about half of that found with non-protected, penta-treated samples. Char depth was only half of that found with untreated poles. Only one penta pole treated with FireSheath ignited, and that took 13 minutes to occur. Char area was approximately one third of that found with unprotected penta poles, while char depth was 7% of that found with unprotected penta poles. While both sets of poles experienced some damage as a result of exposure, the barriers markedly reduce the degree of damage.

Exposure of penta-treated poles receiving the SunFire Defense spray with or without Inconel resulted in ignition in all 9 tests, with an ignition time of 6.6 to 10.2 minutes. Char depth was similar to or greater than that found with unprotected penta poles. This system clearly lacked the ability to reduce fire damage under the conditions tested. This system is typically applied shortly before fire exposure and has been used to protect houses from approaching wildfires. It is unclear why it failed to protect either untreated or penta-treated poles in this test.

Results indicate the burning method we have developed is reproducible, and results can be used to compare treatments. The method remains simple and the test apparatus could be easily constructed with common, off-the-shelf parts. We are continuing to evaluate additional fire retardant systems and will consider developing it as an ASTM Standard to supplement the larger-scale test already proposed.

Table III-6. Effect of exposing untreated and treated Douglas-fir poles to a simulated fire test on time to ignition, char area, and depth of the resulting char.

Initial Treatment	Fire test	Burn time (Min)	Initial Pole Temp. (°C)	Ignition	Ignition Time (min)[cd]	Char Area (cm^2)[d]	Char Depth (mm)[d]
None	None	10	34.5	5/10	5.6 (1.3)	758.9 (412.5)	5.3 (2.8)
	None	15	27.9	10/10	7.8 (1.0)	759.9 (250.6)	5.3 (0.8)
	Fire Guard	10	33.3	0/10	-	168.4 (95.8)	1.9 (2.2)
	FireSheath	10	30.0	0/10	-	353.4 (71.4)	0.00 (n/a)
	Sunfire Defense	10	32.6	2/7	8.9 (n/a)	847.6 (122.6)	5.6 (2.2)
Penta	None	15[a]	22.9	8/10	6.2 (3.6)	1380.1 (763.2)	7.0 (6.1)
	Fire Guard	15[b]	26.9	4/10	5.3 (3.3)	634.6 (504.9)	2.4 (2.5)
	Fire Sheath	15[b]	26.5	1/11	13.0 (n/a)	448.8 (294.4)	0.5 (1.5)
	Sunfire Defense Spray	15	27.2	6/6	6.6 (4.2)	1802.2 (262.0)	5.5 (1.4)
	Sunfire Defense with Inconel	15	24.2	3/3	10.2 (3.9)	1193.3 (26.4)	7.0 (1.7)
CuNaph	none	15	23.9	5/8	2.9 (1.6)	1104.1 (359.1)	7.3 (2.1)

[a]Two poles were only \exposed for 10 minutes
[b]One pole was only exposed for 15 minutes
[c]Values are averages of those poles that ignited
[d]Values represent means of the poles tested while figures in parentheses represent one standard deviation

2. Long Term Performance of Fire Retardants on Douglas-fir Poles

Transmission, and to a lesser extent distribution, lines often pass through forested areas. Vegetation control to limit the potential of trees contacting lines is an important and expensive component of right-of-way maintenance. Despite these practices, poles in areas with heavy vegetation may still be vulnerable to rangeland or forest fires. There are a number of possible methods to limit the risk of fires on poles. In the past, metal barriers were placed around poles in high hazard areas; however, this practice reduced pole service life because the barriers trapped moisture on the pole surface.

As an alternative, poles can be periodically treated with fire retardants. Some of these materials are designed for short-term protection and must be applied immediately prior to fire, while others are longer-lasting and provide 1 to 3 years of protection. While these fire retardant treatments have been available for decades, there is little published information on their efficacy or longevity. In order to develop this information, the following test was initiated.

Douglas-fir pole sections (200-300 mm in diameter by 1.4 m long) that had been removed from service were set in the ground to a depth of 0.6 m at our Peavy Arboretum test site. Poles were allowed to weather for approximately 8 months, then allocated to treatment groups of six or nine poles each. Each set of poles received one of the following treatments, either applied by the manufacturer or according to the manufacturer's instructions:

1. Osmose FireGuard
2. CuRap 20 as a below-ground treatment
3. J.H. Baxter Elastomeric Epoxy Roof Coating
4. Copper Care wrap without copper
5. Copper Care wrap with copper lining
6. No treatment

The Copper Care product was a 100 mm wide flexible tape that was wrapped around the pole. This system was applied in the spring of 2008. The Copper Care wrap with copper was applied in 2009.

Poles were subjected to a field burn beginning 1-year after treatment (2005) and then after 2, 4, and 5 years of exposure. The relative humidity at the time of burn was low, creating good ignition conditions. Wire mesh cages, 2.4 m in circumference, were placed around each pole and 6.8 kg of dry straw was evenly distributed in the cage (Figure III-8). Poles were individually ignited and allowed to burn until no visible flame remained. The effects of the various treatments were measured for depth of char as well as the effective loss of circumference at or near groundline.

The results showed a slight trend towards reduced loss of circumference and decreased char depth with some of the barrier systems; however, the results varied widely from year-to-year because relative humidity and wood moisture content at the time of test strongly affected burn intensity (Table III-7). In addition, it was only possible to burn towards the end of the dry season which severely limited our opportunities to test materials. We also had several years when we could not burn poles because of the severe fire risk at the site. This was the primary reason we moved away from field testing to the controlled fire testing system our lab recently developed.

The poles from this test were left in place at the Peavy Arboretum test site until the summer of 2018, when they were examined in the following test. Poles were removed from the test site and returned to the lab. It was difficult to arrange for a field burn using the previously used procedures. Instead, poles were placed into the fire test apparatus (described above) and were subjected to a 15 minute exposure. Time to ignition, depth of char, and char area were measured. No control poles from the original test were available, so freshly treated penta poles were substituted with an understanding that these more recently treated poles might be more susceptible to fire than the weathered poles used in the original test. The older poles; however, were heavily weathered and checked, which would increase their fire susceptibility.

Six poles treated with either FireGuard or an Elastomeric paint supplied by JH Baxter were evaluated. The coatings had slight surface cracking and abrading, but remained largely intact. Care was taken when removing the poles from the ground because the coatings were fragile and could be easily chipped off. However, they still presented a solid surface barrier.

Most of the freshly-treated penta poles ignited (8/10) within 6.2 minutes of being exposed to the heat source, while only 2 of 6 of the poles treated with either FireGuard or the Elastomeric paint ignited. Those that ignited required 8.3 and 9.9 minutes, respectively (Table III-8). Char area on poles receiving the fire retardant barriers were approximately one third those of freshly treated penta poles, while char depth was similar. In general, the remaining barriers provided some protection to the poles, although differences in char depth were minimal.

This test was originally established to evaluate the longevity of the various external fire retardant coatings. Several systems proved ineffective and evaluations were discontinued, but the two that have remained in test appear to continue to exhibit protective effects.

Figure III-8. Example of a pole section with straw fuel in a wire cage prior to ignition.

Table III-7. Depth of charring and loss in circumference in Douglas-fir pole sections coated with various fire-retardant materials and subjected to a simulated field fire.

Treatment	Mean Circumference Loss (cm)				Mean Depth of Charring (mm)			
	2005	2006	2008	2009	2005	2006	2008	2009
Control	1.9	3.6	6.1	7.2	8.5	10.6	21.2	8.2
CuRap 20	1.6	5.5	NT	NT	1.3	19.1	NT	NT
Elastomeric	0.4	1.5	4.6	NT	1.1	5.8	14.8	NT
FireGuard	+2.8	0.8	4.7	NT	0.8	2.1	14.8	NT
Copper Care	NT	NT	4.0	7.0	NT	NT	15.0	7.6
Cu liner	NT	NT	NT	1.9	NT	NT	NT	2.0

Table III-8. Effect of exposing Douglas-fir poles 14 years after application of fire retardant coatings to a simulated fire test on time to ignition, char area and depth of the resulting char

Fire retardant	Burn time (Min)	Initial Pole Temp. (°C)	Ignition	Ignition Time (min)	Char Area (cm^2)	Char Depth (mm)
None	15	22.9	8/10	6.2 (3.6)	1380.1 (763.2)	7.0 (6.1)
FireGuard	15	23.9	2/6	8.3	369.7 (266.9)	6.8 (1.7)
Elastomeric	15	21.2	2/6	9.0	463.1 (380.0)	6.0 (1.4)

E. Effect of Solvents on Performance of Copper Naphthenate and Pentachlorophenol

Many utilities prefer the use of oil-borne preservatives for protecting their poles against fungal attack. Oil-born systems provide water resistance to poles. More importantly, they make poles easier for line personnel to climb. While these features are important, a more critical aspect of oil-born systems are the potential effects of the solvent on preservative performance. Oil-born systems do not normally fix to the wood. Instead, they are immobilized in the oil within the wood. Solvent characteristics can substantially affect biological performance. For example, liquefied petroleum gas (lpg) was substituted for heavier petroleum solvent to solubilize pentachlorophenol. The lpg rapidly evaporated from wood leaving clean poles that are dry to the touch. These poles were used by a number of utilities interested in structures with a cleaner appearance; however, the lack of residual solvent also sharply reduced the effectiveness of the preservative, leading to the development of extensive surface decay that markedly shortened service life. The issues associated with solvent performance have led the American Wood Protection Association to require that proponents submit performance data when they make substantial changes to solvents used for a given preservative.

Over the past 7 years, we have performed numerous trials to examine solvent effects on performance of both copper naphthenate and penta. The work originally began because of changes in the solvents used to solubilize penta for Douglas-fir treatment. It was common practice for west coast treaters to take large penta blocks, place them in a treating cylinder and circulate hot oil to dissolve penta to proper solution concentrations. This required oils that had sufficient penta solvency, which was generally not a problem. Changing supplies of petroleum-based solvents towards solvents with lower penta solvency created a major concern for treaters. One alternative was to use a penta concentrate that was diluted with diesel oil; however, this solvent mixture had strong odors and the volatile diesel made it difficult to utilize Boulton seasoning (boiling in oil under vacuum to season prior to treatment).

One solution to the problem was the inclusion of biodiesel in the blended oil. Biodiesel can solubilize sufficient quantities of penta and has an added benefit of sharply reducing solvent odors. The mixture could still meet the AWPA Solvent Standard P9 Type A; however, there was concern among some treaters about the efficacy of penta in biodiesel compared to that found in conventional petroleum based oil. Biodiesel is more rapidly degraded than petroleum-based oils in soil contact without biocide, but there were no data concerning the effects of the penta/oil combination.

An extensive laboratory and field study were undertaken to evaluate the efficacy of penta in conventional solvents, diesel with penta concentrate, and penta in a biodiesel blend. The results indicated that biodiesel performed similarly to other solvents in both the laboratory and field tests. Some biodiesel/copper naphthenate treatments were also included in these trials and they suggested that this solvent/preservative combination might be more susceptible to fungal attack. A larger trial was established and the results indicated that the presence of biodiesel negatively affected the performance of copper naphthenate. A number of steps were taken after these results were released. First, the chemical manufacturer and treater both voluntarily stopped using biodiesel based solvents for copper naphthenate treatment. In addition, two utilities who had purchased substantial quantities of copper naphthenate treated poles initiated a field assessment of selected poles in their systems to determine if poles with copper naphthenate in bio-diesel were more sensitive to the development of early decay. These tests are on-going.

At the same time, there were concerns that the original field trials had only evaluated one biodiesel amended solvent system and that system might not be representative of other systems in use. For this reason, we undertook the following study.

Douglas-fir lumber was collected from a local mill shortly after sawing. The lumber was primarily sapwood and had not been subjected to prior chemical treatment. The lumber was kiln dried and then cut into 19 by 19 by 900 mm long stakes and 19 mm cubes that were free of knots, splits and other defects. The samples were weighed and allocated to treatment groups so that each group contained stakes and blocks with approximately similar density distributions. The samples were then treated with combinations of copper naphthenate or penta in mixtures of diesel alone or amended with 30, 50, 70, or 100% biodiesel. In addition, each biocide was examined in an aromatic oil, a paraffinic oil, FPRL oil, and penta concentrate. Penta target retentions were 2.4, 4.8, 6.4, and 9.6 kg/m^3, while those for copper naphthenate were 0.66, 0.99, 1.33, and 1.66 kg/m^3 as Cu.

Samples were weighed prior to treatment and subjected to 30 psi of initial air pressure. Treatment solution was pumped into the vessel and pressure was raised to 150 psi and held for 2 hours. Pressure was released and a 2 to 4 hour vacuum was drawn to relieve internal pressure and recover residual preservative. Stakes continued to lose solvent after treatment and were allowed to stabilize for 2 weeks before being re-weighed to determine net solution uptake (Figure III-9). The net weight gain was used to estimate residual preservative retention which was used to allocate stakes or blocks to given treatment groups. Samples with excessively high or low retentions were not included.

Stake condition was evaluated at 22, 34, and 46 months. Each stake was removed from the soil, wiped clean and probed with an awl for evidence of softening. Stake condition was rated on a scale from 10 to 0 as described in AWPA Standard E7 where:

Grade No.	Description of Condition
10	Sound. Suspicion of decay permitted
9	Trace decay to 3% of cross section
8	Decay from 3 to 10% of cross section
7	Decay from 10 to 30% of cross section
6	Decay from 30 to 50% of cross section
4	Decay from 50 to 75% of cross section
0	Failure

We included two test sites in this study. One was an open field and one was a mature forest, adjacent to each other at our Peavy test site. Each site offers a unique microclimate for fungal decay, with the forest naturally harboring more wood-decay fungi. Stakes in the open field setting tended to have consistently lower degrees of fungal attack than those in the wooded area (Table III-9, III-10). Untreated control stakes in the field site remain in relatively good condition after 46-months of exposure, while those in the forest site are heavily decayed. These differences likely reflect climatic conditions at the site, characterized by long, wet, but mild winters and very dry summers. Stakes in the open field site were very dry when evaluated in September while those in the forest site approximately 200 meters away were moist. Year-round moist conditions should be more conducive to fungal attack. Both sites are extremely wet during the winter, however, the test is still in the early stages of development.

