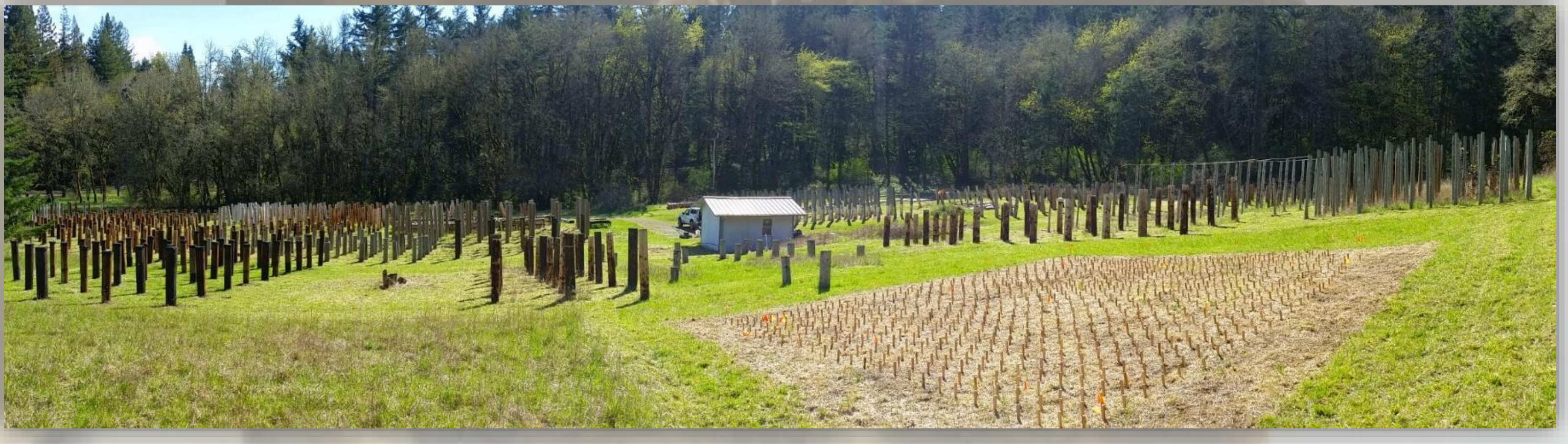
Oregon State University Utility Pole Research Cooperative

Department of Wood Science & Engineering
Oregon Wood Innovation Center
36th Annual Report
2016



By:
J.J. Morrell, M. Konkler, J. Cappellazzi

TABLE OF CONTENTS

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American Transmission Company

Arizona Public Service

Bonneville Power Administration

Brooks Manufacturing Inc.

Clark Public Utilities

Copper Care Wood Preservatives Inc.

BASF Wolman, GMBH

Fortis Alberta

Genics Inc.

Intec Services Inc. (Pole Care Inc.)

ISK Biocides

McFarland Cascade

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

Stella-Jones Inc.

The Pentachlorophenol Working Group

Western Wood Preservers Institute

Wood Care Systems

Xcel Energy

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Gerald Rhode	American Transmission Company
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Jeff Goodson	Xcel Energy

RESEARCH

Principle Investigators

Jeffery J. Morrell
Professor
Department of Wood Science and Engineering

Scott Leavengood
Director
Oregon Wood Innovation Center

Faculty Research Assistants

Jed Cappellazzi
Matt Konkler

Visiting Scientists

XiaoPing Li
Zineb Kebbi Benkeder

Graduate Students

Paola Torres
Ben Romanggi
Shahlinney Lipeh
Selim Uysal
Daniel Trebelhorn
Bryne Miyamoto

EXECUTIVE SUMMARY

The Utility Pole Research Cooperative currently has 12 Utility members and 14 Associate members. Membership continues to fluctuate, primarily in the Associate member category mostly as a result of acquisitions and mergers.

Coop progress and results under each of six objectives will be summarized here.

Objective I examines the performance of internal remedial treatments. Evaluations of dazomet in rod form or in tubes showed rods and cardboard tubes performed in the same manner as the granular system currently in use. Rods offer reduced risk of spilling during application. Basamid in plastic tubes released MITC more slowly, but the levels were still effective. Field trials of boron rods with and without a liquid copper accelerant continue to indicate equivalent performance.

The field trial of internal remedial treatments in Utah continues to show that systems dependent on the presence of moisture for decomposition, such as dazomet or the boron rods, are performing poorly, while metam sodium and MITC-FUME were less sensitive to moisture. The addition of copper naphthenate to the dazomet treatment markedly enhanced performance, although more time was required to produce effective chemical levels in the wood. A follow-up evaluation of cores removed from dazomet treated poles in Arizona revealed a similar trend, with fairly low MITC levels in wood. The results suggest moisture-sensitive treatments either need some form of accelerant or they must be placed further below groundline where moisture conditions will be more favorable for decomposition. Laboratory tests to evaluate the effect of a copper accelerant on dazomet decomposition showed that both evaluated copper systems enhanced MITC production, but the copper naphthenate system was more active than the micronized copper system. Results indicate that copper form has an effect on dazomet decomposition.

Objective II examines methods for limiting internal decay above groundline. We continue to evaluate the potential for pre-treatment with boron as a means for protecting the interior of Douglas-fir poles. Boron can move through wood with moisture; placing it inside the conventional preservative treated shell could allow it to protect poles from aboveground decay. Field trials with poles that were treated with boron followed by a copper naphthenate over-treatment continue to show low, but protective, boron levels in the heartwood. A second trial was installed this year with boron pre-treated poles that were subsequently treated with either pentachlorophenol or copper naphthenate, along with poles treated with boron amended ammoniacal copper zinc arsenate. These poles will be monitored for boron distribution over the coming years. A boron pre-treatment would help reduce the risk of aboveground framing creating pathways for entry of decay fungi into the pole interior.

Objective III examines a variety of activities designed to improve pole or crossarm performance. Polyurea coatings continue to protect penta treated Douglas-fir timbers from weathering, but coatings on non-treated wood have failed to limit entry by decay fungi. Results indicate supplemental preservative protection is essential for coating performance.

Pre-stressing poles to assess strength indicated that the process had a limited ability to sort poles on the basis of predicted modulus of elasticity. The results also indicated that traditional visual selection of the best face for pole alignment was poorly correlated with actual flexural properties.

Testing of various field-applied fire retardant or barrier systems continues. Nearly all of the systems tested provided protection against an initial burn and experienced little or no charring. However, exposure to a second fire event resulted in damage to most systems indicating retreatment would be necessary. Fire tests will continue to evaluate more severe conditions.

A field evaluation of poles in a Canadian utility indicated initial CCA treatment levels remained well above the protective level in most poles. MITC levels in poles receiving metam sodium tended to be more variable, which was not surprising. MITC levels at 4 years were often below the protective threshold level, typical of this treatment system. Boron levels near the surface were low and suggested a further evaluation of the treatment system was warranted.

The copper naphthenate/pentachlorophenol trial assessing the effects of oil carriers was rated after 18 months of exposure. Stakes in the forest setting were experiencing higher levels of decay compared to those at the open field site. The results reflect more uniform moisture conditions present in the forest setting. This test is still in the early stages and we will expect treatments to be more differentiated in coming years.

Objective IV examines the efficacy of external preservative pastes, as well as the ability of barriers to limit moisture ingress or preservative loss. Field trials in Arizona continue to show boron levels in all of the boron-based systems reached effective levels near the surface. However, boron distribution tended to be less uniform than has been found in previous tests under wetter climate regimes. Copper levels in external pole zones also varied widely with formulation, but were generally present at protective levels near the surface. Results illustrate the difference in performance with these systems in drier climates.

A small scale lab test was also completed evaluating the potential for using mixtures of borates with differing water solubilities to more carefully control boron movement into wood. The results indicated boron levels were elevated with any formulation containing disodium octaborate tetrahydrate (DOT). Blocks treated with pastes containing borates with lower water solubilities had much lower boron levels. The results indicate DOT must be present in any multicomponent paste in order to produce short term boron release coupled with slower release over time.

Objective V examines the performance of copper naphthenate. The small scale stake test continues to show copper naphthenate provides excellent protection to western redcedar. Field sampling of Douglas-fir poles treated with copper naphthenate in various diesel and biodiesel solvents indicated treatment quality was lower on biodiesel treated poles, although no decay fungi were isolated. These inspections were initiated because previous laboratory tests indicated the presence of even limited amounts of biodiesel was detrimental to copper naphthenate performance. The poles will be sampled over time to ensure poles treated with copper naphthenate in biodiesel do not experience premature decay.

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; Table I-1). Of these, chloropicrin was most effective, but both were prone to spills and carried health risks to installers. The Utility Pole Research Cooperative (UPRC) identified two alternatives, methylisothiocyanate (MITC, commercialized as MITC-FUME) and dazomet (commercialized as Super-Fume, UltraFume and DuraFume; Table I-1). Both chemicals are solid at room temperature which reduces spill risk and simplifies cleanup.

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 fumigants used for internal remedial treatment of utility poles in North America

Trade Name	Active Ingredient	Conc. (%)	Manufacturer
TimberFume	trichloronitromethane	97	Osmose Utilities Services, Inc.
WoodFume	sodium n-methyldithiocarbamate	33	Osmose Utilities Services, Inc.
ISK Fume			ISK Biosciences
SMDC-Fume			Copper Care Wood Preservatives, Inc.
MITC-FUME	methylisothiocyanate	97	Osmose Utilities Services, Inc.
Super-Fume	Tetrahydro-3,5-dimethyl-2H-1,3,5-thiodiazine-2-thione	98-99	Pole Care Inc.
UltraFume			Copper Care Wood Preservatives, Inc.
DuraFume II			Osmose Utilities Services, Inc.

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 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 of 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. Behavior of Copper-Based Accelerants in Dazomet Treatment Holes

Dazomet labels recommend the addition of 2 % copper metal solutions to accelerate decomposition to MITC, especially in drier climates. Copper naphthenate is typically used for this application. In previous reports, we have examined the ability of copper naphthenate to become evenly distributed within dazomet powder. Investigations of poles at numerous sites suggested that copper naphthenate moves only a short distance within dazomet powder and can form a hardened plug. It is unclear whether this plug inhibits further dazomet decomposition. The opaque nature of wood makes it difficult to assess potential interactions between dazomet and copper naphthenate, but a number of investigators have examined mixing behavior in glass test tubes. This approach does not completely represent the natural system because copper naphthenate cannot move outward into surrounding wood. However, clear tubes do allow examination of copper naphthenate flow around various powdered dazomet formulations.

One hundred mL glass test tubes were filled with 20 g of dazomet from two different sources with slightly different particle sizes (granular and powdered). Various volumes of copper naphthenate (1% as supplied) were added to the tubes to produce differing mass/mass ratios. The behavior of the mixture was studied and photographed over a 24 hour period. These results were reported last year.

In addition, non-treated Douglas-fir posts (87.5 by 87.5 mm) were obtained and cut into 200 mm long sections. The posts were mostly heartwood with a moisture content of approximately 20% when prepared. A 25 mm diameter by 150 mm long hole was drilled at a slight angle at the center of one wide face of each section. These sections were ripped in half lengthwise through the angled hole. The sections were then reattached using silicon sealant between the cut faces and 62.5 mm long galvanized screws to hold the pieces in place. Ten g of dazomet and 3.5 mL of a copper based compound were added to each treatment hole. Copper treatments evaluated were copper naphthenate (1% as metal) and a copper solution (2 % as metal, Hollow Heart CB). Treatment holes were plugged with rubber stoppers and blocks were incubated upright (angled hole down) at room temperature for 4, 8 and 12 weeks. At each time point, three blocks per treatment were cut into thirds lengthwise. The first cut was 20 mm inward from the surface, parallel to the treatment hole. The next cut was 20 mm inward from the opposite surface, again parallel to the treatment hole. This left a 35 mm thick section including the treatment hole. Sections were then cut above and below the treatment hole approximately 5-10 mm, 15-20 mm, and 25-30 mm away from the treatment hole. These sections were immersed in ethyl acetate and extracted for 48 hours at room temperature. A small sub-sample of extract was removed and analyzed for MITC content by gas chromatography. Wood sections were air-dried, then oven dried and weighed. MITC content was expressed on a µg of MITC per oven dried gram of wood. After cutting, blocks were carefully reopened lengthwise. Copper distribution around the dazomet powder was examined to determine depth of penetration and dazomet texture (i.e. did it cause dazomet to harden into a plug).

Dissection of one set immediately after treatment illustrated the differences in results between test tubes and wood blocks (Figure I-1). Copper naphthenate tended to penetrate two-thirds of the dazomet but also moved, to a substantial extent, longitudinally away from the treatment hole. As a result, the bottom third of the treatment hole received no copper accelerant. This observation is consistent with field tests. Some utilities have experimented with adding copper naphthenate in stages (some copper naphthenate first, then dazomet and finally additional copper naphthenate), but this process is somewhat cumbersome. In original field trials, copper accelerant (as copper sulfate powder) was mixed with dazomet powder prior to treatment, providing intimate contact between the two compounds throughout the treatment hole. However, since copper sulfate was not registered for this application, copper naphthenate was substituted. While numerous tests have shown that copper naphthenate is an acceptable accelerant, it clearly has different performance characteristics. These differences probably make little difference in wetter climates where excess moisture is likely to produce acceptable dazomet decomposition to produce MITC, but it becomes more problematic in drier climates.

Figure I-1. Example of a 200 mm long block used to assess copper naphthenate distribution patterns in dazomet treatment holes showing copper naphthenate penetration limited to the upper zone of the treatment hole.

MITC levels 4 weeks after treatment decreased with increasing distance from the treatment hole, regardless of dazomet formulation or copper accelerant (Figure I-2). Levels were approaching threshold in the closest zone, but were below threshold further away. Copper accelerant type appeared to have little initial effect on MITC levels.

MITC levels 8 weeks after treatment were all above threshold immediately adjacent to the treatment hole, then declined with distance (Figure I-3). MITC levels again tended to be similar regardless of dazomet formulation; however, copper accelerant type had a major effect on MITC levels. In outer zones, copper naphthenate usage resulted in MITC levels 1.5 to more than 2 times those found with the Hollow Heart CB copper solution. Universally, MITC levels declined with distance from the treatment hole, but levels 25-30 mm away were still above threshold for blocks with a copper naphthenate accelerant. MITC levels were also above threshold in the same zone with the Hollow Heart CB copper accelerant.

MITC levels were still elevated 12 weeks after treatment, but began to decline. The results were similar to those found at the 8 week sampling (Figure I-4). The differences between the two copper treatments was interesting and likely reflects the state of the metal. Copper naphthenate is a complex between naphthenic acid and copper; as a result copper is readily available for possible reactions with dazomet. Micronized copper is not solubilized but suspended; this approach has some benefits from the perspective of potential migration of copper from treated wood, but it also has the potential to reduce overall copper availability to react with dazomet.

Results indicate that both copper treatments were associated with dazomet decomposition, but solubilized copper produced consistently higher levels of MITC.

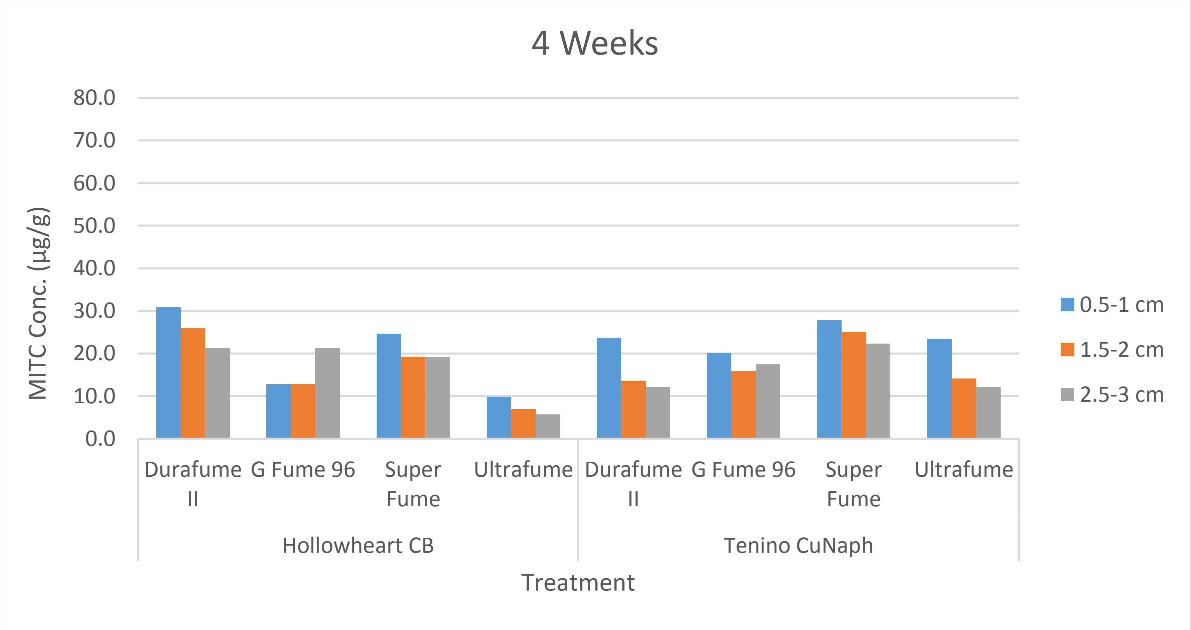


Figure I-2. MITC content above and below a treatment hole 4 weeks after receiving various dazomet formulations with either a micronized copper or copper naphthenate.

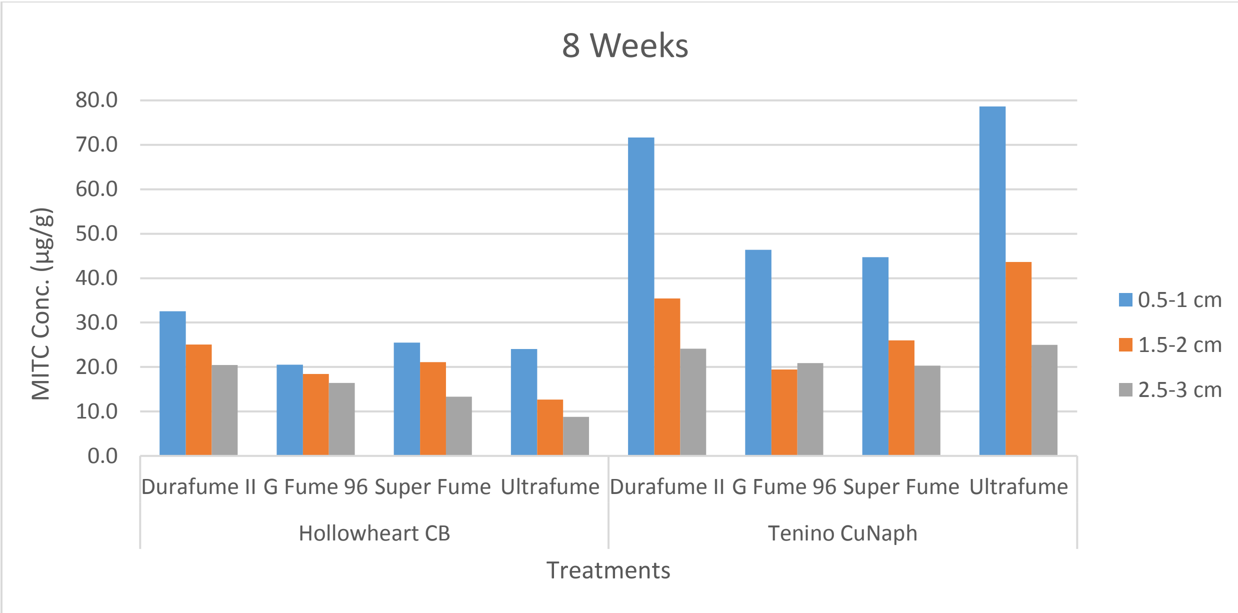


Figure I-3. MITC content above and below a treatment hole 8 weeks after receiving various dazomet formulations with either a micronized copper or copper naphthenate.

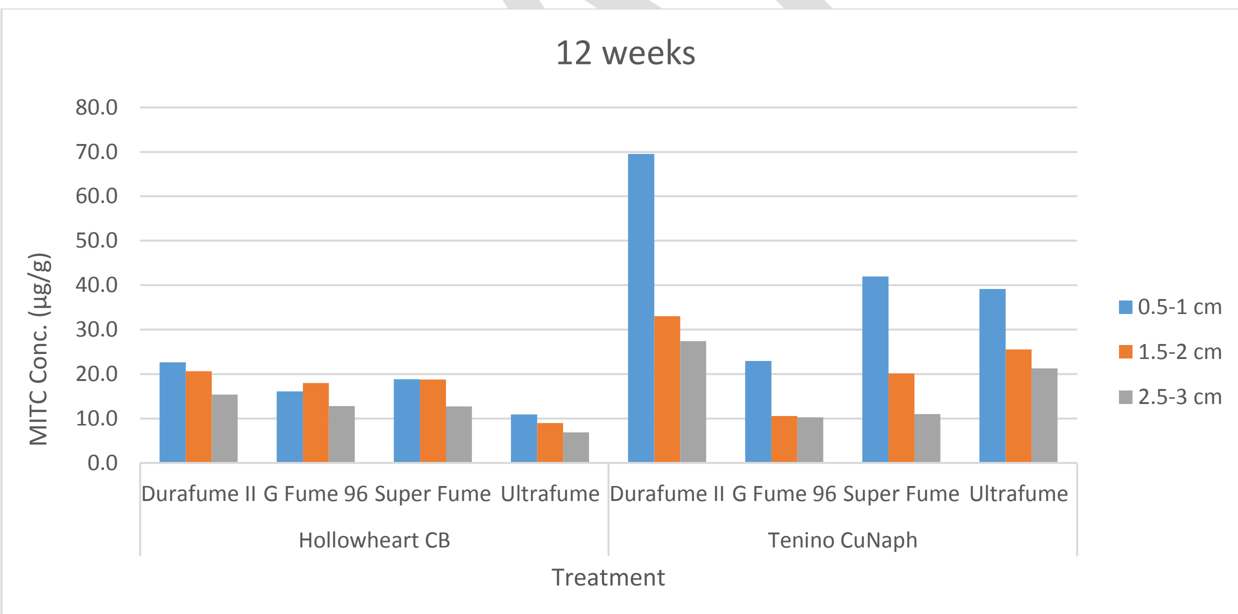


Figure I-4. MITC content above and below a treatment hole 12 weeks after receiving various dazomet formulations with either a micronized copper or copper naphthenate.

3. Performance of Dazomet in Granular and Tube Formulations

Date Established:	August 2006
Location:	Peavy Arboretum, Corvallis, OR
Pole Species, Treatment, Size	Douglas-fir, penta
Circumference @ GL (avg., max., min.)	89, 97, 81 cm

Dazomet has been successfully applied for more than 10 years; however, one concern is the risk of spilling granules during application. In previous tests, we explored the use of dazomet in rod form, but this does not appear to be a commercially viable product. As an alternative, dazomet could be placed in degradable tubes that encase the chemical prior to application. Tubes could affect dazomet decomposition and MITC release. To investigate this, the following trial was established.

Penta-treated Douglas-fir pole sections (2.1 m long by 250-300 mm in diameter) were set to a depth of 0.6 m at Peavy Arboretum. Three 22 mm diameter by 375 to 400 mm long steeply angled holes were drilled into the poles beginning at groundline and moving upward 150 mm and 120º around the pole.

Seventy grams of dazomet was pre-weighed into plastic bottles. The content of one bottle was added to the treatment holes in another 10 poles. Holes in 10 additional poles received a 400 to 450 mm long by 19 mm diameter paper tube containing 60 g of dazomet. Tubes were gently rotated as they were inserted to avoid damaging the paper. Holes in one half of the poles treated with either granular or tubular dazomet were then treated with 7 g of 2% copper naphthenate (as Cu) in mineral spirits (Tenino Copper Naphthenate). Copper naphthenate is currently available over the counter at a 1% copper concentration. The holes were plugged with tight fitting plastic plugs. A second set of poles was treated one year later with an improved Super-Fume tube system using these same procedures. The newer tubes were constructed of perforated degradable plastic which should break down over time so removal would not be required before re-treating occurs.

MITC distribution was assessed 1, 2, 3, 5, 7, and 10 years after treatment by removing increment cores from three locations around the pole 150 mm below groundline, at groundline, as well as 300, 450 and 600 mm above groundline. The outer treated zone of the core was removed and then the inner and outer 25 mm of each core were placed in ethyl acetate, extracted for 48 hours at room temperature and then the extract was removed and analyzed for MITC by gas chromatography (Table I-2). The remainder of each core was placed on 1.5% malt extract agar and observed for evidence of fungal growth. Any fungal growth was examined for characteristics typical of basidiomycetes, a class of fungi containing many important wood decay fungi. Decay fungi were on sporadically isolated (Table I-3).

MITC levels in poles receiving any dazomet treatments were all well above the minimum threshold 150 mm below-ground, at groundline and 300 mm above groundline within one year of treatment. Poles treated with dazomet in plastic tubes were near, but slightly below the threshold in the outer zones at or below groundline (Table I-2; Figures I-5 to 10). Levels were often 2 to 30 times the threshold in the other treatments, indicating that dazomet decomposition was progressing well, regardless of the application method. Levels were slightly more variable 450 or 600 mm above groundline, but were still above threshold over time (Table I-2). MITC levels 450 mm above groundline or higher tended to decline at the ten year sampling point and were often below the threshold for fungal protection, particularly in the outer sampling zone. These results suggest that retreatment would be prudent if the intent was to provide a wider protective zone. However, levels at groundline continue to remain well within protective levels.

Over the course of the test MITC levels tended to be similar in granular and cardboard tube treatments, but were generally lower in poles receiving dazomet from plastic tubes. Plastic tubes appeared to slow either dazomet decomposition or MITC release without necessarily increasing the overall protective period and therefore protective effects appeared to be more confined. The tubes also delivered less dazomet to each treatment hole and this might have affected MITC levels.

The results suggest that the use of cardboard tubes to decrease the risk of spills during dazomet application had little or no effect on resulting chemical levels in the wood while the use of plastic tubes for the same purpose had a slightly negative impact on resulting MITC levels.

MITC levels in nearly all poles remain above threshold 10 years after treatment. Copper naphthenate addition at the time of treatment had a more variable effect on MITC levels, suggesting that ambient moisture conditions onsite were suitable for decomposition alone.

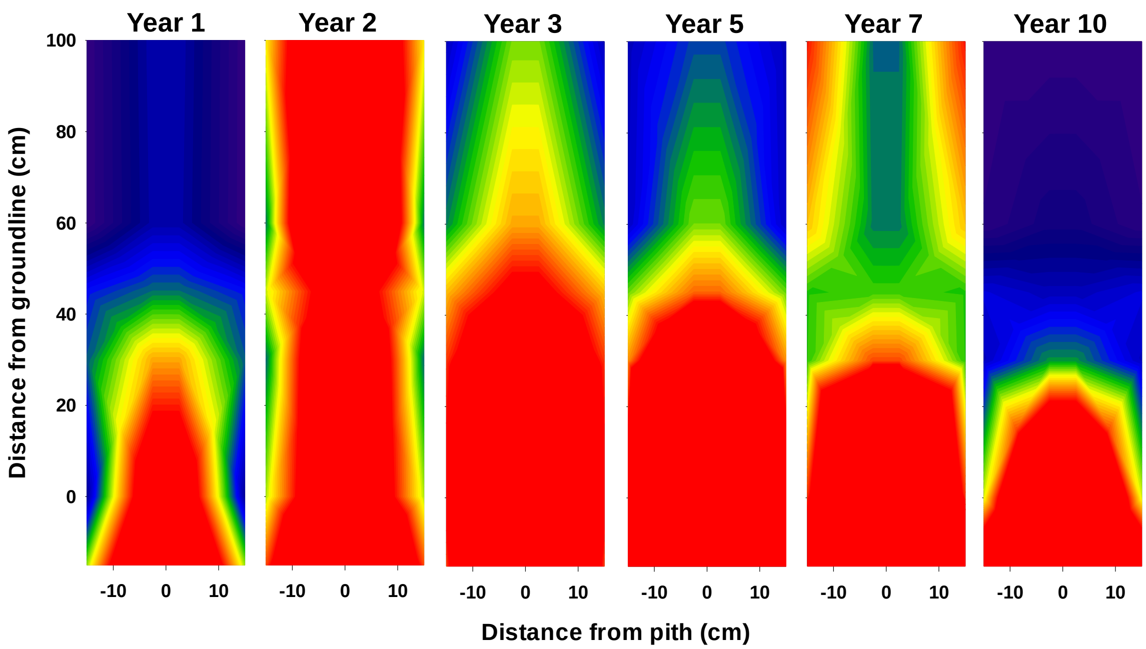


Figure I-5. MITC distribution in Douglas-fir poles 1, 3, 5, 7 and 10 years after treatment with granular dazomet alone with no additional copper naphthenate accelerant. Values moving from light blue to yellow or red signify MITC levels increasingly above the threshold for fungal protection (20 µg/g wood).

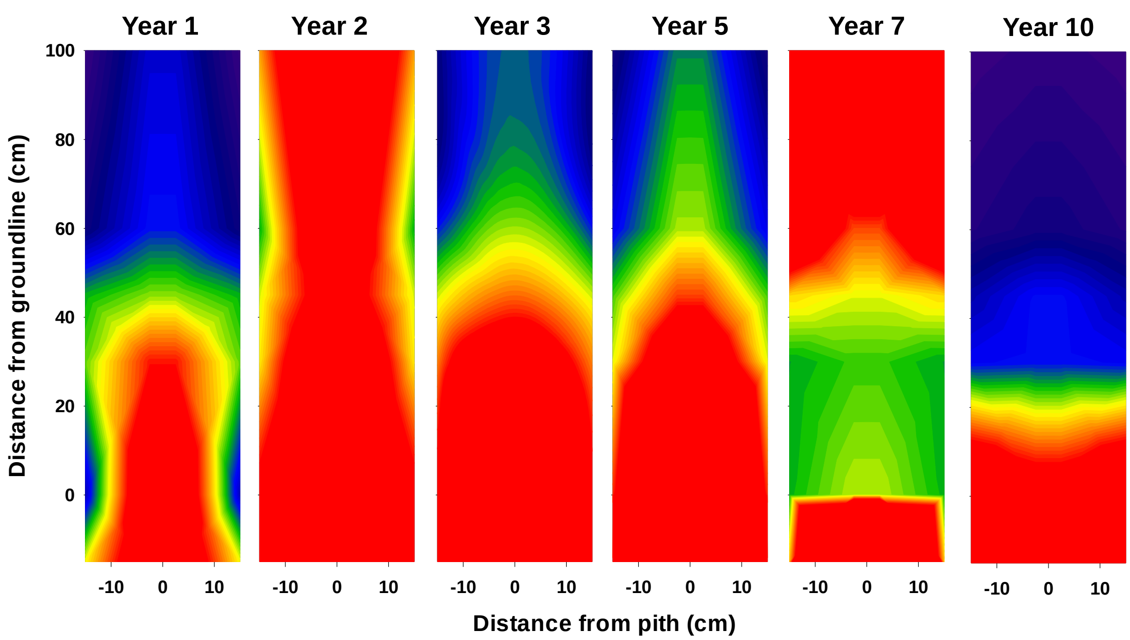


Figure I-6. MITC distribution in Douglas-fir poles 1, 3, 5, 7 and 10 years after treatment with granular dazomet and copper naphthenate accelerant. Values moving from light blue to yellow or red signify MITC levels increasingly above the threshold for fungal protection (20 µg/g wood).

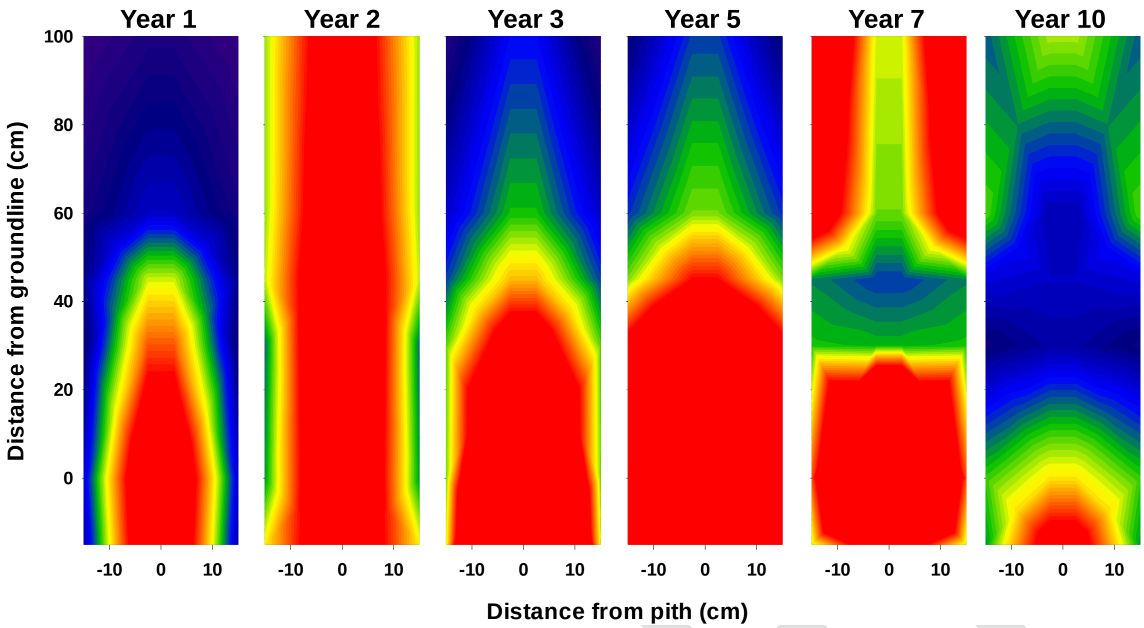


Figure I-7. MITC distribution in Douglas-fir poles 1, 3, 5, 7 and 10 years after treatment with dazomet in a cardboard tube with no additional copper naphthenate accelerant. Values moving from light blue to yellow or red signify MITC levels increasingly above the threshold for fungal protection (20 µg/g wood).