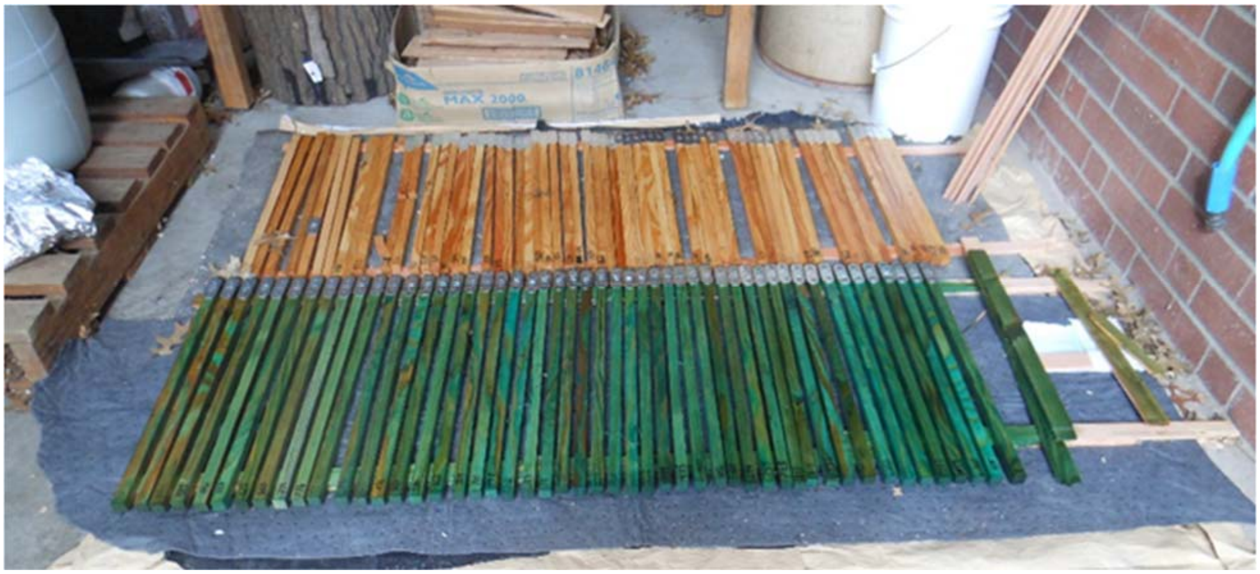


Figure III-9. Stakes drying under cover after treatment with copper naphthenate (bottom) or penta (top).

Non-treated stakes in the open field site averaged 9.90 after 22 months of exposure, while those in the forest site averaged 8.0. Stakes treated with solvent but no biocide were in slightly better condition, especially at the forest site, but differences were slight and we expect them to disappear over time. There were also slight decay spots on stakes in many treatments; however, this test is in the early stages of evaluation and we would expect treatments to differentiate with additional exposure.

Stakes at the open field site were in good condition 32-months after installation, with ratings above 9.0, indicating little evidence of advanced decay. Stakes in the forest site experienced more aggressive decay. The non-treated controls showed evidence of advanced decay (Rating = 5.5) and average ratings for many of the samples treated with solvent alone or solvent plus the lower preservative retentions exhibited decay.

Untreated stakes continued to decline after 46 months of exposure, although effects were greater at the forest site. All penta-treated stakes exposed at the field site remain in good condition after 46-months with ratings above 9, while copper naphthenate stakes with biodiesel have begun to experience measurable decay. Stakes exposed in the forest were in poorer condition and many averaged near 8, including some with pentachlorophenol. The biggest differences were found with stakes using biodiesel-solubilized copper naphthenate. Results are beginning to confirm laboratory results revealing that the detrimental effects of biodiesel on copper naphthenate were

Table III-9. Condition of Douglas-fir sapwood stakes treated with penta or copper naphthenate in various solvents and exposed for 46 months at a meadow site near Corvallis, Oregon.

Field Stake Assessment (2016-2018)									
Treatment	Biodiesel %	Months	Average Stake Condition						
			Target Retentions (kg/m³)						
Pentachlorophenol Carrier			**Water (UTC)**	**0**	**2.4**	**4.8**	**7.2**	**9.6**	**All Retentions**
Water (UTC)	-----	22	9.90 (0.3)						
		34	9.25 (1.3)						
		46	8.80 (1.7)						
Diesel	0	22		10.00 (0.0)	10.00 (0.0)	10.00 (0.0)	9.90 (0.2)	10.00 (0.0)	9.98
		34		9.75 (0.6)	9.85 (0.5)	9.80 (0.6)	9.55 (0.8)	10.00 (0.0)	9.79
		46		9.50 (1.0)	9.70 (0.6)	9.45 (1.0)	9.40 (1.1)	9.90 (0.4)	9.59
	30	22		9.90 (0.2)	10.00 (0.0)	9.95 (0.2)	9.95 (0.2)	9.98 (0.1)	9.96
		34		9.35 (1.2)	9.85 (0.5)	9.95 (0.2)	9.70 (0.5)	9.68 (0.7)	9.71
		46		9.15 (1.3)	9.60 (0.7)	9.95 (0.2)	9.70 (0.8)	9.68 (0.7)	9.62
	50	22		9.70 (0.9)	9.95 (0.2)	9.95 (0.2)	10.00 (0.0)	10.00 (0.0)	9.93
		34		9.25 (1.5)	9.65 (0.8)	9.75 (0.6)	9.75 (0.0)	9.90 (0.3)	9.66
		46		9.25 (1.5)	9.35 (0.9)	9.65 (0.9)	9.75 (0.5)	9.90 (0.3)	9.58
	70	22		9.95 (0.2)	9.98 (0.1)	10.00 (0.0)			9.98
		34		9.65 (0.5)	9.90 (0.3)	10.00 (0.0)			9.85
		46		9.35 (1.0)	9.90 (0.3)	9.95 (0.2)			9.73
Aromatic Oil	0	22		10.00 (0.0)	10.00 (0.0)	9.90 (0.3)	10.00 (0.0)	10.00 (0.0)	9.98
		34		10.00 (0.0)	9.90 (0.3)	9.90 (0.3)	10.00 (0.2)	9.93 (0.2)	9.95
		46		10.00 (0.0)	9.80 (0.4)	9.90 (0.3)	10.00 (0.0)	9.85 (0.3)	9.91
Naphthenic Oil	30	22		10.00 (0.0)	9.95 (0.2)	9.95 (0.2)	9.95 (0.2)	9.98 (0.1)	9.97
		34		9.35 (0.9)	9.85 (0.3)	9.95 (0.2)	9.95 (0.5)	9.90 (0.3)	9.80
		46		9.20 (0.9)	9.85 (0.3)	9.95 (0.2)	9.95 (0.2)	9.83 (0.7)	9.76
Paraffinic Oil	30	22		9.95 (0.2)	10.00 (0.0)	10.00 (0.0)	10.00 (0.0)	10.00 (0.0)	9.99
		34		9.30 (1.5)	9.40 (1.0)	9.90 (0.3)	9.70 (0.3)	9.90 (0.3)	9.64
		46		9.20 (1.9)	9.25 (1.0)	9.90 (0.3)	9.70 (0.5)	9.90 (0.3)	9.59
FPRL Oil	0	22		9.95 (0.2)	9.90 (0.2)	10.00 (0.0)	10.00 (0.0)	9.98 (0.1)	9.97
		34		9.70 (0.7)	9.55 (0.6)	9.90 (0.3)	9.90 (0.6)	9.83 (0.6)	9.78
		46		9.70 (0.7)	9.35 (0.9)	9.90 (0.3)	9.80 (0.6)	9.80 (0.7)	9.71
Ketone Bottoms	0	22		9.90 (0.2)	9.90 (0.3)	9.95 (0.2)	10.00 (0.0)	9.95 (0.2)	9.94
		34		9.45 (1.0)	9.75 (0.5)	9.90 (0.3)	9.95 (0.0)	9.80 (0.5)	9.77
		46		9.15 (1.9)	9.35 (1.2)	9.80 (0.6)	9.95 (0.2)	9.73 (0.6)	9.61
Copper Naphthenate Carrier	Biodiesel %			**0**	**0.66**	**0.99**	**1.33**	**1.66**	
Diesel	0	22			10.00 (0.0)	10.00 (0.0)	9.98 (0.1)	10.00 (0.0)	9.99
		34			10.00 (0.0)	9.80 (0.5)	9.85 (0.5)	10.00 (0.0)	9.91
		46			10.00 (0.0)	9.45 (0.9)	9.70 (0.8)	10.00 (0.0)	9.79
	10	22		9.90 (0.2)	10.00 (0.0)	9.90 (0.2)	9.98 (0.1)	10.00 (0.0)	9.96
		34		9.90 (0.3)	10.00 (0.0)	9.80 (0.3)	9.85 (0.8)	10.00 (0.0)	9.91
		46		9.85 (0.5)	9.80 (0.6)	9.60 (0.7)	9.70 (0.7)	10.00 (0.0)	9.79
	30	22			9.85 (0.3)	10.00 (0.0)	9.93 (0.2)	9.90 (0.3)	9.92
		34			9.30 (1.2)	9.85 (0.3)	9.60 (0.7)	9.95 (0.2)	9.68
		46			9.05 (1.3)	9.85 (0.3)	9.35 (1.1)	9.80 (0.6)	9.51
	50	22			9.90 (0.3)	9.90 (0.2)	9.88 (0.3)	10.00 (0.0)	9.91
		34			9.75 (0.6)	9.40 (0.7)	9.58 (0.3)	9.80 (0.5)	9.63
		46			9.50 (0.7)	9.35 (0.9)	9.43 (0.8)	9.80 (0.5)	9.52
	100	22		9.95 (0.2)	9.95 (0.2)	9.60 (0.9)	9.98 (0.1)	9.95 (0.2)	9.90
		34		9.50 (1.1)	9.75 (0.8)	8.95 (1.4)	9.88 (0.0)	9.50 (1.1)	9.52
		46		8.95 (1.7)	9.70 (0.9)	8.90 (1.4)	9.78 (0.6)	9.35 (1.3)	9.34

Values represent means of 10 stakes per treatment. Figures in parentheses represent one standard deviation. Ratings for non-treated controls averaged 9.90 (0.30), 9.30 (1.3) and 8.80 (1.7) after 22, 34, and 46 months of exposure, respectively. Copper naphthenate values are as Cu metal.

Table III-10. Condition of Douglas-fir sapwood stakes treated with penta or copper naphthenate in various solvents and exposed for 46 months at a forest site near Corvallis, Oregon.

Forest Stake Assessment (2016-2018)									
Treatment	Biodiesel %	Months	Average Stake Condition						
			Target Retentions (kg/m^3)						
Pentachlorophenol Carrier			**Water (UTC)**	**0**	**2.4**	**4.8**	**7.2**	**9.6**	**All Retentions**
Water (UTC)	-----	22	8.00 (2.0)						
		34	5.45 (2.2)						
		46	4.23 (2.5)						
Diesel	0	22		8.70 (1.5)	9.20 (0.9)	9.65 (0.3)	9.95 (0.2)	9.88 (0.4)	9.54
		34		8.35 (2.0)	8.25 (1.8)	9.20 (0.8)	9.65 (0.6)	9.78 (0.6)	9.05
		46		7.80 (2.1)	8.05 (1.7)	8.80 (1.1)	9.25 (0.9)	9.45 (0.9)	8.67
	30	22		9.05 (1.0)	9.50 (0.4)	9.80 (0.3)	9.95 (0.2)	9.65 (0.5)	9.60
		34		8.00 (1.1)	8.95 (0.9)	9.50 (0.5)	9.80 (0.3)	9.18 (1.2)	9.09
		46		7.60 (1.2)	8.80 (0.8)	9.30 (0.5)	9.40 (0.7)	8.58 (1.5)	8.74
	50	22		8.95 (1.0)	9.35 (0.7)	9.45 (0.6)	9.75 (0.4)	9.73 (0.5)	9.49
		34		8.40 (1.2)	8.75 (1.3)	8.80 (1.0)	9.30 (0.7)	9.53 (0.6)	8.96
		46		8.00 (1.7)	8.60 (1.5)	8.70 (1.1)	9.10 (0.8)	9.20 (0.8)	8.72
	70	22		8.75 (1.0)	9.83 (0.5)	9.75 (0.5)			9.58
		34		7.45 (1.4)	9.58 (0.9)	9.75 (0.5)			8.93
		46		7.30 (1.3)	9.25 (1.2)	9.65 (0.6)			8.73
Aromatic Oil	0	22		9.80 (0.3)	9.85 (0.3)	9.95 (0.2)	9.85 (0.5)	9.93 (0.2)	9.88
		34		9.50 (0.7)	9.70 (0.5)	9.85 (0.3)	10.00 (0.0)	9.83 (0.4)	9.78
		46		9.50 (0.7)	9.50 (0.5)	9.60 (0.6)	9.95 (0.2)	9.48 (0.5)	9.60
Naphthenic Oil	30	22		9.45 (0.7)	9.70 (0.5)	9.85 (0.2)	9.90 (0.3)	9.90 (0.3)	9.78
		34		7.80 (1.8)	9.30 (1.0)	9.60 (0.5)	9.75 (0.5)	9.68 (0.8)	9.23
		46		7.00 (1.4)	8.80 (1.4)	9.05 (0.7)	9.15 (1.1)	9.30 (0.8)	8.66
Paraffinic Oil	30	22		9.35 (0.7)	9.30 (1.3)	9.95 (0.2)	9.90 (0.2)	9.70 (0.6)	9.65
		34		8.65 (1.4)	8.45 (2.2)	9.55 (0.8)	9.75 (0.4)	9.45 (0.9)	9.17
		46		8.00 (1.7)	8.10 (2.0)	9.30 (0.9)	9.35 (1.0)	9.40 (0.7)	8.83
FPRL Oil	0	22		9.25 (0.4)	9.60 (0.5)	9.95 (0.2)	9.70 (0.7)	9.98 (0.1)	9.74
		34		8.30 (1.1)	9.05 (1.0)	8.70 (1.1)	9.30 (1.2)	9.88 (0.4)	9.05
		46		7.60 (1.1)	8.35 (1.0)	8.50 (1.0)	9.05 (1.0)	9.53 (0.8)	8.60
Ketone Bottoms	0	22		9.25 (0.8)	9.70 (0.5)	9.90 (0.2)	9.40 (0.7)	9.95 (0.2)	9.69
		34		8.35 (1.1)	9.05 (1.0)	9.65 (0.7)	9.20 (0.9)	9.85 (0.5)	9.22
		46		7.75 (1.3)	8.70 (1.1)	9.05 (1.1)	9.15 (0.7)	9.58 (0.5)	8.85
Copper Naphthenate Carrier	Biodiesel %			**0**	**0.66**	**0.99**	**1.33**	**1.66**	
Diesel	0	22			9.80 (0.3)	9.85 (0.3)	9.88 (0.3)	9.75 (0.4)	9.83
		34			8.90 (1.1)	9.60 (0.7)	9.58 (0.7)	9.55 (0.8)	9.41
		46			8.80 (1.1)	9.50 (0.7)	9.35 (0.9)	9.40 (0.7)	9.26
	10	22		8.85 (1.0)	9.75 (0.5)	9.65 (0.3)	9.68 (0.5)	9.85 (0.2)	9.58
		34		7.65 (1.4)	9.25 (0.9)	9.25 (0.8)	9.23 (1.0)	9.55 (0.4)	8.99
		46		7.30 (1.1)	8.85 (1.1)	9.15 (0.7)	8.93 (0.9)	9.40 (0.5)	8.73
	30	22			9.55 (0.4)	9.25 (0.7)	9.63 (0.5)	9.35 (0.6)	9.48
		34			8.65 (1.3)	8.75 (0.7)	8.63 (1.7)	8.80 (0.5)	8.71
		46			8.50 (1.4)	8.65 (0.8)	8.50 (1.1)	8.50 (0.7)	8.54
	50	22			8.70 (0.9)	9.40 (0.7)	9.23 (0.8)	9.55 (0.6)	9.22
		34			7.50 (1.5)	8.80 (1.3)	8.75 (1.0)	9.15 (1.0)	8.55
		46			7.15 (1.3)	8.10 (1.2)	8.55 (1.0)	8.80 (0.9)	8.15
	100	22		8.60 (1.6)	8.60 (1.2)	8.85 (1.1)	9.35 (0.7)	8.95 (1.2)	8.95
		34		7.25 (2.4)	8.45 (1.4)	8.10 (1.9)	8.75 (1.2)	8.25 (1.5)	8.16
		46		6.55 (2.6)	7.25 (1.6)	7.60 (1.8)	8.25 (1.1)	8.25 (1.5)	7.58