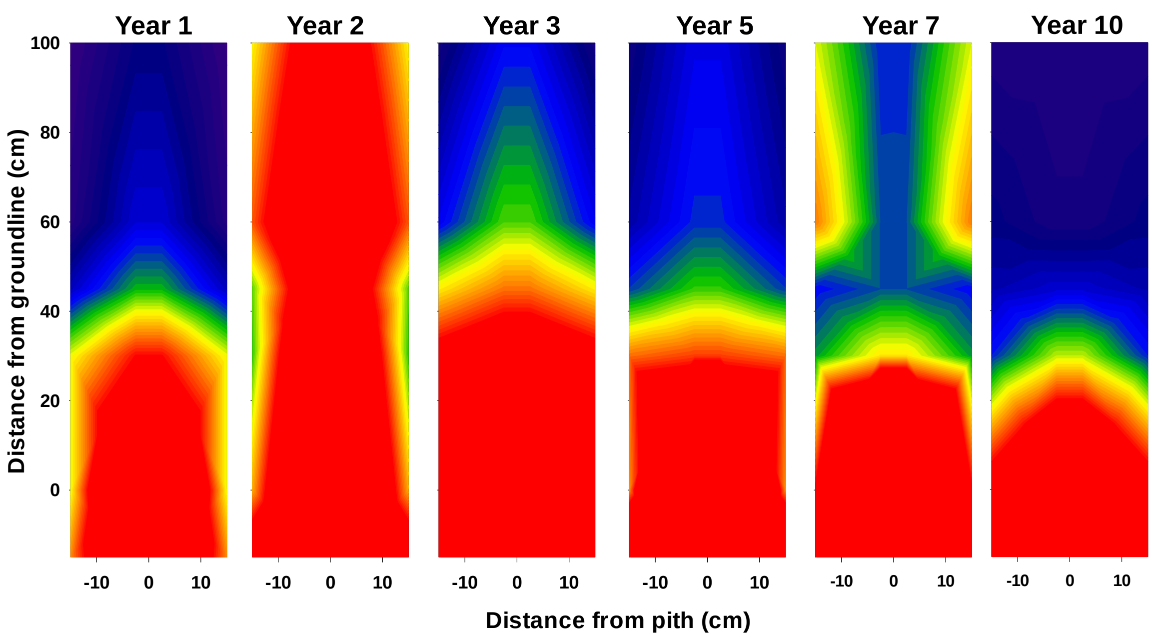


Figure I-8. MITC distribution in Douglas-fir poles 1 to 10 years after treatment with dazomet in a cardboard tube along with a copper naphthenate accelerant. Values moving from light blue to yellow or red signify MITC levels increasingly above the threshold for fungal protection (20 µg/g wood).

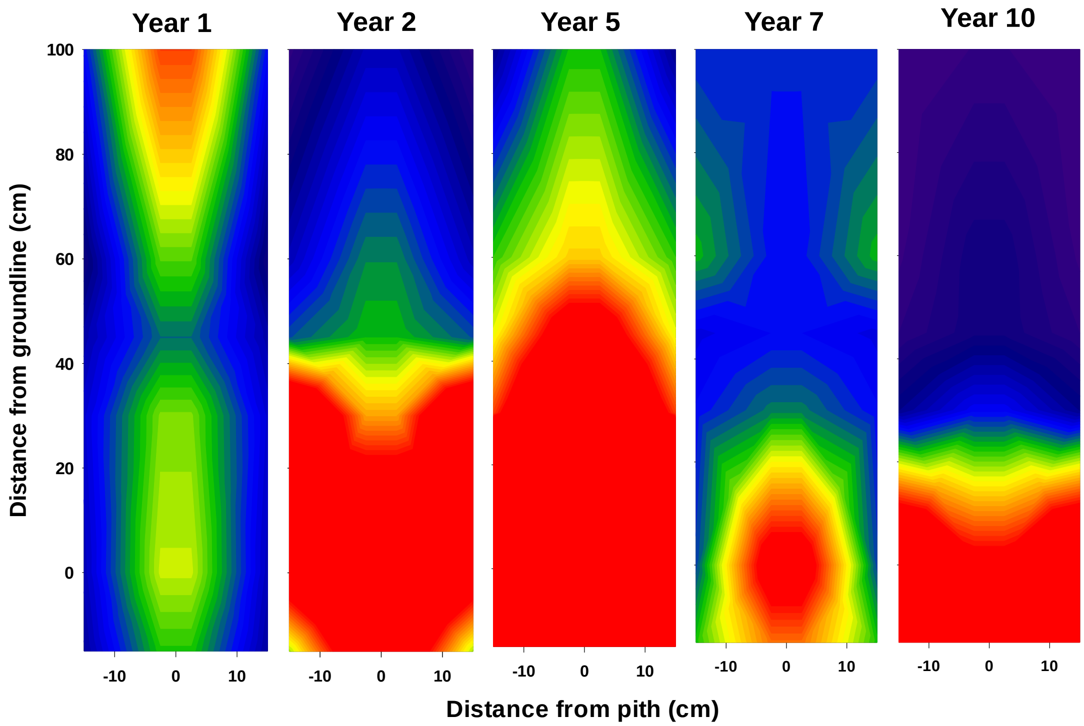


Figure I-9. MITC distribution in Douglas-fir poles 1 to10 years after treatment with dazomet in a plastic tube followed by a copper naphthenate accelerant. Values moving from light blue to yellow or red signify MITC levels increasingly above the threshold for fungal protection (20 µg/g wood).

Table I-2. Residual MITC content at selected distances above and below the groundline of Douglas-fir poles 1 to 10 years after application of granular dazomet or dazomet in cardboard or plastic tubes.

Treatment	Dosage (g/pole)	Supple-ment	Years after treatment	Residual MITC (µg/g of wood)[a]											
				-15 cm				0 cm				30 cm			
				Inner		Outer		Inner		Outer		Inner		Outer	
Granular	210	CuNaph	1	**108**	(56)	**53**	(87)	**114**	(66)	19	(23)	**79**	(38)	**45**	(56)
			2	**173**	(225)	**96**	(102)	**131**	(158)	**88**	(62)	**122**	(72)	**56**	(40)
			3	**180**	(64)	**91**	(143)	**132**	(56)	**66**	(59)	**83**	(31)	**60**	(42)
			5	**681**	(1041)	**78**	(78)	**267**	(200)	**76**	(94)	**112**	(48)	**52**	(39)
			7	**525**	(1490)	**60**	(78)	**50**	(57)	**39**	(41)	**43**	(28)	**38**	(22)
			10	**176**	(169)	**116**	(127)	**185**	(202)	**52**	(45)	**37**	(39)	**20**	(15)
		None	1	**144**	(111)	**48**	(64)	**108**	(49)	15	(24)	**63**	(21)	**32**	(44)
			2	**189**	(241)	**73**	(80)	**119**	(77)	**49**	(49)	**126**	(83)	**33**	(24)
			3	**232**	(145)	**74**	(62)	**215**	(158)	**85**	(100)	**135**	(92)	**75**	(52)
			5	**477**	(521)	**100**	(77)	**520**	(695)	**97**	(79)	**151**	(92)	**65**	(36)
			7	**482**	(1377)	**102**	(139)	**331**	(648)	**75**	(96)	**73**	(62)	**42**	(36)
			10	**141**	(80)	**151**	(147)	**98**	(62)	**120**	(208)	**27**	(22)	**26**	(25)
Paper Tube	180	CuNaph	1	**133**	(99)	**66**	(97)	**158**	(111)	**53**	(59)	**81**	(40)	**53**	(59)
			2	**138**	(94)	**103**	(106)	**154**	(166)	**62**	(50)	**135**	(93)	**42**	(34)
			3	**284**	(249)	**137**	(93)	**278**	(112)	**137**	(107)	**101**	(38)	**89**	(53)
			5	**481**	(440)	**155**	(133)	**751**	(936)	**191**	(202)	**141**	(38)	**89**	(59)
			7	**1180**	(2740)	**97**	(105)	**321**	(437)	**83**	(75)	**56**	(35)	**37**	(20)
			10	**202**	(97)	**121**	(110)	**144**	(104)	**94**	(127)	**50**	(25)	**28**	(23)
		None	1	**108**	(59)	16	(31)	**112**	(108)	**21**	(32)	**72**	(52)	10	(12)
			2	**103**	(104)	**55**	(47)	**117**	(139)	**37**	(23)	**122**	(84)	**34**	(26)
			3	**269**	(142)	**53**	(36)	**205**	(179)	**46**	(30)	**100**	(50)	**45**	(17)
			5	**503**	(510)	**107**	(51)	**505**	(630)	**275**	(679)	**134**	(49)	**74**	(33)
			7	**101**	(141)	**50**	(70)	**308**	(556)	**72**	(66)	**39**	(37)	**41**	(21)
			10	**92**	(73)	**144**	(200)	**88**	(109)	**124**	(165)	**25**	(48)	14	(21)
Plastic Tube	103	CuNaph	1	**41**	(73)	16	(25)	**51**	(49)	19	(19)	**47**	(35)	**21**	(36)
			2	**104**	(53)	**48**	(67)	**129**	(121)	**97**	(158)	**64**	(45)	**118**	(222)
			4	**162**	(109)	**142**	(178)	**256**	(577)	**65**	(63)	**75**	(32)	**69**	(81)
			6	**69**	(60)	**41**	(44)	**92**	(114)	**31**	(25)	**35**	(20)	**26**	(22)
			10	**94**	(97)	**37**	(47)	**56**	(65)	**42**	(70)	16	(11)	11	(14)
Control	0	None	1	0	0	1	(5)	8	(31)	0	0	1	(3)	0	0
			2	0	0	0	0	1	(3)	0	0	0	0	0	0
			3	1	(3)	0	0	0	0	0	0	1	(3)	0	0
			5	2	(5)	2	(7)	0	0	0	0	2	(5)	3	(8)
			7	1	(1)	2	(6)	0	(0)	1	(1)	0	(1)	0	(1)
			10	0	0	0	0	0	0	0	0	0	0	0	0

[a]Values in bold type are above the toxic threshold, while those in parentheses represent one standard deviation from the mean of 15 measurements.

Table I-2. Residual MITC content at selected distances above and below the groundline of Douglas-fir poles 1 to 10 years after application of granular dazomet or dazomet in cardboard or plastic tubes.

Treatment	Dosage (g/pole)	Supple-ment	Years after treatment	Residual MITC (ug/g of wood)[a]					
				45 cm		60 cm		90 cm	
				Inner	Outer	Inner	Outer	Inner	Outer
Granular	210	CuNaph	1	**47** (27)	**39** (33)	**27** (17)	10 (14)	**21** (34)	1 (3)
			2	**92** (58)	**51** (63)	**109** (103)	**39** (35)	**134** (196)	**64** (69)
			3	**58** (19)	**56** (56)	**45** (15)	**30** (16)	**30** (8)	14 (8)
			5	**74** (32)	**43** (50)	**49** (22)	**24** (16)	**35** (27)	9 (9)
			7	**52** (38)	**58** (56)	**74** (87)	**122** (142)	**171** (334)	**81** (88)
			10	19 (20)	**22** (41)	9 (17)	4 (8)	3 (6)	3 (6)
		None	1	**34** (13)	**27** (42)	17 (28)	2 (5)	17 (43)	2 (5)
			2	**94** (115)	**51** (87)	**167** (256)	**35** (40)	**132** (117)	**55** (70)
			3	**87** (31)	**61** (54)	**63** (35)	**35** (29)	**46** (39)	19 (16)
			5	**70** (43)	**45** (58)	**46** (22)	20 (10)	**31** (14)	19 (29)
			7	**43** (17)	**41** (30)	**35** (30)	**60** (61)	**34** (50)	**79** (109)
			10	**26** (28)	17 (22)	9 (10)	6 (10)	3 (8)	1 (3)
Paper Tube	180	CuNaph	1	**39** (21)	19 (20)	**22** (13)	5 (7)	12 (25)	2 (4)
			2	**109** (84)	**44** (44)	**118** (112)	**72** (114)	**99** (77)	**54** (41)
			3	**69** (22)	**55** (30)	**44** (14)	**24** (10)	**26** (9)	9 (9)
			5	**81** (31)	**47** (31)	**46** (13)	**29** (19)	**30** (12)	11 (9)
			7	**32** (18)	**26** (16)	**32** (42)	**68** (112)	**28** (50)	**52** (94)
			10	**21** (20)	17 (18)	8 (9)	13 (17)	7 (10)	7 (12)
		None	1	**51** (34)	14 (24)	**20** (11)	9 (15)	7 (16)	1 (4)
			2	**108** (163)	**50** (62)	**103** (106)	**48** (69)	**96** (86)	**48** (49)
			3	**61** (20)	**31** (8)	**40** (14)	**21** (7)	**26** (13)	6 (6)
			5	**95** (41)	**53** (31)	**59** (16)	**42** (39)	**40** (29)	14 (8)
			7	**30** (13)	**36** (15)	**46** (49)	**109** (98)	**51** (44)	**135** (142)
			10	9 (21)	4 (7)	9 (27)	2 (4)	2 (5)	0 0
Plastic Tube	103	CuNaph	1	**34** (44)	17 (27)	**44** (47)	10 (13)	**74** (153)	**26** (41)
			2	**40** (17)	**32** (24)	**36** (18)	19 (27)	18 (16)	3 (6)
			4	**42** (18)	**30** (43)	**29** (22)	16 (17)	**23** (22)	10 (18)
			6	**26** (13)	**23** (23)	**27** (18)	**39** (59)	**28** (45)	**28** (37)
			10	**20** (16)	**22** (54)	18 (22)	**44** (78)	**49** (79)	**33** (58)
Control	0	None	1	0 0	0 0	2 (7)	0 0	0 0	0 0
			2	0 0	0 0	1 (3)	0 0	0 0	0 0
			3	2 (3)	0 0	3 (11)	0 0	1 (2)	0 0
			5	2 (5)	0 0	2 (4)	1 (3)	2 (6)	12 (46)
			7	0 (1)	0 (1)	0 (1)	0 0	0 0	0 (1)
			10	0 0	0 0	0 0	0 0	0 0	0 0

[a]Values in bold type are above the toxic threshold. Numbers in parentheses represent one standard deviation from the mean of 15 measurements.

Table I-3. Frequencies of decay and on decay fungi in increment cores removed from Douglas-fir poles 1 to 10 years after treatment with dazomet in granular form, in a cardboard tube or in a plastic tube.

Treatment	Dosage (g/pole)	CuN	Years after treatment	Fungal Frequency (% Cores)[a] Height above Groundline (cm) -15		0		30		45		60		90	
Granular	210	Yes	1	0	0	0	0	0	0	0	7	0	7	0	0
			2	0	0	0	7	0	0	0	7	0	7	0	0
			3	0	0	0	0	0	20	0	0	0	0	0	13
			5	0	0	7	0	0	0	0	0	0	13	0	0
			10	0	0	0	0	0	0	0	0	0	0	0	0
		No	1	0	7	0	0	0	0	0	0	0	7	0	0
			2	0	0	0	0	0	7	0	7	0	0	0	0
			3	0	0	0	0	0	0	0	7	0	7	0	13
			5	0	13	0	7	0	13	0	13	0	13	0	0
			10	0	0	0	0	0	0	0	1	0	0	0	0
Paper Tube	180	Yes	1	0	0	0	0	0	0	0	7	0	0	0	0
			2	0	0	0	0	0	0	0	0	0	0	0	7
			3	0	0	0	0	0	0	0	7	0	0	0	13
			5	0	7	0	0	0	0	0	0	0	0	0	0
			10	0	0	0	0	0	0	0	0	0	0	0	0
		No	1	0	0	0	13	0	13	0	0	0	7	0	0
			2	0	0	0	0	0	0	0	0	0	0	0	0
			3	0	0	0	7	0	0	0	7	0	7	0	0
			5	0	0	0	13	0	0	0	0	0	0	0	0
			10	0	0	0	0	0	1	0	0	0	0	0	0
Plastic Tube	103	Yes	1	0	11	0	0	0	0	0	0	0	0	0	0
			2	0	0	0	0	0	6	0	0	0	0	0	6
			4	0	0	0	0	0	0	11	11	0	0	0	0
			10	0	0	0	0	1	1	0	0	0	3	0	0
Control	0	No	1	0	7	0	0	0	0	0	0	0	0	0	0
			2	0	7	0	20	0	13	0	13	0	7	0	0
			3	0	7	0	13	0	13	0	13	0	0	0	13
			5	0	67	0	60	7	60	0	80	7	40	7	53
			10	0	9	0	6	3	5	4	6	1	6	1	6

[a] Values represent percentage of 15 cores that contain decay fungi while the superscript represents % of cores containing non-decay fungi

B. PERFORMANCE OF WATER DIFFUSIBLE PRESERVATIVES AS INTERNAL TREATMENTS

While fumigants have long been an important tool for utilities seeking to prolong service lives of wood poles and limit the extent of internal decay, some users have expressed concerns about the risks of these chemicals. 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. 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 the 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 plus 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

While boron has been found to move with moisture through most pole species (Dickinson et al., 1988; Dietz and Schmidt, 1988; Dirol, 1988; Edlund et al., 1983; Ruddick and Kundzewicz, 1992), our initial field tests showed slower movement in the first year after application. One remedy for slow movement has been the addition of glycol. Glycol is believed to stimulate boron movement through dry wood that would normally not support diffusion (Bech-Anderson, 1987; Edlund et al., 1983).

Penta-treated Douglas-fir pole sections (259 to 315 mm in diameter by 2.1 m long) were set to a depth of 0.6 m in the ground at Peavy Arboretum. The test site receives an average yearly precipitation of 1050 mm with 81% falling between October and March.

Four 19 mm diameter holes were drilled at a 45° downward sloping angle in each pole, beginning 75 mm above the groundline, then moving 90 degrees around and up to 230, 300, and 450 mm above the groundline. An equal amount of boron (227 g BAE) was added to each pole, but was delivered with different combinations of water or glycol (Table I-4). Borate rods were 100 mm long by 12.7 mm in diameter and weighed 24.4 g each. An equal weight of boron composed of one whole rod and a portion of another, were placed in each hole followed by the appropriate liquid supplement or were left dry. Holes were plugged with tight fitting wooden dowels. Each treatment was replicated on five poles.

Table I-4. Combinations of boron rod and various boron additives used to treat Douglas-fir poles. All treatments delivered 227 g boric acid equivalent per pole.

B Rod (g)	Supplement	Supplement Amount (g)	Total glycol (g)	Total Water (g)	Source	Formulation
156	None	0	0	0	-	-
137	Boracare (1:1)	118	28	65	Nisus Corp	DOT plus poly and monoethylene glycol
137	Boracol 20	122	77	20	Viance LLC	DOT plus 20 % PEG
104	Boracol 40	164	95	0	Viance LLC	DOT plus 40 % PEG
156	Polyethylene glycol	100	100	0	VWR	-
146	Timbor (10 %)	118	0	106	RioTinto	DOT

Pole sections were sampled 1, 2, 3, 5, 7, 10, 12, 15 and 20 years after treatment by removing two increment cores 180 degrees apart from 30 cm below groundline, and cores from three equidistant locations around the pole 150 and 300 mm above groundline. Analysis revealed that glycol provided long term enhancement to boron movement. Results also indicated that boron was present at effective levels for up to 15 years after treatment. This test was not sampled in 2016.

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

The ability of boron and copper to move from fused rods was assessed by drilling holes perpendicular to the grain in penta-treated Douglas-fir poles beginning at groundline and moving upward 150 mm and either 90 or 120º around the pole. Poles were treated with either 4 or 8 copper/boron rods or 4 boron rods. Holes were plugged with tight fitting plastic plugs. Chemical movement was assessed 1, 2, 3, 5, 7, 9, 11 and 14 years after treatment by removing increment cores from locations 150 mm below groundline, at groundline, and 300 or 900 mm above-ground. The outer 25 mm treated shell was discarded, and the core was divided into inner and outer halves. Cores from a given zone on each set of poles were combined and ground to pass a 20 mesh screen. Ground wood was hot water extracted prior to being analyzed according to procedures described in American Wood Protection Standard A65, the Azomethine-H assay (AWPA, 2012). Results were expressed on a kg of boric acid equivalent (BAE)/cubic meter of wood basis. Previous studies in our lab have indicated the threshold for protection of Douglas-fir heartwood against internal decay is approximately 0.5 kg/m^3 BAE (Freitag and Morrell 2005).

Boron levels in pole sections were below the protective threshold one year after treatment, but gradually increased over the threshold the next 2 years (Figures I-10 & 11). Treatment levels appeared to drop slightly between 5-7 years after treatment, although they remained above threshold in many cases. Moisture is critical for boron movement, so it was no surprise that boron levels tended to be highest at groundline and 150 mm below-ground, reflecting the tendency for poles to be wetter in these regions. Boron levels tended to be higher in inner zones of increment cores, reflecting the positioning of rods towards the pole center. Boron levels tended to be below threshold 300 or 900 mm above groundline, reflecting the lower moisture regimes present in these zones.

Boron levels in poles sampled nine years after treatment rose sharply at a number of locations in the pole. In previous boron rod studies, we could equate these rises in boron level to an exceptionally wet year. Rainfall levels were normal for the year, but rain continued well till the end of June. Normally, rainfall would taper off sharply at the end of April and wood would begin to dry. The prolonged wet period may have enhanced boron movement, although it is difficult to see how this would make a difference so far into the test when rods have largely disintegrated.

Boron levels in poles 11 and 14 years after treatment were above threshold in the inner zone at groundline and 150 mm below. There appeared to be no consistent differences in boron levels between the two treatments nor did application to holes spaced at 90 or 120º intervals around the pole make a noticeable difference in boron levels. Boron levels in outer zones tended to be more variable, although they were over threshold in some instances. As with all internally applied remedial treatments, sloping application holes and the area occupied by the plug would tend to enhance chemical movement toward pole center. The presence of protective boron levels in poles 14 years after treatment indicates that these systems can deliver a sufficient amount of boron to poles in wetter climates where there is sufficient moisture for diffusion.

Boron levels in poles receiving fused borate and fused borate plus copper rods appeared to be equally effective at establishing threshold levels in application zones, suggesting that copper use had little influence on either initial boron diffusion or subsequent retention in wood.

Increasing rod dosage from 4 to 8 rods per pole did not appear to markedly enhance resulting boron levels in poles (Figure I-12). Boron levels in outer zones tended to be low over the entire test period. While there was some indication that boron levels might be slightly higher in outer zones for poles receiving higher dosages, these differences were slight and probably not meaningful in terms of wood protection. As noted above, sloping holes will tend to move chemical inward, but higher dosages have the potential to place rods immediately adjacent to a poles surface and should result in higher boron levels in outer zones. It is unclear why this did not occur although it could reflect varying moisture regimes closer to the surface that would be less suited for boron diffusion. In addition, increased boron dosages have been expected to help maintain boron levels in poles for a longer period; however, there appeared to be no real difference in boron levels after 14 years.

Copper levels were well below the protective threshold throughout the test. No copper was detected seven years after treatment, while slight amounts were detected in years 9 and 11. Similarly, this may reflect wetter conditions at the test site (Figure I-13). While copper levels increased, they were still well below those required to provide any substantive wood protection. We have established several tests with blocks containing diffusible treatments, but have had difficulty establishing threshold levels for copper amended boron. We will continue to work to better understand the possible interactions between copper amended boron.

Culturing of the increment cores revealed the presence of decay fungi, especially at groundline (Table I-5). Some decay fungi were isolated 300 or 900 mm above groundline; however, overall low levels of boron in these zones suggest that rod application had little or no consistent effect on fungal colonization at these distances above groundline. Fungal isolations near groundline tended to be more prevalent in poles receiving 4 fused borate rods using either 90 or 120º spacing, although the isolation levels were very low (10% of cores sampled). No decay fungi were isolated at or below groundline for poles treated with either 4 or 8 fused borate/copper rods. Given the very low levels of copper associated with these treatments, it is unclear why there is any substantial difference in isolation frequency. Further assessment will be needed to determine if copper enhances performance as boron levels decline.

Results indicate that boron, from fused borate and fused borate/copper rods, is diffusing into Douglas-fir heartwood at rates capable of protecting against fungal attack. While there are some slight differences in chemical levels and decay fungi presence, results suggest the two treatments provide similar protection over the 14 year test.

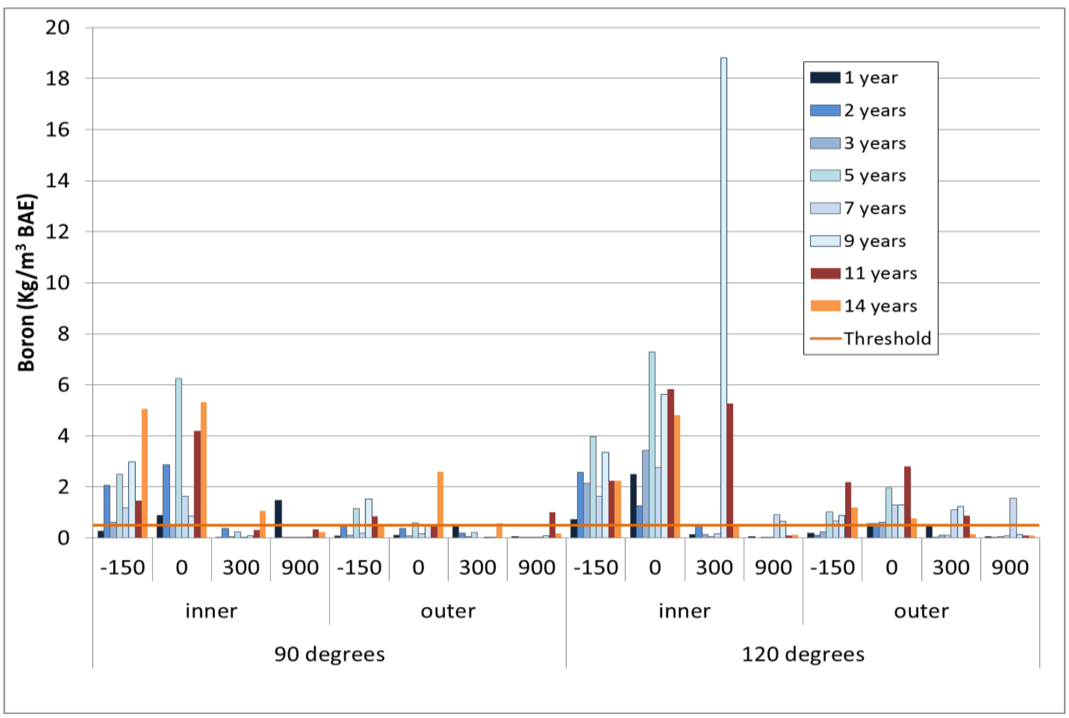


Figure I-10. Boron levels at selected locations above or below groundline in Douglas-fir poles 1 to 14 years after treatment with 4 boron/copper rods.

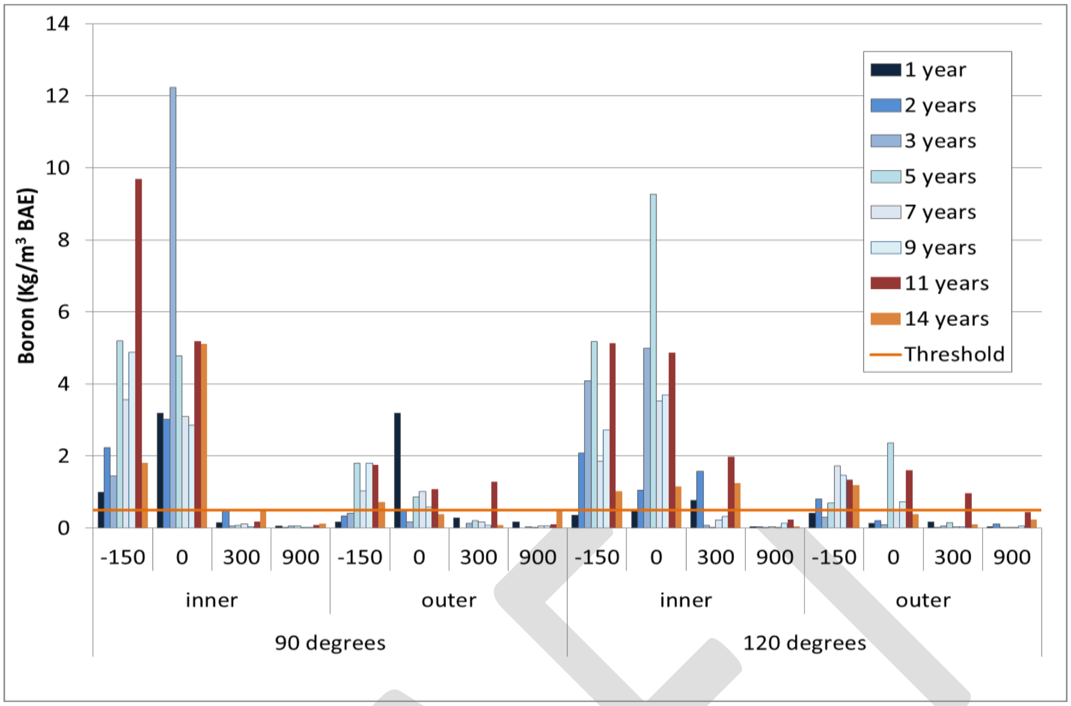


Figure I-11. Boron levels at selected locations above or below groundline in Douglas-fir poles 1 to 14 years after treatment with 4 boron rods. The elevated values at 300 mm in the inner zone of poles treated using a 120 degree spacing likely reflect one very high value from a sample removed immediately adjacent to the original treatment hole.

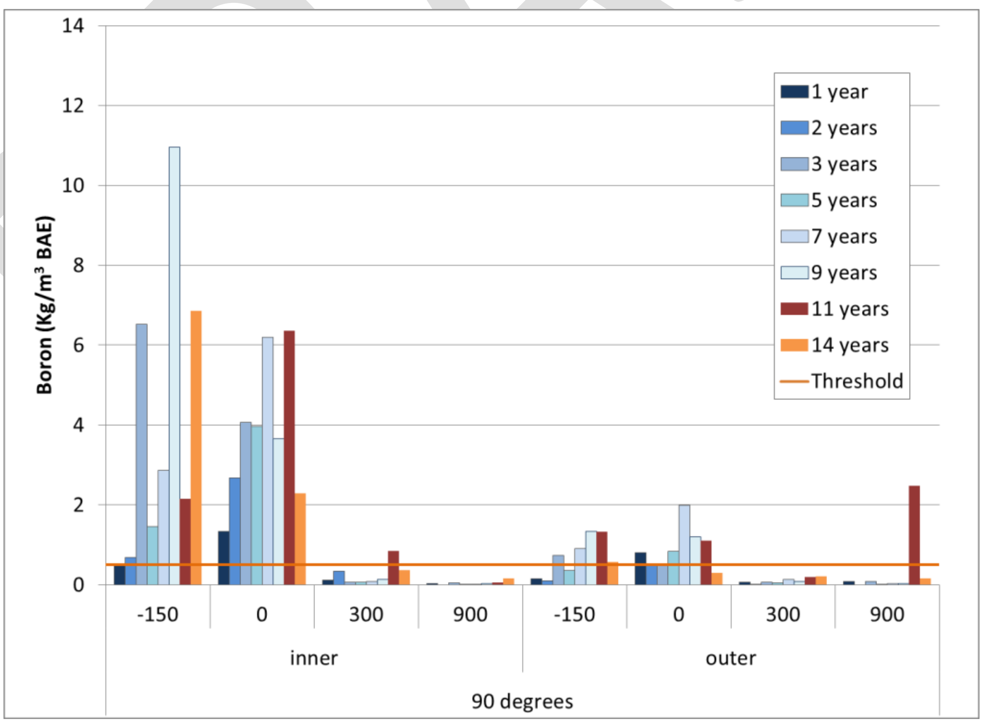
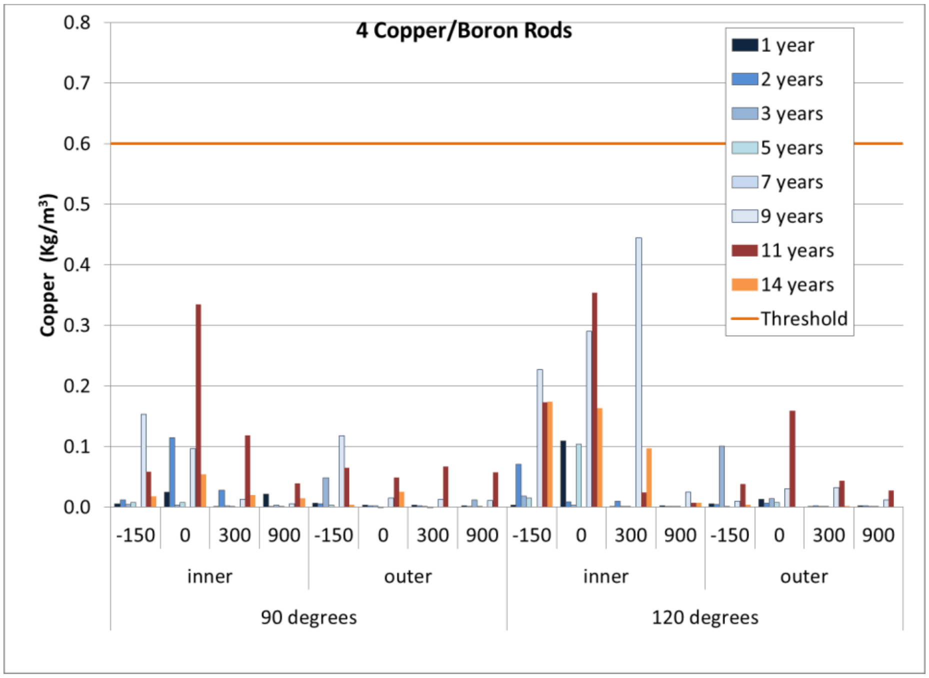


Figure I-12. Boron levels at selected locations above or below groundline in Douglas-fir poles 1 to 14 years after treatment with 8 boron/copper rods.



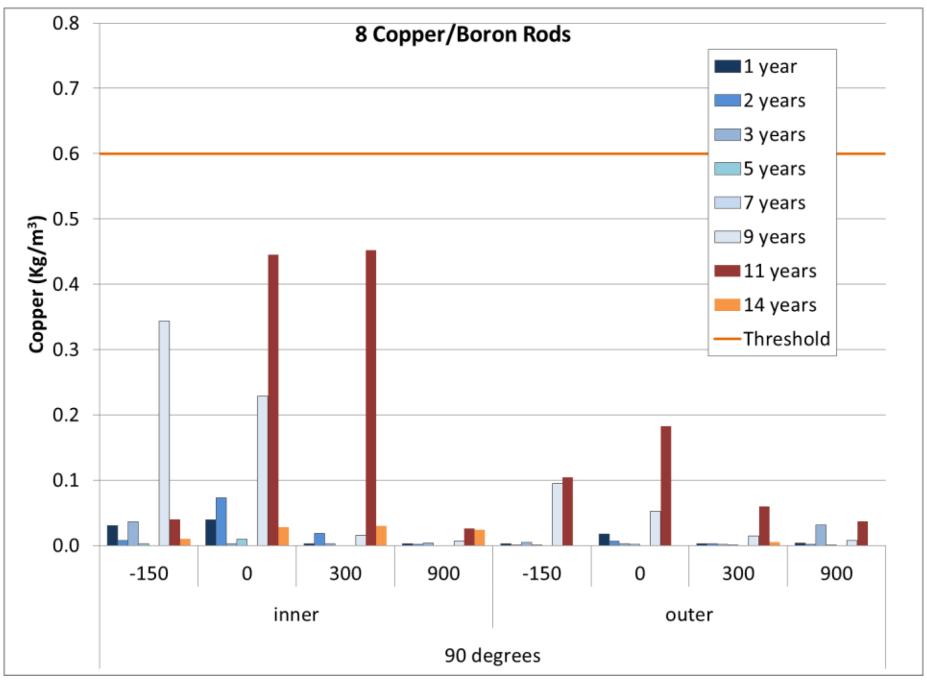


Figure I-13. Copper levels at selected locations above or below groundline in Douglas-fir poles 1 to 14 years after treatment with 4 or 8 boron/copper rods.