Values represent means of 10 stakes per treatment. Figures in parentheses represent one standard deviation.
Ratings for the non-treated control averaged 8.0 (2.0), 5.5 (2.2), and 4.23 (2.5) after 22, 34, and 46 months of exposure, respectively.
Copper naphthenate values are as Cu metal.

representative of field performance (AR 2015). Stakes treated with copper naphthenate in petroleum diesel/biodiesel blends exhibited increased decay with increasing biodiesel levels, with the heaviest decay in stakes treated using 100% biodiesel (Figures III-10, III-11, and III-12). It is important to note that stakes treated with petroleum diesel are performing well. The status of our biodiesel field trails in 2017 is shown in Figure III-13, while selected stakes and the trial site are shown in figures III-14 and III-15.

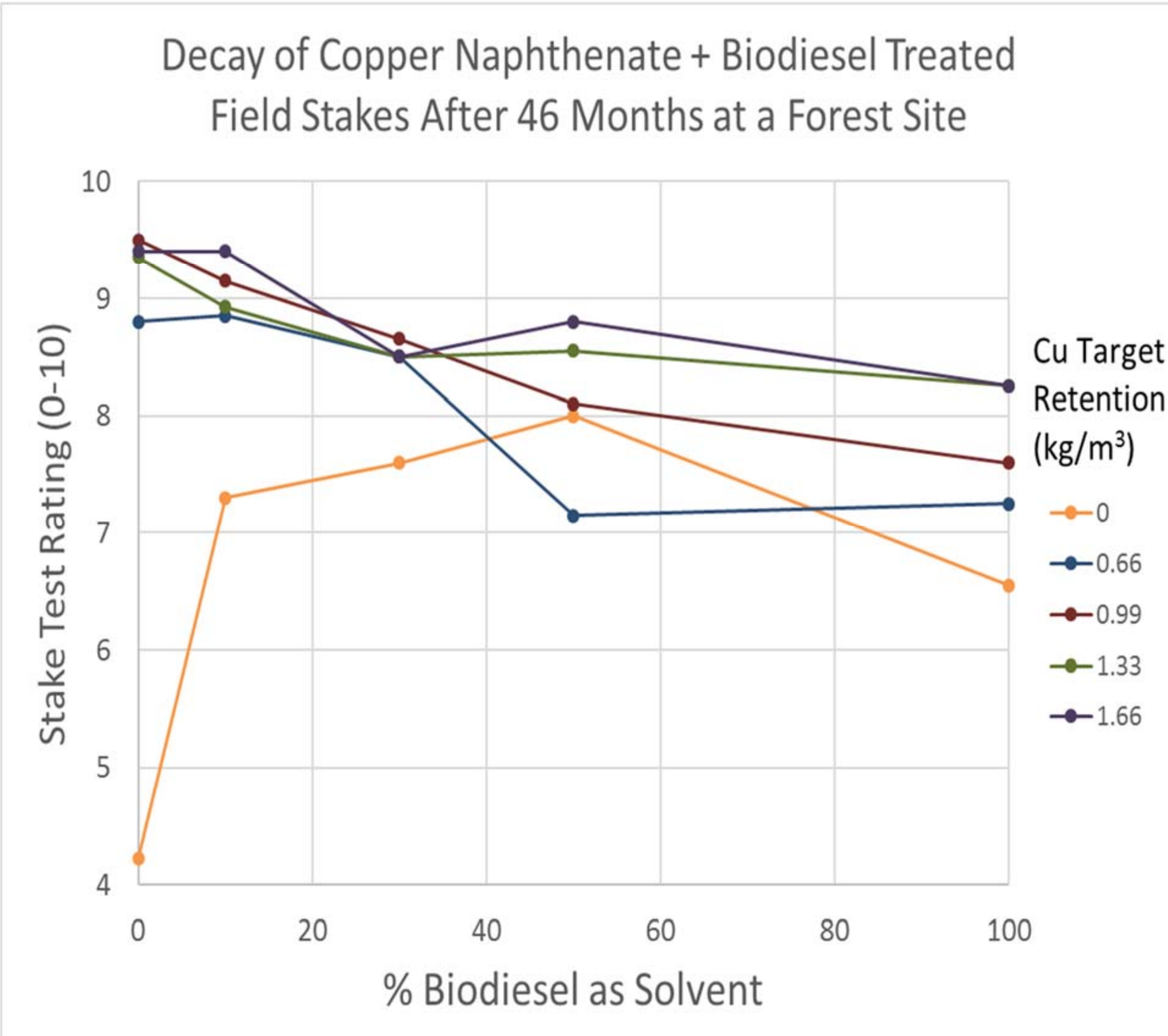
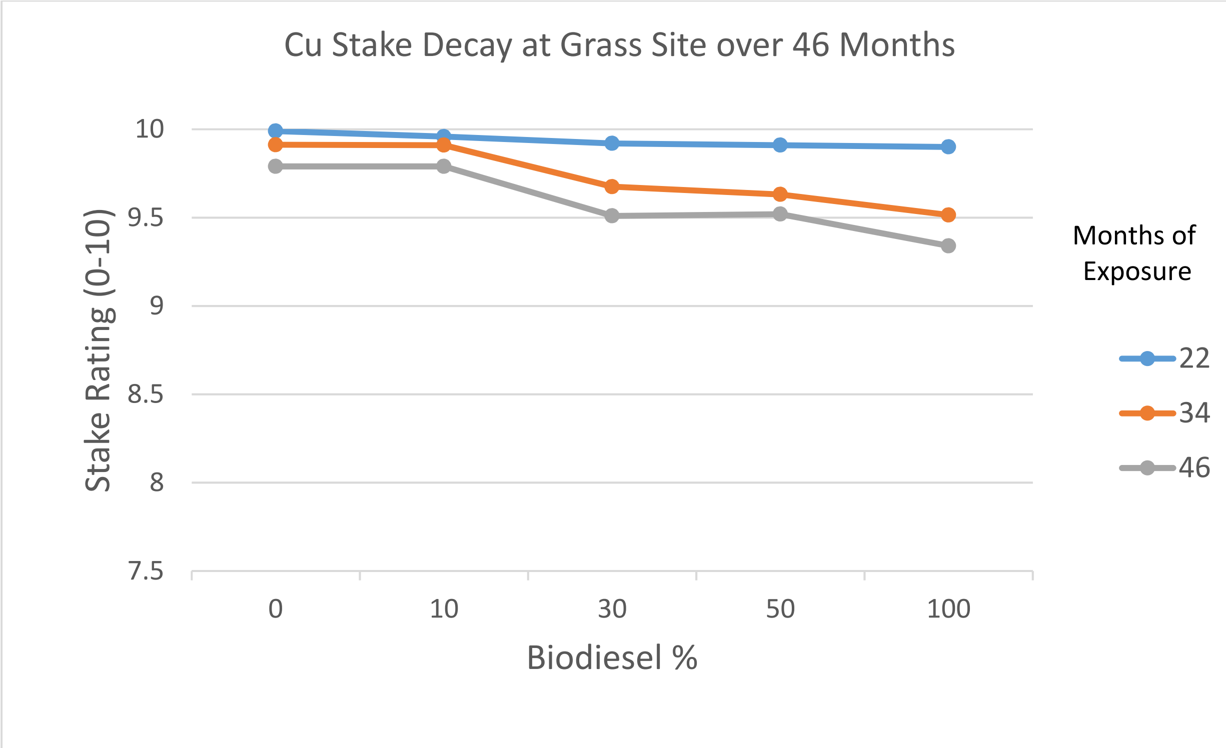


Figure III-10. Average ratings of Douglas-fir sapwood stakes at the forest site treated with copper naphthenate in mixtures of petroleum and bio-based diesel after 46 months of exposure in soil showing the relationship between increased biodiesel content and increased decay.



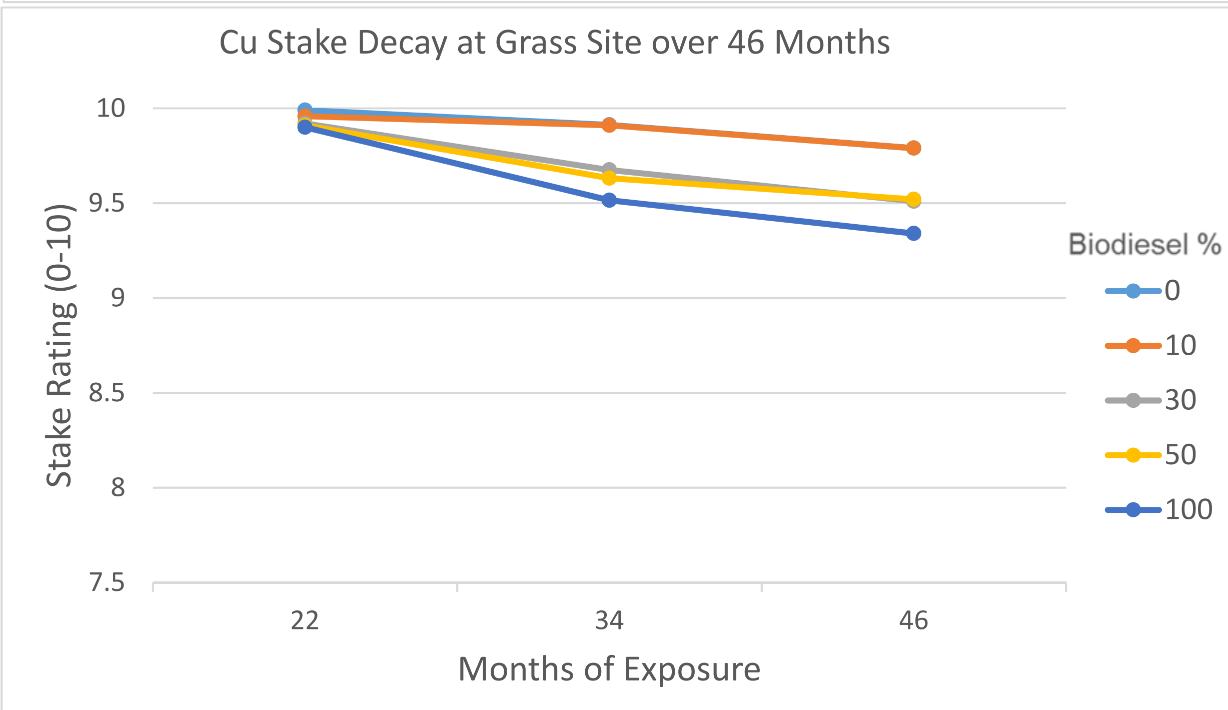
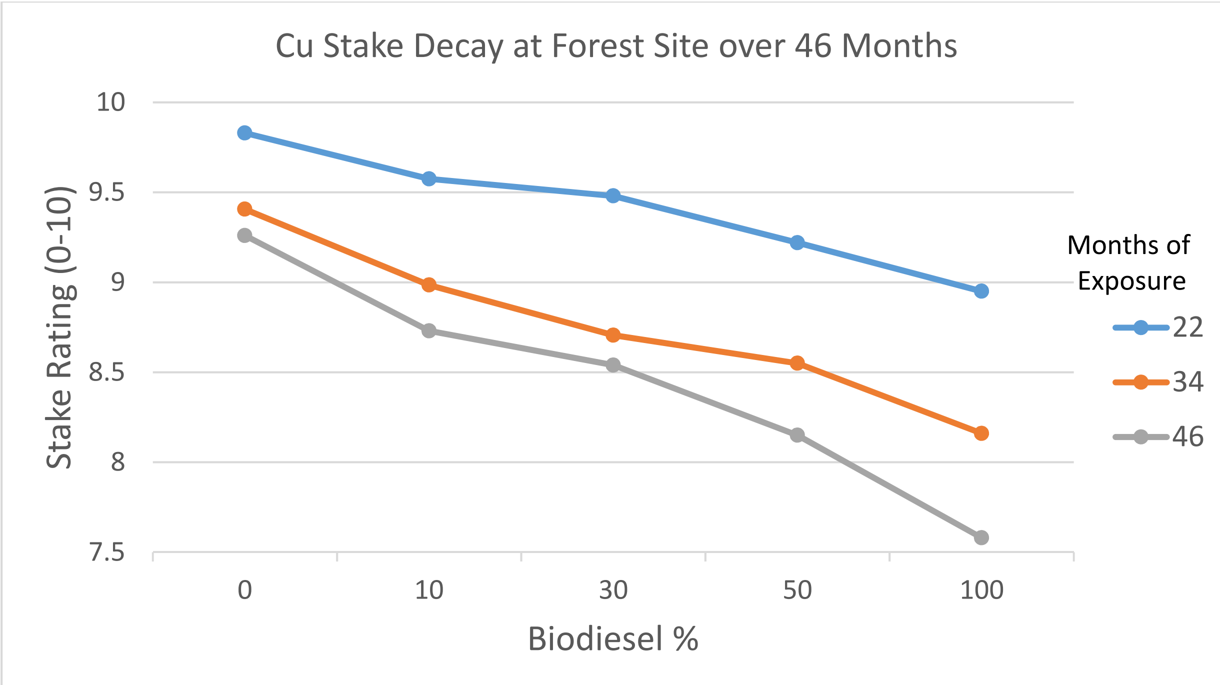


Figure III-11. Average ratings of Douglas-fir sapwood stakes at the grass site treated with copper naphthenate in mixtures of petroleum and bio-based diesel over 46 months of exposure in soil showing the relationship between increased biodiesel content and increased decay. These data combined all of the Cu retentions for each individual biodiesel level.