Table I-5. Fungi (decay$^{non-decay}$) isolated from Douglas-fir poles 1 to 14 years after treatment with fused boron or copper/boron rods applied in varying dosages and patterns.

Treatment	Rod Spacing	Year Sampled	Isolation Frequency (%)			
			-150 mm	0 mm	300 mm	900 mm
4 copper/boron rods	90º	1	0^{7}	0^{10}	0^{20}	0^{7}
		2	0^{33}	0^{20}	0^{10}	7^{0}
		3	0^{27}	0^{10}	0^{0}	7^{13}
		5	0^{33}	0^{30}	20^{0}	7^{13}
		7	0^{44}	0^{14}	20^{20}	0^{11}
		9	0^{38}	0^{0}	0^{25}	0^{14}
		11	0^{27}	0^{10}	0^{11}	0^{0}
		14	0^{22}	0^{25}	8^{33}	17^{17}
4 copper/boron rods	120º	1	0^{40}	0^{0}	0^{0}	0^{13}
		2	0^{33}	0^{20}	0^{0}	0^{0}
		3	0^{47}	0^{30}	0^{0}	7^{7}
		5	0^{40}	0^{10}	0^{10}	0^{0}
		7	0^{9}	0^{14}	0^{13}	29^{0}
		9	0^{13}	0^{25}	0^{0}	31^{19}
		11	0^{6}	0^{0}	0^{0}	0^{0}
		14	0^{61}	0^{50}	0^{50}	11^{22}
4 boron rods	90º	1	0^{7}	0^{10}	0^{0}	0^{0}
		2	0^{20}	10^{10}	0^{0}	7^{0}
		3	0^{40}	10^{50}	0^{0}	13^{7}
		5	7^{27}	10^{20}	10^{0}	13^{0}
		7	10^{40}	0^{33}	0^{0}	0^{0}
		9	0^{14}	0^{0}	0^{18}	0^{0}
		11	0^{0}	0^{8}	0^{8}	0^{0}
		14	0^{56}	8^{25}	0^{17}	6^{17}
4 boron rods	120º	1	0^{0}	0^{0}	0^{0}	0^{20}
		2	0^{20}	10^{10}	0^{0}	7^{0}
		3	0^{40}	10^{50}	0^{0}	13^{7}
		5	0^{47}	10^{30}	0^{10}	7^{0}
		7	0^{0}	0^{50}	0^{0}	0^{0}
		9	0^{0}	0^{0}	0^{0}	7^{0}
		11	0^{0}	0^{0}	0^{0}	0^{0}
		14	0^{61}	0^{42}	0^{25}	11^{11}
8 copper/boron rods	90º	1	0^{0}	0^{0}	0^{0}	0^{7}
		2	0^{0}	0^{0}	0^{20}	0^{7}
		3	0^{27}	0^{10}	0^{0}	0^{0}
		5	0^{33}	0^{0}	0^{0}	13^{33}
		7	0^{0}	0^{0}	0^{0}	0^{0}
		9	0^{25}	0^{0}	0^{0}	0^{7}
		11	0^{12}	0^{0}	0^{0}	0^{0}
		14	0^{44}	0^{17}	0^{17}	0^{22}

a. Numbers in superscript are percentages of non-decay fungi.

3. Diffusion of Boron Through Preservative Treated Wood

Last year, we reported on efforts to determine a mass balance for the amount of remedial treatment applied vs the amount found within the wood. The first attempt was made with boron rods and it suggested that 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.

Douglas-fir 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-14).

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.

Last year, we reported on diffusion tests that had been underway for only 22 days. Results showed that boron movement was slower through wafers that had been impregnated with biodiesel. The results were useful; however, the system developed leaks and needed to be rebuilt.

Figure I-14. Photograph of five of the diffusion apparatus used to assess boron movement through non-treated or diesel oil treated Douglas-fir lumber. A wood sample is resting on the fourth chamber to provide a measure of scale.

More recent tests include 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 increased at a much more rapid rate after 40 days of exposure (Figure I-15). Concentrations on the receiving ends of control samples have continued to increase at a much faster rate than treated samples. Boron concentrations were 2 to 5 times higher in control samples at 100 days (Figure I-16).

Results indicated that the preservative treated shell slowed boron movement. Previous studies of railroad ties dipped in boron prior to air-seasoning and creosote over-treatment, have shown that 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 that boron losses are slowed by preservative treated shells, even when continuously exposed to liquid water. We will continue to expose samples until we reach a plateau of boron movement. 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.

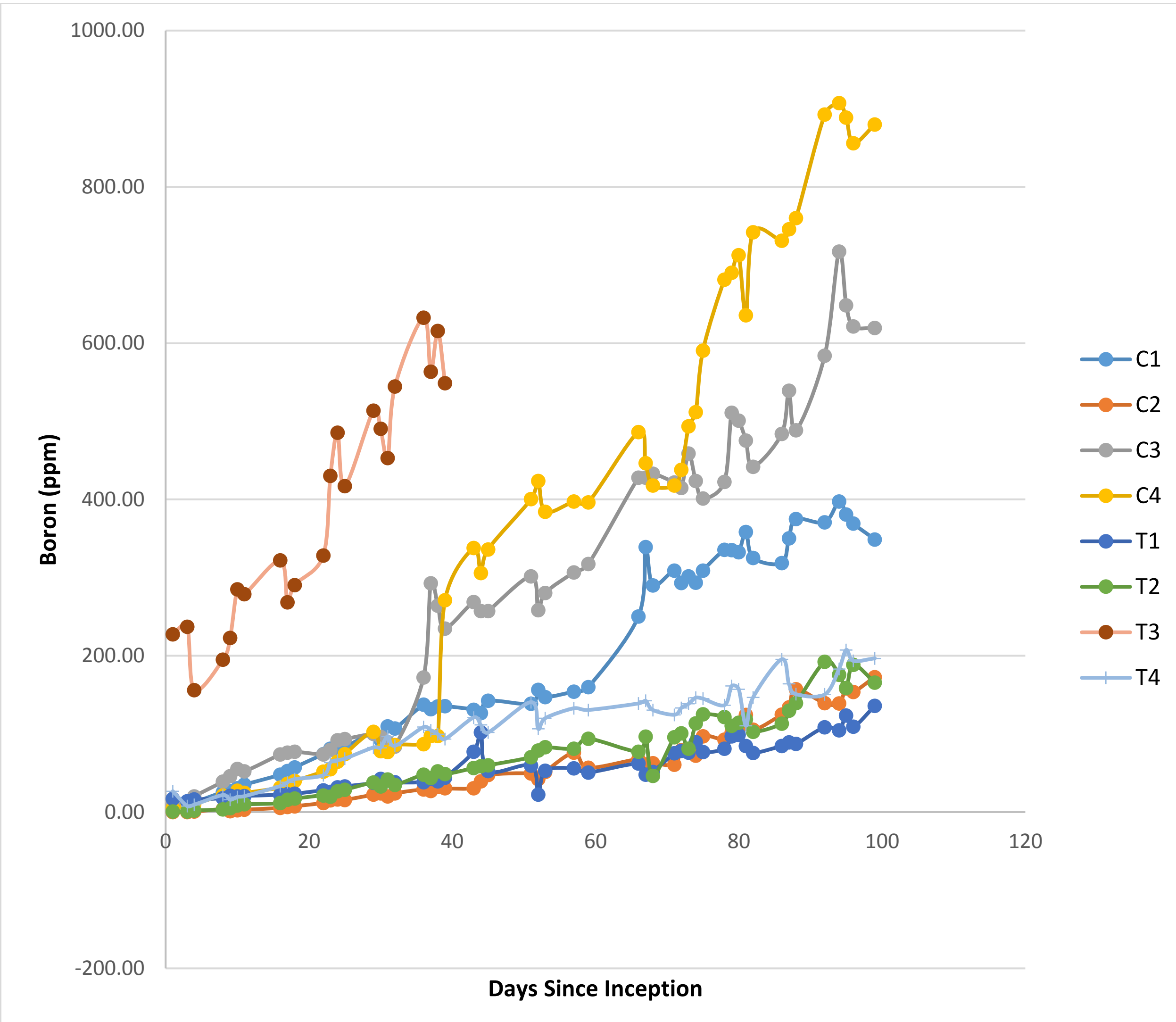
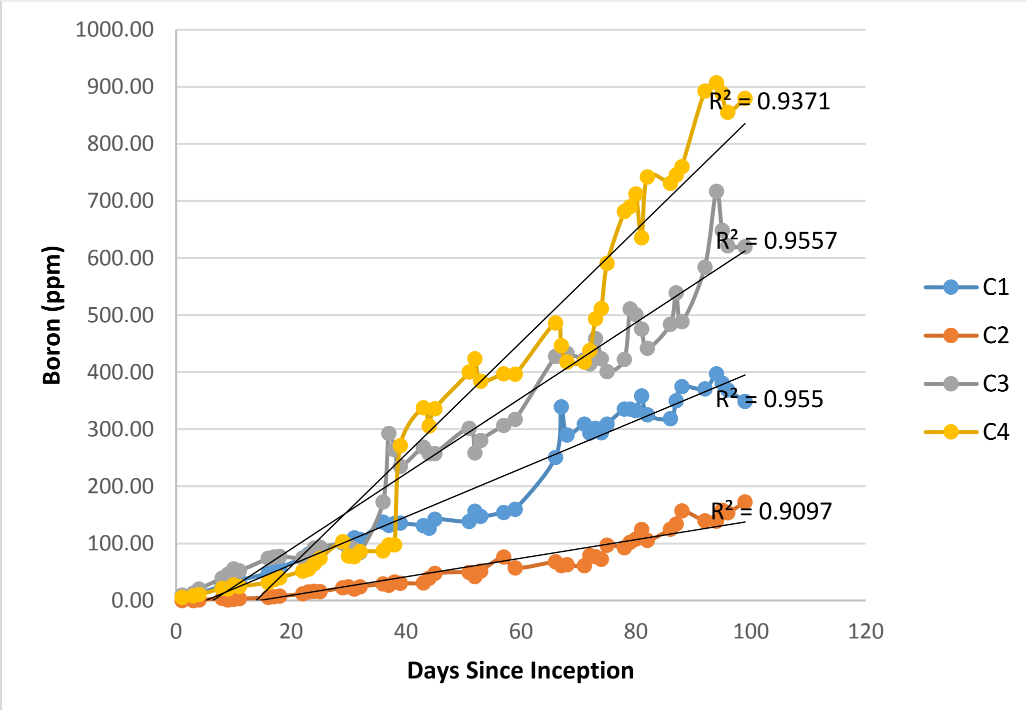


Figure I-15. Boron concentrations on the receiving end of diffusion tests using radially oriented Douglas-fir sapwood with or without a biodiesel treatment where C= no treatment and T= diesel treated samples. The T-3 sample developed a leak and was dropped from the test.



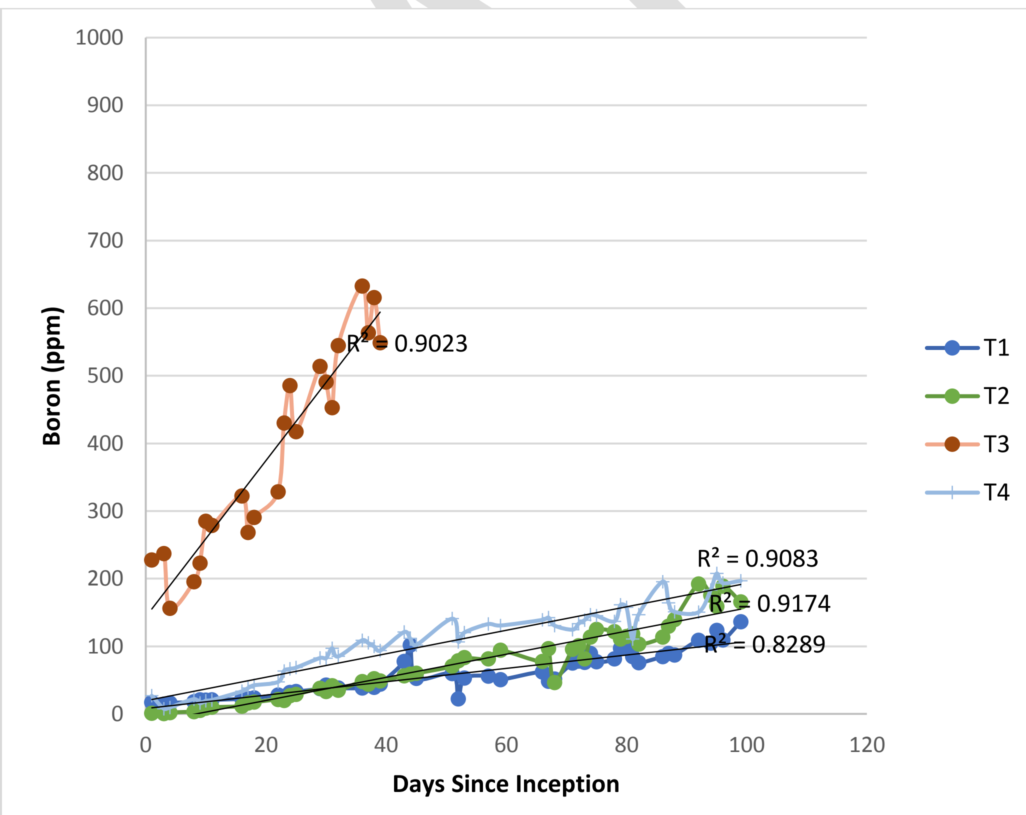


Figure I-16. Boron concentrations vs time on the receiving end of diffusion tests using radially oriented Douglas-fir sapwood with (T samples) or without a biodiesel treatment (C samples). Test sample T3 developed a leak and was dropped from the test

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, Size	Douglas-fir, penta
Circumference @ GL (avg., max., min.)	102, 117, 86 cm

Over the past 3 decades, we have established numerous field trials to assess the efficacy of internal remedial treatments. Initially, these tests were designed to assess liquid fumigants, but we have also established a variety of tests with solid fumigants, water diffusible pastes and rods. Methodologies in these tests have often varied in terms of treatment pattern and sampling patterns employed to assess chemical movement. While these differences seem minor, they can make it difficult to compare data.

We addressed this issue by establishing a single large scale test of all the internal remedial decay control treatments that were EPA registered at the time of our test at our Corvallis test site (Table I-6).

Table I-6. Internal remedial treatments evaluated on Douglas-fir poles at the Peavy Arboretum test site.

Product	Common name	Dosage (g)	Active ingredient	Additive
Durafume II	Dazomet	280	Tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2-thione	Cu Naph
SUPER-FUME				
UltraFume				
Basmid				
Basamid Rods		264		
MITC-FUME	Methylisothiocyanate	120	Methylisothiocyanate	None
WoodFume	Metam sodium	475	Sodium n-methyldithiocarbamate	None
SMDCFume				None
PolFume				None
TimberFume	Chloropicrin	475	Trichloronitromethane	None
Impel Rods	Boron rod	238	Anhydrous disodium octaborate	None
FluRods	Fluoride Rod	180	Sodium fluoride	None

PoleSaver Rods	Boron/Fluoride Rod	134	Anhydrous disodium octaborate/sodium fluoride	None

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 poles beginning at groundline and moving upward 150 mm and around the pole 120º. Various remedial treatments were added to treatment holes at recommended dosages for a poles diameter. Copper naphthenate (2% Cu) was added to all dazomet treatments. Accelerant was poured on top of dazomet in the treatment holes until 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. Treatment holes were plugged with removable plastic plugs.

Chemical movement in the poles was assessed 18, 30, 42, 54 and 89 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. The outer, preservative-treated shell was removed, and the outer and inner 25 mm of each core was retained for chemical analysis using treatment appropriate methodology. Fumigants were analyzed by gas chromatography. Chloropicrin was detected using an electron capture detector while MITC was determined with a flame-photometric detector. The remainder of each core was plated on malt extract agar and observed for fungal growth. Boron treatments were analyzed using the Azomethine-H method. Fluoride based systems were analyzed using neutron activation analysis.

This test was not sampled this year and will not be sampled again until 2019.

2. Performance of Internal Remedial Treatments in Arid Climates: Rocky Mountain Power Test

Date Established:	August 2010
Location:	Utah
Pole Species, Treatment, Size	Pine, cedar, Douglas-fir, penta, creo, cellon
Circumference @ GL (avg., max., min.)	87, 107, 71 cm

Internal treatments are widely used to arrest internal fungal decay in poles. These treatments have proven to be extremely effective, rapidly eliminating fungi and protecting against reinvasion for 7 to 10 or more years. While these treatments are highly effective, nearly all testing has been performed in wet, temperate climates. There are few data on the efficacy of these treatments in dry conditions common to most of the western United States. While decay risk is also lower in these locations, the absence of moisture in wood at the time of treatment can result in inadequate release of fungicidal compounds. Moisture can be a critical requirement for decomposition of dazomet to produce MITC and it is essential for diffusion of boron from fused boron rods. Performance of internal remedial treatments was assessed on Douglas-fir, western redcedar and lodgepole pine poles located 220 kilometers south of Salt Lake City, Utah (Table I-7). Poles were selected on the basis of accessibility and absence of prior internal treatment. This high desert site receives little rainfall (Salt Lake gets an average of 400 mm of rain and 1400 mm of snow/year); approximately 150-200 mm of precipitation, primarily as snow, per year.

Each pole was sounded, then inspection/treatment holes were drilled beginning at groundline adjacent to the largest check and moving around the pole 120 degrees and upward 150 mm. Poles were treated, following label recommendations, with dazomet, dazomet with 1% copper naphthenate (10% w/w), MITC-FUME, metam sodium, fused borate rods (one 75 mm long rod/hole) with water (10% w/w), fused borate rods without water or were left untreated. Treatment holes were sealed with tight fitting plastic plugs.

Applied Treatments:

- Dazomet with accelerant (2% elemental copper)
- Dazomet with no accelerant
- MITC-FUME
- Metam sodium
- Fused boron rods with water
- Fused Boron rods without water
- Non-treated control

Poles were sampled 14, 36 and 60 months after treatment by removing increment cores from three equidistant locations around a pole at heights of 150 mm below groundline, at groundline, as well as 300, 450, 600 and 900 mm above groundline. The treated shell was discarded and the outer and inner 25 mm was removed. The 25 mm long core segments from poles treated with dazomet, metam sodium or MITC-FUME were placed into a glass vial and sealed with a Teflon lined cap. The remainder of the core was placed into a plastic drinking straw, labeled with the pole #/sampling height, location and stapled shut. For poles treated with fused boron rods, the entire core was placed in a drinking straw. Vials and straws were returned to Oregon State University for processing.

Table I-7. Characteristics of poles evaluated in the Rocky Mountain Power System

OSU Pole #	*RMP Pole #*	*Species*	*Primary Treatment*	*YI*	*Class*	*Length*	*Treatment*
301	196502	L. pine	penta	1981	5	40	dazomet
308	193501	L. pine	penta	1981	5	35	
315	191505	L. pine	penta	1981	4	40	
322	301701	cedar	creosote	1999	4	40	
331	303900	Douglas-fir	cellon (penta)	1996	5	35	
336	197705	cedar	penta	1999	4	40	
303	195501	L. pine	penta	1971	4	35	dazomet + CuNaph
310	193500	L. pine	penta	1980	5	35	
317	191503	L. pine	penta	1983	4	35	
324	301702	cedar	creosote	1999	5	30	
329	301906	Douglas-fir	penta	1999	4	30	
338	197700	Douglas-fir	penta	2008	4	35	
306	194501	L. pine	penta	1981	5	40	metam sodium
320	191600	L. pine	penta	1983	4	40	
332	194406	Douglas-fir	penta	2000	5	30	
334	199406	cedar	penta	2005	4	40	
341	194901	cedar	penta	2002	4	45	
307	194508	L. pine	penta	1971	5	35	Control
321	197504	L. pine	penta	1981	5	40	
335	199312	cedar	penta	2007	3	40	
305	195503	L. pine	penta	1984	4	40	MITC-FUME
312	192500	L. pine	penta	1981	5	35	
319	191500	L. pine	penta	1983	5	40	
326	301930	Douglas-fir	penta	1995	4	35	
328	301905	cedar	creosote	1999	5	30	
340	186200	cedar	penta	2006	4	35	

In the lab, cores were transferred to individual tubes containing 5 mL ethyl acetate and extracted at room temperature for a minimum of 48 hours. Extracts were analyzed for MITC by gas chromatography. Cores were oven-dried and weighed. MITC was expressed on a µg MITC/oven dried gram of wood basis. Outer and inner 25 mm core segments from boron treated poles were combined from three cores from the same pole height, ground to pass a 20 mesh screen and hot water extracted. The resulting extract was analyzed by the Azomethine H method. Results were expressed on a kg/m^3 BAE.

Remaining center sections of all cores were briefly flamed to reduce the risk of surface contamination and then placed on 1% malt extract agar in plastic petri dishes. Cores were observed for evidence of fungal growth on the agar and any growth was examined for characteristics typical of wood decay fungi.

Previous studies have shown that the fungal protection threshold for MITC is approximately 20 μg/m^3, and the boron threshold is approximately 0.5 kg/m^3 BAE. These values were used to assess the relative movement of various internal treatments and estimate the degree of protection provided.

No MITC was detected and only background levels of boron were present in poles not receiving treatment. The presence of some boron in the wood is consistent with our previous results. These levels do not measurably affect fungal growth. In fact, boron is an essential micronutrient for many organisms.

MITC levels in poles treated with MITC-FUME were one to two orders of magnitude above the reported threshold in the inner zone 150 mm below groundline as well as at groundline and 300 mm above-ground 14 months after treatment (Table I-8, Figure I-17). MITC levels declined markedly at all three sampling heights 36 months after treatment, but were still at least 10 times the threshold in the inner zone and 1 to 15 times the threshold in the outer zone. MITC levels were slightly lower 450 mm above groundline in Douglas-fir and lodgepole pine poles, but were still well above the protective level. MITC levels were very high at this level in western redcedar poles even after 36 months. MITC levels tended to be 80 to 90% lower in outer zones than in the inner zones of same poles at a given location, but were still well above threshold. MITC levels remained above threshold 900 mm above groundline in western redcedar poles treated with MITC-FUME, but were much lower in Douglas-fir and lodgepole pine poles. Extremely high levels of MITC in poles treated with MITC-FUME are consistent with previous studies showing that this chemical rapidly moves at very high levels throughout wood. MITC levels have steadily declined between 36 and 60 months after treatment, but were still above threshold at or below groundline as well as at selected locations 450 and 600 mm above groundline. The declines are slightly more rapid than those found in tests at Peavy Arboretum, but they still indicate that the treatment is performing well.

MITC levels in poles treated with metam sodium were 7-15 times the threshold in the inner zone of cores removed 150 mm below groundline, a bit lower at groundline and were elevated at 300 or 450 mm above groundline 14 months after treatment (Figure I-18). MITC levels were sharply lower 36 months after treatment at or below groundline, but were above threshold in inner zones 300 to 900 mm above groundline. MITC levels in outer zones tended to be much lower than those in inner zones. These trends are consistent with previous studies and reflect treatment being directed toward the pole center. MITC levels tended to be higher in Douglas-fir poles than either western redcedar or lodgepole pine. Metam sodium tends to release high levels of MITC shortly after treatment, then chemical levels decline within 2-3 years. Results at 14 and 36 months are consistent with these performance characteristics. MITC levels 60 months after treatment were almost all below threshold for pine poles, but were all above that level for Douglas-fir, even 300 mm above groundline. MITC levels in wester redcedar were generally below threshold except in the inner zone 150 mm below groundline. A more rapid loss of MITC from pine is consistent with the higher degree of permeability of this wood species. Western redcedar; however, is relatively impermeable and would be expected to retain MITC for longer periods.

Poles treated with dazomet alone contained extremely low levels of MITC that only exceeded the threshold for fungal protection at a few locations. MITC levels were low below groundline where moisture levels were expected to be more suitable for dazomet decomposition over the first 36 months of the test (Figure I-19). Results indicate that conditions were not suitable for dazomet decomposition when no copper accelerant was added. The most recent analysis revealed the presence of MITC levels above threshold in selected locations. MITC levels tended to be highest in the inner zones, which reflects both the tendency for the sloping treatment holes to direct chemical in this direction as well as the reduced likelihood of diffusion outward from these zones. MITC distribution; however, was spotty and barely above threshold. MITC levels were highest in pine poles. The limited rate of decomposition to produce MITC in poles receiving only dazomet required 5 years for effective levels of chemical to develop. This would allow decay fungi to continue to degrade the wood, which would be unacceptable. Results indicate that applying dazomet to poles in drier regions without an accelerant does not result in an adequate release of active ingredient.

MITC levels in poles treated with dazomet plus copper naphthenate were higher than those found with dazomet alone 14 months after treatment, but much lower than those found with either metam sodium or MITC-FUME (Figure I-20). MITC levels were above the toxic threshold in the inner zone 150 mm below groundline and at groundline, but not in the outer zone at either level. MITC was detectable further up the pole, but levels were below threshold. MITC levels increased markedly 36 months after treatment at groundline and below, especially in Douglas-fir poles. Results illustrated the benefits of copper naphthenate accelerant for improving dazomet decomposition to MITC, but they also indicated that the resulting chemical levels were much lower than levels found in previous studies in wetter locations. MITC levels 60 months after treatment were above threshold in inner zones 150 mm below groundline and at groundline for Douglas-fir and pine poles, but below that level in western redcedar poles. They were also above threshold in outer zones for pine. The spotty distribution of MITC in poles over the course of the test suggests that even the addition of an accelerant does not produce rapid decomposition typically found in wetter climates. Results suggest that alternative methods need to be developed for applying dazomet under drier regimes. For example, increasing the amount of copper available to accelerate decomposition might improve performance. One utility had proposed a step wise treatment whereby smaller amounts of copper naphthenate and dazomet were alternately introduced into treatment holes to improve the degree of copper/dazomet interaction. This process increases treatment time. Another approach might involve using less dazomet and more copper. This approach might be useful since field trials have shown that dazomet in wetter climates continues to release MITC that remains at threshold levels for over a decade in Douglas-fir. The fact that metam sodium is effective even though MITC only remains at fungitoxic levels for 3-5 years after treatment suggests that a lower amount of dazomet might still result in protective levels being present for a typical retreatment cycle. This might allow dazomet to be used under drier conditions. Another alternative would be to drill treatment holes further below groundline to place chemical where moisture levels are likely to be more suitable for both fungal attack and dazomet decomposition. However, this increases inspection costs because of additional digging.

In addition to substantial differences in MITC levels between the four fumigant treatments, MITC levels in outer zones were far lower than those in the interior. While an inner/outer gradient is consistent with previous studies showing the tendency of angled treatment holes to direct chemical toward the pole center, the differences observed were far greater than those observed in studies in wetter climates. The reasons for these differences are unclear, although they may reflect the presence of much drier wood or the high summer temperatures to which these poles were exposed. Elevated temperatures could increase chemical movement out of the pole. Regardless of the cause, results indicate that dazomet is ineffective without added accelerant and is unlikely to be useful when applied aboveground in these regions.

Boron levels in poles treated with fused boron rods alone tended to be extremely low over the 60 months in test (Table I-9). Only 6 assays indicated the presence of boron at protective levels near groundline and the level in one (6.23 kg/m^3 in the inner assay zone at groundline) suggested that the sample came in contact with the original boron rod. The addition of water to treatment holes at the time of application should have improved release to some extent; however, boron levels remained well below threshold in most poles. Boron requires moisture for movement. These data clearly indicate that pole moisture levels were too low to allow boron movement from rods. If boron based materials are used in poles in drier climates, it will be important to place the chemicals well below groundline where there is a potential for subsurface moisture to create conditions suitable for boron diffusion to occur. This may require a reconsideration of treatment patterns used.

Table I-8. MITC levels at selected distances above or below the groundline in western redcedar, Douglas-fir or lodgepole pines poles 14, 36, & 60 months after application of MITC-FUME, metham sodium or dazomet with or without an accelerant. Bolded values are above the threshold for fungal protection.

Treatment	Species	n	Time (Months)	MITC Level (ug/g of wood)											
				-150 mm		0		300 mm		450 mm		600 mm		900 mm	
				inner	outer	inner	outer	inner	outer	inner	outer	inner	outer	inner	outer
control	cedar	1	14	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	8 (14)	0 (0)	0 (0)	0 (0)	0 (0)
			36	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			60	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	pine	2	14	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			36	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			60	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
dazomet	cedar	2	14	10 (12)	1 (3)	16 (25)	3 (8)	9 (17)	0 (0)	5 (7)	3 (4)	3 (5)	1 (3)	2 (4)	0 (0)
			36	10 (16)	2 (5)	**39** (72)	2 (4)	7 (11)	2 (5)	25 (57)	2 (6)	5 (6)	0 0	1 (4)	0 (0)
			60	**47** (104)	13 (25)	8 (19)	**51** (124)	17 (43)	2 (4)	23 (47)	4 (10)	5 (8)	2 (4)	1 (3)	8 (19)
	DF	1	14	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			36	0 (0)	0 (0)	1 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			60	**215** (372)	13 (22)	**37** (41)	10 (18)	**52** (50)	14 (24)	16 (28)	16 (27)	**21** (22)	19 (16)	**27** (25)	12 (21)
	pine	3	14	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (5)	0 (0)	5 (10)	**20** (59)	1 (3)	0 (0)
			36	6 (12)	3 (5)	15 (13)	4 (7)	5 (8)	1 (4)	0 0	0 (1)	12 (12)	0 0	**27** (64)	4 (9)
			60	**23** (67)	**34** (41)	19 (32)	**30** (39)	**26** (60)	16 (29)	3 (7)	12 (30)	9 (21)	8 (14)	4 (9)	7 (13)
dazomet + Cu	cedar	1	14	19 (12)	0 (0.0)	**33** (14)	0 (0.0)	11 (13)	9 (16)	**158** (193)	0 (0)	16 (18)	0 (0)	14 (24)	0 (0)
			36	**341** (559)	0 0	10 (4)	0 0	12 (11)	9 (16)	**98** (153)	6 (11)	**50** (87)	5 (9)	0 0	0 0
			60	3 (3)	**33** (51)	0 0	0 0	0 0	0 0	1 (2)	10 (17)	0 0	0 0	0 0	0 0
	DF	2	14	**67** (72)	12 (24)	**54** (69)	1 (3)	18 (7)	3 (7)	10 (6)	0 (0)	3 (4)	0 (0)	0 (0)	0 (0)
			36	**679** (757)	**75** (97)	**323** (513)	**153** (337)	**145** (159)	**75** (118)	**35** (52)	**91** (188)	**49** (69)	**74** (88)	**74** (139)	**164** (235)
			60	**23** (26)	**32** (43)	**20** (24)	10 (11)	19 (21)	2 (4)	12 (15)	8 (9)	0 (1)	0 0	0 0	0 0
	pine	3	14	17 (17)	7 (21)	**31** (27)	0 (0)	2 (3)	2 (6)	0 (0)	0 (0)	0 (0)	1 (4)	0 (0)	0 (0)
			36	**43** (58)	8 (9)	**52** (73)	1 (2)	12 (16)	0 0	5 (14)	0 0	0 0	0 0	2 (5)	1 (2)
			60	**32** (48)	**83** (143)	**27** (30)	**23** (26)	**20** (36)	3 (5)	3 (6)	**29** (53)	10 (13)	6 (15)	4 (7)	1 (2)
metham sodium	cedar	2	14	**155** (215)	15 (12)	**64** (34)	**29** (21)	**148** (18)	**48** (44)	**239** (127)	**34** (36)	**121** (79)	**22** (25)	**34** (30)	9 (15)
			36	7 (3)	0 0	10 (6)	2 (3)	**36** (27)	3 (6)	**34** (19)	3 (5)	**40** (17)	2 (3)	**39** (26)	2 (4)
			60	**60** (104)	17 (30)	16 (36)	13 (20)	7 (10)	3 (5)	15 (23)	20 (29)	5 (12)	2 (5)	0 0	3 (7)
	DF	1	14	**290** (355)	**37** (5)	**124** (54)	**76** (50)	**96** (82)	**88** (137)	**497** (306)	5 (8)	**187** (154)	4 (7)	19 (14)	0 (0)
			36	8 (9)	0 (0)	6 (5)	7 (8)	**104** (86)	**23** (14)	**78** (20)	7 (7)	**132** (92)	16 (21)	**44** (44)	4 (6)
			60	**63** (12)	**49** (11)	**114** (51)	**52** (12)	**56** (33)	**44** (16)	**72** (19)	19 (17)	**30** (26)	12 (11)	**30** (9)	**21** (14)
	pine	3	14	**158** (165)	**169** (336)	**108** (75)	**48** (53)	**181** (209)	14 (21)	**23** (25)	**48** (44)	2 (5)	**34** (45)	0 (0)	6 (12)
			36	5 (8)	0 (0)	**44** (40)	3 (4)	**105** (155)	4 (6)	**35** (34)	2 (5)	**26** (51)	12 (21)	11 (28)	3 (7)
			60	1 (1)	19 (21)	**65** (54)	6 (11)	17 (37)	3 (7)	0 0	0 0	2 (5)	0 0	1 (1)	0 0
MITC-FUME	cedar	2	14	**1537** (887)	**227** (255)	**2954** (3080)	**439** (890)	**3902** (2648)	**527** (594)	**3019** (2235)	**557** (556)	**2083** (1094)	**329** (473)	**183** (158)	**94** (201)
			36	**222** (126)	**28** (30)	**297** (84)	**91** (69)	**387** (370)	**193** (162)	**488** (554)	**217** (224)	**369** (338)	**220** (200)	**234** (283)	**197** (125)
			60	19 (22)	**64** (69)	**85** (43)	**112** (51)	**60** (42)	**88** (40)	6 (11)	10 (12)	**31** (24)	14 (12)	**32** (32)	19 (15)
	DF	1	14	**3616** (2938)	**420** (530)	**6911** (2969)	**332** (381)	**2136** (1589)	**178** (304)	**462** (783)	**67** (62)	**96** (137)	3 (6)	0 (0)	0 (0)
			36	**840** (340)	**323** (414)	**1316** (234)	**173** (151)	**369** (82)	**162** (91)	**273** (243)	**54** (53)	**116** (81)	**42** (9)	13 (12)	**27** (47)
			60	**106** (26)	**128** (35)	**78** (53)	**75** (32)	**59** (54)	6 (11)	**46** (17)	**48** (33)	**62** (27)	**32** (13)	15 (13)	10 (14)
	pine	3	14	**1549** (1454)	**149** (130)	**5647** (7469)	**195** (239)	**833** (1278)	**85** (218)	**60** (157)	**487** (1371)	0 (0)	8 (17)	1 (2)	0 (0)
			36	**557** (377)	**300** (412)	**755** (556)	**263** (288)	**543** (336)	**145** (195)	**133** (180)	**37** (58)	6 (13)	10 (14)	2 (4)	2 (3)
			60	**109** (87)	**72** (40)	**114** (35)	**30** (33)	8 (14)	0 0	**54** (80)	**55** (107)	**23** (19)	0 (1)	1 (3)	0 0

Results indicate that MITC movement from MITC-FUME and metam sodium treated poles was not affected by low moisture levels in poles in a dry climate. Dazomet and boron rods were both substantially affected by low pole moisture contents, which suggests the need for changes in how these systems are employed in drier climates. Placement of dazomet or boron rods in holes above groundline is not advisable in these poles unless there is evidence that external wetting occurs.

No decay fungi were isolated from any poles over the course of testing. Decay fungi can be difficult to isolate from western redcedar and pine poles, but it is unclear why no fungi were isolated form non-treated Douglas-fir. While no decay fungi were isolated, a variety of non-decay fungi were isolated (Table I-10). These fungi play a variety of roles in wood including conditioning wood to enhance growth of decay fungi or inhibiting attack by other decay fungi. In this case, they can serve as indicators for suitable fungal growth. Very few fungi were isolated 14 months after treatment, perhaps reflecting the treatments applied to poles. Fungi were increasingly prevalent in the 36 and 60 month sampling points. Fungi tended to be more common in Douglas-fir poles, but there was considerable variation in isolation frequency.

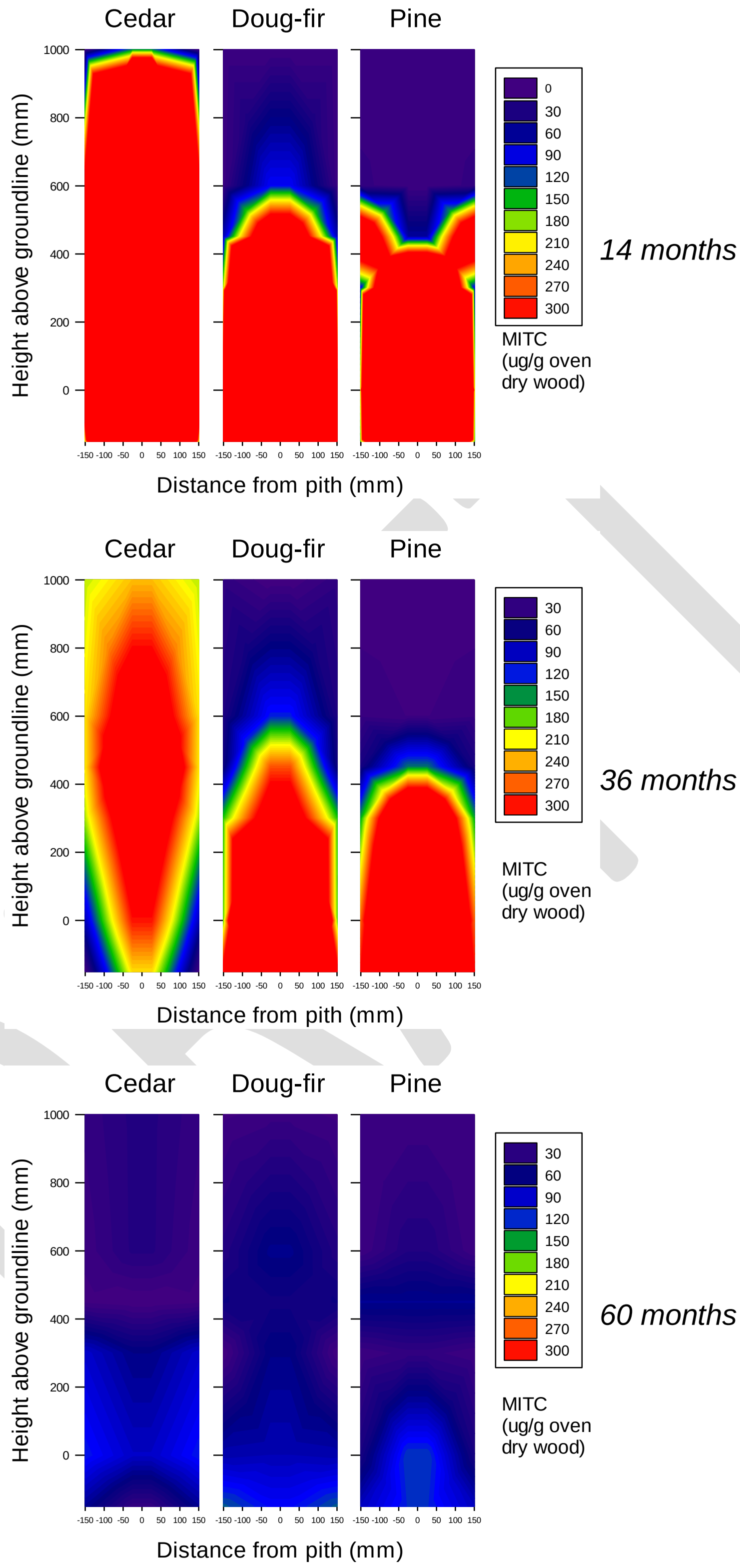


Figure I-17. Diagram showing MITC levels about the groundline in poles 14, 36 or 60 months after application of MITC-FUME. Red colors indicate elevated levels above the toxic threshold.

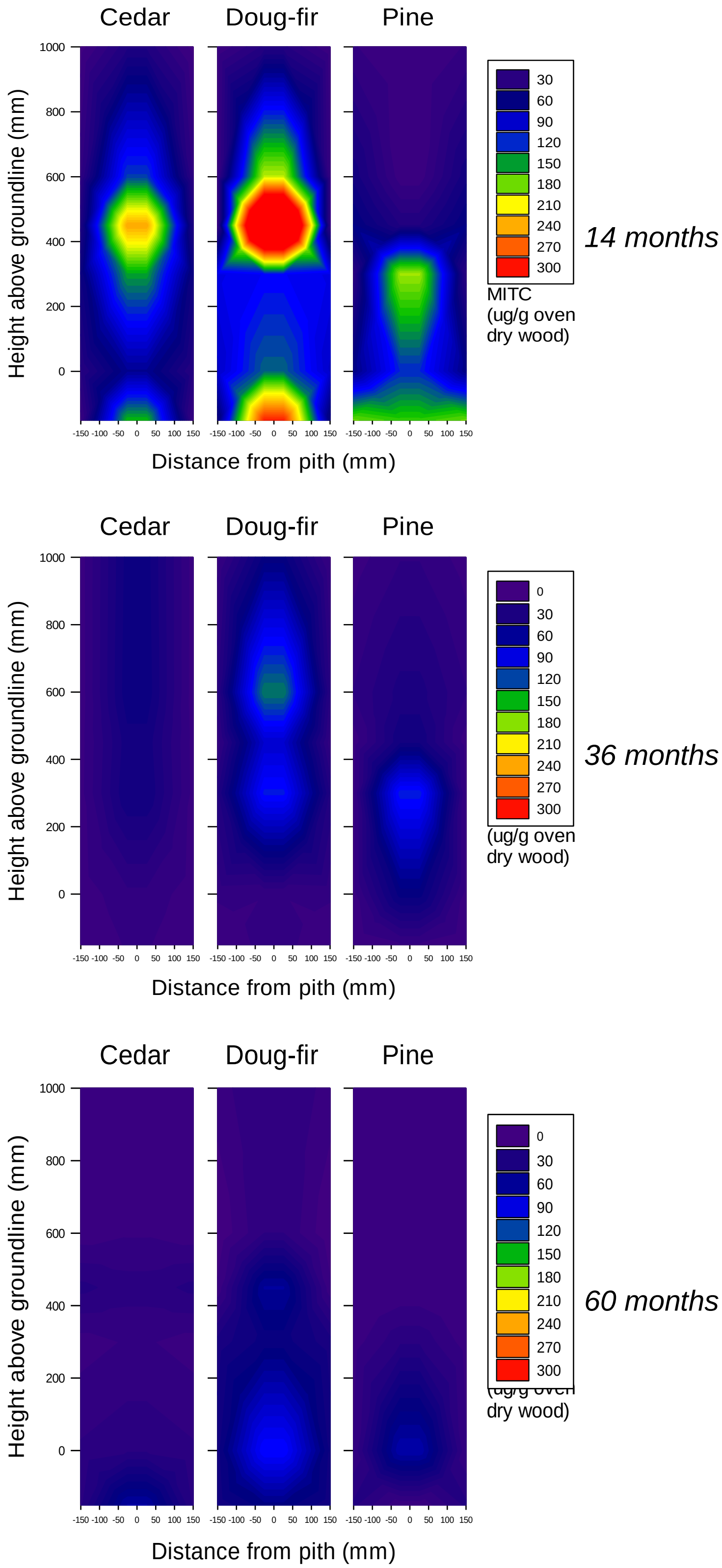


Figure I-18. Diagram showing MITC levels about the groundline in poles 14, 36 or 60 months after application of metam sodium. Red colors indicate elevated levels above the toxic threshold.

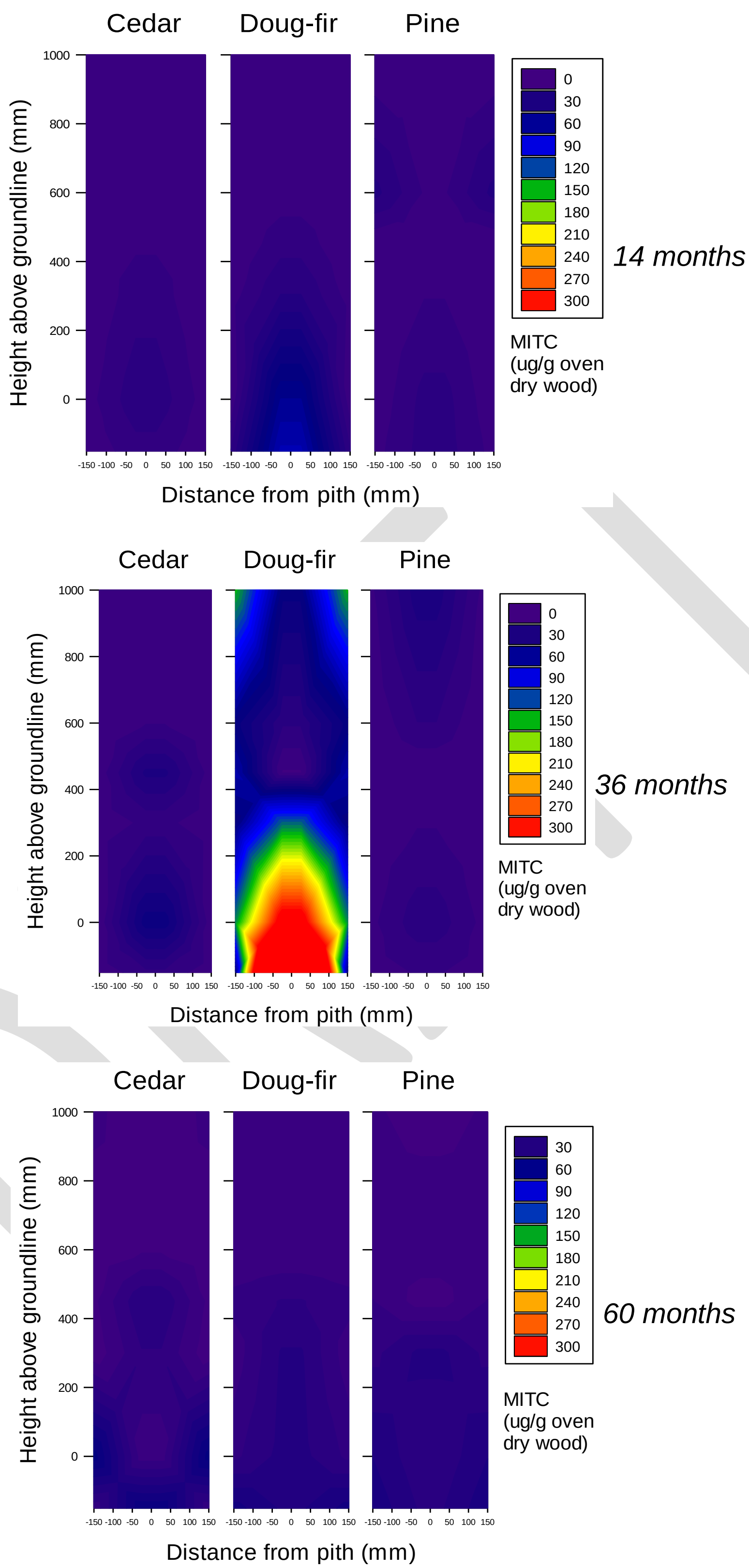


Figure I-19. Diagram showing MITC levels about the groundline in poles 14, 36, or 60 months after application of dazomet without accelerant. Red colors indicate elevated levels above the toxic threshold.

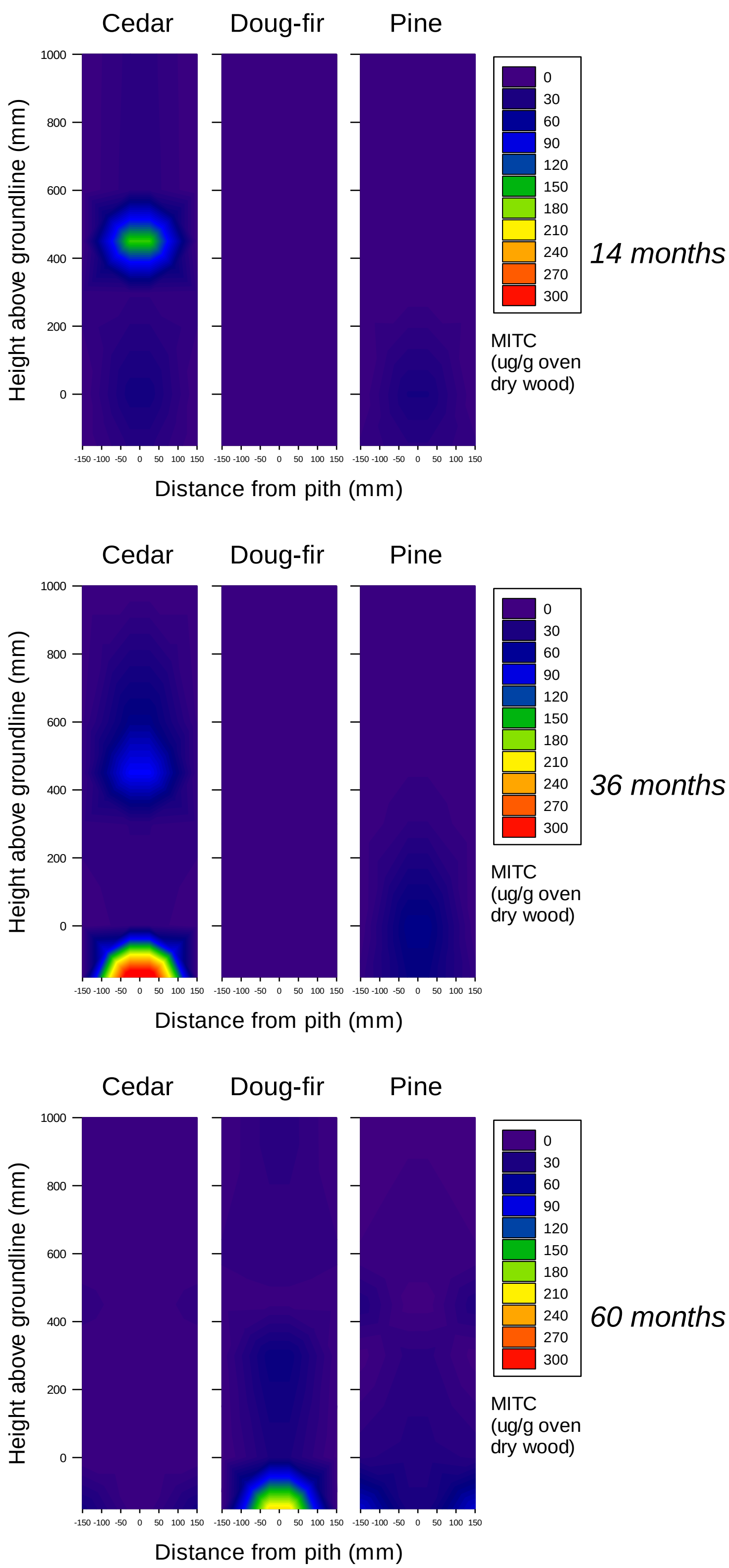


Figure I-20. Diagram showing MITC levels about the groundline in poles 14, 36, or 60 months after application of dazomet with copper naphthenate accelerant. Red colors indicate elevated levels above the toxic threshold.

Table I-9. Boron levels at selected distances above or below the groundline of western redcedar, Douglas-fir or lodgepole pine poles 14, 36 & 60 months after application of fused borate rods with or without added water.

Treatment	Species	n	Time (Months)	Height above groundline (mm)											
				-150 mm		0		300 mm		450 mm		600 mm		900 mm	
				inner	outer	inner	outer	inner	outer	inner	outer	inner	outer	inner	outer
Control	cedar	1	14	0.05	0.03	0.01	0.06	0.02	0.08	0.03	0.05	0.07	0.04	0.05	0.10
			36	0.19	0.26	0.07	0.36	0.14	0.37	0.14	**10.13**	0.19	**0.61**	0.15	**1.64**
			60	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.20	0.00	0.19	0.00	0.00
	DF	1	14	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00 (0)
			36*												
			60*												
	pine	1	14	0.00	0.01	0.00	0.00	0.00	0.00	0.03	0.02	0.02	0.02	0.00	0.03
			36	0.12	0.01	0.10	0.55	0.14	0.05	0.03	0.06	0.04	0.14	0.03	0.03
			60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fused boron rods	cedar	2	14	0.06 (0.06)	0.04 (0.02)	0.01 (0.02)	0.03 (0.00)	0.03 (0.03)	0.04 (0.02)	0.03 (0.00)	0.07 (0.01)	0.00 (0.00)	0.08 (0.01)	0.02 (0.03)	0.07 (0.01)
			36	0.13 (0.00)	**0.63** (0.56)	0.12 (0.05)	0.25 (0.08)	0.06 (0.07)	0.29 (0.10)	0.08 (0.06)	0.20 (0.03)	0.12 (0.02)	0.27 (0.13)	0.10 (0.06)	0.27 (0.02)
			60	**2.13** (2.89)	**0.76** (0.92)	0.18 (0.07)	0.05 (0.03)	0.05 (0.07)	0.12 (0.17)	0.06 (0.08)	0.06 (0.08)	0.05 (0.06)	0.06 (0.08)	0.03 (0.04)	0.06 (0.08)
	DF	1	14	0.01	0.04	0.01	0.00	0.00	0.03	0.00	0.01	0.00	0.03	0.01	0.02
			36	0.18	0.09	**6.23**	0.06	0.14	0.09	0.06	0.10	0.08	0.18	0.05	0.09
			60	0.04	0.05	0.00	0.00	0.00	0.05	0.00	0.02	0.00	0.00	0.00	0.00
	pine	3	14	0.26 (0.38)	0.02 (0.02)	0.05 (0.01)	0.01 (0.02)	0.06 (0.03)	0.04 (0.04)	0.02 (0.02)	0.02 (0.02)	0.02 (0.02)	0.03 (0.02)	0.03 (0.04)	0.03 (0.02)
			36	0.16 (0.13)	0.08 (0.05)	0.06 (0.06)	0.20 (0.09)	0.14 (0.07)	0.09 (0.04)	0.08 (0.03)	0.08 (0.06)	0.15 (0.07)	0.07 (0.03)	0.27 (0.34)	0.07 (0.07)
			60	0.39 (0.23)	0.00 0.00	0.00 0.00	0.00 0.00	0.02 (0.04)	0.05 (0.08)	0.05 (0.08)	0.00 0.00	0.01 (0.02)	0.01 (0.02)	0.05 (0.09)	0.11 (0.10)
Fused boron rods + water	cedar	1	14	**0.74** (1.00)	0.02 (0.02)	0.05 (0.02)	0.06 (0.01)	0.02 (0.03)	0.29 (0.32)	0.03 (0.02)	0.01 (0.02)	0.03 (0.04)	0.03 (0.03)	0.04 (0.01)	0.05 (0.03)
			36	0.49 (0.46)	0.40 (0.25)	0.42 (0.37)	0.32 (0.01)	0.19 (0.02)	0.32 (0.04)	0.28 (0.04)	0.38 (0.06)	0.30 (0.17)	0.30 (0.15)	0.17 (0.01)	0.31 (0.19)
			60	0.33 (0.37)	0.06 (0.09)	0.07 (0.10)	0.12 (0.18)	0.08 (0.11)	0.05 (0.07)	0.09 (0.13)	0.05 (0.07)	0.10 (0.14)	0.06 (0.09)	0.09 (0.13)	0.04 (0.06)
	DF	2	14	0.06	0.22	0.07	0.00	0.01	0.00	0.06	0.02	0.00	0.00	0.00	0.00
			36	0.38	0.16	0.08	0.31	0.06	0.16	0.10	0.18	0.13	0.14	0.05	0.17
			60	**0.79**	0.10	0.26	0.22	0.09	0.12	0.04	0.06	0.06	0.05	0.06	0.12
	pine	3	14	0.57 (0.96)	0.02 (0.02)	0.10 (0.02)	0.02 (0.02)	0.01 (0.01)	0.03 (0.03)	0.03 (0.03)	0.01 (0.01)	0.03 (0.06)	0.02 (0.02)	0.02 (0.02)	0.02 (0.03)
			36	0.31 (0.17)	0.07 (0.05)	0.21 (0.25)	0.12 (0.07)	0.08 (0.09)	0.07 (0.11)	0.12 (0.11)	0.06 (0.00)	0.07 (0.06)	0.09 (0.08)	0.26 (0.24)	0.74 (1.10)
			60	0.31 (0.29)	0.01 (0.02)	0.01 (0.01)	0.00 0.00	0.00 0.00	0.00 0.00	0.02 (0.04)	0.00 0.00	0.00 0.00	0.00 0.00	0.02 (0.04)	0.07 (0.13)

* Pole not sampled in 2013 or 2015

Table I-10. Frequency of non-decay fungi in western redcedar, Douglas-fir and pine poles 14 to 60 months after application of various remedial treatments

Treatment	Species	Cores with Fungi (%)											
		-150 mm below GL			Groundline			300 mm above GL			450 mm above GL		
		14 mo	36 mo	60 mo	14 mo	36 mo	60 mo	14 mo	36 mo	60 mo	14 mo	36 mo	60 mo
Boron/H_2O	Cedar	0	100	100	0	17	0	0	0	0	0	0	0
	Doug-fir	0	100	100	0	89	78	0	44	29	0	56	14
	pine	0	67	0	0	0	0	0	0	0	0	0	0
Impel Rods	Cedar	0	63	83	0	0	0	0	0	0	0	0	0
	Doug-fir	56	100	100	44	100	86	0	67	71	0	89	63
	Pine	67	100	100	0	67	67	0	100	33	0	67	33
Dazomet	Cedar	0	17	0	0	0	0	0	0	0	0	0	0
	Doug-fir	0	67	67	0	44	56	0	11	44	0	56	56
	Pine	100	67	100	100	67	100	33	67	100	33	100	100
Dazomet/Cu	Cedar	0	0	0	0	0	0	0	0	0	0	33	0
	Doug-fir	22	33	44	0	33	67	0	56	78	0	33	56
	Pine	17	0	0	0	0	0	0	0	0	0	0	0
Metam sodium	Cedar	0	0	0	0	0	0	0	0	0	0	0	0
	Doug-fir	0	50	55	0	33	33	0	33	67	0	50	67
	Pine	0	0	-	0	0	-	0	0	-	0	0	-
MITC-FUME	Cedar	0	0	0	0	0	0	0	17	0	0	33	0
	Doug-fir	0	33	38	0	22	44	0	33	56	0	44	22
	Pine	0	67	0	0	0	0	0	0	0	0	0	0
Control	Cedar	0	67	100	0	34	50	0	0	34	0	0	0
	Doug-fir	0	67	100	0	100	0	0	100	67	0	50	100
	Pine	75	55	58	50	50	67	0	50	67	0	83	67

3. MITC Content and Fungal Colonization of Increment Cores Removed from Utility poles in the Salt River Project System

Dazomet is widely used for arresting internal fungal decay in utility poles. The original dazomet we evaluated was a crystalline material that decomposed to methylisothiocyanate (MITC) which is the primary fungicidal component in this treatment. The more recent dazomet formulations are more granular, but must still decompose to be effective. MITC has activity against a range of fungi and can diffuse as a gas for long distances from the point of application. As noted in the previous section on the Rocky Mt Power test, Dazomet decomposition rates are closely tied to wood moisture content, with more MITC production at higher moisture levels. The decomposition rate can also be enhanced by adding copper based compounds such as copper sulfate or copper naphthenate. Copper naphthenate is commonly added to treatment holes at the time of dazomet application.

Moisture needs for effective decomposition have raised questions about the use of dazomet for internal remedial treatment of poles in dry climates. While sub-surface moisture levels do create conditions that should be suitable for dazomet decomposition, there is always the potential for sub-surface moisture to be below the area where dazomet was applied. In most cases, poles in dry areas are excavated to a depth of 600 to 750 mm below groundline to inspect for external decay and bored to detect internal decay. The steep angle of the inspection hole should result in detection of internal decay, but there are questions about whether this inspection hole intersects areas that are wet enough for dazomet to decompose. Anecdotally, re-visits to poles have shown that holes nearer the surface are full of crystalline dazomet, indicating fumigant is providing little or no protection in that zone.

SRP is approaching its second cycle using dazomet, providing an excellent opportunity to assess residual fumigant content in poles. In this report, we describe chemical assays of increment core segments removed from poles in the SRP system to determine how dazomet is performing as a remedial treatment.

Materials and Methods: Increment cores were removed from 30 poles at groundline, 300 mm above groundline as well as 150, 450 and 600 mm below groundline. All sampling was performed by SRP personnel or their representatives. The outer and inner 25 mm of each core were removed and individually placed into glass vials which were tightly sealed with Teflon lined caps to retard loss of fumigant. Vials were sent to OSU for analysis and the remainder of each increment core was placed in a plastic drinking straw which was stapled shut and also returned to OSU for processing.

The poles sampled had been treated 1-8 years earlier with an internal remedial treatment (dazomet) and were between 24-57 years old. The majority of poles inspected were Douglas-fir, but there were several southern and western pine poles. Poles had been initially pressure-treated with creosote, pentachlorophenol in P9 Type A oil (penta/oil), or pentachlorophenol in either liquified petroleum gas or methyl chloride (penta/gas; Table I-11). Pole locations were classified as being either wet or dry. In principle, wetter sites should support more effective dazomet decomposition.

Table I-11. Distribution of poles sampled for residual MITC content in the SRP system by initial preservative treatment, time since remedial treatment and service conditions.

Wood Species	Service Condition[a]	Remedial Treatment (Yr)	Number of Poles Sampled		
			Creosote	Penta (Type A)	Penta (Gas)
Douglas-fir	Dry	1	1	2	2
		2	1	2	1
		3	1	1	1
		4	1	-	1
		5	-	2	-
		6	1	1	-
		7	1	1	1
		8	1	-	-
	Wet	1	-	1	1
		2	-	-	1
		3	1	-	-
		4	-	-	1
		8	-	1	-
Western Pine	Wet	3	-	-	1
Southern Pine	Wet	2	1	-	

[a] Wet and dry signify relative proximity to moisture sources (usually irrigated lawns)

Upon arrival at OSU, vials were opened and filed with 5mL of ethyl acetate which has a high affinity for MITC. Cores were extracted for 48 hours before the ethyl acetate was poured off for analysis of MITC by gas chromatography. Cores were then oven dried and weighed so MITC content could be expressed on a µg of MITC/oven dried g of wood basis.

Previous studies of MITC-based fumigants have shown that the threshold for protection of wood from fungal attack is approximately 20 µg/oven-dried gram of wood. This value is a relative guide since there can be relatively large variations in fumigant levels within a pole, but the level represents a reasonable target for protection. Fumigant levels below threshold do not necessarily mean that the pole will be instantly attacked by decay fungi. Fungal colonization of wood poles is a slow process that occurs primarily through checks or other gaps in the initial treated shell. Fumigants tend to eliminate fungi from the interior of the pole and remain detectable in the wood for 3-12 years, depending on the chemical involved. Fungi then slowly recolonize once chemical levels decline below threshold. This often takes 3-5 more years. Thus, the presence of sub-threshold MITC levels does not mean that poles will immediately begin to decay, but it does indicate the need for re-treatment.

Increment core segments in straws were removed, briefly flamed to reduce contaminating fungi on the wood surface and placed on malt extract agar in plastic petri dishes. Plates were incubated for 30 days at room temperature. Any fungi growing from the cores were examined for characteristics typical of the Class Basidiomycotina, a group containing many important wood degrading fungi. Isolation of fungi from the wood does not necessarily mean that the wood is being actively degraded, but it does indicate that decay fungi are present and thus pose a risk of decay. Other fungi present were classified as non-decay and some of these were further categorized as being dark pigmented or dematiaceous. Non-decay fungi are not necessarily a concern for pole integrity, but their presence does indicate that fumigant protection levels are declining. The presence of the dark-pigmented fungi is of interest because many of these fungi are more tolerant of preservatives and some are associated with surface degradation (soft rot).

The data must be viewed with some care because of the limited pole numbers for any given initial treatment and age or time since remedial treatment. A given category (wood species/site/initial treatment/time since remedial treatment) is only represented by one or two poles. For the purposes of analysis, initial pole treatment was ignored as was pole age since it was likely to have less of an effect than time since remedial treatment.

MITC Levels: As expected, MITC levels varied widely with pole treatment, distance from groundline and whether the wood was near the surface or near the center of a pole (outer/inner zones). Fumigant levels tended to be higher near the center of the pole (Table I-12). This is consistent with previous tests and likely reflects the use of steep angled holes that tend to direct fumigant towards the center of the pole as well as the tendency for fumigant to be lost from the wood as it gets closer to the surface.

MITC levels should be highest within 1-2 years after treatment. In the case of dazomet, which slowly decomposes, these levels should remain elevated for 3-9 years after treatment. The treatment pattern employed by SRP should result in higher MITC levels at or below groundline where it is most needed to arrest fungal attack. MITC levels tended to be over the threshold in the inner zone of poles at groundline or 150 mm below groundline in poles receiving a variety of initial treatments. MITC levels were several times the threshold in most of these locations even 4-5 years after dazomet treatment. The exception was the older creosoted poles, which tended to have lower MITC levels, but there were even variations with these results, with very high MITC levels at groundline in creosoted Douglas-fir poles 8 years after treatment.

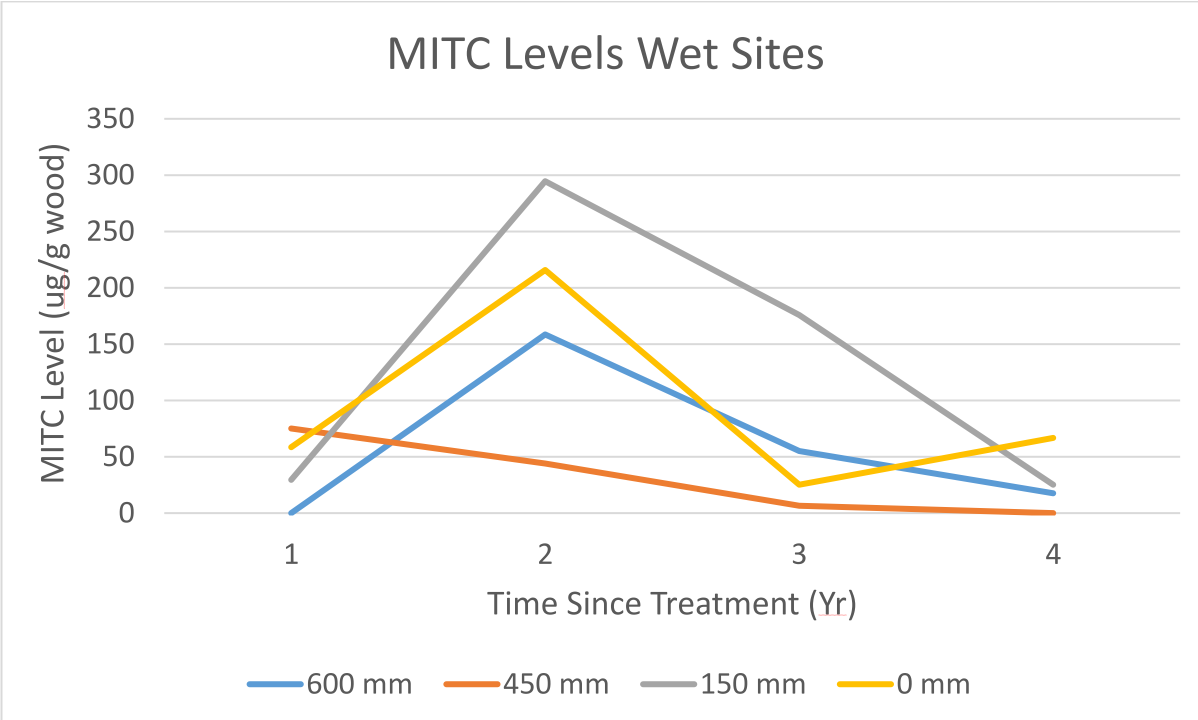
MITC levels in poles that were in areas classified as being wet tended to be more consistently above threshold, although average MITC levels did not differ from those in poles from areas classified as dry.

MITC levels further below groundline tended to be more variable. For example, creosoted Douglas-fir poles had sub-threshold MITC levels 600 and 450 mm below groundline in poles treated 1, 7 and 8 years earlier, but threshold levels 2 and 6 years after treatment in the inner zone. It is important to remember that all poles were inspected at the same time, but were treated over an 8 year period. Differences in applicator quality or specific conditions at a given pole may play important roles in performance.

Ideally, MITC levels should decline with increasing time since remedial treatment. While there are some slight trends downward with time, there are also a number of inconsistencies.