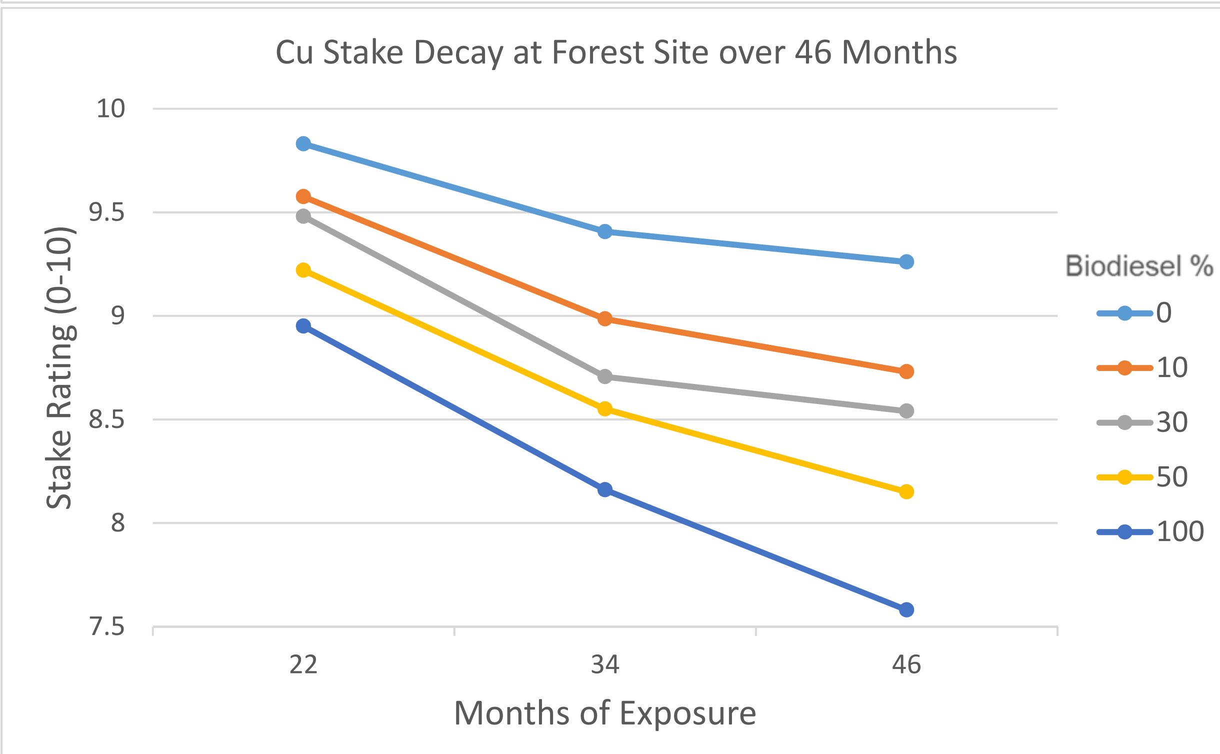


Figure III-12. Average ratings of Douglas-fir sapwood stakes at the forest site treated with copper naphthenate in mixtures of petroleum and bio-based diesel over 46 months of exposure in soil showing the relationship between increased biodiesel content and increased decay. These data combined all of the Cu retentions for each individual biodiesel level.

Figure III-13. Composite photo showing a control stake at the field site, the forest site, and the field site in early September 2017.

Figure III-14. Photos showing the same control stake from the wood site in 2016 (left) and 2018 (right).

Figure III-15. Photos from the field site in 2018 showing various levels of decay.

F. Flexural Properties of Douglas-fir Crossarms (M.S. Thesis for Hunter Anderson, a Wood Science/Civil Engineering Student Supported by the UPRC)

Although we typically think about the utility pole as a support for transmission wires, it is important to note that most wires are supported on poles using wooden crossarms. Wood is economical and reliable and provides excellent service life. The primary species used to produce crossarms is Douglas-fir, which has excellent strength properties and dimensional stability.

The rigorous loading and environmental conditions to which crossarms are exposed require careful selection of materials for this application. These specifications appear in the West Coast Lumber Inspection Bureau standards and place substantial limitations on wood characteristics, such as the slope of grain and growth rate, but the most critical parameters are the presence and location of knots.

These limitations have produced exceptional reliability, but they also sharply limit the supply of wood that can meet these specifications. While wood crossarms have been used for over a century to support overhead lines, there are surprisingly few data examining the effects of various defects on properties. These data could provide a more rational system for selecting arms to ensure they meet the required performance attributes, but also ensure specifications do not inadvertently eliminate acceptable materials.

The purpose of this work is to compare the flexural properties of Douglas-fir distribution arms that are currently acceptable with those that have been rejected due to various defects (primarily knots).

Test Method: Two hundred fifty Douglas-fir crossarms (87.5 mm by 112.5 mm by 2.4 m long) were provided by Brooks Manufacturing for the study. All arms had been predrilled and incised, but not treated. Fifty arms met the current ANSI 05.3 specification for wooden cross arms, while the remainder had been rejected for various reasons, including knot size and location.

Knot Mapping: Each specimen was numbered and arbitrarily labeled on each long side as A-D. Knot diameters were measured to the nearest 1.5 mm on all four faces. The knots were delimited into zones (Figure III-16) and total knot area was calculated for each zone.

Flexural Testing: The difficulty in assessing knot effects on crossarm performance is designing a test apparatus that actually stresses the area containing the knot. Conventional third or fourth point loading tests do not completely assess knot effects because they only load a small area at the center and the knot may lie outside that area.

Preliminary calculations were performed to determine a reasonable angle to use in order to simulate an ice load on an arm in the field. This angle was determined to be 17.5 degrees and assumed a 25 mm thick ice layer on the line. The test apparatus attached an arm to a steel beam mounted to the floor. Load was applied at an angle from the bottom of each arm to simulate the reaction that develops from the line hanging from the opposite end. The orientation of the arm was determined by ensuring the worst defects on the arm were placed in a tension zone wherever possible. The arm was pinned in the center to the steel beam. Spacers were used to ensure the beam could deflect between the pins without resting on steel, therefore changing boundary conditions. An actuator was fixed through the pre-drilled hole intended for mounting the transmission lines. This actuator utilized a custom bracket that allowed the load to be applied at the same 17.5 degree angle previously described.

The actuator had a potentiometer that provided deflection data along the line of load application. The actuator was controlled by the potentiometer and load was applied at 1 inch of deflection per minute. Load and deflection were continuously monitored. Arms tended to fail within 5 to 7 minutes. A total of 250 arms were tested using these procedures.

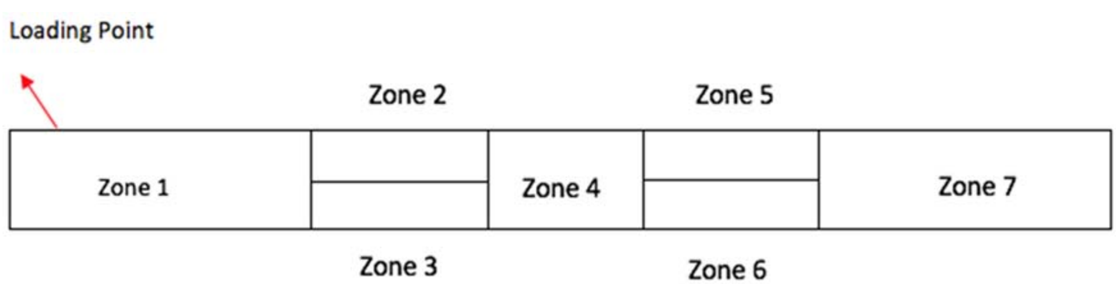


Figure III-16. Zone delimitation for crossarms used to separate defects.

The resulting data were used to calculate Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) and were compared with arm characteristics that included knot diameter and location. Data analysis focused on comparisons of knot area in different zones with MOR. The zone of failure was determined by post-test visual assessment and the total defect area in that zone was compared to the total area observed in failure zones of the other arms. Knot areas of tension zones were compared in a similar fashion, as was the total defect area in the bottom half of the arm. Relationships between knot area in a zone and strength of the arm were examined. Arms that failed in zones with no obvious defect were highlighted in order to establish a threshold where knot area in zones outside of critical tension zones did not affect arm failure.

The arms failed in a variety of modes, but the majority failed in tension along a defect. The ANSI 05.3 standard specifies a minimum MOR of 7800 psi for Douglas-fir arms. MOR values were above this minimum for 49 of the 50 acceptable arms and the value for the one arm below this minimum was nearly 7000 psi (Figure III-17). Results indicated 98% of the currently acceptable arms met the minimum value and the majority of arms had MOR values between 10000 and 13000 psi. One positive attribute of wood variability is the fact that we establish minimum values well below those for a majority of a population. This means that systems have a substantial amount of excess capacity that helps them perform well under extreme loading conditions.

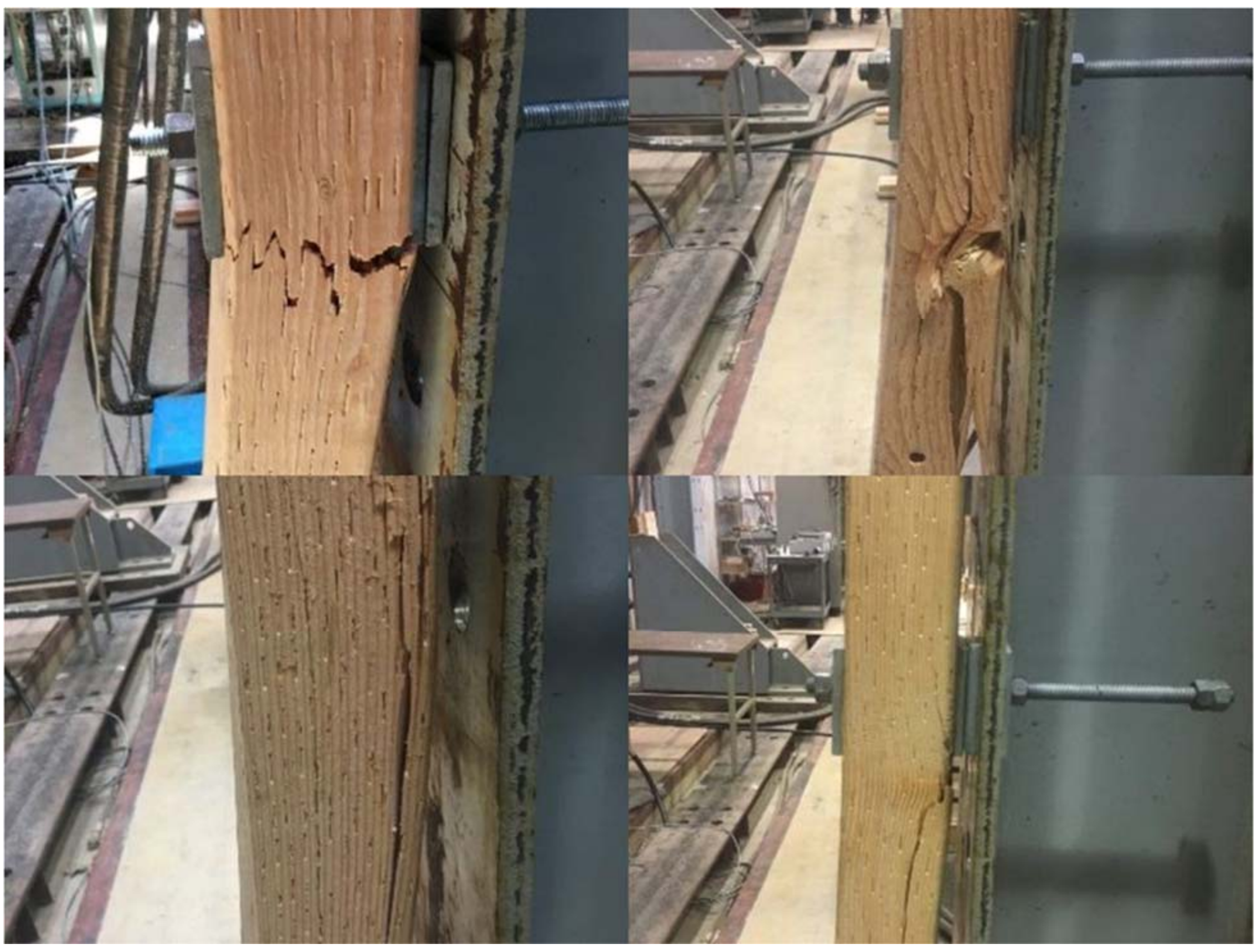


Figure III-17. Examples of various failures of Douglas-fir crossarms tested to failure in bending.

Forty two of the 200 reject arms tests had MOR values below 8000 psi (Figure III-18). Interestingly, three reject arms had MOR values that were higher than the strongest acceptable arm. The results highlight the variability of wood, but they also suggest that the current specification rejects a high proportion of acceptable arms

There is currently no minimum MOE value for crossarms, but plotting MOR vs MOE suggests that values for acceptable arms fell within the range of those for the reject arms (Figure III-19).

The vast majority of both acceptable and unacceptable arms failed in Zone 4, near the center of the arm (Figure III-20). This is consistent with the stresses produced by the loading system and would simulate a downward load on the end of a crossarm, such as that produced by either heavy ice-loading or a sudden impact on the wires. The results illustrate the critical role of defects near the center of the arm.

While it is clear that many reject arms had acceptable flexural properties, this information serves little purpose if there is no way to identify these materials. Knot dimensions are a critical factor in crossarm grading, both in terms of location and dimension. Knots are an easily detected defect and are known to reduce material properties. Total knot area was poorly correlated with MOR for both acceptable and reject arms (Figure III-21). However, it is important to note that total knot area includes knots on all four sides of the arm, while MOR is most heavily affected by knots on the tension face, followed by the compression face. Knot area on the tension face and MOR were also poorly correlated, suggesting that more subtle defects were affecting crossarm properties.

These data are still being analyzed to determine if various aspects of knot size, geometry, position, or other wood quality factors can be used to identify arms that might appear defective but are, in fact, capable of performing as well as, while identifying arms that are, clearly incapable of performing. These results will be presented in the 2019 annual report. For now, examples of the apparatus (Figure III-22) and various crossarm failures (Figure III-23) are presented.

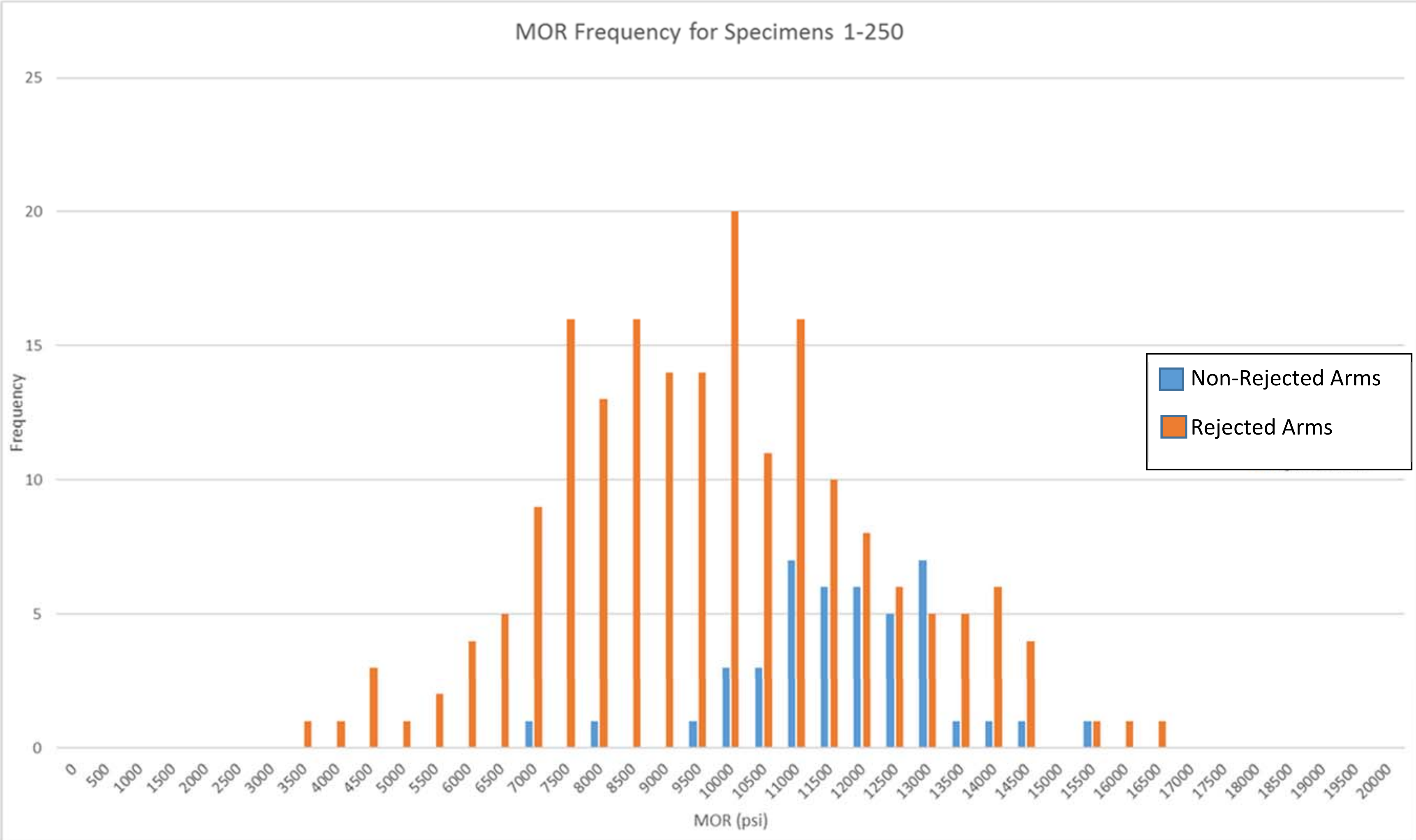


Figure III-18. Distribution of MOR values for Douglas-fir crossarms either meeting current ANSI 05.3 requirements or failing to do so because of defects.

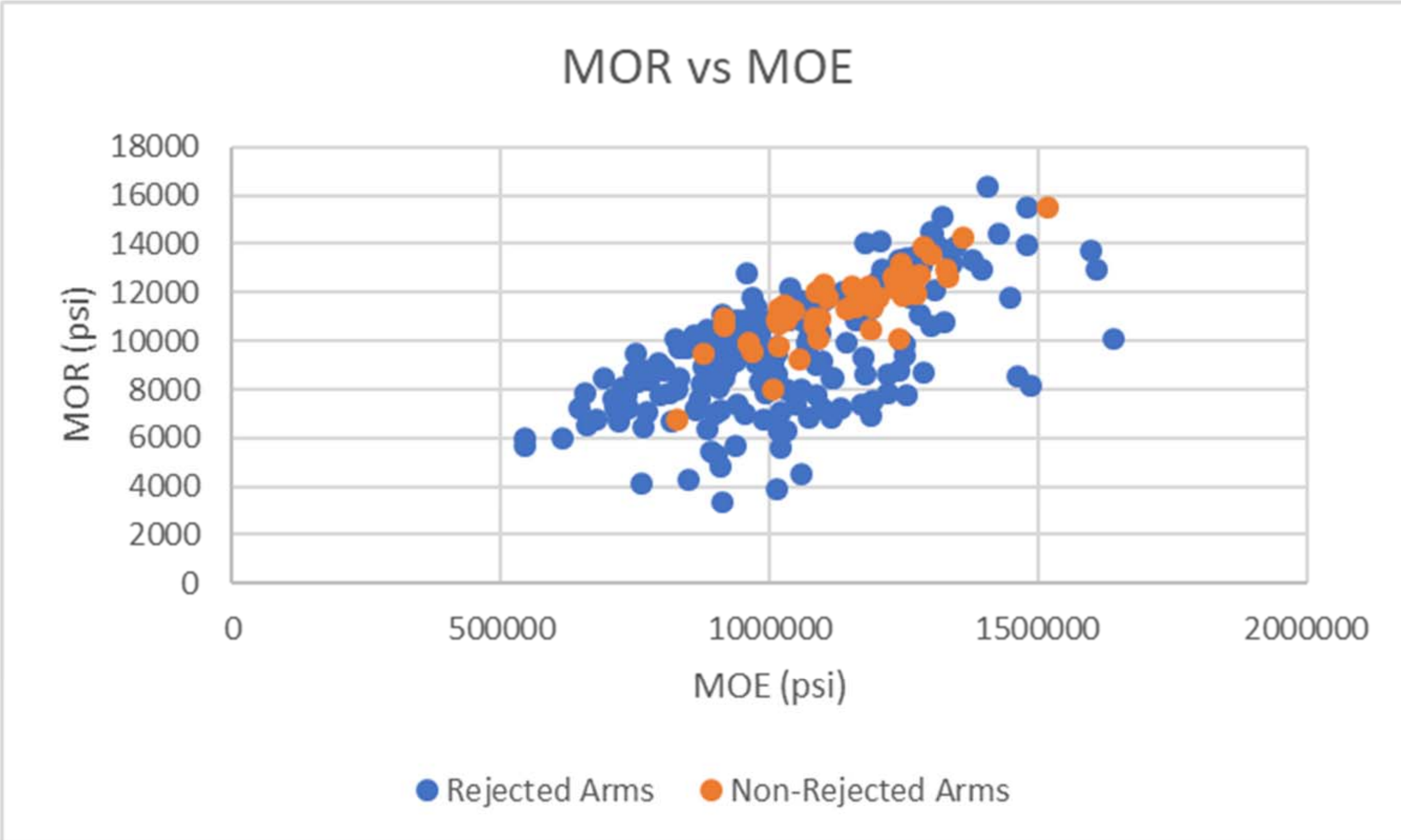


Figure III-19. MOR vs MOE for Douglas-fir crossarms either meeting current ANSI 05.3 requirements or failing to do so because of defects.

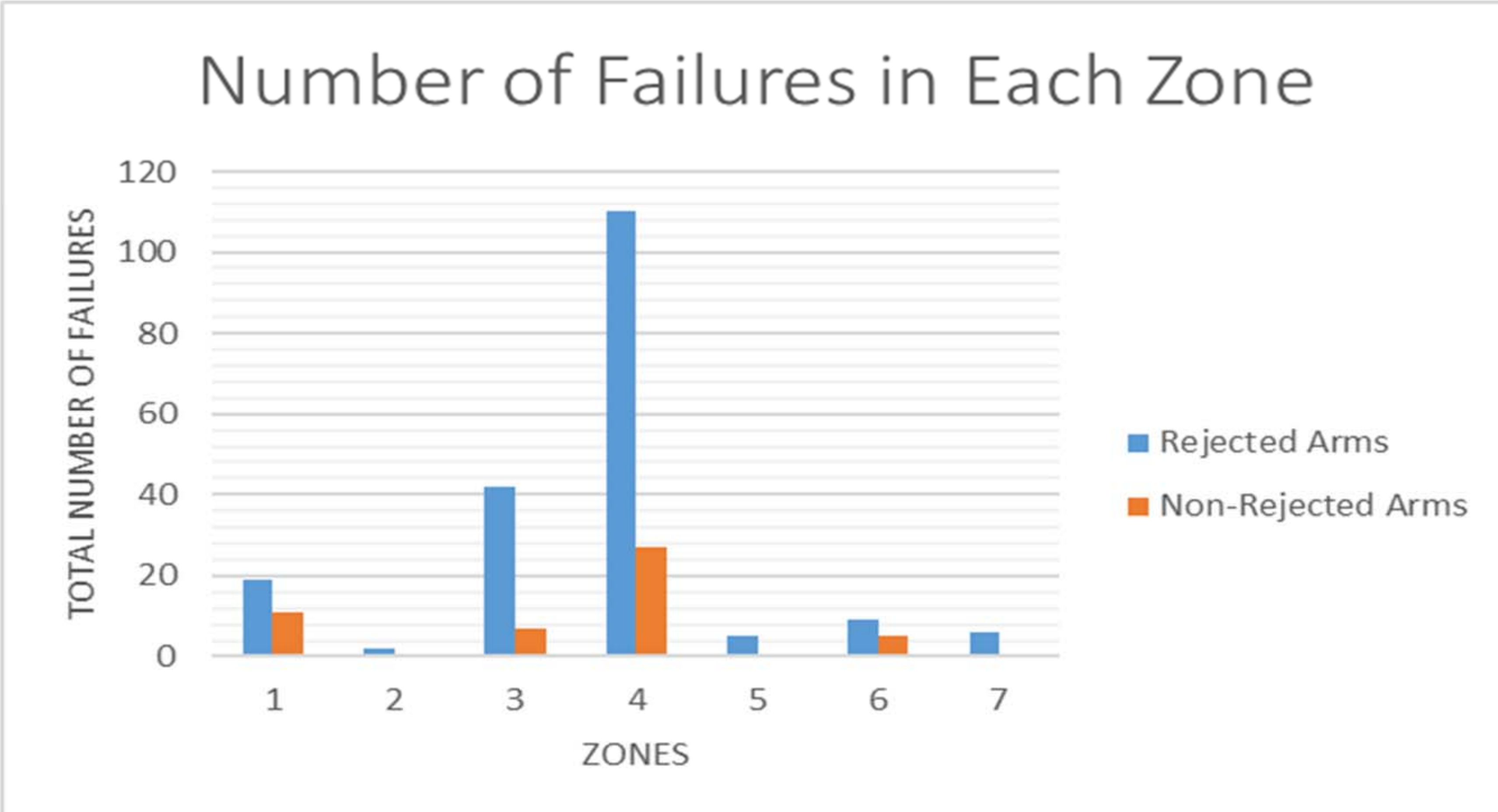


Figure III-20. Failure locations on Douglas-fir crossarms either meeting current ANSI 05.3 requirements or failing to do so because of defects.