The tendency for reduced MITC levels 450 and 600 m below groundline is especially important since these locations are also where subsurface moisture conditions should be more conducive to fungal attack. Results suggest that either MITC is not moving far enough down the pole from the point of application at levels capable of arresting fungal attack or the decomposition rate is too slow to produce effective levels in the wood. The solutions to this problem will vary with the ability to inspect to this depth on a regular basis. Drilling treatment holes further down a pole should place dazomet in a location more likely to be wet and therefore more likely to support decomposition. However, this would increase treatment costs. Alternatively, the use of additional accelerant could foster more rapid decomposition; however, the levels of MITC near groundline suggest that decomposition is already occurring; the chemical is just not moving far enough to reach lower pole sections.

Site did appear to influence MITC levels. As noted, a wetter site should result in more dazomet decomposition and there was a definite trend to higher levels of MITC in wood removed form poles classified as being in wet sites (Figure I-21). Again, these numbers must be viewed cautiously because of limited sample size, particularly with wet site poles; however, they do suggest a definite site effect that must be considered when using this fumigant in dry conditions.



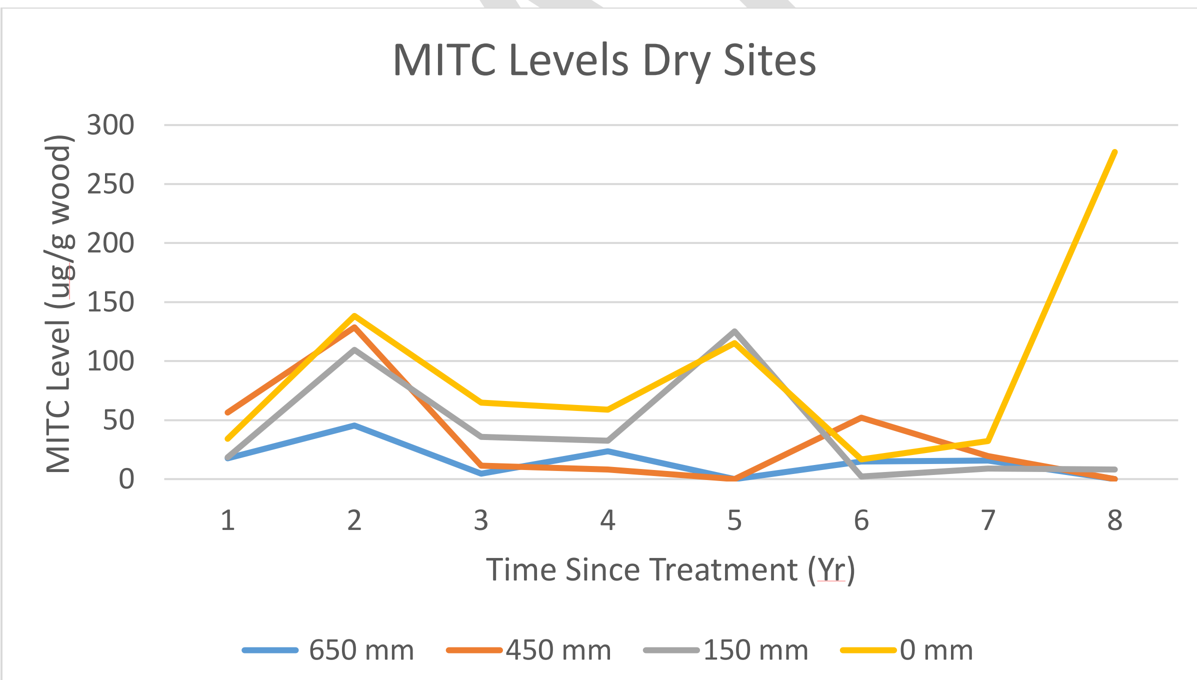


Figure I-21. Residual MITC levels between groundline and 600 mm below groundline in the inner zones of Douglas-fir poles in wet or dry sites 1 to 8 years after dazomet treatment.

Pole age might also be a factor in fumigant performance. Older poles are more likely to have experienced some level of decay, although heavily decayed older poles were likely replaced in the first treatment cycle. There were no discernible trends with MITC level with pole age. For example some of the higher MITC levels in penta/oil Douglas-fir poles were found in the oldest poles inspected. These results indicate that pole age is not necessarily a good indicator of remedial treatment performance. Other factors such as initial treatment quality, site conditions and remedial treatment quality play more important roles in performance.

Fungal isolations: Seven decay fungi were isolated from poles (Table I-13). The highest frequency of isolation was from poles sampled one year after treatment, but all four isolates were obtained from the same pole. Decay fungi were also isolated 3 and 6 years after treatment but only from one pole apiece. All decay fungi were isolated from poles classified as being in dry sites. The presence of decay fungi one year after treatment is consistent with the time required for dazomet to decompose and produce MITC and for that MITC to then diffuse into the surrounding wood. This effect would be more pronounced in poles from dry locations. No decay fungi were isolated from any poles classified as being in wet areas. This would be consistent with moisture enhancing dazomet decomposition. The presence of some decay fungi 3 years after treatment is disconcerting and suggests inconsistent protection. The low number of fungal isolations suggests that decay is limited in these poles; however, caution must be exercised because of limited sample size.

Table I-12. MITC levels in poles in the SRP system at selected locations above and below the groundline of poles 1 to 8 years after application of an internal remedial treatment.

Species	Dry/ wet	Initial Treatment	Year	Residual MITC (ug MITC/g wood)[a]									
				-600 mm		-450 mm		-150 mm		0		300 mm	
				inner	outer	inner	outer	Inner	Outer	inner	outer	inner	Outer
Douglas-fir	Dry	Creosote	1	0	0	0	**43.7**	0	**40.9**	0	0	0	0
			2	**24.1**	0	**49.6**	0	**149.6**	0	**303.4**	0	**156.7**	0
			3	0	0	13.7 (19.4)	**27.0 (38.1)**	**34.1 (21.8)**	17.6 (24.9)	**91.1 (67.4)**	8.0 (1.3)	**33.1 (8.9)**	8.7 (12.3)
			4	**45 (6.4)**	0	11.7 (16.5)	0	**46.3 (21.8)**	0	**81.5 (17.6)**	0	**28.5 (27.4)**	0
			6	**29.5**	0	**100.8**	0	4.2	0	17.6	0	2.6	0
			7	0	0	0	0	0	0	0	0	6.8 (9.6)	5.3 (7.5)
			8	0	0	0	0	8.2 (11.6)	0	**277.2 (388.5)**	0	8.8 (12.5)	0
		Penta/Gas	1	**43.9 (91.6)**	**78.4 (175.3)**	18.7 (37.8)	3.7 (8.2)	14.1 (24.2)	**29.8 (66.6)**	**45.5 (52.5)**	4.8 (10.7)	3.5 (5.0)	6.8 (9.6)
			2	11.0 (15.5)	10.6 (15.0)	**448.9 (615.8)**	9.4 (13.2)	**37.4 (10.0)**	0	**42.2 (39.8)**	**21.5 (30.4)**	**29.6 (13.7)**	4.1 (5.9)
			3	13.6 (2.4)	0	0	0	**71.5 (20.9)**	1.9 (19.6)	**40.9 (1.8)**	0	7.2 (3.4)	0
			4	2.3 (4.0)	0	4.3 (7.5)	0	18.5 (20.4)	0	**35.9 (11.7)**	0	1.0 (1.8)	0
			7	**47.2 (57.0)**	**24.1 (41.7)**	0	0	**20.8 (29.3)**	0	0.9 (1.5)	0	0	0
		Pent/oil	1	0	0	**97.5 (80.3)**	0	**31.8 (14.8)**	0	**79.6**	14.5 (20.5)	14.8 (20.9)	0
			2	**73.2 (69.2)**	**20.0 (43.8)**	15.9 (5.6)	6.9 (12.9)	**125.2 (131.4)**	4.4 (5.8)	**82.6 (33.0)**	0	9.9 (10.5)	3.0 (0.3)
			3	**0**	**0**	**20.3 (18.3)**	0	2.2	0	**62.8**	0.8	**40.9**	4.7 (4.1)
			5	**27.4**	**25.2 (19.8)**	0	**26.2 (39.8)**	**101.0 (102.7))**	5.7 (3.7)	**120.6 (40.7)**	7.9 (1.5)	**43.2 (36.2)**	0
			6	0	0	3.2 (4.5)	0	0	2.2 (3.1)	15.8 (5.5)	0	8.9 (12.60	0
			7	0	0	**58.9 (3.0)**	0	5.6 (7.9)	0	**96.8 (126.1)**	3.2 (4.5)	16.0 (19.9)	20.6 (0.7)
	Wet	Creosote	3	**55.2 (31.7)**	**52.2 (70.1)**	6.5 (6.7)	**44.1 (57.7)**	**175.7 (10.6)**	**193.8 (266.4)**	**321.8 (126.4)**	**34.7 (15.4)**	**81.0 (29.5)**	4.3 (6.1)
		Penta/Gas	1	0	0	**75.1 (49.7)**	0	**29.6 (41.9)**	0	**58.4 (82.6)**	**29.6 (41.8)**	**32.9 (21.9)**	**36.6 (37.5)**
			2	**158.6 (143.9)**	**49.9 (54.3)**	**44.0 (29.5)**	**21.0 (12.9)**	**294.6 (126.1)**	**31.1 (18.2)**	**215.8 (99.8)**	**166.1 (126.1)**	**27.0 (19.7)**	0
			4	17.6 (3.7)	0	0	0	**25.2 935.6)**	0	**66.7 (67.8)**	0	0	0
		Penta/oil	1	**76.2 (41.7)**	**72.7 (125.9)**	3.8 (25.7)	**42.6 (73.7)**	**149.1 (175.2)**	**47.7 (82.7)**	**132.9 (84.4)**	14.0 (24.3)	**124.5 (202.4)**	15.9 (23.6)
			8	0	0	**50.8 (87.9)**	0	0	0	0	0	0	15.9 (23.6)
S. pine	Wet	Creosote	2	**40.8 (37.5)**	**32.2 (45.6)**	0	**25.7 (36.3)**	**157.3 (31.4)**	**22.8 (17.1)**	**139.3 (21.4)**	**31.5 (44.6)**	**56.9 (23.2)**	**38.3 (0)**
W. pine	Wet	Gas	3	17.8 (25.1)	0		0	0	0	4.3 (6.1)	0	3.2 (4.6)	0

[a]Values represent means while those in parentheses represent one standard deviation. Bolded values are above the 20 ug/g of wood threshold for fungal protection.

Non-decay fungi and dark pigmented fungi do not cause internal decay, but they can serve as an indicator that chemical protection is declining. Dark pigmented fungi are actually a sub-set of non-decay fungi. As noted earlier, some of these pigmented fungi have the ability to detoxify preservatives and cause decay on the wood surface. Very few dark pigmented fungi were isolated from the cores and no non-decay or dark pigmented fungi were isolated from poles in wetter areas. Non-decay fungi were present in dry poles sampled one year after treatment, declined in year 2 and then gradually rebounded to a slightly higher level by year four. The presence of these fungi in poles does not mean that the wood is being degraded, it just indicates that fumigant protection may be declining in some areas.

Table I-13. Frequency of decay, non-decay and dark-pigmented fungi in increment cores removed from Douglas-fir poles 1 to 8 years after treatment.

Condition[a]	Time Since Treatment	Poles (#)	Cores (#)	Fungal Frequency (%)		
				Decay	Non-Decay	Dark pigmented
Wet	1	3	27	0	0	0
	2	1	10	0	0	0
	3	1	10	0	0	0
	8	1	7	0	0	0
Dry	1	6	53	13.2	18.9	0
	2	1	10	0	0	0
	3	5	37	2.7	13.5	0
	4	2	24	0	25.0	0
	5	2	24	0	29.2	0
	6	3	35	5.7	31.4	8.6
	7	3	34	0	26.5	0
Total		29	271	2.6	17.7	3.4

[a] Wet or dry refers to the conditions around the pole at the time of sampling.

Conclusions: MITC levels varied widely in poles within the SRP system, but several trends were noteworthy:

-MITC levels were clearly higher towards the center of poles

-MITC levels tended to be higher at groundline and 150 mm below groundline

-MITC levels tended to be more consistent in poles classified as coming from wetter sites

- MITC levels tended to be very variable 450 and 600 mm below groundline, suggesting that dazomet was not decomposing at sufficient levels to arrest fungal attack.

-There were no apparent trends in MITC content with pole age.

-Some decay fungi were present, but their numbers were low.

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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 be supplementally protected 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 for damage done as 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 Copper Naphthenate 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 the greatest risk of internal decay, fungi can attack non-treated heartwood above this zone. Decay aboveground poses great future risk. Entities attaching equipment to poles are almost all field-drilling holes for these attachments. Non-treated, field-drilled holes represent access paths into non-treated heartwood for decay fungi. While progression of fungal attack and decay is slower aboveground, these field drilled holes eventually become sites for decay. 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 heartwood as a pole dries and then be over-treated with conventional oil-borne preservatives such as copper naphthenate, penta or creosote to help retain the 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 that boron and fluoride could inhibit fungal attack, but their protection was limited and needed to be followed by over-treatment with a traditional non-diffusible wood preservatives.

The potential for boron as a pre-treatment has also been explored on railroad ties in the southern United States. Extensive studies at Mississippi State University have clearly demonstrated that dip or pressure treatment with boron followed by air seasoning and

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

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.

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 pre-treatment of utility poles. 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 suggests that the threshold of boron for protecting Douglas-fir from internal decay is far lower (0.8 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 were considered, poles would contain an average of 2.36 kg/m^3 BAE, or about half the required level. These values are skewed by one pole that had extremely high boron levels in four of the six assay zones. The remaining four poles had much lower boron levels. Most boron was largely confined to the outer 25 mm.

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

Pole #	Boron Retention (kg/m^3)					
	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

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 III-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 that 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 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-4. Boron levels in Douglas-fir poles immediately after pressure treatment with disodium octaborate tetrahydrate and drying/treatment.

Pole #	Boron Retention (kg/m^3)					
	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	5.40	0.39	0.04	0.02	0.06	0.22
Standard deviation	3.50	0.31	0.03	0.02	0.10	0.56

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

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 in the poles (Figure II-2, Table II-6). The field site receives ~1200 mm of rainfall per year and tends to be extremely wet during the winter. Previous tests have shown that the interior pole MC 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 that 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 those at groundline. This suggests that boron

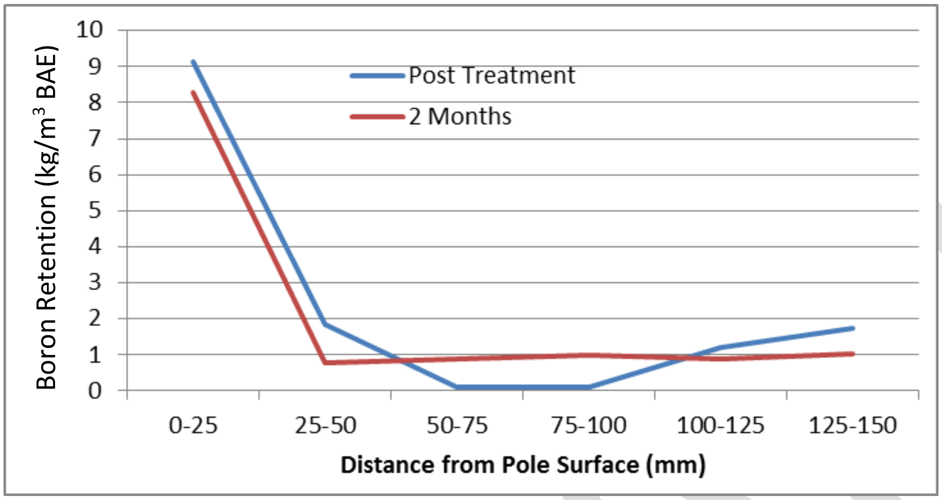


Figure II-1. Boron retentions in 25 mm increments inward from the surface in Douglas-fir poles immediately after pressure treatment with disodium octaborate tetrahydrate and again 2 months later.

was moving 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 (Table II-6). Boron levels in the outer zone tended to be much higher 1.2 m above the groundline, suggesting that some boron was leaching from the 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.

These results are quite different 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 treatment. Thus, the 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 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 tie work was performed on hardwoods. Boron movement through Douglas-fir has tended to be much slower than in other species, although it also appeared to remain in the wood for longer periods of time.

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 the threshold. The failure of boron to become more evenly distributed is perplexing, especially near the groundline where moisture levels should be more than adequate for diffusion to occur.

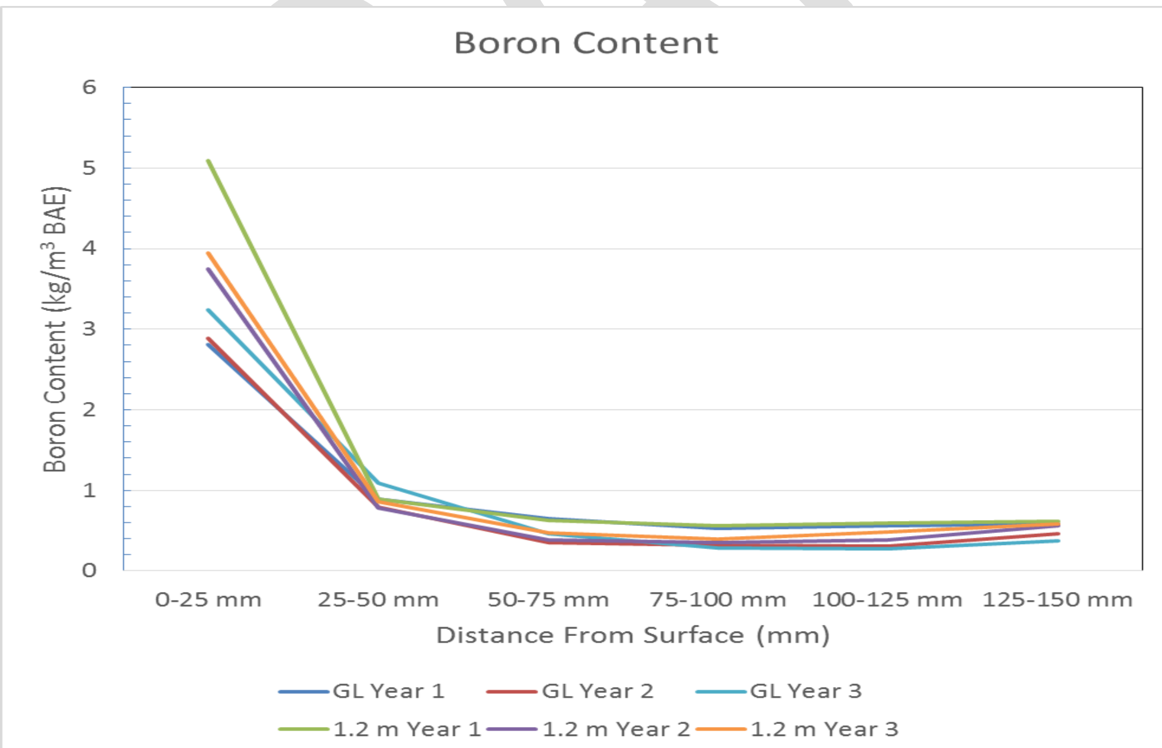


Figure II-2. Boron content at 25 mm increments from Douglas-fir pole surface one to three years after pre-treatment with disodium octaborate tetrahydrate followed by either kiln drying or Boulton seasoning and copper naphthenate treatment. Red line indicates 0.6 kg/m3 BAE.

Table II-6. Boron content in increment cores removed from the groundline or 1.2 m above the groundline of Douglas-fir poles 1, 2, or 3 years after pre-treatment with disodium octaborate tetrahydrate followed by kiln drying or 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	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		**5.55**	**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 90.26)	0.33 (0.16)	0.44 (044)	0.34 (0.9)	0.37 (0.31)
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	0.40	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	0.08
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)	0.21 (0.21)	0.54 (0.69)	0.41 (0.24)	0.41 (0.24)	**0.81 (0.81)**

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

B. 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 this past year 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. Sixteen poles were tagged and then sent to be commercially treated with an 8% solution of disodium octaborate tetrahydrate (DOT) as part of a lumber charge. After treatment, the poles were then commercially treated to the AWPA UC4 retention with copper naphthenate (1.44 kg/m^3) or pentachlorophenol (9.6 kg/m^3). The remaining eight 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 pole. These cores were divided into 25 mm long segments and the 8 segments from a given depth were combined from a single 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-7). For example, boron levels ranged from at the limit of detection (0.04 kg/m BAE) to 7.64 kg/m^3 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. 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 present 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.

These poles have been set at the Peavy Arboretum test site and will be monitored over time to determine how boron redistributes in the wood.

Table II-7. Boron levels at 25 mm increments inward from the surface of Douglas-fir poles dual treated with DOT and copper naphthenate, pentachlorophenol or ACZA.

Treatment	Rep	Boron retention (kg/m^3 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)**

Literature Cited

Morrell, J.J., R.D. Graham, M.E. Corden, C.M. Sexton, and B.R. Kropp. 1989. Ammonium bifluoride treatment of air-seasoning Douglas-fir poles. Forest Products Journal 39(1):51-54.

Morrell, J.J., M.A. Newbill, and C.M. Sexton. 1991. Basidiomycete colonization of Douglas-fir poles after polyborate treatments. Forest Products Journal 41(6):28-30.

OBJECTIVE III

EVALUATE PROPERTIES AND DEVELOP IMPROVED SPECIFICATIONS FOR WOOD POLES

A well-treated pole will provide long, 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 initial treatment methods, explore the potential for new species, assess various inspection tools and explore methods for producing more durable wood poles.

A. Performance of Polyurea-Coated Douglas-fir Crossarm Sections Exposed in Hilo Hawaii: 72 month report

Preservative treated Douglas-fir performs extremely well when exposed above-ground, out of soil contact, for example as a crossarm to support overhead electrical lines in a distribution system. However, checks that open beyond the depth of the original preservative treatment can permit the entry of moisture, fungi, and insects that can result in deterioration and premature failure. Douglas-fir contains a high percentage of difficult-to-treat heartwood and it is generally not feasible to completely penetrate this material with preservative. One alternative is to coat the exterior of the arm to retard moisture entry and presumably limit fungal and insect entry. Polyurea coatings have been employed to protect a variety of surfaces and appear to have potential as wood coatings in non-soil contact. We have been evaluating the use of these coatings for protecting Douglas-fir cross arms.

Douglas-fir cross arm sections were either left non-treated or pressure treated to the AWPA Use Category requirement with pentachlorophenol (penta) in P9 Type A oil. Half of the arms from each treatment group were then coated with polyurea. The arms were then shipped to Hilo, Hawaii, where they were exposed on test racks 450 mm above the ground. The site receives approximately 5 m of rainfall per year and the temperature remains a relatively constant 24-28 °C. The site has an extreme biological hazard (280 on the Scheffer Climate Index Scale which normally runs from 0 (low) to 100 (high) decay risk within the continental U.S.) and a severe UV exposure. Non-treated pine sapwood exposed aboveground normally fails within 2 years at this site, compared to 4 to 5 years in western Oregon. The cross arms were installed in June 2009. Primarily visual assessment consisted of examining coating condition on the upper (exposed) and lower surfaces (Figure III-1). Additional coated samples were exposed in June, 2011.

The non-treated, non-coated Douglas-fir samples had begun to experience decay on the sides and undersides where moisture collected and there was evidence of fungal fruiting bodies 4 years after installation (Figures III-2, 3). These samples had an average rating of 7.0 on a scale of 10 (perfectly sound, no evidence of biological attack) to 0 (complete failure). Non-coated penta treated samples had some weathering on the upper surfaces, but remained sound and free of decay. All of the penta treated, non-coated samples rated 10.

Figure III-1. Polyurea coated and non-coated samples shortly after exposure in Hilo Hawaii.

Polyurea coated samples are challenging to evaluate without damaging the coating. Two years ago, one sample from each treatment was removed and dissected to determine the degree of damage inside the coating. Penta treated samples were sound and free from decay, although there were differences in coating thickness on the upper, UV-exposed surface and the bottom that had not been exposed to sunlight (Figure II-2, 3). Penta had also migrated through the surfaces of the polyurea coated samples to a limited extent, but the samples otherwise appear to be free of attack.

The non-treated, but coated samples also appeared to be free of fungal attack, but there were a few differences in appearance. The upper coated surfaces on these samples were more heavily degraded. Cutting revealed the sample had decay pockets immediately beneath the coating. These results suggest the coating was not a complete barrier against fungal attack.

Figure III-2. Example of lower, non-UV exposed surface of a coated, penta treated section showing evidence of oil migration towards the surface after 6 years of exposure in Hilo, Hawaii.

Figure III-3. Example of a non-treated, non-coated wood sample after 6 years of exposure in Hilo, Hawaii, showing evidence of fungal decay and fruiting bodies.

Coatings on the two samples were carefully separated from the wood and the thickness was measured on upper and lower surfaces. Coatings were then tension-tested to determine peak load. Results were limited because only one sample from each treatment was examined, but they suggested coatings on non-treated wood experienced thickness loss on the UV exposed surface. Coating thickness also declined slightly on the coated, penta treated, samples, but the difference was slight. The reduced effect on the penta treated samples was attributed to migration of oil from the original penta treatment through coating and to the surface. This material provided some UV protection.

Table III-1. Condition of polyurea coatings removed from the upper (UV exposed) and lower (non-UV exposed) surfaces of non-treated and penta treated Douglas-fir sections exposed for 48 months in Hilo, Hawaii.[a]

Treatment	Top/Bottom	Thickness (mm)	Density (g/cm^3)	Peak Load (N)
None	Top	0.89	0.88	257
	Bottom	1.85	0.99	455
Penta	Top	1.68	0.94	533
	Bottom	1.85	1.05	709

[a] Values represent means of 2 samples per material exposure.

This past year, an additional two samples were removed from each treatment group for further examination. While removing more samples might provide a better indication of condition, we are concerned about leaving too few samples for long-term evaluation. This would be especially true for the penta treated materials which have experienced relatively little change in condition (Figure III-4).

Samples collected after 6 years were cut lengthwise in approximately four equal sections so that the upper (UV) and lower (non-UV) surfaces were exposed. The sections were examined for evidence of decay. Penta treated samples were sound and exhibited no evidence of visible decay or discoloration. Non-treated samples had small pockets of decay on both the upper and lower surfaces immediately adjacent to the coating. This was interesting because we might expect to see fungal attack on the upper surface where the coating had thinned to the point where fungal hyphae could penetrate into the wood, but the coating on the lower surface was thick enough to provide a barrier against fungal attack (Figure III-4). One possibility is that the fungi grew around the timbers along the wood/coating interface so that attack was occurring all around the timber. We plan further assessments to determine the possible point

Figure III-4. Photos of the upper surfaces of coated, non-treated control samples after 6 years of exposure in Hilo, Hawaii showing erosion of the coating and complete loss of coating on the corner.

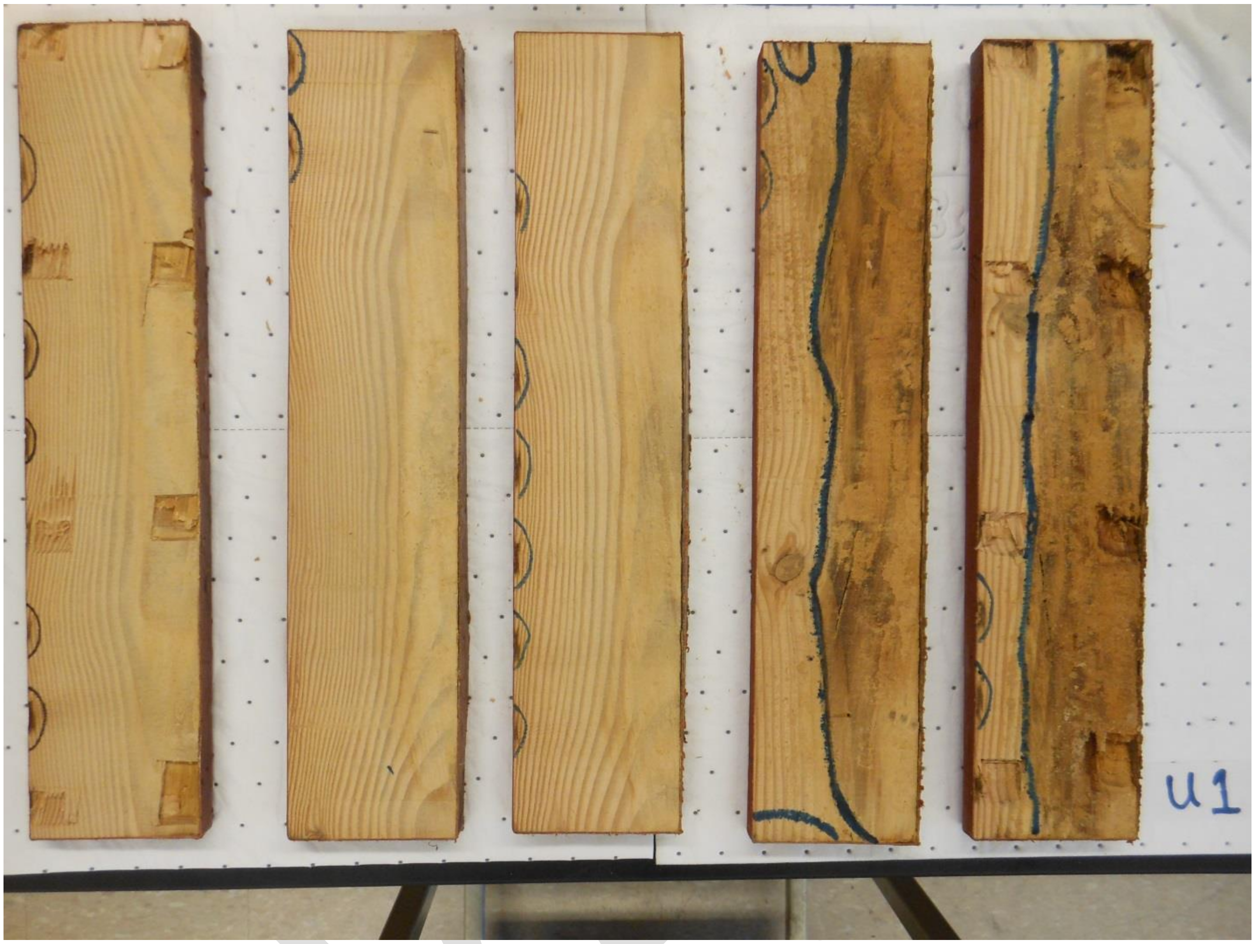


Figure III-5. Interior of a coated, untreated Douglas-fir section after 6 years of aboveground exposure in Hilo, Hawaii.

where fungal attack was initiated. In addition, the coating was carefully separated from the wood and thickness was measured using digital calipers. Finally, small samples were cut from the decayed zones and placed onto benlate amended malt extract agar (Figure III-5). The plates were examined for evidence of growth of basidiomycetes.

A variety of fungi were isolated from both treated and non-treated sections. More than 140 fungi were isolated from 120 samples removed from non-treated arms, while 94 fungi were isolated from 101 samples from penta treated arms (Table III-2). Only 3 decay fungi were isolated from penta treated arms, while 43 decay fungi were isolated from non-treated arms. While the barrier was not able to completely protect penta treated sections, it markedly reduced the ability of decay fungi to enter penta treated wood. In addition, the frequency of dematiaceous fungi was higher in penta treated arms. Dematiaceous fungi are typically more tolerant of preservatives and many are capable of producing soft rot decay. While no decay was evident in the penta treated samples, the presence of these fungi might eventually cause wood damage.

Table III-2. Fungi isolated from non-treated and penta treated Douglas-fir timbers coated with polyurea and exposed above ground near Hilo Hawaii from 84 months.

Fungus	Non-treated	Treated
Attempts	120	101
Decay Fungi	43	3
Non-Decay Fungi	102	91
Dematiaceous Fungi	31	82

The purpose of the barriers is to limit fungal attack. Examination of the barriers on both treated and non-treated samples revealed that polyurea coating thickness decreased on both the upper and lower surfaces of the non-treated samples, although the effect was most noticeable on the upper surfaces (Table III-3). The barrier on the upper surface was only 0.70 mm thick while the lower surface was 1.33 mm thick. The upper surface was heavily discolored and thinned. Interestingly, decay was not located directly beneath the thinned barrier but rather on the lower surface where the barrier was thickest. The upper surface may have been less attractive for attack because it was exposed to continuous sunlight that might have heated the wood to levels less suitable for fungal growth. The lower surface would be shaded and have temperatures more conducive to fungal growth. The polyurea coating was also thinner on the lower surfaces of the penta treated samples, but the differences were much smaller. Oil in penta treated arms diffused into the coating and this material might have protected the coating from ultra-violet light degradation.

The results indicate the polyurea coating provided some protection against fungal attack, even on untreated wood although the effect was only temporary. Coatings were much more effective on penta treated wood, although even these coatings experienced some loss in thickness over time. The results indicate polyurea coatings alone would not be suitable for protecting non-treated wood, but might be useful for limiting UV damage on treated wood.

Table III-3. Thickness of polyurea coatings on non-treated and penta treated Douglas-fir timbers after 84 months of above-ground exposure near Hilo, Hawaii.

Replicate	Coating Thickness (mm)			
	Non-Treated		Treated	
	Upper Surface	Lower Surface	Upper Surface	Lower Surface
1-1	0.90	1.17	1.54	2.47
1-2	0.86	1.06	1.54	2.40
1-3	0.97	1.08	1.76	2.37
1-4	0.99	1.12	1.75	2.18
1-5	0.92	1.10	1.82	2.15
2-1	0.19	1.53	1.16	2.01
2-2	0.26	1.77	1.18	2.42
2-3	0.46	1.38	1.42	2.02
2-4	0.30	1.40	1.66	1.66
2-5	0.40	1.48	1.94	2.16
3-1	0.84	1.40	1.22	1.30
3-2	0.84	1.36	1.13	1.18
3-3	1.03	1.37	1.06	1.35
3-4	1.00	1.34	0.76	1.54
3-5	0.50	1.38	0.68	1.48
Average (SD)	0.70 (0.31)	1.33 (0.19)	1.37 (0.38)	1.91 (0.45)

B. Potential for predicting the flexural properties of Douglas-fir utility poles

Wood poles play a critical role in supporting the electrical transmission and distribution system in North America with over 160 million poles currently in service. Utility poles fall under the specifications of American National Standards Institute (ANSI) 05.1 prior to preservative treatment (ANSI, 2015). This group establishes minimum standards for peeled, green poles of a number of wood species. The standard is based on extensive full scale and small scale testing of wood for each species (Wood et al. 1960), and provides a minimum fiber strength that encompasses 95% of strength distribution for poles of a given class (Wolfe et al. 2001). The standard primarily takes a visual approach to pole selection with maximum allowances for wood defects such as knot size and frequency, slope of grain, and growth rate. The producer also uses these characteristics to choose a best face of the pole which is marked with an identification tag or brand. This tag or brand is then used by the utility crew to install the pole with the tag oriented in the line direction. The line direction is subject to the greatest forces and deflections, therefore the strongest side should be oriented in that direction; however, there is no mechanical verification ensuring that the face chosen is actually the strongest. While the ANSI approach has resulted in a highly reliable electric distribution system, many utilities question the use of pole size as the primary sorting criteria when wood strength is known to vary widely within poles of the same dimensions.