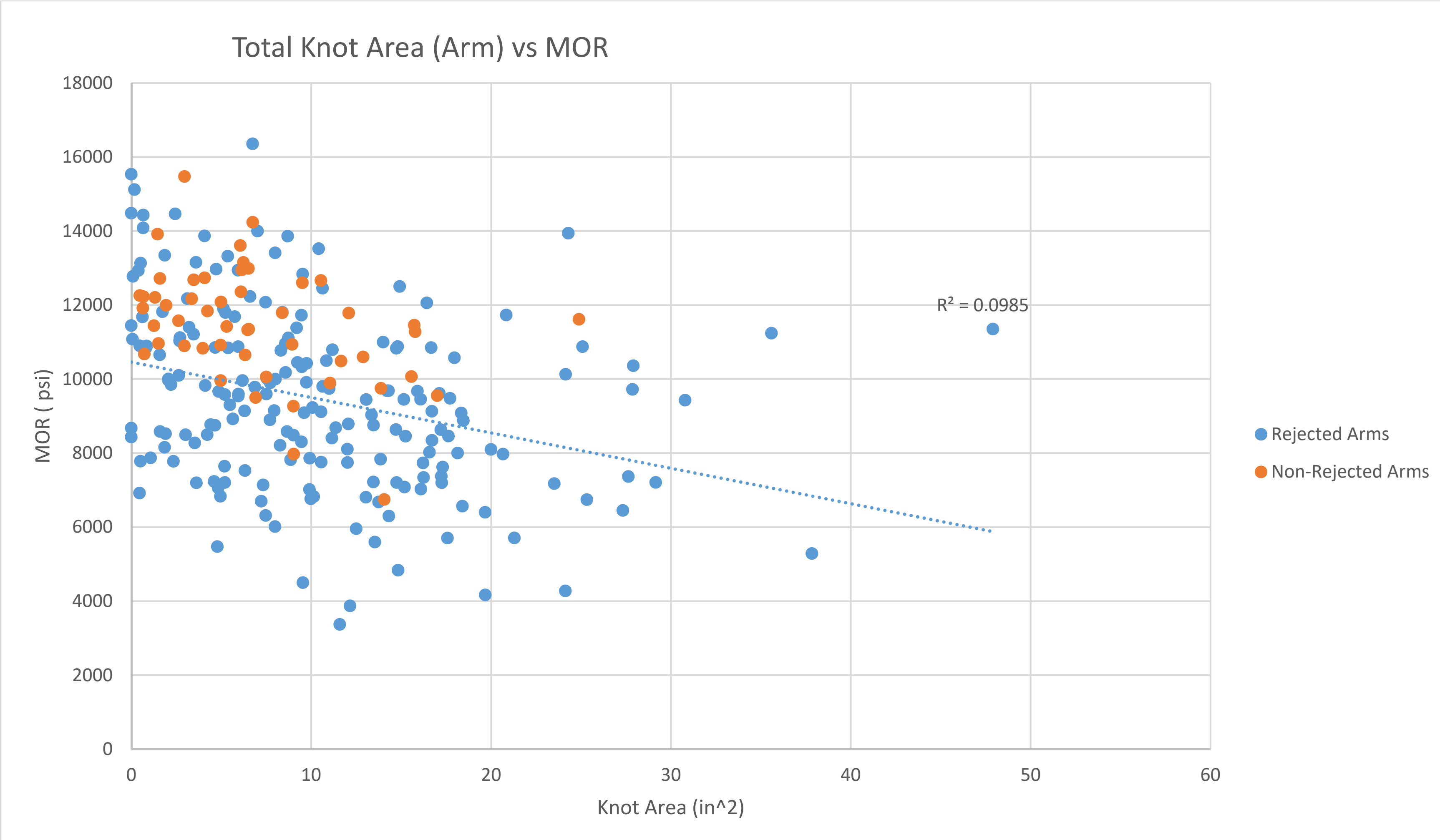


Figure III-21. Relationship between total knot area and MOR for acceptable and reject Douglas-fir crossarms.

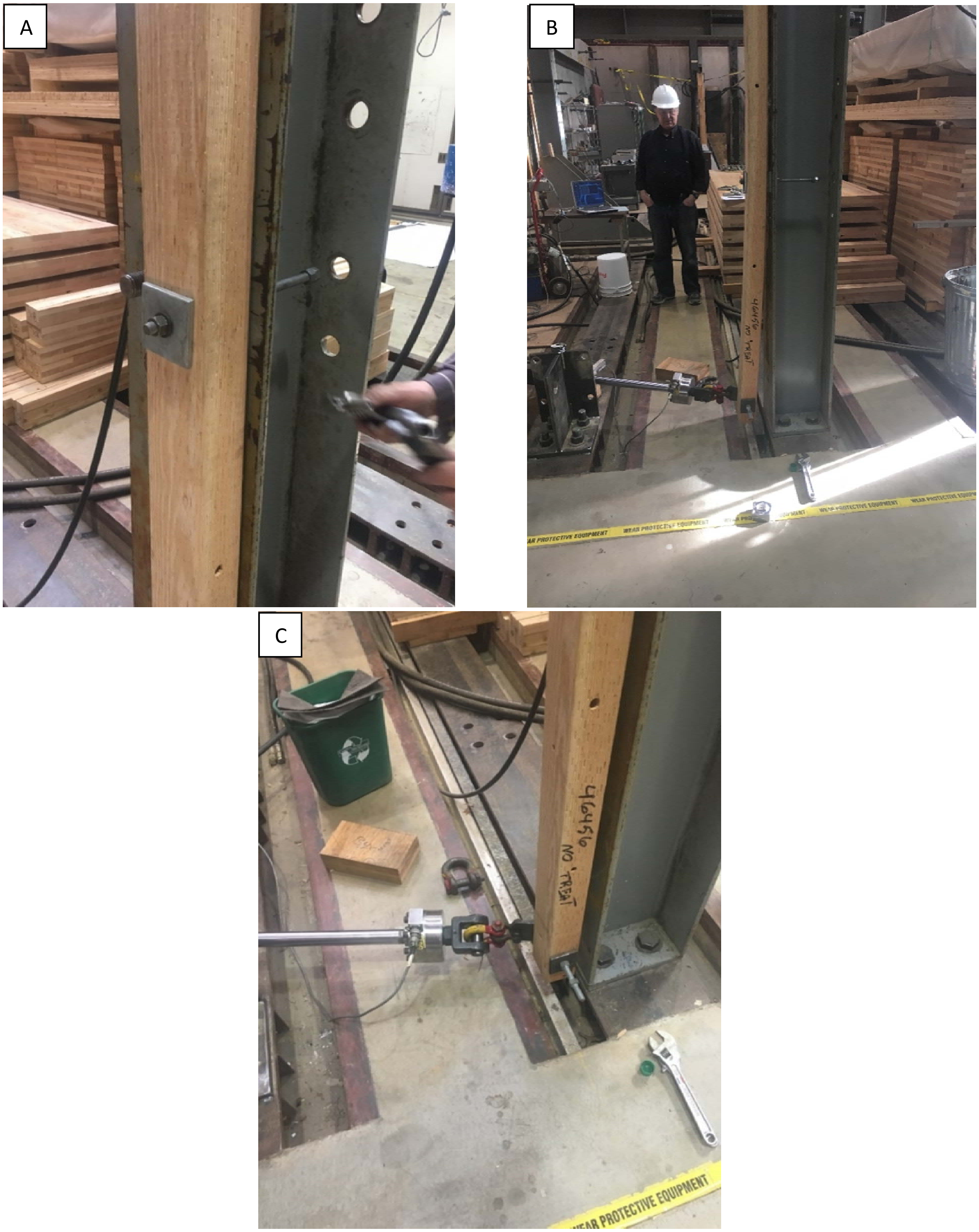


Figure III-22. Photos of the test set up used to assess crossarm properties showing: A) an arm bolted to the steel bracket, B) an arm showing deflection under load as it is tested, and C) the hydraulic rod used to pull the arm.

Figure III-23. Examples of crossarm failures (red arrows) following full-scale flexural testing.

G. Disposal of Industrial and Residential Treated Wood (Presented to AWPA Sub-committee S-3)

Overview: Preservative treated wood has a markedly longer service life than non-treated materials, but eventually it must enter the disposal stream. This section reviews the options available for reuse, recycling and disposal of wood treated for residential and industrial applications. While there are many possible options for reuse and disposal, most are currently not economically or logistically feasible.

Background: Preservative treated wood has many excellent attributes. Among the most important is the ability to extend the useful life of a wood product 10 or more times longer than the life of a similar untreated product. Eventually, however, treated wood must be removed from service and disposed of. Disposal of treated wood is often raised as an issue among wood users and regulators because most wood preservatives are inherently toxic to a variety of organisms. The current recommendations for treated wood that has ended its useful life are:

- Reuse in a similar application consistent with the original use.
- Disposal in a properly-permitted waste disposal facility. This would typically include a municipal solid waste facility with lined cells and some type of leachate-management system.

It is important to note that these guidelines refer to the treated wood commodity, not any wastes created in a treatment facility, but the guidelines leave considerable latitude for wood users to identify creative methods to avoid landfill disposal.

While recommendations seem simple, the ability to safely dispose of treated wood at the end of its useful life has become a concern among wood users, particularly on the industrial side. There have been a number of symposia on disposal of treated wood, but questions continue to arise.

The purpose of this section is to present a general overview of current treated-wood disposal options and outline future areas of consideration.

Treated wood generally falls into two broad categories (industrial and residential) which are convenient break-points for discussion of disposal.

Treated wood use in residential applications generally involves the use of water-born preservatives. The majority of wood used in these applications prior to 2003 was treated with chromated copper arsenate (CCA). The withdrawal of CCA from residential applications led to substitution alkaline copper quaternary (ACQ) or alkaline copper azole (CA) compounds. More recently, the majority of wood treated in the southeastern U.S. is treated with micronized copper azole. While minor use of copper naphthenate for residential use remains, and some residual penta-treated wood remains service, the majority of treated wood in these applications contains copper with lesser amounts of chromium or arsenic. The triazoles and quaternary ammonium compounds used as co-biocides in these systems are generally not considered a disposal issue.

Treated wood in residential uses has several characteristics that differentiate it from industrial products and make it less attractive for reuse. First, most of the material comes in dimensional lumber sizes (2x4 or 2x6 inch) or posts (4x4 or 4x6 inch) and has often been cut or otherwise fabricated. It also contains numerous fasteners that complicate reuse. As a result, direct re-use of treated lumber is often difficult. It can also be difficult to determine if a material has been treated since surface-weathering can mask the original preservative color. The only regions where treated wood is easily detected are the western U.S. and Canada, where the lumber is incised prior to treatment and is often stained a brownish color to make it appear similar to western redcedar or redwood.

A second characteristic of residential treated-wood is its wide dispersal, making efficient collection difficult and costly. Wood is bulky and this material would have relatively low value. As a result, collection would likely require some form of subsidy to make it feasible. While there is growing interest to increase the percentage of recycled waste, the volumes of treated wood are likely too small to warrant such a subsidy.

Finally, most users of residential products have relatively little understanding about the chemicals used or disposal practices. The current recommendations appear to recognize this lack of knowledge by allowing residential treated-wood to be disposed in regular trash collections. The dispersed nature of the materials and the relatively low percentage that it represents in the total disposal scheme generally make this acceptable. However, instances where high volumes of treated wood enters the waste stream can become problematic. The best example occurred in Florida in the late 1990's when treated wood was being sent to construction and demolition facilities where it was then burned to produce energy. Florida uses a much higher percentage of treated wood than other parts of the U.S. and much of this material is removed from service while it still contains very high levels of the original chemical treatment, but has physically degraded due to splitting, checking, or ultraviolet degradation. The resulting ash produced when this material was burned contained high heavy-metal levels that posed health concerns. This led to extensive research on treated wood in waste-streams as well as detection methods to ensure removal prior to combustion. In most other North American locations, treated wood represents a small part of the waste-stream and its presence in either C&D waste or regular municipal solid waste likely has very little impact.

Ultimately the costs for collecting treated wood waste from residential areas far outweigh the benefits of segregation. The increasing use of lined landfill cells and leachate management systems further reduces potential environmental impacts of material disposal. Although the volume of material treated for residential use makes it a tempting recycling target to manufacture or reuse, the collection logistics currently make it infeasible. However, reduced landfill capacities, decreases in availability of virgin wood, or the emergence of new utilization technologies could easily alter this premise.

Industrial Treated Wood: Industrial treated wood differs from the residential market in a number of important aspects. While dimensional lumber is used in this market, the majority of materials tend to be utility poles, pilings, or larger timbers. These sizes can create transportation challenges, but also create the potential for reuse, resawing, and other activities that enhance recovery value. Another advantage in this market is that most users have a better understanding of the chemicals involved and the transportation logistics. They are also typically institutional and therefore have resources necessary to collect and move large materials. The negative aspect associated with industrial materials involves preservative-type. For example, heavy metals in some systems limit the potential for combustion as a disposal method.

Retreatment: Although not feasible with residential lumber, retreating has been occasionally used with utility poles, particularly with western redcedar in the Pacific Northwest, U.S.A. This species has a thin, easily-treated sapwood surrounding a highly durable heartwood. Some utilities historically performed soaking treatments on site, creating considerable contamination concerns. More recent efforts involved returning poles to a conventional pressure treatment facility. Laboratory tests indicate retreated wood does not perform as well as freshly-treated material, but does extend pole life. However, transportation logistics and negative economics largely limit this practice.

Reuse: Treated wood in horizontal exposures such as decking is often removed because its appearance has diminished, but it retains its structural value. Ideally, this wood could be reused in its current form, but there would be considerable difficulties with collection and reuse.

Industrial reuse of treated wood is possible in a limited number of applications. Utility poles and pilings have reuse potential. Most utility poles are removed because they have degraded to the point where their structural properties fall below the minimum levels specified in the National Electric Safety Code. However, some poles are removed for road widening or upgrades and may be reasonably sound. Some utilities reuse these poles if they are less than a certain service-age. Poles are inspected and returned to a general inventory. This approach entails some risk, but if the time-in-service is limited, risk is low.

There have also been attempts to reuse pilings, most often marine pilings that have been cut and removed. These pilings have then been used for foundations. This reuse can work, provided the residual treatment-level is still above the minimum for the originally-intended application and there is no evidence of marine borer attack. Detecting internal marine borer damage, however, can be difficult and most users prefer using freshly treated pilings to avoid risk.

Reuse of dimensional lumber poses a much greater challenge for many of the same reasons noted for residential lumber.

Resawing: Many times, decay or insect attack may only be present in limited zones of a large timber, leaving a large amount of recoverable, sound wood. Resawing can be an option in these cases. There have been several attempts to resaw utility poles into timbers and decking. Generally, these efforts have concentrated on durable heartwood species such as western redcedar. While there may be small pockets of internal decay in these materials, they can be discarded prior-to, or during, processing. The outer, weathered sapwood is removed in sawing, exposing clear interior wood. This sapwood would be removed in a typical sawmill and recovery studies suggest lumber recovered from used poles and saw logs are similar, although the outer jacket of used pole boards becomes a disposal cost, while those from freshly cut logs can be sold as a by-product for other uses. The other factor that affects pole resawing is the presence of metal. Considerable care must be taken to scan poles for metal prior to sawing. While mills processing freshly-cut logs also have metal detectors ahead of saws, poles tend to contain much higher levels of metal that can severely impact blades. Most conventional sawmills will not accept poles because of concerns about how to deal with metals and treated-wood waste, leaving this approach to those with smaller, portable sawmills.

BC Hydro and Bonneville Power Administration (BPA) have both experimented with resawing poles through small sawmill operators. BPA undertook two efforts, one in western Oregon and the other in Montana. In both cases, poles and shipping were provided at no cost. This eliminated transportation costs, making the process more economically attractive. However, an analysis of potential costs of operating without the transportation subsidy indicated that these facilities operated under many of the same constraints as a normal sawmill and could not economically move poles more than 150 miles.

Disposal of waste wood must also be considered; however, this material could be disposed of in a Municipal Solid Waste (MSW) facility in the areas where operations are located and tipping fees are low. The Oregon operation created a niche market for products under the name Rediscovered Wood Products. The operation ceased activity when the owner wanted to retire and provided an excellent example of difficulties involved in running small operations on thin profit margins.