One approach to narrowing the distribution of pole properties would be to use a pre-sorting non-destructive tool. Various acoustic techniques have been explored for this purpose on in-service poles including acoustic (Goodman 1990), transverse vibration (Wang and Bodig 1990, Torran et al. 2009), ultrasonic waves (Goncalves et al. 2006), and transverse loading, but there have been limited attempts to apply these technologies to select new poles. Acoustic velocity is already employed in some mills to grade logs for structural and nonstructural uses (Ross 2015). Work at Colorado State University suggested that wood poles could be sorted using time of flight measurements and a field prototype was developed, but the process was never commercialized because of concerns from wood suppliers about possible loss of wood value and from utilities about the possibility of high-grading poles for specific customers.

Most nondestructive technologies find the modulus of elasticity (E), and correlate that value to the modulus of rupture (MOR) (Ross 2015). These correlations are generally validated by comparisons with destructive tests using small clear specimens. E and MOR are highly correlated (R^2=0.90), while correlations between dynamic modulus and static bending modulus can reach R^2=0.96-0.99 (Ross 2015). The relationship holds for larger samples that are clear, machined and free of defects, but becomes much weaker for utility poles which contain many defects, are tapered, and may have sweep. Correlations between bending derived E and MOR range from 0.27-0.52 for utility poles (Torran and Zitto, 2009) to 0.60 for sawn machined logs (Green et al., 2006). Correlations around 0.65 are achieved for sawn lumber with most Machine Stress Rating Systems (Ross 2015). These results suggest that a bending test well below the proportional limit could be used to categorize poles into broad classes or, at the very least, to identify abnormally weak poles.

Pre-flexing could be easily applied in production because the poles could be tested immediately after peeling when they were also at their highest moisture content. In addition, pre-flexing could be used to identify the “Best Face” by rotating the pole and performing multiple tests. Multiple measurements around the poles would simultaneously improve prediction accuracy. Flexural testing would not completely eliminate visual grading since some defects, such as compression breaks would be difficult to detect unless the defect was directly in the loading path. The system could ultimately be used to more accurately sort poles into appropriate load classes based on strength rather than size. This process could also allow utilities to use more of the capacity of a pole.

The potential for using E as a pre-sorting device was investigated on freshly peeled Douglas-fir poles. The objectives of the work were to determine the ability of E to predict MOR of poles, to assess disparities between marked and measured “Best Face”, and determine how many measurements around the circumference were needed to correlate E and MOR.

Ninety two green, untreated Douglas fir poles (*Psuedotsuga menziesii* (Mirb) Franco) were obtained from multiple locations in Western Oregon and Washington. The poles were used as part of a larger study to assess the effects of through boring, radial drilling and deep incising on flexural properties (Morrell et al., 2013, 2014). These processes are typically applied within a zone 900 mm below to 600 mm above the intended groundline and applied prior to arrival. Previous studies had shown that the groundline treatment processes had no significant effect on pole flexural properties (Elkins et al., 2007; Elkins, 2005). Poles were maintained in the green condition until testing. Class 4 (13 m) poles were chosen for this study as they are one of the most widely used pole sizes.

The poles were first tested non-destructively and then cut into two 6.5 m long sections (hereafter labeled tip and butt). Each pole half was then tested to failure in a destructive test.

Non-destructive flexural tests were performed by placing each end of the pole on Douglas-fir saddles with the saddles approximately 12 m apart. Each pole was center-loaded at a rate of 0.25 mm/second using a 200 kip hydraulic actuator attached to a frame bolted to a concrete reaction floor to a load of 1360 kg (ASTM, 2015; Crews et al., 2004). Applied load was calculated using a separate load cell attached to the hydraulic actuator. The first test was performed with the pole tag oriented upward then the pole was rotated 45 degrees for each subsequent test. In principal, loading conditions for tests 1 & 5, 2 & 6, 3 & 7 and 4 & 8 should be fairly similar. The face side is referred to in ASTM D1036 as the concave side of the greatest curvature in pole (ASTM, 2015). Deflection was measured using string potentiometers referenced to the ground. Load and deflection were continuously recorded and the resulting data were used to calculate E for each of the eight loading orientations for each pole.

The poles were then cut into two 6.5 m long sections for destructive testing. The butts of the poles were tested to failure without further manipulation; however, the 6.5 m long tips were further processed by drilling a series of steeply sloping 21 mm diameter by 450 mm long holes at an approximately 45 degree angle beginning 1.7 m from the butt then moving upward 300 mm and 120 degrees around the pole. Poles received a total of either 3 or 6 holes as part of a secondary experiment to evaluate the effects of field drilling holes for application of remedial treatments on pole flexural properties.

Poles are generally tested in two different ways as described in ASTM D1036 (ASTM, 2015); three-point bending or cantilever methods. For this study, a four point offset asymmetric bending method was used. Load conditions were biased 1:5 towards the butt end of the poles (Figure III-6), as previously used by Elkins et al. (2007). This configuration has advantages over cantilever or three point tests since it maintains a near constant moment in the high moment zone near the ground line, which is representative of conditions poles would face in field loading. The applied moment was not perfectly constant, due to rounding of the load heads for ease of design. Douglas-fir load heads and saddles were used to minimize stress concentrations and limit material bearing.

The poles were loaded until failure, which was defined as either catastrophic failure or a 30% decrease in load after peak load was attained. The type of failure was noted, photographs of the failure zone taken, and any significant features that may have led to the failure were noted. Fifty mm thick samples were cut from near the failure zone. These sections were weighed, oven dried to constant weight at 104 °C and reweighed to determine moisture content. The number of rings per section was then counted, paying particularly attention to the number of rings in the outer 50 mm of each section. While there was a 12 month time gap between testing of the tips and butts, the tips were rewetted prior to testing to ensure that all testing was performed while the wood was above the fiber saturation point.

Data analysis: E was calculated from the non-destructive test data using readings taken from 10% of maximum load to maximum load (11360 kg) to determine the slope since the pole was in the elastic region for the duration of the test. The calculation assumed a prismatic member using Formula 1.

$$(1) \quad E\ (MPa) = 98.2P/(\Delta d^4)$$

For the destructive tests, the slope P/Δ was taken from readings at 10 to 30% of maximum load which was still in the elastic region. Pole diameter was measured at the groundline, while circumference was measured at each end of the pole to calculate taper. Modulus of Rupture (MOR) was calculated using the section modulus at the groundline, and the moment at the point of failure.

The MOE data for the destructive tests were compared with MOR for the tip and butt sections using linear regression. E derived from the nondestructive tests was then compared to the corresponding E and MOR for the destructive tests. Two sample t-tests were used to compare E between different radial sections, bottom, and tip values (α=0.05). The average E's were taken from the best face to the 4th face, and from the 5th to 8th, to examine differences between test faces. Average E was calculated for different combinations of faces to determine the effect of increased testing on the ability to predict actual E and MOR.

Moisture contents of the poles at time of testing ranged from 26 to 70%, with an average of 40%, indicating that moisture content did not affect strength as the poles were above fiber saturation point. Pole weights averaged 405.5 kg (350.8 to 476.5 kg) while pole circumference averaged 882.5 mm (837.5 to 975 mm). The maximum circumference of a Class 4 pole is 900 mm, so many poles were oversized which helps to explain higher pole weights (ANSI 2015).

Full scale destructive data initially indicated that neither the groundline treatment (radial, drilling, through boring or deep incising) of the butts nor the inspection holes in the tip sections of the poles significantly affected pole properties (Morrell et al., 2011, 2014).

Subsequent analysis suggested that MOR of the butt sections differed significantly between poles that were radial drilled or incised. Consequently, data from the tips were combined for comparison with the non-destructive test methods while those from the butt were analyzed separately by groundline treatments (incised, radial drilled or through bored) (Table III-3). In addition, the predicted E values determined from each of the 8 flexural tests performed per pole were combined for comparison with the physical test data.

The MOE of Douglas-fir is reported to be 10.8 GPa (USDA, 2010), while the MOE observed for tip and butt sections were 11.55 and 10.52 GPa, respectively. The MOE for tip and butt sections were statistically different (P = 0.0001). The coefficient of variation (COV) observed was well below the expected value previously reported (USDA, 2010). Predicted E from the non-destructive testing averaged 12.27 GPa. The overall average values suggest E was a reasonable predictor of actual MOE. The minimum variability for the 8 measurements for each pole ranged from 1% to 11% while the average was 4.2%. This observed variability within a pole is expected given the inherent flaws and features in a wood poles.

MOR averaged 53,000 kPa for Douglas-fir (USDA, 2010), while the average MOR's for the tips and butts in the current study were 42,330 and 40,470 kPa, respectively. The differences in MOR were statistically significant (P<0.05). The COV of both tip and butt sections were in the range of those previously reported (USDA 2010). MOR values were considerably lower than previous reports using an identical test apparatus (Elkins et al., 2007). The poles in the earlier test were obtained from a relatively limited geographic area while more recent tests used a population collected from a much larger region. Despite variations, the population should be useful for comparing predicted vs actual flexural properties. MOR and MOE of the tips and butts were generally correlated (r^2= 0.641 and 0.455, respectively) (Figure III-7).

Ability to select the best face: The process of producing a pole includes identifying a so-called "best face" which is typically placed in the line direction. The face is identified by the presence of visible defects as well as deviation from the vertical. There are no direct data demonstrating that the "best face" is the strongest or if there is a mechanical difference in stiffness in different directions. The NDE flexural tests were performed at 8 locations beginning with the best face. The modulus of elasticity value reported by NDE method is hereafter referred to E. The first and fifth, second and sixth, third and seventh and fourth and eight tests should produce similar results since they are testing through the same orientation, although the tension and compression faces will clearly differ. Average E values for each of the orientations varied widely at each position, but there was a general trend for values to be similar between the paired tests (Figure III-8). There was a significant difference between the best E and the perpendicular face (P<0.05 level) in the bottom sections which included the groundline pre-treatments (radial drilling, through boring or deep incising). These pre-treatments removed fiber from the section where destructive testing produced maximum stress. Pre-flexing could identify the best and worst faces as well as poles with large disparities between the two faces that might suggest a pole not suitable for use.

A comparison between predicted E and actual MOE indicated that visual assessment accurately predicted the best face 35% of the time. Predicted E suggested that the best face was actually 90 degrees around the pole on 17% of poles. The remaining poles had best faces as predicted by pre-flexing that were in the other locations. The results indicate that visual assignment of the best face is highly variable and suggests non-destructive flexural testing might improve selection of the best or worst faces, although other defects such as knots outside the stressed area might alter the assessment.

Ability of NDE flexural testing to predict MOE and MOR: The original goal of the study was to determine if flexing poles could be used as a sorting system for wood quality. The simplest way to use this approach would be to set a minimum threshold for E that would ensure that any poles with an MOR below a minimum value were identified and excluded from the pole population. The next approach would be to use predicted E data to further sort poles into strength categories. While that would require a much larger database to produce reliable predictions, the current population could be used to assess the merits of this approach.

Comparisons between actual MOE and predicted E for the tip and butt populations showed that the predicted values were marginally correlated with MOE (r^2=0.51 and 0.55, respectively) (Table III-4, Figure III-9). The pole population tested did not contain any extremely weak poles, making it difficult to determine how well pre-flexing identified very weak poles; however, there was no evidence pre-flexing over-predicted MOE. One aspect of the test approach that limits potential method prediction power was the need to pre-flex poles at the center and then test halves of the pole in a test configuration that drove the maximum stresses to within 1.5 m of the end of each pole section. Ideally, MOE should be similar for both NDE and destructive tests. However, the span to depth ratio and the fact that the deflection values were not corrected for shear caused some discrepancies. The correlations were actually slightly lower for the tip than the butts of the poles.

Comparisons between actual MOR and predicted E tended to be poorer than the comparison between predicted E and actual MOE (Figure III-10). Correlations between actual MOR and E for the tip were slightly better than those for the butts (r^2= 0.33 vs. 0.28), but the differences were small and inconclusive. The primary goal of a sorting system would be to identify extremely weak poles so they could be excluded from the system. In general, higher NDE predicted E values were associated with higher MOR's, although there were inconsistencies. The inability to predict properties could reflect the shift in load application associated with testing full length for E and half pieces for the destructive tests in addition to the change in span-to-depth ratio. The presence of ground line treatments might reduce the ability to predict MOR with destructive MOE. Elkins (2005) found that the presence of holes reduced correlation coefficients from

0.72 to 0.45. The results indicate that pre-flexing in the current configuration is a poor predictor of MOR values, but can be useful for predicting trends.

While pre-flexing would fit well within the pole peeling process, it will be important to determine how many tests would be required to accurately predict properties. As noted, eight tests per pole were used in this experiment, but the tests were paired as the load paths matched on opposite faces of a given pole. Pre-flexing through the best face as selected by the manufacturer should be most directly related to the actual MOE and MOR values since the destructive test loads were applied through the same face; however, the tests were not directly comparable because the destructive tests were applied to halves of the pole.

As expected, MOE tended to be more closely correlated with predicted E than MOR. This is consistent with previous studies that showed relatively low correlations for poles and other materials. Although it is certainly incorporated, MOE is not normally considered to be as important as MOR in utility pole design. The highest correlations between MOE and predicted E were found for the tip sections with r^2 values ranging from 0.39 to 0.79 (Table III-5). Correlations between predicted E and MOR ranged from 0.24 to 0.52. The best correlations between E and MOR were found with butt sections that had been radially drilled and incised. In general, predicted E was poorly correlated with MOR, suggesting that it would be a poor predictor of pole properties. Previous studies have found similarly low correlations between MOE and MOR. For example, Hron and Yazdani (2011) reported an R^2=0.249 between a nondestructive MOE and actual MOR of new poles. Green et al. (2006) reported an R^2 of 0.56 for comparisons between nondestructive MOE and destructive MOR; however, these logs were machined and excluded sweep, splits, and other defects normally present in utility poles. The previous results as well as the current tests illustrate the difficulty of accurately predicting MOR using non-destructive flexural testing and the limits that can be expected. The limited correlation would make it difficult to develop an accurate strength based sorting system. Furthermore, test data from different pole classes and a larger population would be needed to be able to upgrade or downgrade poles based on E to MOR ratios.

One approach to improving correlations would be to increase the number of tests per pole. However, increasing the number of tests from 1 to 8 did not increase the correlation between predicted and actual MOE or MOR for the tips or the butts (Table III-5). The lack of improvement and conflicting results in prediction capability may again reflect the fact that the first pre-flexing test was performed in the same direction as the destructive testing while additional faces were not directly tested. Results suggest flexing in even one direction might be adequate for identifying weaker poles.

Conclusions: Pre-flexing poles to develop predicted MOE values was reasonably correlated with actual MOE, while the relationship between predicted E and actual MOR was much weaker, even when the different pretreatments were separated. Increasing the number of flexural tests around the pole did not improve the correlations due to the test setup. Pre-flexing poles suggested that visual determination of the best pole face was not accurate. Based on this and previous research, pre-flexing has limits to the degree of accuracy and at this time cannot predict strength to the accuracy needed for an MSR system.

Table III-4. MOE and MOR of tip and butt halves of Douglas-fir poles tested to failure in bending.[a]

	E (GPA)	MOE (GPa)		MOR (KPa)	
		Tip	Bottom	Tip	Bottom
Average	12.27	11.55	10.52	42,330	40,470
StDev	2.06	1.65	1.52	5,630	6,860
COV	16.40	14.30	14.50	13.30	17.00

[a] Values represent averages of 92 sections each for the tip and butt.

Table III-5. Correlations between numbers of pre-flexing tests applied to a pole used to calculate a predicted E and the actual MOE and MOR of Douglas-fir poles tested to failure in bending.

Pole Group	E Comparison	Correlations (r^2)								
		One test	2 tests	3 tests	4 tests	5 tests	6 tests	7 tests	8 tests	Best face & 90° around
Butt Radial	MOE	0.39	0.42	0.49	**0.51**	0.46	0.45	0.47	0.48	**0.51**
	MOR	0.38	0.42	0.45	0.45	0.44	0.45	0.45	0.45	0.45
Butt Incised	MOE	0.46	**0.52**	**0.56**	**0.50**	**0.54**	**0.55**	**0.56**	**0.55**	**0.55**
	MOR	0.44	0.49	**0.51**	0.45	**0.50**	**0.51**	**0.52**	**0.52**	**0.51**
Butt-Bored	MOE	**0.55**	**0.59**	**0.60**	**0.60**	**0.59**	**0.59**	**0.59**	**0.60**	**0.58**
	MOR	0.27	0.26	0.27	0.27	0.26	0.26	0.26	0.25	0.24
Combined	MOE	0.46	**0.52**	**0.59**	**0.55**	**0.53**	**0.54**	**0.55**	**0.55**	**0.57**
	MOR	0.27	0.29	0.30	0.28	0.28	0.28	0.29	0.28	0.30
Tip Combined	MOE	**0.79**	**0.50**	**0.50**	**0.51**	**0.51**	**0.51**	**0.51**	**0.51**	**0.50**
	MOR	0.41	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34

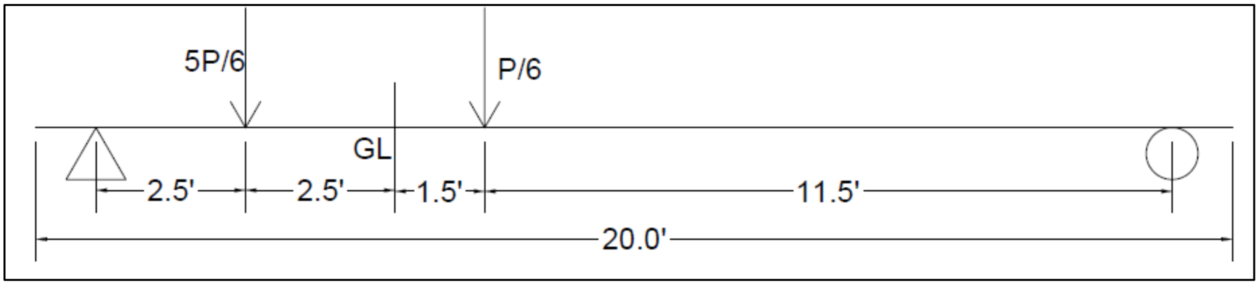
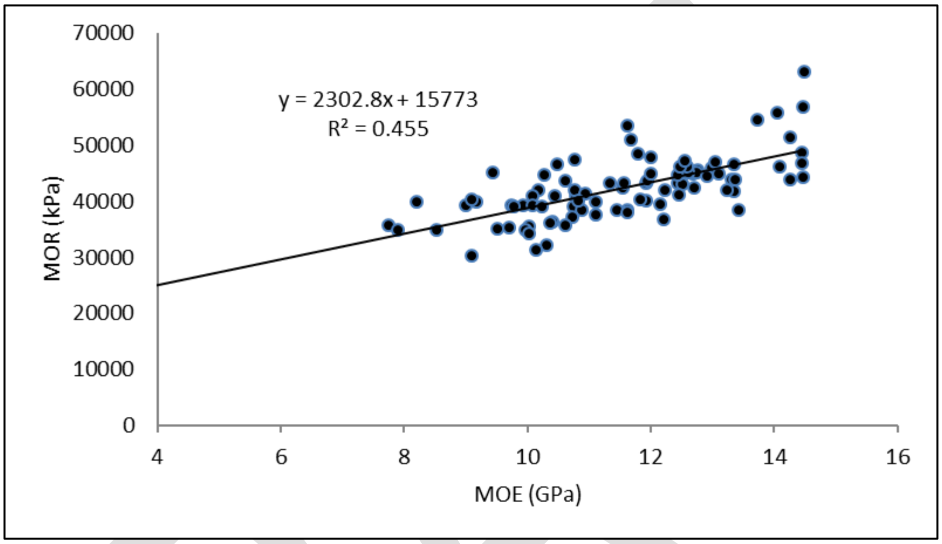
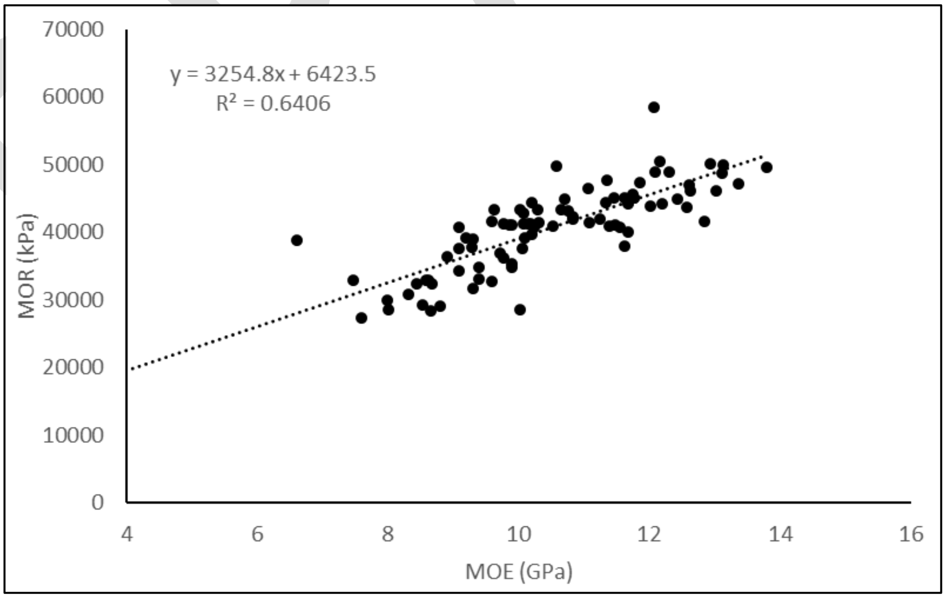


Figure III-6: Diagram of the load distribution in the destructive tests.



(a) Tip section



(b) Butt section

Figure III-7. Relationship between actual MOE and MOR of (a) tip and (b) butt 13.3 meter long sections cut from 26.6 m long Douglas-fir pole sections tested to failure in bending.

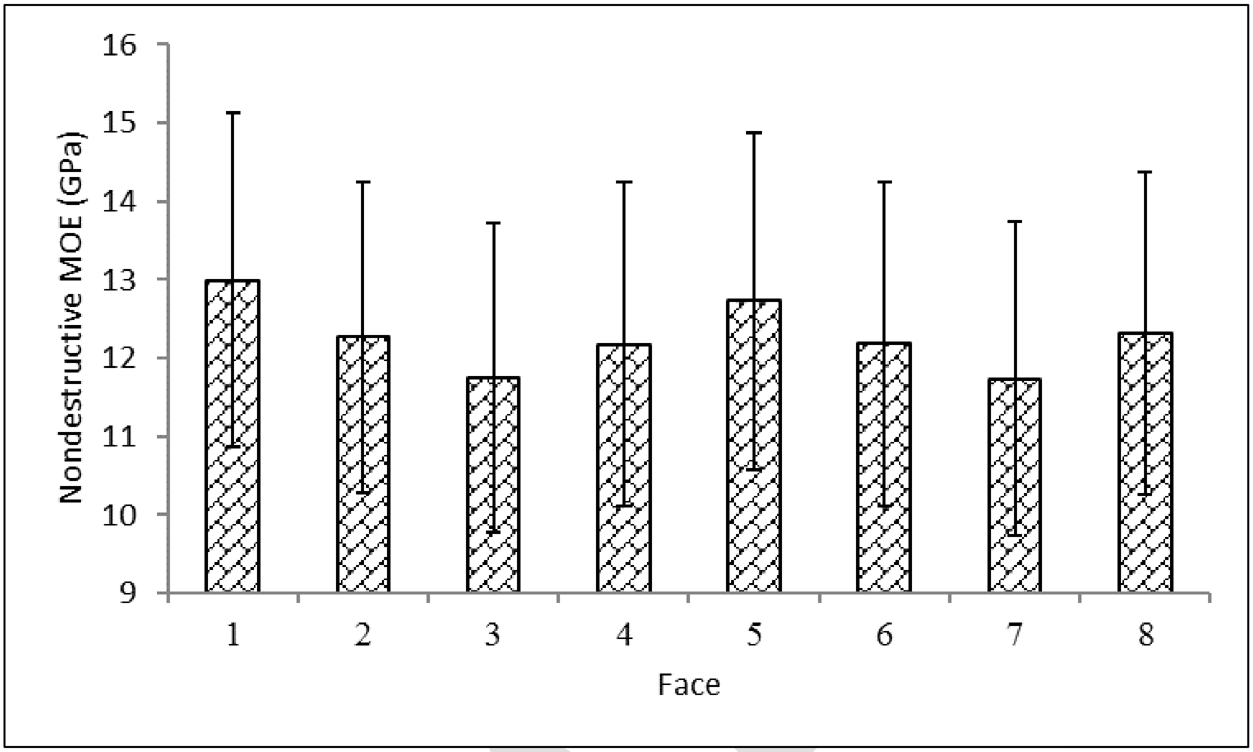
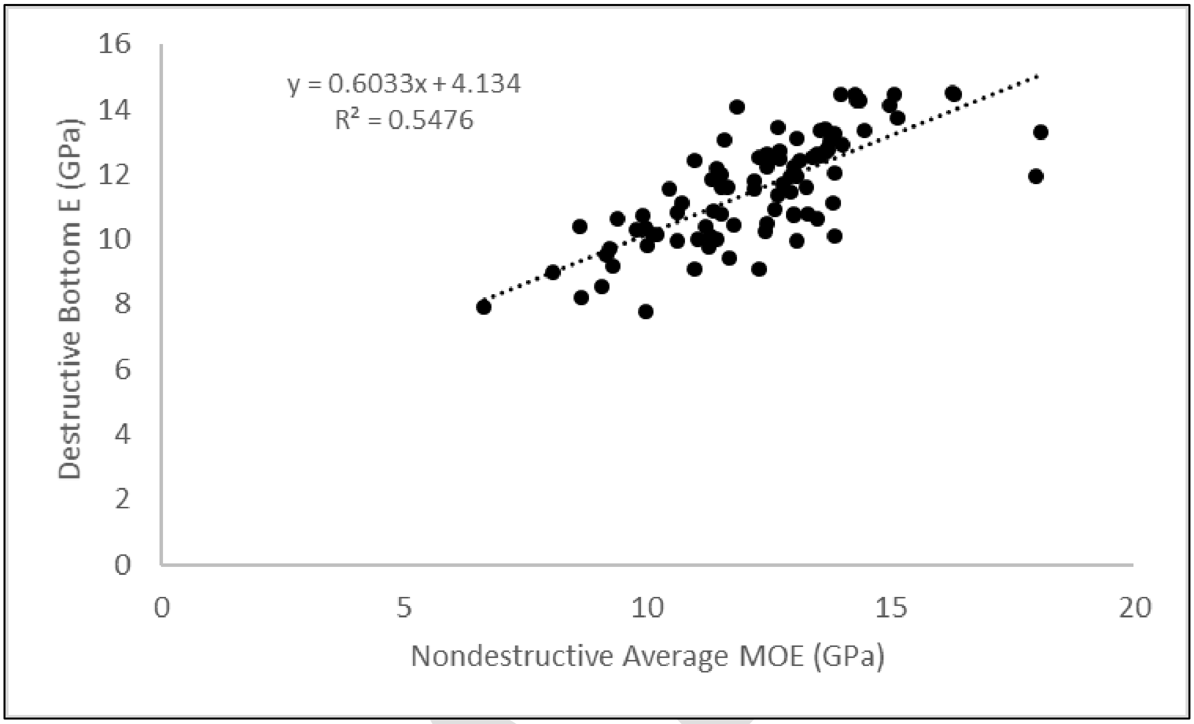
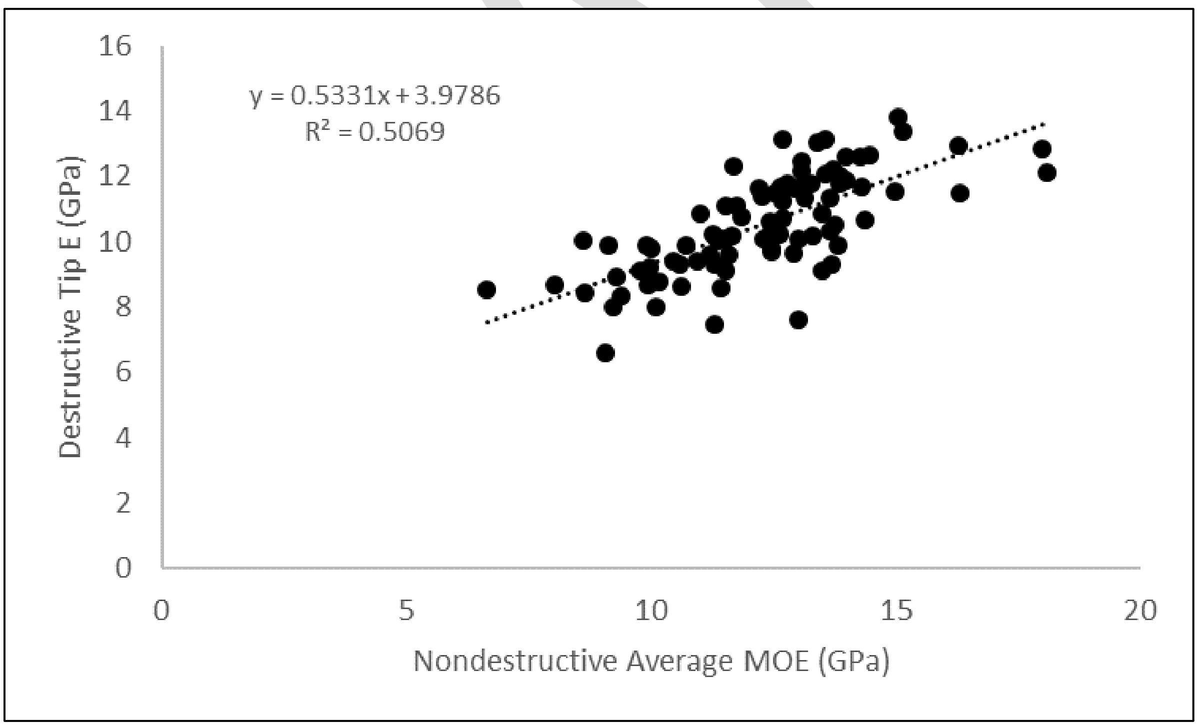


Figure III-8. Average predicted MOE as determined by pre-flexing at the mid-point at 8 equidistant locations around 92 Douglas-fir utility poles.

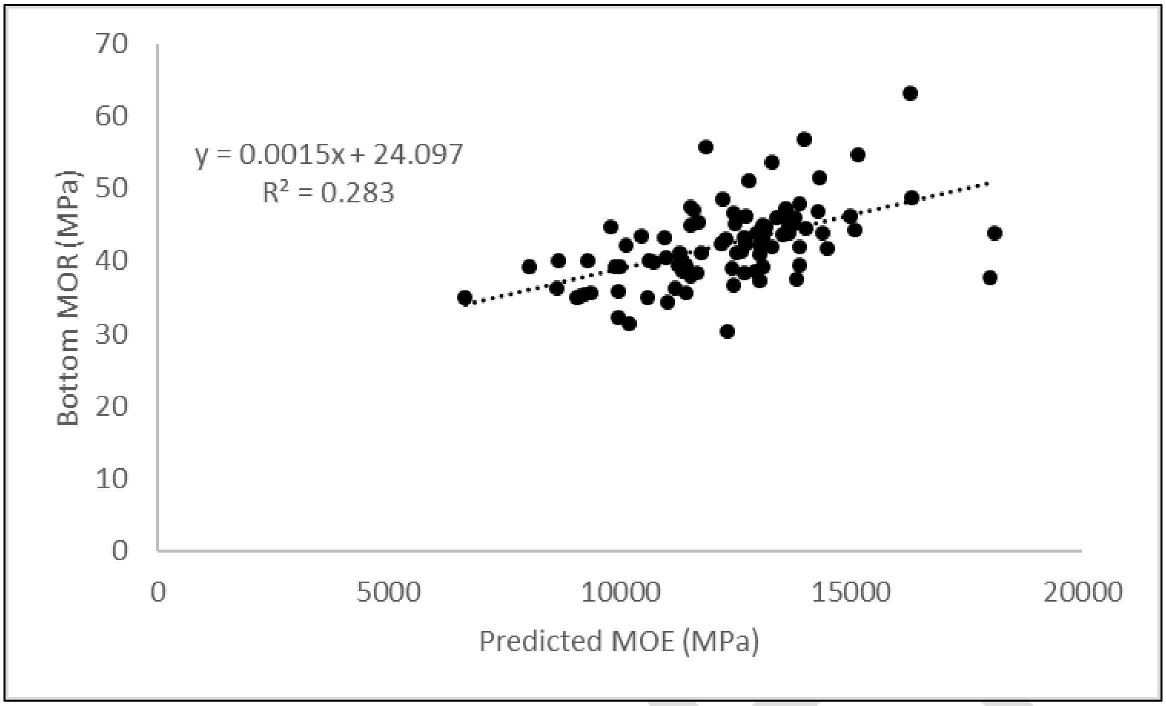


(a) Predictive correlation of NDE E with bottom section tested MOE

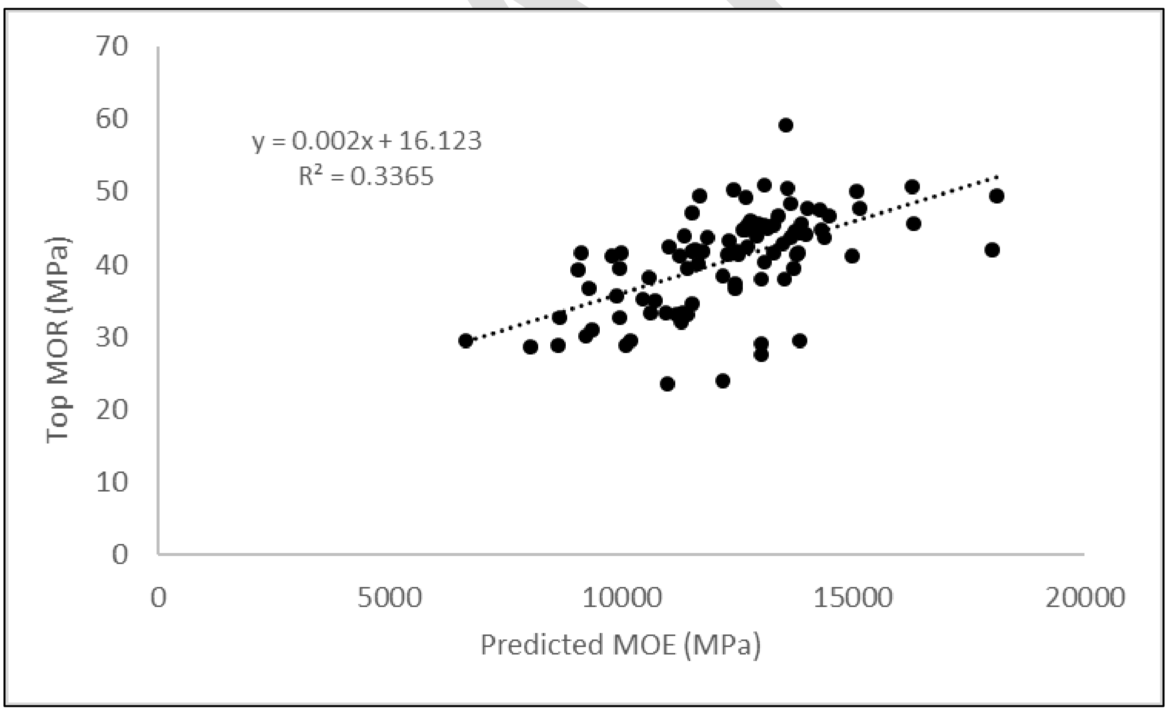


(b) Predictive correlation of NDE E with tip section tested MOE

Figure III-9. Predicted MOE determined by center loading of 13.3 m long Douglas-fir poles below the proportional limit vs actual MOE determined by destructive bending tests of the bottom (a) and top (b) 6.75 m long sections of the same pole.