There have also been limited efforts to remanufacture southern pine and Douglas-fir poles into lumber and timbers. Rediscovered Timbers resawed Douglas-fir poles into timbers, but recoveries were low due to high percentages of treated sections and internal decay. There were also concerns about residual treatment presence, although tests indicated visual detection was sufficient for identifying zones with chemical treatment. The final problem was that the material lacked grade stamps and could not be used in structural applications. While the lack of grade stamps could be addressed, it added another hurdle to a low value process.

Attempts to resaw southern pine poles and timbers faced different challenges due to the higher percentage of treated wood. Original plans called for selling this material as treated; however, resawing resulted in boards with a range of preservative retentions. This would have required some form of retreatment which made the cost of the final product non-competitive with conventionally-produced materials.

An excellent example of treated wood reuse outside North America is Kennedy Timbers PTY, located outside Brisbane, Australia. Many poles, wharfs, and bridges in Australia were built using naturally durable timbers, often with CCA or some other preservative sapwood treatment. As with western redcedar in the U.S., these poles have a relatively thin band of sapwood surrounding a very durable heartwood core. Kennedy has contracts with electric utilities to recycle poles and bids on timbers removed from bridge and pier infrastructure upgrades. They maintain a large inventory of material on site and only cut when they receive a product order. While this means they hold a larger inventory, their purchase costs are low and they minimize their financial inputs until a customer appears. They also have ready access to a MSW facility that will take their waste wood, while they sell high-value products.

These operations clearly show that resawing of poles and larger timbers is economically feasible, but also illustrate the limitations of such an approach.

Composite Panel Production: In many cases, treated wood slated for disposal still contains elevated levels of chemical, but is in poor condition and is unsuitable for direct reuse. There have been a number of efforts to chip or grind this material for use in wood-based composites often with the goals of producing durable panels from waste material. The major concerns with this approach have been the potential for preservative off-gassing during pressing and the potential effects of treatment on bond strength. Off-gassing can be addressed by proper gas venting, while the use of modified resins can mitigate bonding issues. A secondary concern with these types of materials would be the variable treatment quality of the chips or flakes. Preservative treatment is rarely complete and it typically follows a gradient from high retentions near the surface to lower levels inward. The resulting flakes or chips will have similar variations in treatment quality that might affect finished panel durability.

At present, preservative treated waste wood is not used in composite manufacturing because virgin fiber remains readily available and inexpensive.

Combustion: Wood is a useful energy source and, prior to the current glut of petroleum or natural gas, there was tremendous interest in bioenergy. The value of treated wood as a biomass source and the potential issues with combustion differ with treatment.

Creosote-treated wood is the easiest material to use in a combustion scheme. Creosote contains a high amount of energy and poses few issues if combustion temperatures are suitable for complete reduction to carbon dioxide. Creosote is the primary treatment for railroad ties making it relatively simple to collect and use in energy schemes. The major difficulty in combusting other creosoted materials is sorting. For example, there are a sizable number of creosote-treated poles and timber bridges that could be used for bioenergy production; however, it can be difficult to reliably identify and economically sort these materials from those treated with oil-borne preservatives such as pentachlorophenol.

In principal, pentachlorophenol-treated wood should be an attractive energy source owing to high oil levels. On average, a utility pole will contain 15-25% oil by weight, markedly increasing the material energy value. Unfortunately, the combustion of pentachlorophenol carries with it the potential to create and/or release dioxins, furans, and a range of concerning pollutants. Higher combustion temperatures reduce release risk, but relatively few facilities see the value in this process. As a result, relatively little penta-treated wood is currently used for bioenergy.

While copper naphthenate represents a small portion of treated-wood waste, this material can be used in co-generation facilities. This is particularly important because it is now being used for railroad bridges and the ability to eventually dispose of this material along with creosoted ties makes its use more attractive.

The water-born, heavy metal-based, preservatives are used in virtually every treated wood application. As noted earlier, concerns about the presence of treated wood in the waste stream originated with a study showing the presence of elevated metal levels in ash from a co-generation facility that inadvertently burned CCA-treated materials. In general, wood treated with water-born, heavy-metal preservatives can only be burned in facilities equipped to capture metal emissions. As with penta, there are relatively few facilities capable of meeting these requirements. As a result, most of this wood is placed in MSW facilities. However, small quantities of this wood could be combusted in lime kilns for cement production. One issue affecting the potential for using treated wood in cogeneration is the low price of natural gas that has made bioenergy less cost-competitive.

Remediation: Although treated wood can currently be placed into MSW landfills at the end of its useful life, some users have expressed concerns about regulation changes. Chemical and biological remediation have both been proposed as possible disposal methods. Chemical treatments have primarily been proposed for remediating wood treated with water-born heavy-metal based systems. In some form, metals used in preservation bind to wood. Strong acids or bases can be used to disrupt these bonds, allowing dissociation of the treatment chemical. Oil-born systems could be extracted, leaving residual wood for other uses. This wood can presumably be used to produce a composite, or combusted for energy, while the chemical could be reused. Unfortunately, this approach is generally not economically feasible.

Biological treatments have been proposed for both metals and organic systems. A variety of fungi have evolved the ability to mobilize copper. These fungi are applied to treated wood that is chipped and amended with nutrients to stimulate microbial growth. Fungi mobilize the metals, which are leached from the wood. Most fungi lack the ability to remove all metals and typically can only act on one component, but these pre-treatments can reduce the energy or chemical inputs required to remove other components. One disadvantage is that fungi are primarily aerobic; thus, these approaches only work near the soil surface where oxygen is not limiting.

Organic preservatives are much more suited for bioremediation. It has long been known that organic preservatives migrating into soil from treated wood are slowly degraded to where they are no longer detectable more than 600-900 mm away. A variety of bacteria and fungi can degrade creosote, pentachlorophenol, and a host of other molecules. Bioremediation has been used with some success on a number of heavily contaminated sites, but it has not been employed to remove preservatives from treated wood waste. At present, the lack of any regulatory driver limits interest in this disposal approach.

Landfilling: The disposal option of last resort is the landfill. There are many misconceptions about treated wood disposal. Many users incorrectly assume that treated wood must go to a secure hazardous waste facility. This can be the case with some wastes generated within a treating plant; however, treated wood waste generated outside the treating plant can be disposed of in a MSW facility equipped with a liner and leachate-management system. Some entities require wood pass a toxicity characteristic leaching profile. Creosote, pentachlorophenol, and copper naphthenate all easily pass this test, while the water-born inorganic systems have an exemption. Thus, treated wood should be easily disposed of at the end of its useful life if no other application can be found. One additional advantage of landfilling is the sequestration of carbon and chemical for long periods, which may fit in well with a carbon-capture scheme.

Table III-11. Relative merits for various methods for dealing with treated wood commodities at the end of their initial useful life.

Chemical	Commodity	Potential for Use of Method					
		Reuse	Resaw	Retreat	Composites	Combustion	Landfill
Creosote	Poles	L	M	L	L	H	H
	Piling	M	M	L	L	H	H
Penta	Poles	M	M	L	L	M	H
	Piling	M	M	L	L	M	H
	Timbers	L	L	L	L	M	H
CuNaph	Poles	L	M	L	L	H	H
	Piling	M	M	L	L	H	H
	Timbers	L	L	L	L	H	H
CCA/ ACZA	Poles	L	M	L	L	L	H
	Piling	M	M	L	L	L	H
	Timbers	L	L	L	L	L	H
	Lumber	L	L	L	L	L	H
ACQ/CA	Poles	L	M	L	L	L	H
	Piling	M	M	L	L	L	H
	Timbers	L	L	L	L	L	H
	Lumber	L	L	L	L	L	H

Where L=low probability for this category, M=moderate probability, and H=high probability.

Conclusions: While there are a wide variety of methods for potentially reusing treated wood at the end of its service life, most are not feasible because of the resource condition, collection and transport difficulties, or the economics against competing materials. Thus, there remains a continued need for evaluating new technologies to capture value from treated wood at the end of its service life.

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OBJECTIVE IV

PERFORMANCE OF EXTERNAL GROUNDLINE PRESERVATIVE SYSTEMS

While preservative treatments provide excellent long-term protection against fungal attack in a variety of environments, there are a number of service applications where treatments eventually lose efficacy. Soft rot fungi can then decay the wood surface, gradually reducing the effective circumference of the pole until replacement is required. In these instances, pole service life can be markedly extended by periodic belowground application of external preservative pastes that eliminate fungi near the wood surface and provide a protective barrier against fungal re-invasion from surrounding soil.

For many years, pastes incorporated a diverse chemical mixture including pentachlorophenol, potassium dichromate, creosote, fluoride, and an array of insecticides. In the 1980s, the U.S. Environmental Protection Agency re-examined pesticide registrations and designated many compounds as restricted use. This action encouraged utilities and chemical suppliers to examine alternative preservatives. While these chemicals had prior applications as wood preservatives, there was little data supporting their use as preservative pastes. This lack of data led to the establishment of Objective IV. The primary goal of this objective is to assess laboratory and field performance of external preservative systems to protect belowground portions of wood poles.

A. Previous External Groundline Treatment Tests

Over the past 20 years, we established a number of field trials for external groundline preservative pastes on pole stubs at our Peavy Arboretum field site or poles in active utility lines. Most of these trials have been completed. A trial summary can be found in Table IV-1 along with references to the annual report in which results are presented.

B. Effect of External Barriers on Pole Performance

Preservative treatment is a remarkably effective barrier against biological attack, but these chemicals can migrate into surrounding soil. A number of studies documenting chemical migration have shown movement occurring for short distances around treated structures. Generally, the levels present do not pose environmental or disposal hazards. Despite these data, some utilities have explored external barriers to contain migrating

Table IV-1. Summary of completed tests evaluating external groundline preservatives.

Location	Year Initiated	Wood Species	Primary Treatments	Treatments tested	Manufacturer	Final report
Corvallis, OR	1989	Douglas-fir	none	CuNap-Wrap	Tenino Chem. Co (Viance)	1996
				CuRap 20 II	ISK Biosciences	
				Pol-Nu	ISK Biosciences	
				Cop-R-Wrap	ISK Biosciences	
				CRP 82631	Osmose Utilities Services, Inc.	
Corvallis, OR	1990	Douglas-fir	none	CuRap 20	ISK Biosciences	1993
				Patox II	Osmose Utilities Services, Inc.	
				CuNap-Wrap	Viance	
Merced, CA	1991	Douglas-fir W. redcedar S. pine	penta	CuNap-Wrap	Viance	2002
				CuRap 20	ISK Biosciences	
				Patox II	Osmose Utilities Services, Inc.	
Binghamton, NY	1995	W. redcedar S. pine	penta creosote	CuRap 20	ISK Biosciences	2003
				CuNap-Wrap	Viance	
				Cop-R-Wrap	ISK Biosciences	
Corvallis, OR	1998	Douglas-fir	none	Propiconazole	Janssen Pharm.	2003
				Dr. Wolman Cu/F/B	BASF	
				CuRap 20	ISK Biosciences	
Beacon, NY	2001	S. pine	penta	COP-R-PLASTIC	Osmose Utilities Services, Inc.	2009
				PoleWrap	Osmose Utilities Services, Inc.	
				Dr. Wolman Wrap Cu/F/B	BASF	
				Dr. Wolman Wrap Cu/B	BASF	
				Cobra Wrap	Genics, Inc.	
				Cobra Slim	Genics, Inc.	
Douglas, GA	2004	S. pine	creosote	Cu-Bor (paste and bandage)	Copper Care Wood Preserving, Inc.	2010
				CuRap 20 (paste and bandage)	ISK Biosciences	
				Cobra Wrap	Genics, Inc.	
				COP-R-PLASTIC	Osmose Utilities Services, Inc.	
				PoleWrap (Bandage)	Osmose Utilities Services, Inc.	

preservative. These barriers, while not necessary in terms of environmental issues, may have the secondary benefits of both retaining the original chemical and limiting moisture and fungal entry.

The potential for barriers to limit moisture uptake in poles was assessed on pole sections where two different barriers were installed in either soil or water. Poles were maintained indoors and were not subjected to overhead watering. Results showed that, even with barriers, considerable moisture wicked up poles and moisture contents at groundline were suitable for decay development. As might be expected, poles immersed in water wetted more quickly than those in wet soil; however, all poles were generally wet enough for decay to occur within two-years of installation. These poles have subsequently been moved to our field site and set so the barriers extend 150 mm above the soil. These pole sections were then sampled for wood moisture content at groundline, 150 mm, and 300 mm above groundline immediately after installation and two-years after installation as described above.

In 2007, an additional set of penta-treated Douglas-fir pole stubs were encased in the newest generation of Biotrans liners and set in the ground at our Peavy Arboretum research site. Poles were sampled prior to installation to determine chemical penetration, retention, and baseline moisture content. Five poles received a Biotrans liner extending 150 mm above groundline, five received a Biotrans liner extending 300 mm above groundline, and eleven poles were left without liners.

Pole moisture content was assessed by removing increment cores 150 mm below groundline and dividing these cores into four zones (0-13, 13-25, 25-50, 50-75 mm). Core segments were placed into tared vials that were tightly capped and then weighed prior to being uncapped and oven dried at 105°C for 24 hours. Differences between initial and final weight were used to determine wood moisture content. Coring holes were plugged and any damage to the coatings were repaired to limit the potential for moisture to move into the poles through damaged coatings. The poles were sampled at the time of installation as well as 6, 12, 18, 42, 45, 77, and 95-months after installation.

Another aspect of this test was evaluating the potential effects of barriers on preservative migration into surrounding soil. We did some initial sampling but the results were inconclusive. This past year, we sampled the soil around poles with and without barriers.

Soil samples were removed from the upper 100 mm of soil immediately adjacent to the poles. Additional background soil samples were removed uphill where there had been no prior use of preservative. Five g of dried soil was placed into a 40 mL amber scintillation vial. Twenty five mL of isooctane was added to each vial and the sample was sonicated for 3 hours. After cooling, an aliquot was removed, placed into an auto sampler vial, and analyzed.

Pentachlorophenol was quantified with high resolution gas chromatography – low resolution mass spectrometry (HRGC-LRMS). Analysis was carried out by injecting 1 µL of sample into a Shimadzu HRGC-LRMS system class 5000 equipped with an RXI-5ms column (0.25 mm inner diameter by 30-mm long) at a flow rate of 1.0 mL/min. The carrier gas was helium (grade 5) and the system was operated in splitless mode. The injector and detector temperature were 250°C and 280°C, respectively. The oven was programmed to hold for 2 minutes at 40°C, ramp to 80°C at 40°C/min, then ramp to 260°C at 25°C/min. The system was flushed with isooctane between injections to minimize risk of chemical carryover.