(a) Predictive correlation of NDE E with bottom section MOR



(b) Predictive correlation of NDE E with tip section tested MOR

Figure III-10. Predicted MOE determined by center loading of 13.3 m long Douglas-fir poles below the proportional limit vs actual MOR determined by destructive bending tests of bottom (a) and top (b) 6.75 m long sections of the same poles.

C. Effect of Capping on Pole Moisture Content

We have long advocated for utilities to protect the tops of utility poles with a water shedding cap. While the original preservative treatment does afford some protection, checks that develop on the exposed end-grain can allow moisture to penetrate beyond the original depth of treatment. We have observed extensive top decay in older (>50 to 60 years old) Douglas-fir distribution poles which might ultimately reduce pole service life. Capping can prevent this damage, but there is relatively little data on the ability of these devices to limit moisture entry.

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 on the pole sections were then plugged with tight fitting wood or plastic plugs to retard 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.

The effect of the caps on MC was assessed 4 to 90 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-6). The cores were processed as described above.

This test was not evaluated this past year but will be assessed over the coming winter.

Table III-6. Moisture contents in Douglas-fir poles with or without water shedding caps as determined over 90 months.

Exposure Time (Mo)	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

D. Evaluation of Polyurea Coating as a Method for Controlling Moisture Levels in Douglas-fir Pole Tops

Polyurea barriers have proven to be durable on crossarm sections in sub-tropical exposures at Hilo, Hawaii. 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-11). 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-7). The poles, installed in the spring of 2011, were sampled after 4, 12, 16 and 24 months of exposure to assess the effect of the coating on internal moisture. Increment cores were removed in the same manner as previously described and MC was determined for each pole. 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.

As with the other capping test, this test was not evaluated this year, but will be assessed next year.

Figure III-11. Example of a polyurea capped pole top.

Table III-7. Moisture content beneath the tops of Douglas-fir poles with and without a water-shedding polyurea coating.

Exposure Time (mo)	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

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

E. Effect of Pole Top Configuration on Moisture Absorption

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 activity that we often note in pole specifications is the use of either sloping top or a roofed top. The presumption is that the slope encourages water to run off of the wood more quickly. 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. Small micro-checks on the upper surface 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. This past year, we had an opportunity to establish a small scale test to examine moisture behavior in poles with differing roofing patterns.

Douglas-fir poles were cut into twenty four 3 foot 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 was cut at a 30 degree angle while the final set was cut with two sloping sides coming to a point (Figure III-12).

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 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 will be periodically weighed over the coming months to assess effects of top style on moisture uptake.

Figure III-12. Examples of the different pole top roofing patterns assessed for their ability to resist moisture ingress.

F. 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. These risks have raised major concerns among electric utilities whose distribution and transmission lines run through these at-risk areas. These 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, less well considered is the tendency of steel to melt and deform when exposed to elevated temperature. 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 for limiting 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 so the material used to support overhead lines. 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 initial 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 that 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 limit treatment to the surface, a substantial amount of the intended fire retardant will be delivered to the interior where it will serve little purpose except as a possible long-term reservoir for replenishing chemical on the surface. 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 range goal. Given the long 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.

In Service Pole Protection: Protecting poles against fire is not a new concern. Utilities have attempted to use various methods for limiting 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 systems. 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 increased as utilities become aware of their potential 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 given 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 in developing improved methods for evaluating these systems.

There is a critical need for the development of a simple, mobile system for assessing the effectiveness of both initial and supplemental fire retardants on poles. The system would:

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

Last year, we reported on our new method for assessing the performance of various 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-13). Two infrared heating elements are placed along the stainless steel walls. A thermocouple is placed into the pole from the backside (non-heated side) of the pole 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 temperature of the air between the heating elements and the 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 of a system). In order to reduce the potential for smoke complaints, the burn time was shortened to 10 minutes in subsequent tests. The degree of protection afforded by a given 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 first evaluated on a limited number of poles without supplemental fire protection (Figure III-14). 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 system allows the test conditions to be varied in terms of 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. Further tests are underway using fire retardant treated materials.

Figure III-13. Example of the small scale fire test apparatus showing the heating shield on a tripod and close up of the heating elements.

The system was then 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 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-15). 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 the 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-8). The remaining systems did not ignite although they did experience surface charring on either the barrier or the applied film (Table III-7). 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 and 197°C. The systems also affected the observed heating pattern.

Figure III-14. 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.

Poles treated with the barrier systems (Brooks and CuCare) both tended to experience charring of the barrier, however, there was little damage beneath the burned barrier (Figures III-16-19). This would necessitate replacement of the barrier, but the pole would remain sound and free of damage. The Fire Guard and Fire Sheath systems both also experienced charring of the film, but relatively little damage beneath the surface. As with barriers, these systems would need to be reapplied to provide continued protection. The SunSeeker system provided the lowest degree of protection. It is unclear whether the addition of a thicker coating of SunSeeker would have helped this system perform better; however, the system provided little protection at the rate applied.

The final measures of treatment efficacy were the maximum char depth and char area (Table III-7). Fire Guard along with Brooks and CuCare barrier systems all experienced less than 1 mm of charring, while FireSheath experienced 2 mm of charring. SunSeeker experienced 5 mm of charring compared with 8 mm of char for the control. Char area was more variable, with FireGuard and Fire Shield treated poles experiencing 20 and 90 cm^2 of char area, compared with the entire surface for the control and SunSeeker treated poles. Brooks and CuCare wraps experienced 480 and 200 cm^2 of char area; however, as the photos illustrate, char was confined to the barrier itself, which acted as a sacrificial shield for the wood beneath. Char area may be a less useful method for assessing fire resistance because damage can be extensive but superficial. In addition, some systems may char quickly as a means for limiting further fire ingress, artificially inflating the area.

This past year, we continued our tests by examining additional treatments and more replicates. In addition, we examined the ability of the systems to protect poles from multiple fires. Poles were subjected to heating for 20 minutes. If ignition occurred, the pole was allowed to continue burning for 5 minutes, then extinguished. If ignition did not occur in 20 minutes, the pole was allowed to cool for 24 hours and was then subjected to another 20 minute burn period. Char depth was determined, as was time to ignition and maximum temperature. The process was then repeated to determine if systems could withstand repeated burning without repair.

Figure III-15. Example of char scrapped from the pole surface to reveal non-burned wood beneath.

Figure III-16. Brooks fire retardant wrap after test showing charred area of the barrier that protected the pole from fire.

Figure III-17. CopperCare barrier system showing damage to the barrier but only slight charring beneath after the barrier was removed.

Figure III-18. Example of SunSeeker fire retardant treated pole on fire and pole condition after the fire

Figure III-19. Example of a FireGuard treated pole section showing slight charring where the barrier was sacrificed.

Continued testing this past year increased the number of samples examined per treatment and subjected treatments to multiple fires. Non-treated controls experienced 6 mm of char after the first exposure and a total of 11 mm of char after the second, illustrating the overall susceptibility of an unprotected pole to fire (Table III-9). Pole sections treated with Fire Guard experienced 2.7 mm of char after the first fire and 5 mm of char after the second (Figure III-20). Surface temperatures gradually increased on poles treated with Fire Guard, but ignition did not occur for 9 to 17 minutes (depending on the pole section), while one pole failed to ignite over the 20 minute exposure period (Figure III-21). Although the second burn produced additional char, the depth was only half of that found with the control.

Poles treated with Fire Shield experienced char depths that were similar to those found with Fire Guard; 2.5 mm of char after the first fire and 3.0 mm after the second. Ignition of Fire Shield poles took 10 to 11 minutes (Figure III-22). These results again illustrate the benefits of a fire retardant coating.

Poles wrapped with the Copper Care copper lined barrier system never ignited during either of the two fire exposures and therefore experienced no char (Table III-8). Similar poles equipped with a steel pole frame protector also failed to ignite and experienced no charring. These results illustrate the benefits of a solid coating material on the poles. Brooks wrap, which contains fire retardant but no metal liner did ignite on one pole but not the other, but only experienced 0.5 mm of char during the first burn and 3.5 mm of char during the second. The first time to ignition was 13 minutes, indicating this system provided some protection. This wrap was clearly effective on the first burn, but lost its protective effect during the second exposure.

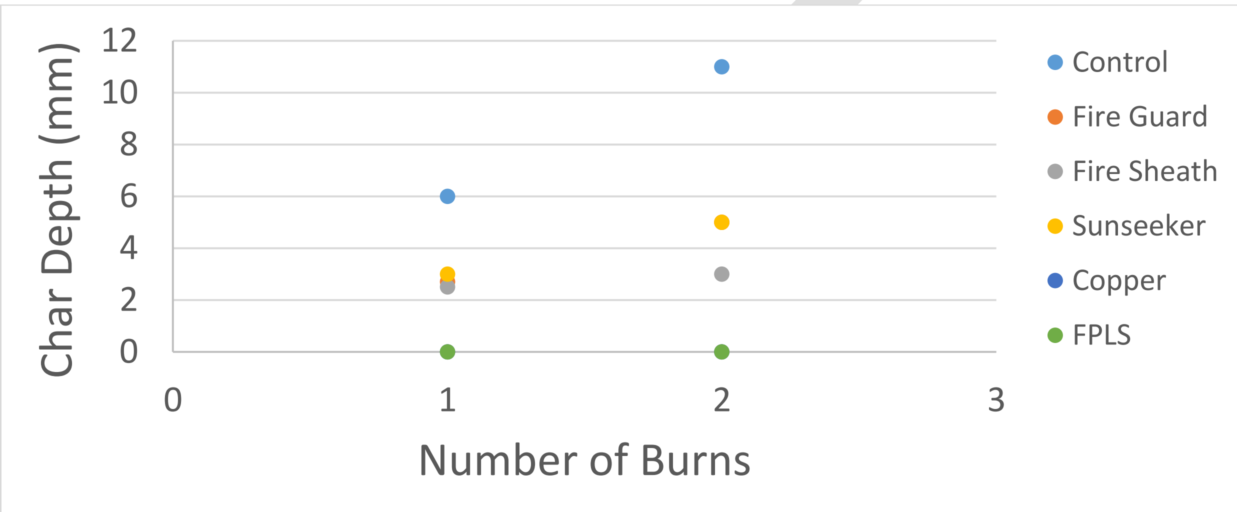


Figure III-20. Char depth on penta treated Douglas-fir pole sections with or without a fire retardant barrier after to two simulated fire exposures.

Table III-8. Characteristics of pole sections treated with various surface fire retardants and exposed to a fire test.

Treatment	Char Area (cm^2)	Char Depth (mm)	Ignition	Ignition Temp (°C)	Time to Ignition (Min)	Maximum Temperature (°C)
None	Total	8	Yes	145	10	438
FireGuard	20	>1	No	-	-	182
Fire Sheath	90	2	No	-	-	187
SunSeeker	Total	5	Yes	157	12	365
Brooks Barrier	480	>1	No	-	-	197
CuCare Barrier	200	>0.5	No	-	-	271

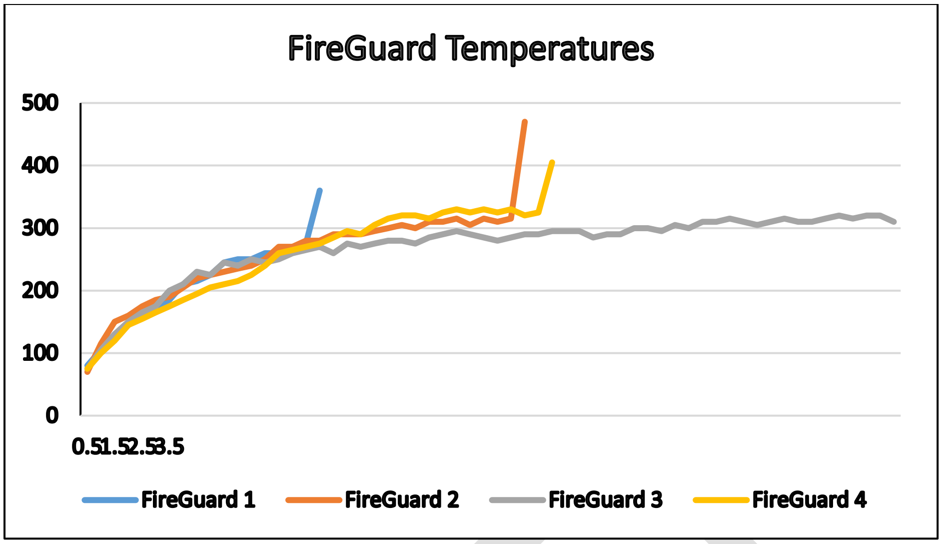


Figure III-21. Surface temperatures on poles treated with Fireguard and subjected to infra-red heating for 30 minutes or until ignition of the wood surface.

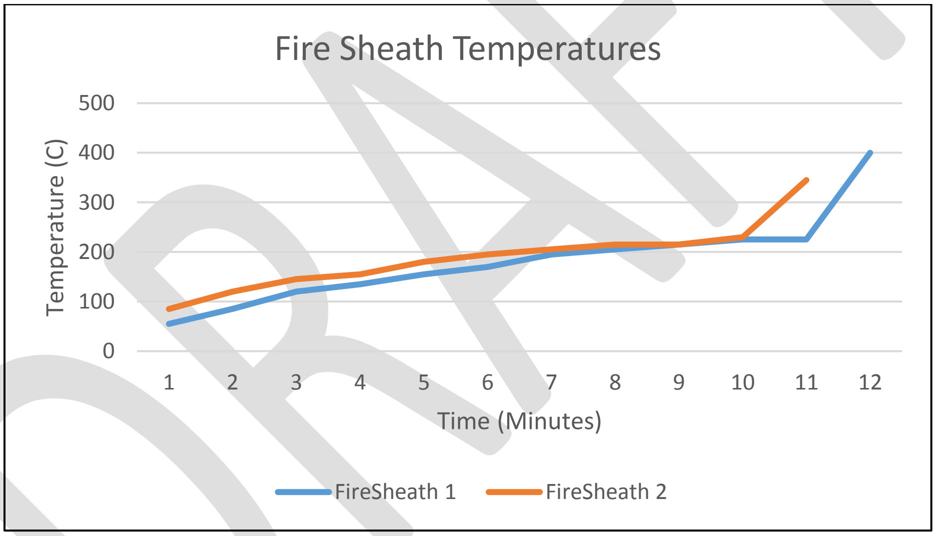


Figure III-22. Surface temperatures on poles treated with FireShield and subjected to infra-red heating for 30 minutes or until ignition of the wood surface.

Table III-9. Average depth of char (mm) on penta treated Douglas-fir pole sections with or without a fire retardant barrier after exposure to two simulated fire exposures.

Treatment	First Burn		Second Burn	
	N	Char Depth	N	Char Depth
None	3	6.0	2	11.0
FireGuard	3	2.7	2	5.0
FireShield	3	2.5	2	3.0
Sunseeker	1	3.0	1	5.0
CopperCare	2	0	2	0
Steel Shield	2	0	2	0
Brooks Wrap	2	0.5	2	3.5

G. Further Assessments of Western Redcedar and Lodgepole Pine Poles in Alberta, Canada

The development of an effective inspection and maintenance program is essential for maximizing the service life of any material. Wood poles are no exception to this premise. While there are a number of standard inspection processes and remedial treatment systems available in North America for this purpose, the process must be tailored to each utility based upon regulatory requirements, wood species, initial treatment types, climatic conditions and prior activities. One approach to refining an inspection/maintenance program is to examine a sub-sample of the pole population in the system to determine residual preservative protection, the incidence of decay fungi, and the amounts of remedial treatments remaining in the wood. These data can then be used to optimize program elements.

In 2009, the OSU UPRC and Fortis Alberta undertook an evaluation of wood power poles, under the care and control of Fortis Alberta, to determine both the residual retentions of original preservative as well as levels of remedial treatments that had been applied. A total of 44 poles were inspected: two creosote treated, six chromated copper arsenate (CCA) treated and the remainder were treated with penta. The majority of the poles treated with penta had been installed between 1958 and 2004. Some of the poles had been treated with metam sodium, while 27 poles received an external groundline paste. The poles were a mixture of lodgepole pine and western redcedar. The area is characterized by relatively low rainfall (~365 mm/year for Edmonton) which should result in slightly slower chemical diffusion. However, it is important to remember that site characteristics can vary widely, even within so called dry areas.

Retention results suggested the poles were properly treated, while the methylisothiocyanate (MITC) levels (the primary fungitoxic breakdown product of metam sodium) remaining in poles varied widely. The suggestion was that these poles would need to be re-treated within 2 to 3 years. Residual boron content in poles that received a supplemental surface treatment were somewhat lower than expected, but the sample size was fairly small. Copper was found near the surface, which is typical of poles treated with these external preservative paste systems.

In 2015, the Co-op and Fortis Alberta sampled an additional 176 poles (Tables III-9-12). The population included 44 CCA treated lodgepole pine, 43 CCA treated western redcedar, 44 penta treated lodgepole pine and 45 penta treated western redcedar poles.

Objectives: To determine if Fortis Alberta's current pole testing treatment cycle was sufficient to protect poles in the system. In order to achieve this objective, the following questions were addressed:

1. Are CCA and penta levels in poles sufficient to provide continued protection against decay?

2. When should the fumigant metam sodium be applied to provide continuous protection to poles?
3. Are boron levels in poles receiving external preservative bandages sufficient to provide protection against renewed decay?

Methods: Increment cores were removed at six equidistant locations around the pole at groundline and 300 mm above that zone to provide enough wood for analysis. The outer assay zones for each core were removed and these segments were combined for each pole before being ground to pass a 20 mesh screen and analyzed for residual CCA or penta by x-ray fluorescence spectroscopy. The remainder of each core was further divided by taking the outer and inner 25 mm segments and placing each into 5 ml of ethyl acetate. The cores were extracted in ethyl acetate for 48 hours before the ethyl acetate was poured off for analysis of MITC by gas chromatography. The core was then oven dried and weighed so that MITC content could be expressed on a ug/oven dried g of wood basis. Increment cores removed from some poles were placed on malt extract agar and observed over 28 days for evidence of fungal growth. This growth was examined for characteristics typical of basidiomycetes, a group of fungi containing many important wood decayers. These data provide a measure of the ability of various treatments to exclude decay fungi.

Results: Average CCA and penta retentions tended to be higher in western redcedar than in lodgepole pine, although CCA differences were slight (Figure III-23).

The current CSA O80 *"Wood Preservation"* specified retention for CCA treatment of lodgepole pine is 9.6 kg/m^3. Retentions in all of the CCA treated lodgepole pine poles were over that level, averaging 13.76 kg/m^3 (Tables III-10-13; Figure III-24). Retentions averaged 19.14 kg/m^3 for poles installed in 2000, 15.13 kg/m^3 for poles installed between 1990 and 1999, and 13.41 kg/m^3 in poles installed between 1986 and 1988. While there is a slight downward trend in retention with pole age, the differences are small and standard deviations are such that it would be difficult to say that the differences were meaningful. These results indicate CCA retentions remain far in excess of those needed for wood protection and no supplemental external treatment would be required for these poles.

According to CSA O80 *"Wood Preservation,"* the required initial CCA retention for western redcedar poles is 16 kg/m^3; however, this level is far in excess of that required for wood protection. All but four of the poles sampled had retentions in excess of 10 kg/m^3 and 22 had retentions over 16 kg/m^3, indicating these poles required no supplemental protection (Tables III-12-13; Figure III-24). One pole installed in 1994 had a retention of 6.11 kg/m^3 suggesting the need for this pole to be more carefully monitored over time, but even this retention approached the ground contact retention for CCA in most other applications. CCA retentions averaged 18.52 kg/m^3 for poles installed in 1975, 15.39 kg/m^3 for poles installed between 1988 and 1989, 14.39 kg/m^3 for poles installed between 1990 and 1996 and 14.69 kg/m^3 for poles installed in 2000. The results clearly indicate that CCA remains in western redcedar poles at protective levels.

According to CSA O80 *"Wood Preservation,"* the initial penta retention required for lodgepole pine is 9.6 kg/m^3. Penta retentions in lodgepole pine poles installed between 1971 and 1979 averaged 7.14 kg/m^3, while those installed in 1981-1986 averaged 6.14 kg/m^3, and retentions averaged 7.01 kg/m^3 for poles installed in 2000 (Tables III-10-13; Figure III-23). All of the averages were below the minimal level required for initial treatment and only five poles contained the required amount of penta, although they were still well above the ground contact threshold required for other penta applications. Averages can be deceptive, since they overlook poles where retentions are below the protective threshold. Twenty three of the 45 penta treated lodgepole pine poles examined had retentions below 6.4 kg/m^3, suggesting that these poles were losing sufficient amounts of penta to make it prudent to consider application of supplemental surface treatments. It is also important to note that half of the poles installed in 2000 had retentions below 6.4 kg/m^3, suggesting a need for more careful monitoring of initial treatment levels prior to pole installation. The results would argue for application of a protective supplemental preservative bandage below groundline when these poles are inspected.

According to CSA O80 *"Wood Preservation,"* the initial penta retention required for western redcedar is 12.8 kg/m^3. Retentions in poles installed between 1961 and 1965, and those installed between 1971-1978, averaged 4.63 and 4.81 kg/m^3, respectively (Tables III-12-14; Figure III-24). These poles were clearly in the range where retreatment would be prudent. All but two of the poles contained less than the minimum initial retention and 10 of 17 had retentions below 6.4 kg/m^3, further reinforcing the need for application of a supplemental preservative bandage. Retentions in poles installed between 1986 and 1988 averaged 10.36 kg/m^3, suggesting that the poles did not need retreatment; however, two poles had extremely low retentions ($<$2.00 kg/m^3). These results indicate that poles in this age group might merit further investigation to determine if retreatment would be prudent. Inspection of poles installed in 2000 showed that the poles had an average retention of 3.66 kg/m^3 and none met the minimal retention level. It is unclear why these poles were so poorly treated and it might be prudent to sample additional poles to determine if these data are consistent with the general population of poles of this vintage. The low retentions do, however, suggest the need for supplemental groundline treatment when poles are inspected.

Average MITC levels in most poles were lower in the outer zones, reflecting the tendency for the fumigant to diffuse out of the poles and into the surrounding atmosphere and the application of the tubes downward towards the pole center (Table III-15). Average MITC levels in the inner zones were above the threshold in lodgepole pine but well below that level in western redcedar.

Table III109. Characteristics of CCA treated lodgepole pine poles inspected in the Fortis Alberta system. Values in bold text are below the ground contact retention.				
Pole #	Year Installed	Age (Yr)	Year Fumigated	CCA Retention (kg/m^3)
7069050	2000	15	0	17.03
6156573	2000	15	0	19.02
6575770	2000	15	0	19.98
7184252	2000	15	0	18.93
6575653	2000	15	0	17.86
6476362	2000	15	0	21.93
6628137	2000	15	0	21.38
6932105	2000	15	0	17.74
6360567	2000	15	0	22.46
6102912	2000	15	0	18.95
6102913	2000	15	0	13.00
6102917	2000	15	0	21.89
6407917	2000	15	0	22.37
6863419	2000	15	0	15.39
6700079	1986	29	2013	15.08
6547826	1986	29	2013	13.52
6243431	1986	29	2013	12.31
6396281	1986	29	2013	14.50
6790107	1986	29	2015	11.79
6848120	1986	29	2014	17.17
6862573	1986	29	2012	11.46
6387866	1986	29	2012	10.97
6387710	1986	29	2012	13.37
6669875	1986	29	2012	8.73
6898418	1986	29	2008	12.77
6291211	1986	29	2008	11.22
6443018	1986	29	2008	16.51
7202680	1986	29	2008	15.95
6442505	1986	29	2008	12.32
6629536	1988	27	2009	15.50
6173062	1994	21	2009	15.70
6173073	1990	25	2009	10.00
6325310	1990	25	2009	11.00
6933275	1990	25	2009	13.23
7050438	1987	28	2010	14.80
6639817	1994	21	2010	19.27
7096124	1994	21	2010	19.70
6183471	1994	21	2010	16.99
6335733	1994	21	2010	15.23
6385989	1996	19	2011	18.40
6781462	1994	21	2011	16.56
6629687	1994	21	2011	13.94

6933646	1994	21	2011	10.47
6173367	1994	21	2011	16.74

Table III-11. Characteristics of penta treated lodgepole pine poles inspected in the Fortis Alberta System. Values in bold text are below the ground contact retention.

Pole #	Year Installed	Age (Yr)	Year Fumigated	Penta Retention (kg/m^3)
6581564	2000	15	0	7.74
7190021	2000	15	0	**6.00**
6581565	2000	15	0	**5.47**
6581566	2000	15	0	**5.83**
6429846	2000	15	0	8.54
6760795	2000	15	0	9.97
6359636	2000	15	0	8.29
6171852	1999	16	0	**3.60**
6019610	2000	15	0	8.22
6779952	1999	16	0	**4.35**
6102916	2000	15	0	**5.04**
6407912	2000	15	0	**6.19**
6863420	2000	15	0	**5.83**
7168076	2000	15	0	8.88
6711386	2000	15	0	8.47
6559689	2000	15	0	9.70
6055671	1986	29	2013	**4.01**
6664430	1986	29	2013	**4.08**
6055670	1986	29	2013	**3.78**
6512583	1986	29	2013	**4.23**
6208081	1986	29	2013	**3.75**
6902174	1986	29	2012	10.62
7168287	1986	29	2012	**3.73**
6559901	1986	29	2012	**6.05**
6558977	1986	29	2012	**4.14**
6862870	1986	29	2012	7.09
6730273	1986	29	2008	**5.96**
6832695	1986	29	2008	7.41
6275161	1986	29	2008	6.83
6579080	1986	29	2008	**4.52**
6730929	1986	29	2008	**5.05**
6629529	1986	29	2009	6.85
6850539	1983	32	2009	12.74
6090172	1979	36	2009	8.78
7176278	1971	44	2009	**4.77**
6156608	1975	40	2009	10.21
6879707	1977	38	2010	**5.60**
6575349	1970	45	2010	**2.90**
6575450	1982	33	2010	**5.73**
6933449	1982	33	2011	6.72
6781459	1981	34	2011	6.40

7089298	1982	33	2011	9.17
6477826	1979	36	2011	9.42
6477971	1979	36	2011	8.33

Table III-12. Characteristics of CCA treated western redcedar poles inspected in the Fortis Alberta system. Values in bold text are below the ground contact retention.

Pole #	Year Installed	Age (Yr)	Year Fumigated	CCA Retention (kg/m^3)
6452015	2000	15	0	8.49
6452016	2000	15	0	19.89
6147287	2000	15	0	15.04
7212101	2000	15	0	8.77
6299638	2000	15	0	19.03
6457030	2000	15	0	17.35
6000559	2000	15	0	13.88
6341930	2000	15	0	16.72
6610314	2000	15	0	12.47
6476363	2000	15	0	17.91
6787116	2000	15	0	10.91
6232497	2000	15	0	17.10
6840422	2000	15	0	17.29
6536634	2000	15	0	17.25
6992395	2000	15	0	8.21
6980742	1987	28	2010	14.89
6408529	1986	29	2015	11.14
7015766	1986	29	2015	11.80
7206585	1986	29	2015	17.05
6902472	1986	29	2015	16.62
7206584	1986	29	2015	16.78
6144803	1989	26	2008	14.33
7057331	1989	26	2008	17.70
7057332	1989	26	2008	14.74
7203608	1989	26	2008	12.63
6899332	1989	26	2008	18.69
6477822	1988	27	2009	18.16
7085457	1990	25	2009	18.78
7069088	1975	40	2009	20.90
6004545	1975	40	2009	12.99
6612139	1975	40	2009	21.68
2000219403	1989	26	2010	18.33
7095858	1994	21	2010	14.07
6943631	1994	21	2010	13.07
6666232	1994	21	2010	17.44
6666485	1994	21	2010	**6.11**
6689987	1996	19	2011	16.89
6477772	1989	26	2011	17.48
6951796	1988	27	2011	13.49
6648117	1988	27	2011	16.70

6191930	1988	27	2011	11.15

Table III-13. Characteristics of penta treated western redcedar poles inspected in the Fortis Alberta system. Values in bold text are below the ground contact retention.				
Pole #	Year Installed	Age (Yr)	Year Fumigated	Penta Retention (kg/m^3)
6693231	2000	15	0	**3.19**
6541167	2000	15	0	**2.81**
6389318	2000	15	0	**3.42**
6541169	2000	15	0	**2.41**
7149688	2000	15	0	**3.47**
6912543	2000	15	0	**5.29**
6457031	2000	15	0	**0.90**
6760798	2000	15	0	**1.90**
6914473	2000	15	0	**1.79**
6476365	2000	15	0	**4.14**
7015279	2000	15	0	**4.04**
7168078	2000	15	0	**6.17**
6178532	2000	15	0	**5.34**
6939368	2000	15	0	**4.21**
6787025	2000	15	0	**5.86**
6760655	1986	29	2014	**1.48**
6456799	1986	29	2014	13.46
6760593	1986	29	2014	8.51
7064796	1986	29	2014	9.73
6152172	1986	29	2014	8.30
6407539	1986	29	2012	9.22
6407247	1986	29	2012	**4.41**
6557100	1986	29	2009	**1.75**
6626973	1986	29	2009	7.42
6931023	1986	29	2009	8.34
6274849	1986	29	2008	13.84
7034966	1986	29	2008	9.20
6122926	1986	29	2008	13.77
6122631	1986	29	2008	10.77
6883173	1986	29	2008	10.84
6781510	1961	54	2009	**3.92**
6781329	1961	54	2009	**3.85**
6020962	1988	27	2009	**3.76**
6629530	1961	54	2009	**4.81**
6933598	1977	38	2009	**5.31**
7171005	1973	42	2010	**1.90**
6423583	1978	37	2010	7.38
6879592	1971	44	2010	6.48
6727356	1971	44	2010	**3.18**

6119020	1971	44	2010	**4.62**
6173469	1965	50	2011	**3.39**
6477814	1965	50	2011	**5.18**
6325572	1965	50	2011	**5.14**
6781566	1965	50	2011	6.48
6478144	1965	50	2011	**4.26**

Table III-14. Preservative retentions in lodgepole pine and western redcedar poles treated with CCA or penta as shown by time of installation.

Species	Treatment	Year Installed	N	Retention (kg/m^3)[a]	
				Average[a]	Range
LPP	CCA (9.6 kg/m^3)[b]	1986-1988	17	13.41 (2.27)	8.73-17.17
		1990-1996	13	15.13 (3.20)	10.00-19.70
		2000	14	19.14 (2.81)	13.00-22.46
	Penta (9.6 kg/m^3)	1971-1979	7	7.14 (2.73)	2.90-10.21
		1981-1986	21	6.14 (2.39)	3.73-12.74
		2000	16	7.01 (1.95)	3.60-9.97
WRC	CCA (16 kg/m^3)	1975	3	18.52 (4.81)	12.99 -21.68
		1988-1989	17	15.39 (2.58)	11.11-18.69
		1990-1996	6	14.39 (4.58)	6.11-18.78
		2000	15	14.69 (3.98)	8.21-19.89
	Penta (12.8 kg/m^3)	1961-1965	8	4.63 (0.98)	3.39-6.48
		1973-1978	6	4.81 (2.04)	1.90-7.38
		1986-1988	16	8.43 (3.91)	1.48-13.84
		2000	15	3.66 (1.56)	0.90-6.17

[a] Values in parentheses represent one standard deviation.
[b] CSA required retention for that species

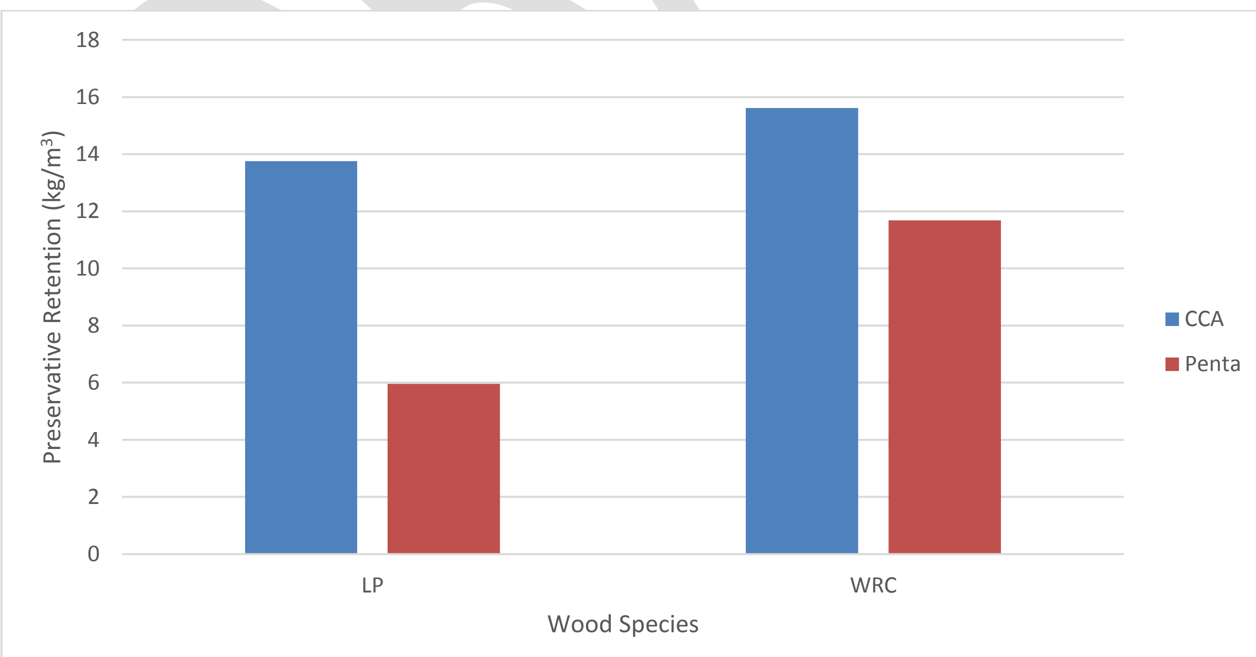
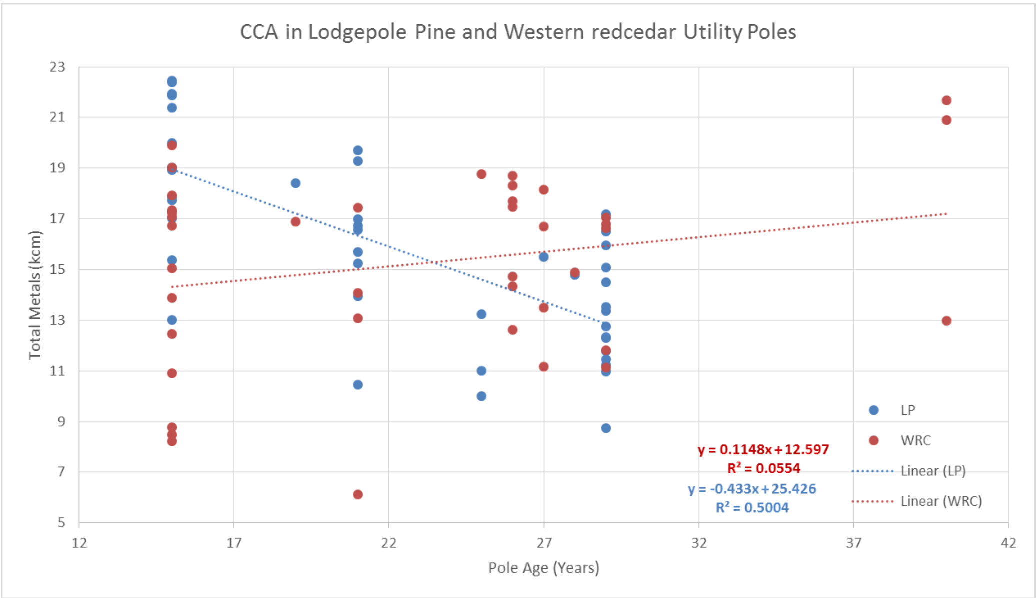


Figure III-23. Residual penta or CCA retention in lodgepole pine and western redcedar poles. Minimum CSA retention levels for CCA at 9.6 and 16.0 kg/m^3 for lodgepole pine and western redcedar, respectively. Minimum CSA retention levels for penta are 9.6 and 12.8, kg/m^3 respectively, for the same species.