Pentachlorophenol was scanned and identified using the National Institute of Science and Technology (NIST) Mass Spectral Library #107 software. Retention time was 9.70 min and the selected ion for quantitation was m/z = 266, with reference ions of 264 and 268. HRGC-LRMS auto tuning was performed with perfluorotributylamine (PTFB). A 6-point calibration curve was employed for penta quantitation. Standard concentrations were 25, 100, 200, 300, 400, & 500 µg/mL. The limit of detection (LOD) was estimated to be 0.025 ng/mL as defined in the Federal Register Part 136, Appendix B, procedure (b), as three times the standard deviation of replicate analyses of the analyte.

Pentachlorophenol levels were below the detection limit in soil samples removed around penta-treated poles with an external barrier. Penta levels in poles without a barrier wrap were high in the soil directly next to the pole (Table IV-2). These results are consistent with previous studies showing that penta migrates from poles into soil. We plan an extensive survey of soils around poles during the summer of 2019, but will need to be careful in our assessment because soil immediately adjacent to poles has been disturbed a number of times to collect wood moisture samples. The preliminary results look promising.

While barriers are not necessary in most applications, these wraps may be useful in sensitive environments such as wetlands, where the use of preservative treated wood may be restricted.

Table IV-2. Pentachlorophenol levels in soil samples immediately adjacent to treated Douglas-fir poles without a barrier.

Pole #	Pentachlorophenol Level (µg/g soil)
1	402.4
2	2250.6
3	981.7
4	75.6

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OBJECTIVE V

PERFORMANCE OF COPPER NAPHTHENATE TREATED WESTERN WOOD SPECIES

Copper naphthenate has been available as a wood preservative since the 1940s and it was used as a creosote extender during the second World War, but commercial use as a stand-alone treatment for utility poles has only occurred in the last 25 years as utilities sought less restrictively labeled chemicals. Copper naphthenate is currently listed as a non-restricted use pesticide, meaning applicators do not require special licensing to apply this chemical. This has little bearing on the use of preservative treated wood, since there are no restrictions on who can use any preservative treated wood products currently on the market (although there are recommended practices for the use of each product). However, some users have sought to soften their environmental image by shifting to alternative preservatives such as copper naphthenate. Many utilities include copper naphthenate in their specifications as an alternative treatment.

Copper naphthenate has a history of successful use on a variety of species. We performed a number of tests to ensure the suitability of this system for use on western wood species, notably Douglas-fir and western redcedar. Initial tests examined copper naphthenate performance on western redcedar, but concerns about the effects of solvent substitutions on biocide performance encouraged us to set up field evaluations of copper naphthenate poles in service. Our first work examined the condition of Douglas-fir poles treated with copper naphthenate and diesel as the primary solvent and we found no evidence of early decay in poles exposed in Oregon or California. More recently, data suggesting the addition of biodiesel as a co-solvent to reduce diesel odors had a negative effect on performance led us to evaluate poles in the Puget Sound area. We will continue to evaluate copper naphthenate performance to ensure that utilities are aware of the effects of process changes on performance.

A. Performance of Copper Naphthenate Treated Western Redcedar Stakes in Soil Contact

Copper naphthenate has provided good protection in a variety of field stake tests and is incorporated in a variety of American Wood Protection Association Standards for use in ground contact (Use Category, UC 4), but there were relatively few long term-data on western wood species when this chemical was initially standardized. To help develop this information, the following test was established. The test has been in place for many years and has been retained to provide continuous expose data under reasonable decay hazards.

Western redcedar sapwood stakes (12.5 by 25 by 150 mm long) were cut from freshly sawn lumber and the outer surfaces of the above-ground zones of utility poles in service for approximately 15 years. The latter poles were butt-treated, but had not received any supplemental above-ground treatment. The weathered stakes were included because the cooperating utility was interested in retreating older poles for reuse.

Stakes were conditioned to stable weight at 23°C and 65% relative humidity (12% moisture content, weighed prior to pressure treatment with copper naphthenate diluted in diesel oil to produce target retentions of 0.8, 1.6, 2.4, 3.2, and 4.0 kg/m^3. Each retention was replicated on ten freshly sawn and ten weathered stakes. In addition, sets of ten freshly sawn and weathered stakes were each treated with diesel oil alone or left without treatment to serve as controls.

Stakes were then exposed in a fungus cellar maintained at 30°C and approximately 90% relative humidity. Soil moisture cycled between wet and slightly dry to avoid favoring soft rot attack (which tends to dominate in soils that are maintained at high moisture levels). Stake condition was visually assessed on an annual basis using a scale from 10 (completely sound) to 0 (completely destroyed).

In 2007, we replaced the decay chambers, which had degraded to the point where they did not tightly seal. This often resulted in drier conditions that were less conducive to decay. The new chambers created more suitable decay conditions as evidenced by subsequent drops in ratings for all treatments after the change.

Freshly sawn stakes continue to out-perform weathered stakes at all retention levels (Figures V-1, V-2). Non-treated stakes failed within 180 months while stakes treated with diesel have average ratings of approximately 0.9 after 336 months of exposure. Diesel is not generally believed to provide protection against fungal attack. All freshly sawn stakes treated with copper naphthenate to retentions of 4.0 kg/m^3 continue to provide excellent protection after 336 months with average ratings of 7.1. While some decay is present, it remains relatively minor and the wood is still serviceable. The conditions of stakes treated to the two lower retentions continued to decline over the past 3-years and both treatments have ratings near 4, indicating the presence of substantial decay. Ratings for the intermediate retention were just 5.5, indicating continued loss of treatment efficacy. The exposure conditions used in this test are designed to encourage soft rot and this type of damage is evident on a number of stakes, exhibiting damage at the bottom of the stakes - giving the samples an hour glass shape from the groundline to the tip (Figure V-3). This suggests conditions were more suitable for decay deeper in the soil.

These tests are normally performed over shorter periods, but these results illustrate the resistance of copper naphthenate-treated wood to soft rot.

Weathered stakes have consistently exhibited greater degrees of damage at a given treatment level; their condition continues to slowly decline and the stakes would be considered to be non-serviceable. The non-treated and diesel treated controls were destroyed after 200 months. The three lowest retentions had average ratings below 2.0, indicating the presence of substantial external decay (Figure V-3). Stakes treated to 3.2 or 4.0 kg/m^3 had average ratings of 3 and 4, respectively. These stakes are nearing the end of their service life, but they do illustrate the potential for retreating field exposed wood to extend service life. Clearly, prior surface degradation from both microbial activity and UV light sharply reduced performance of the weathered material.

As noted, weathered wood was included in this test because the cooperating utility planned to remove poles from service for re-treatment and reuse. While this process remains possible, it is clear that the performance characteristics of weathered, retreated material differed substantially from freshly sawn material. The effects of these differences on overall performance may be minimal. Even if the outer, weathered wood were to degrade over time, this zone is relatively shallow on western redcedar and would not markedly affect overall pole properties.

Copper naphthenate should continue to protect weathered western redcedar sapwood above-ground, allowing utility personnel to safely climb these poles. Any slight decrease in aboveground protection would probably take decades to emerge given the prolonged performance of this material in soil contact. As a result, retreatment of western redcedar still appears feasible for avoiding pole disposal and maximizing the value of the original investment.

A more reasonable approach might be to remove weathered wood and treat the poles. This process would be very similar to processes that have been used for removing sapwood on freshly peeled poles to produce a so-called “redbird” pole. Since weathered wood is already physically degraded, it likely has little strength and contributes little to overall material properties. Thus, treatment serves little practical purpose. Removal of this more permeable, weaker wood would effectively reduce the pole class, but might result in a better performing pole. Resulting treatments on shaved poles would be shallower given the resistance of western redcedar to preservative treatment, but any gaps in the treatment barrier would only expose durable heartwood.

The results with freshly sawn and treated western redcedar clearly show good performance. These results are consistent with field performance of this preservative on western species. We continue to seek copper naphthenate treated Douglas-fir poles in the Northwest so that we can better assess the field performance of this system.

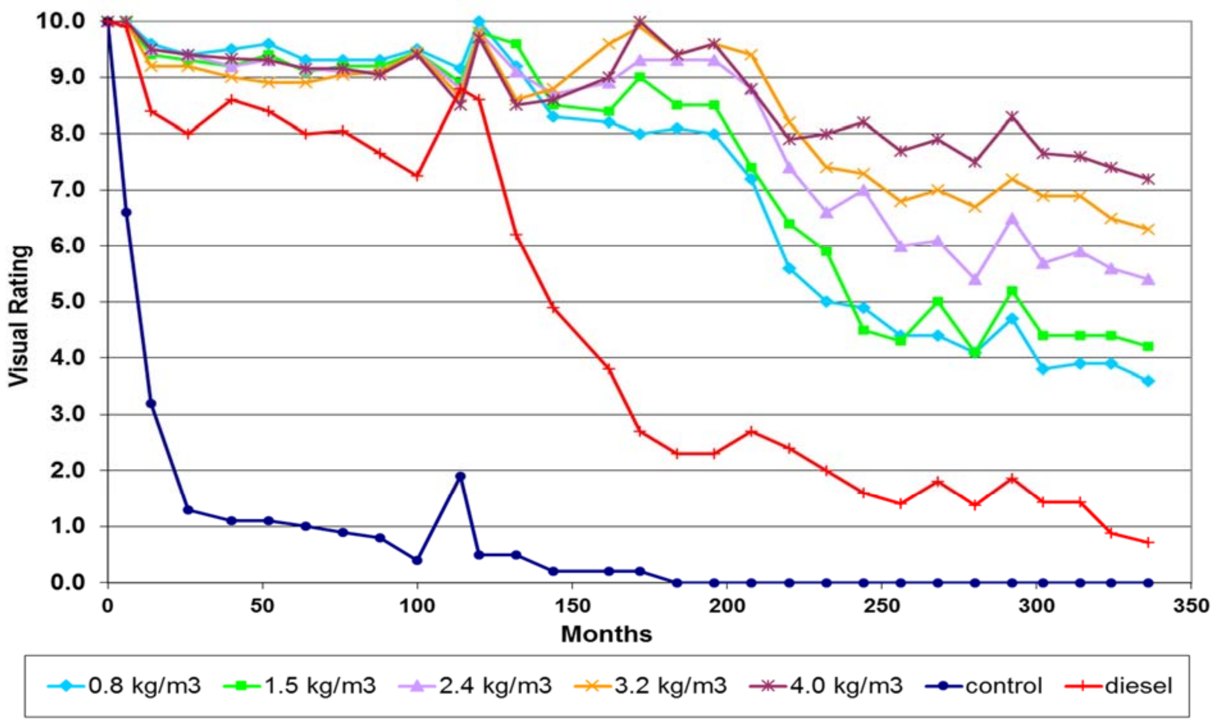

Figure V-1. Condition of freshly sawn western redcedar sapwood stakes treated with selected retentions of copper naphthenate in diesel oil and exposed in a soil bed for 336 months.

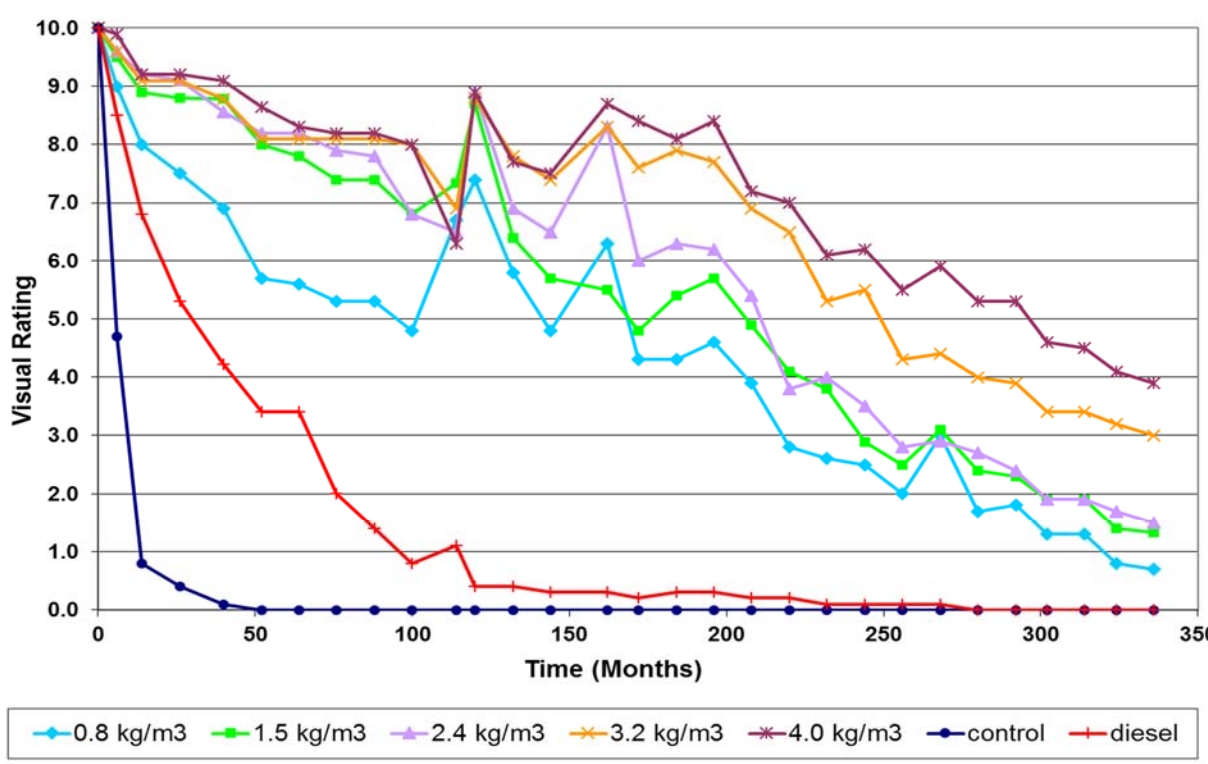

Figure V-2. Condition of weathered western redcedar sapwood stakes treated with selected retentions of copper naphthenate in diesel oil and exposed in a soil bed for 336 months.

Figure V-3. Examples of western redcedar stakes cut from weathered poles and freshly sawn lumber that have failed in test showing a tendency for the wood to decay towards the lower end of the samples.