As expected, MITC levels varied widely among poles and at different locations within a pole (Table III-15). These data must be viewed with caution since we lack data on initial treatment quality, nor do we know how well the initial chemical moved through the wood. MITC is the primary fungitoxic decomposition product of metam sodium, the only fumigant allowed in Canada for pole treatment by Health Canada's Pest Management Regulatory Agency (PMRA); however, decomposition is rather inefficient. It is estimated that only 12% of the total weight of metam sodium applied to a pole is converted to MITC. Previous studies have shown that this MITC is rapidly released and kills established decay fungi within 1 year of application. The protective period produced by metam sodium; however, is far lower than the periods provided by other internal treatments because the initial MITC release appears to rapidly exit the wood. Typically, MITC remains at effective levels in metam sodium treated Douglas-fir poles for only 3 to 4 years. The protective period will be even lower in poles of more permeable wood species which lose chemical more rapidly. By comparison, MITC levels in poles treated with two other fumigants used for this application, MITC-FUME or dazomet, remain at effective levels for 8 to 14 years after treatment. Ideally, Fortis Alberta would switch their program to use either of these treatments; however, neither of these chemicals is currently registered for application to wood in Canada.

The MITC threshold for fungal protection is approximately 20 ug/g of wood. Analysis of increment cores removed from 4 to 7 years after treatment indicated MITC was detectable in most poles near the groundline as well as 300 mm above that zone. The levels, however, were generally below the threshold at most sampling sites. Interestingly, MITC levels were sometimes higher 300 mm above groundline than at groundline. The short residence time of MITC in the poles following metam sodium treatment in this test is consistent with those found in other tests with this chemical. There also appeared to be little difference in MITC levels between lodgepole pine and western redcedar, suggesting that differences in wood chemistry and permeability did not alter MITC behavior over time.

Examining MITC levels in poles at groundline 4 to 7 years after metam sodium treatment showed levels trended downward except for the lodgepole pine inner assay zones, which appeared to increase (Figure III-25). These data must be considered carefully because they are taken from poles that were not all treated at the same time and were likely treated by different entities. For example, MITC levels were above threshold in the inner zones at groundline and 300 mm above groundline in only 2 and 1 poles, respectively, for the five penta treated lodgepole pine poles 7 years after treatment. Thus, the average suggests continued protection in these zones, but less than half the poles tested actually contained protective levels of chemical. These



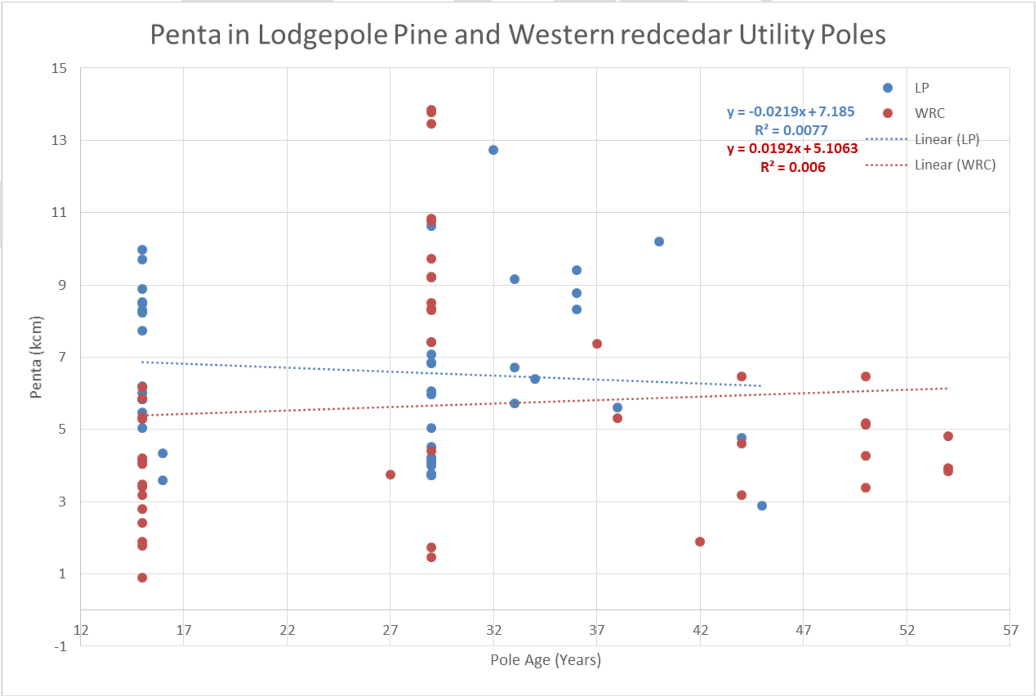


Figure III-24. Distribution of preservative retentions by pole age in CCA and penta treated lodgepole pine and western redcedar poles.

variations reflect pole condition, site, or remedial treatment quality. In general, however, MITC levels at 7 years clearly indicate treatment should be reapplied to provide continued protection against fungal invasion.

There is a tendency to think decline in MITC content below threshold translates to near immediate recolonization by decay fungi. However, the primary benefit of metam sodium as a fumigant is its ability to decompose to produce high levels of MITC (the active ingredient) to kill fungi within 300 to 900 mm of the point of application. The chemical then dissipates, leaving poles with relatively few active fungi. The recolonization process is slow and often takes several years before fungi can continue to degrade wood. Thus, the protective period is somewhat longer than the 3-4 years predicted by chemical level. Variations in chemical levels after 7 years, however, do indicate that reapplication of metam sodium might be prudent.

Table III-15. Residual MITC levels in lodgepole pine or western redcedar poles 4 to 7 years after application of metam sodium (NaMDC). Values represent means of 3 assays from each of 5 poles, while figures in parentheses represent one standard deviation.

Wood Species	Treatment	Years Since fumigation	Residual MITC Level (ug/g of wood) (MITC threshold for fungal protection is ~20 ug/g of wood)			
			Groundline		300 Above Groundline	
			Inner 25 mm	Outer 25 mm	Inner 25 mm	Outer 25 mm
LP+-P	CCA	4	4.45 (7.56)	**34.13 (27.22)**	12.03 (19.03)	**24.60 (19.75)**
		5	10.17 (11.98)	7.88 (15.91)	17.39 (25.51)	13.63 (16.68)
		6	**27.20 (27.11)**	15.69 (23.58)	**38.80 (43.45)**	6.85 (15.82)
		7	15.13 (11.65)	4.20 (8.55)	**36.37 (22.67)**	14.67 (20.06)
	Penta	4	13.53 (18.93)	**40.32 (28.57)**	**22.63 (25.59)**	**50.40 (40.24)**
		5	4.87 6.47)	0 (0)	10.46 (13.26)	**20.05 (46.25)**
		6	19.00 (29.66)	11.36 (25.59)	19.79 (20.95)	5.83 (9.57)
		7	**38.44 (56.30)**	2.60 (6.00)	**28.24 (36.63)**	9.48 (13.35)
WRC	CCA	4	4.35 (13.74)	8.31 (17.10)	1.68 (2.06)	14.19 (29.67)
		5	2.11 (6.11)	4.39 (16.74)	10.85 (15.82)	7.82 (12.89)
		6	1.88 (5.11)	0.08 (0.33)	4.11 (11.79)	0 (0)
		7	1.19 (4.47)	0.98 (2.60)	1.44 (3.40)	0.31 (1.05)
	Penta	4	12.64 (24.61)	**20.25 (20.89)**	**35.33 (29.41)**	**34.15 (31.56)**
		5	9.38 (20.64)	4.48 (10.77)	**23.79 (25.73)**	3.68 (7.76)
		6	3.07 (6.11)	5.81 (13.63)	**26.89 (29.58)**	3.24 (4.77)
		7	12.57 (10.56)	2.68 (4.59)	14.31 (15.18)	7.34 (9.31)

Boron is typically added to groundline pastes to provide protection against fungi away from the wood surface, while enhancing protection against surface decay fungi. There is no specific threshold for boron for fungal protection in groundline applications because boron mobility makes it difficult to assess and it has been difficult to accurately test the effect of combinations of low levels of the initial preservative and boron on fungal attack. As a result, the threshold used for measuring the efficacy of external preservative bandages have ignored initial preservative treatment and assumed all protection must come from the bandage. Using that approach, the threshold level for external protection with boron has been estimated at 0.825 kg/m^3 boron oxide, while the threshold for protecting wood away from the surface has been estimated at 0.300 kg/m^3 boron oxide.

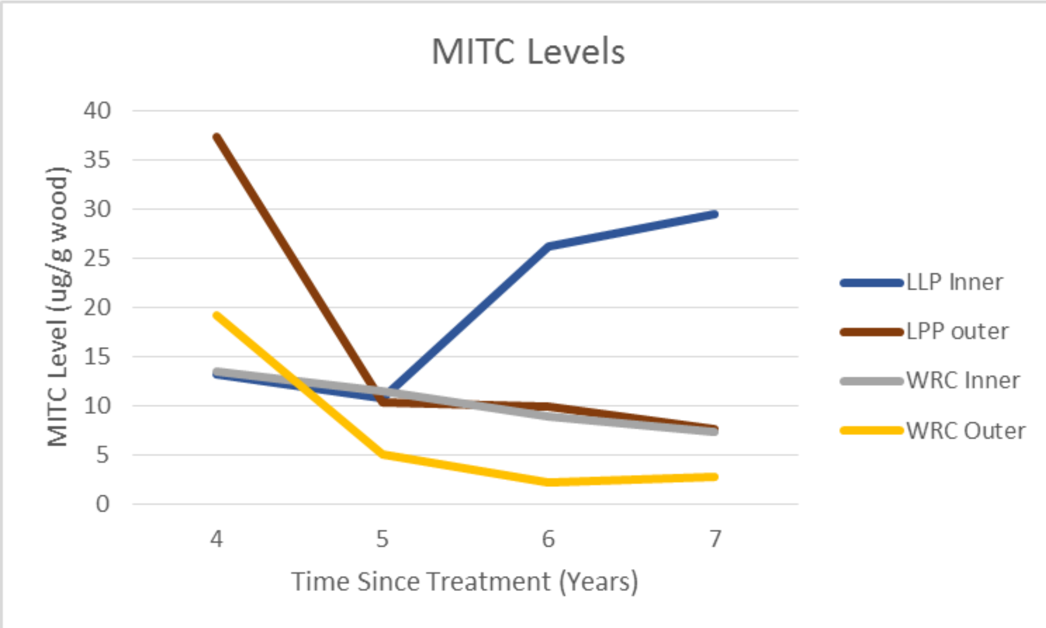


Figure III-25. MITC content in the inner and outer 25 mm of increment cores removed from the groundline of lodgepole pine (LPP) or western redcedar (WRC) poles 4 to 7 years after treatment with metam sodium.

Boron levels in poles sampled 1 to 7 years after treatment ranged from 0 to 0.566 kg/m^3 (Table III-16). None of the levels met the threshold for surface protection, while samples at four locations met the threshold for internal protection against fungal attack (Figure III-26). Results suggest boron levels are generally too low to be protective except shortly after application.

Boron levels in poles receiving a groundline preservative bandage tended to be lower in lodgepole pine than in western redcedar (Figure III-26). Boron levels were fairly uniform with distance from the wood surface, indicating boron diffused into the wood over time.

Boron is very mobile in water and will rapidly diffuse from wood, especially in wet areas. Results suggest groundline paste application should be further evaluated to ensure the treatment is achieving the desired protective goals.

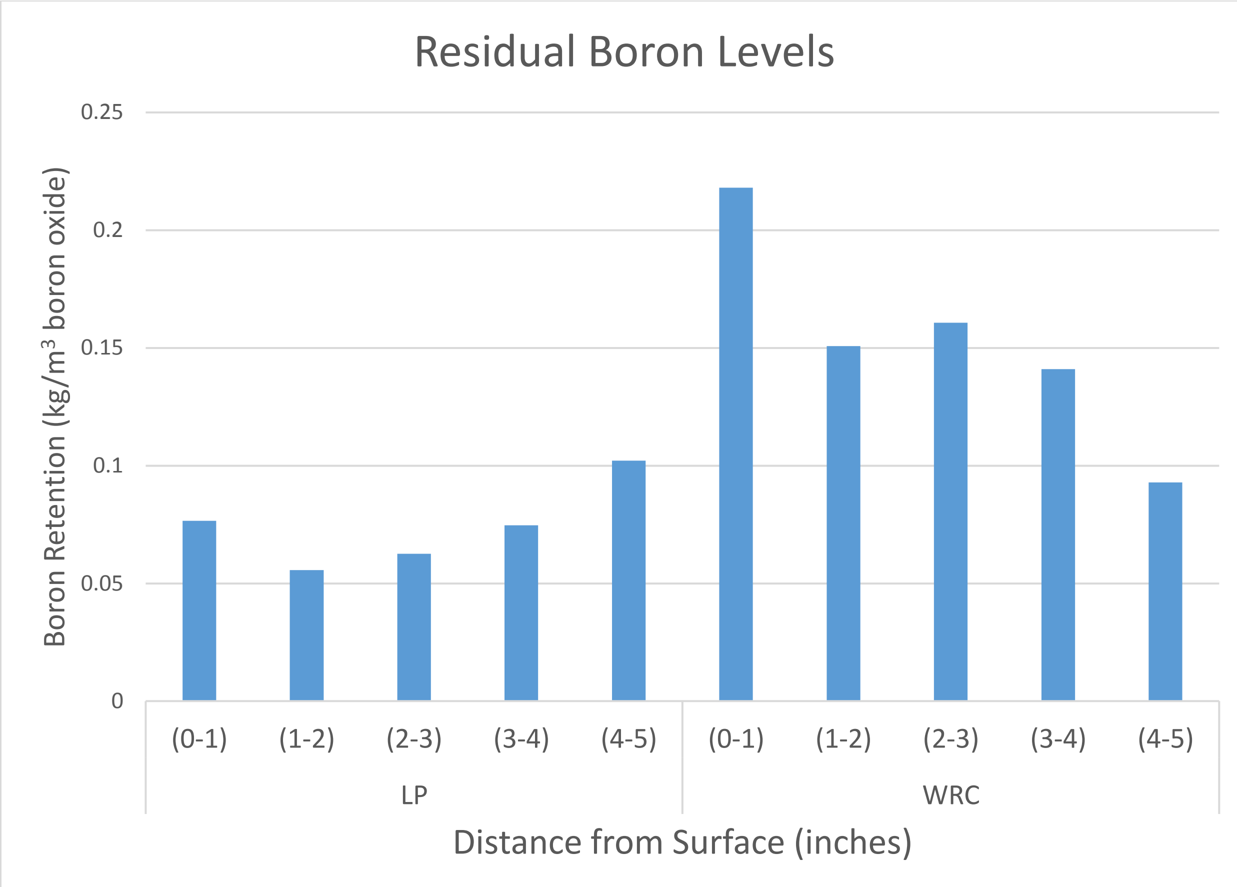


Figure III-26. Residual boron levels in western redcedar and lodgepole pole pine poles sampled after various treatment periods.

Table III-16. Residual boron levels at selected distances from the wood surface in western redcedar and lodgepole pine poles 1 to 7 years after application of an external preservative system. Values in bold are above the internal decay threshold.

Wood Species	Time Since Treatment	Residual Boron Content (kg/m^3 boron oxide)				
		0-25 mm	25-50 mm	50-75 mm	75-100 mm	100-125 mm
Lodgepole pine	1	0.211	0.171	0.232	**0.338**	**0.368**
	3	0.060	0.000	0.000	0.000	0.016
	6	0.021	0.003	0.015	0.015	0.082
	7	0.082	0.073	0.055	0.044	0.032
Cedar	0	**0.566**	0.247	**0.368**	0.185	0.113
	6	0.180	0.161	0.147	0.161	0.097
	7	0.131	0.080	0.088	0.075	0.073

Conclusions: The original objective of this work was to determine if Fortis Alberta's current program was achieving its goals. These will be addressed as they were listed in the original objectives.

1. *Are levels of CCA and penta in the poles sufficient to provide continued protection against decay?*

CCA retentions in poles remain well above the levels required to provide protection against fungal attack in nearly all of the poles tested. CCA reacts with wood and is strongly resistant to leaching. Pole retention levels suggest continued protection. As these poles age, it would be prudent to periodically select a small population of poles that would be checked for CCA retention to confirm levels remain sufficient for continued protection.

Penta retentions are more problematic. Many poles contained penta levels below the current minimum specified retention and a number are well below the threshold for protection. These results indicate the need for application of supplemental preservative treatments when these poles are inspected to help maintain a level of protection against fungal attack. It might also be prudent to inspect more recently installed poles to determine if the low residual penta levels are the result of depletion in the field or low initial retentions. The latter would suggest a re-evaluation of the vendor to ensure that they are providing poles that meet Fortis Alberta's specifications.

2. *When should the fumigant metam sodium be applied to provide continuous protection to poles?*

Fumigant levels vary widely in the poles examined and this is not surprising. MITC levels in most poles were very low 4 years after metam sodium application. As noted, this chemical provides a relatively short period of active chemical protection and fungi slowly re-enter the wood. The current 7 year retreatment cycle accounts for this sequence. While some utilities use longer cycles (10 years), they also accept more risk of decay developing in some poles in the system as a result of inherent variability in treatment quality and rate of fungal attack. The current cycle minimizes this risk of renewed pole degradation.

3. *Are boron levels in poles receiving external preservative bandages sufficient to provide protection against renewed decay?*

Boron levels in poles were slightly elevated shortly after application of an external preservative bandage, but these levels declined rapidly with time after treatment and none of the levels were completely protective against surface decay. Levels deeper in the poles were slightly higher and some would be protective against internal fungal attack. Boron levels were slightly higher in western redcedar poles than lodgepole pine, but the overall low boron levels in these poles suggest the need for re-examination of the systems being used for this purpose.

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

Over the past 6 years, we have performed a number of trials examining the effects of solvents on performance of both copper naphthenate and penta. The work originally began because of changes in the solvents used to solubilize penta for treatment of Douglas-fir. It was common practice for west coast treaters to take large blocks of penta, place them in the treating cylinder and circulate hot oil to dissolve the penta to the proper solution concentration. This required oils that had sufficient penta solvency, but this was generally not a problem. Changing supplies of petroleum based solvents towards solvents with much lower penta solvency created a major concern for these treaters. One alternative was to use a penta concentrate that was then diluted with diesel oil; however, this solvent mixture had strong odors and the more 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 has the ability to 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 was undertaken to evaluate the efficacy of penta in conventional solvents, diesel with penta concentrate and penta in a biodiesel blend. These results indicated that the 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 any amount 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 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 wood was primarily sapwood and had not been subjected to any 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 (Figure III-27).

Samples were weighed prior to treatment and subjected to approximately 30 psi of initial air pressure. Treatment solution was pumped into the vessel and the pressure was raised to 150 psi and held for at least 2 hours. The pressure was released and a 2 to 4 hour vacuum was drawn to relieve internal pressure and recover residual preservative solution. The stakes continued to lose solvent after treatment and were allowed to stabilize for at least 2 weeks before being re-weighed to determine net solution uptake (Figure III-27). The net weight gain was used to estimated residual preservative retention which was used to allocated stakes or blocks to given treatment groups. Samples with excessively high or low retentions were not included.

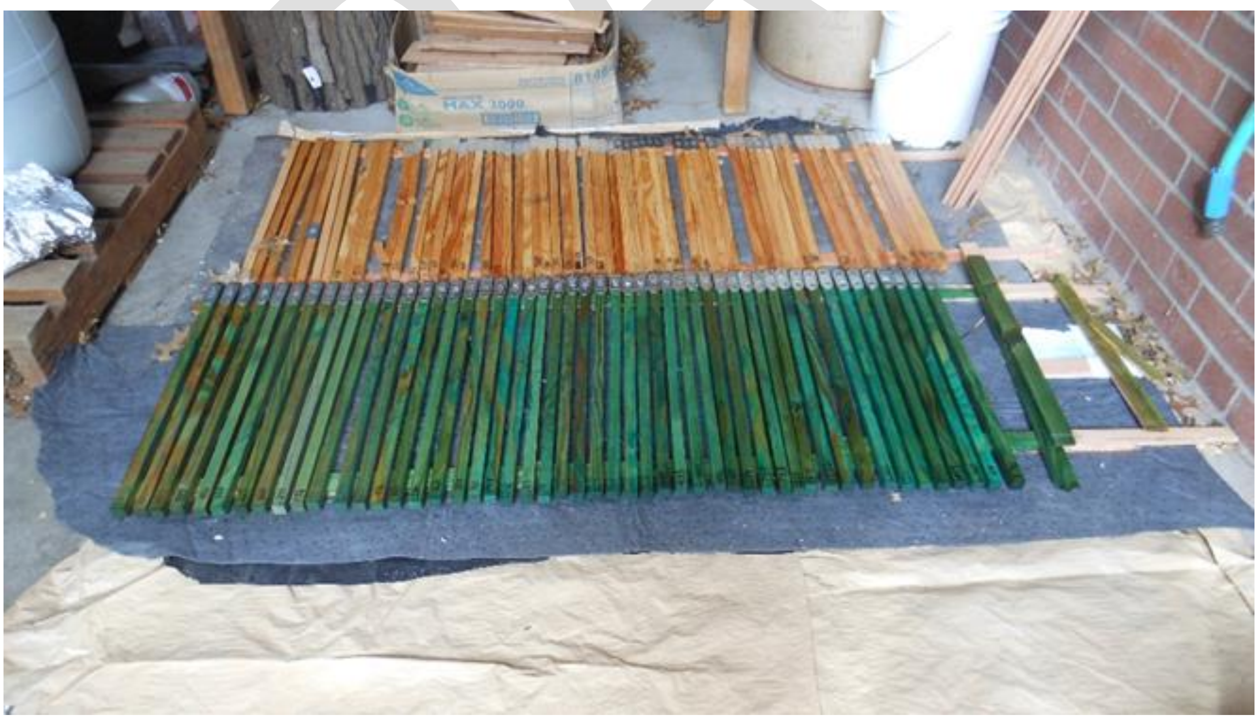


Figure III-27. Stakes drying under cover after treatment with copper naphthenate (bottom) or penta (top).

Stake condition was evaluated at the Corvallis site after 18 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

Stakes in the open field setting tended to have lower degree of fungal attack than those in the wooded area (Tables III-17, 18). This reflects climatic conditions at the site which is characterized by having 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 still 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. Non-treated stakes in the open field site averaged 9.90 while those in the forest site averaged 8.0. Stakes treated with solvent but no biocide tended to be in slightly better condition, especially in the forest site, but differences were slight and we would 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.

Table III-17. Condition of Douglas-fir sapwood stakes treated with penta or copper naphthenate in various solvents and exposed for 18 months in a meadow site near Corvallis, Oregon.

Treatment	Carrier	Biodiesel (%)	Average Stake Condition				
			Control	*2.4 kg/m³*	*4.8 kg/m³*	*7.2 kg/m³*	*9.6 kg/m³*
Penta	Diesel	0	10.00 (0.0)	10.00 (0.0)	10.00 (0.0)	9.90 (0.2)	10.00 (0.0)
		30	9.90 (0.2)	10.00 (0.0)	9.95 (0.2)	9.95 (0.2)	9.98 (0.1)
		50	9.70 (0.9)	9.95 (0.2)	9.95 90.2)	10.00 (0.0)	10.00 (0.0)
		70	9.95 (0.2)	9.98 (0.1)	10.00 (0.0)	-	-
	Aromatic oil	0	10.00 (0.0)	10.00 (0.0)	9.90 (0.3)	10.00 (0.0)	10.00 (0.0)
	Naphthenic oil	30	10.00 (0.0)	9.95 (0.2)	9.95 (0.2)	9.95 (0.2)	9.98 (0.1)
	Paraffinic oil	30	9.95 (0.2)	10.00 (0.0)	10.00 (0.0)	10.00 (0.0)	10.00 (0.0)
	FPRL oil	0	9.95 (0.2)	9.90 (0.2)	10.00 (0.0)	10.00 (0.0)	9.98 90.1)
	Ketone bottoms	0	9.90 (0.2)	9.90 (0.2)	9.95 (0.2)	10.00 (0.0)	9.95 (0.2)
Copper Naphthenate	Diesel	-	*Control*	*0.66 kg/m³*	*0.99 kg/m³*	*1.33 kg/m³*	*1.66 kg/m³*
		0	-	10.00 (0.0)	9.98 (0.1)	9.98 (0.1)	10.00 (0.0)
		10	9.90 (0.2)	10.00 (0.0)	9.98 (0.1)	9.98 (0.1)	10.00 (0.0)
		30	-	9.85 (0.3)	9.93 90.2)	9.93 (0.2)	9.90 (0.3)
		50	-	9.90 (0.3)	9.88 (0.3)	9.88 (0.3)	10.00 (0.0)
		100	9.95 (0.2)	9.60 (0.9)	9.98 (0.1)	9.98 (0.1)	9.95 (0.2)

Values represent means of 10 stakes per treatment. Figures in parentheses represent one standard deviation. Ratings for the non-treated control averages 9.90 (Standard deviation = 0.30). Copper naphthenate values are as Cu metal.

Table III-18. Condition of Douglas-fir sapwood stakes treated with penta or copper naphthenate in various solvents and exposed for 18 months in a forest site near Corvallis, Oregon.

Treatment	Carrier	Biodiesel (%)	Average Stake Condition				
			Control	*2.4 kg/m³*	*4.8 kg/m³*	*7.2 kg/m³*	*9.6 kg/m³*
Penta	Diesel	0	8.70 (1.5)	9.20 (0.9)	9.65 (0.3)	9.95 (0.2)	9.88 (0.4)
		30	9.05 (1.0)	9.50 (0.4)	9.80 (0.3)	9.95 (0.2)	9.65 (0.5)
		50	8.95 (1.0)	9.35 (0.7)	9.45 (0.6)	9.75 (0.4)	9.73 (0.5)
		70	8.75 (1.0)	9.83 (0.5)	9.75 (0.5)	-	-
	Aromatic oil	0	9.80 (0.3)	9.85 (0.3)	9.95 (0.2)	9.85 (0.5)	9.93 (0.2)
	Naphthenic oil	30	9.45 (0.7)	9.70 (0.5)	9.85 (0.2)	9.90 (0.3)	9.90 (0.3)
	Paraffinic oil	30	9.35 (0.7)	9.30 (1.3)	9.95 (0.2)	9.90 (0.2)	9.70 (0.6)
	FPRL oil	0	9.25 (0.4)	9.60 (0.5)	9.95 (0.2)	9.70 (0.7)	9.98 (0.1)
	Ketone bottoms	0	9.25 (0.8)	9.70 (0.5)	9.90 (0.2)	9.40 (0.7)	9.95 (0.2)
Copper Naphthenate	Diesel	-	*Control*	*0.66 kg/m³*	*0.99 kg/m³*	*1.33 kg/m³*	*1.66 kg/m³*
		0	-	9.80 (0.3)	9.85 (0.3)	9.88 (0.3)	9.75 (0.4)
		10	8.85 (1.0)	9.75 (0.5)	9.65 (0.3)	9.68 (0.5)	9.85 (0.2)
		30	-	9.55 (0.4)	9.25 (0.7)	9.63 (0.5)	9.35 (0.6)
		50	-	8.70 (0.9)	9.40 (0.7)	9.23 (0.8)	9.55 (0.6)
		100	8.60 (1.6)	8.60 (1.2)	8.85 (1.1)	9.35 (0.7)	8.95 (1.2)

Values represent means of 10 stakes per treatment. Figures in parentheses represent one standard deviation. Ratings for the non-treated control averages 8.0 (Standard deviation = 2.0).

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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 wood surfaces, gradually reducing effective circumference until pole 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 penta, potassium dichromate, creosote, fluoride and an array of insecticides. In the 1980s, the U.S. Environmental Protection Agency reexamined 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 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 Peavy Arboretum or on poles in active utility lines. Most of these trials have been completed (Table IV-1).

B. Performance of External Groundline Treatments in Drier Climates

External groundline preservatives are applied throughout the United States. We have previously established field trials in Oregon, California, Georgia and New York to assess the effectiveness of these treatments under a range of environmental conditions. We have neglected to collect field performance data is dry climates. Conditions in these areas markedly differ from those in wet climates. While soil moisture content near the surface may be low, subsurface moisture contents can be conducive to decay. Also, soil conditions may be more alkaline in arid climates. These characteristics may alter the performance of supplemental groundline treatments.

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.	

In order to assess this possibility, western pine, southern pine, western redcedar and Douglas-fir poles in both the Salt River Project and Arizona Public Service systems were selected for study (Table IV-2). Pole population consisted of poles treated with creosote or penta in AWPA Solvent Types A, B, and D. Solvent Types B and D are both volatile systems that evaporate from wood after treatment, leaving a clean and dry surface, while Solvent P9 Type A remains in the pole. There has been a long history of performance issues related to Solvent Types B and D use. The absence of residual solvent tends to render penta less effective against soft rot fungi and these poles tend to experience substantial surface degradation in relatively short times after installation. While neither Solvent Types B nor D are still being used, hundreds of thousands of poles that were initially treated this way remain in service.

Seven treatments (Table IV-3) were applied to an equal number of poles of each species/solvent combination when possible. The exception was Bioguard Tri-Bor paste, which was applied only to Douglas-fir poles treated with penta in Solvent P9 type A. The area around each pole was excavated to a depth of 600 mm, and any decayed surface wood was removed. Pole circumference was measured to ensure each pole retained sufficient sectional area. Small pieces of surface wood were removed from poles and placed in plastic bags for culturing. These wood samples were placed on malt extract agar in petri dishes and any fungi growing from the wood were examined for characteristics typical of decay fungi. The goal was to characterize surface fungi present at time of treatment versus subsequent post-treatment years.

Pole circumference was measured at groundline. Treatments were supplied in paste form and amounts applied were calculated using a products unit weight and recommended thickness (Table IV-3). Paste was applied to poles 75-460 mm below groundline. The bucket used for applying pastes was weighed before and after application to ensure that the calculated paste coverage per unit area was achieved. Pastes were covered with the recommended barrier and soil was replaced around the pole.

The degree of chemical migration was assessed 17, 30, or 56 months after treatment by excavating one side of each pole, removing a small section of external barrier (100 by 100 mm) 150 mm below groundline and scraping away excess paste. Wraps on poles damaged by animal gnawing (Figure IV-1) were noted wherever present. Two sections of shavings were removed with a 38 mm diameter Forstner bit at the first two sampling times; the first sample from the outer surface to about 6 mm and the second continuing in the same hole to about 12 mm. A portion of the shavings were briefly flamed and placed on malt extract agar in Petri plates to determine soft rot fungal presence. The remainder of the shavings were ground to pass a 20 mesh screen. One half was analyzed for copper and boron, if necessary, and the other half was analyzed for any organic preservative present. At all three sampling times, an additional six increment cores were removed from the exposed zone. The cores were segmented: 0-6, 6-13, 13-25, 25-50 and 50-75 mm from the surface. Cores from each zone were combined and ground to pass a 20 mesh screen. It was necessary to combine wood from 0-6 and 6-16 mm zones from several poles in a treatment to accumulate sufficient material for copper analysis. Material from three poles of the same utility were combined for these zones resulting in two copper analyses per treatment. The resulting wood samples were analyzed for residual chemical using the most appropriate method. Boron was analyzed by the Azomethine-H method while copper was analyzed by x-ray fluorescence

Table IV-2. Characteristics of poles receiving external preservative treatments in the Phoenix, Arizona area. APS = Arizona Public Service, SRP = Salt River Project.

Species	Primary Treatment	Year	Class/Length	Site	Treatment	Fungal isolations[b] (before treatment)
SP	penta	1997	1/40	APS	Osmose EP[a]	Non-decay
WP	gas	1986	5/40	APS	MP400-EXT	
WP	gas	1985	5/40	APS	Bioguard	
DF	gas	1983	5/40	APS	CuBor	
WP	gas	1983	5/40	APS	Osmose EP	Soft rot
WP	gas		5/40	APS	Control	
WP	gas	1983	5/40	APS	COP-R-PLASTIC II	
WP	gas	1972	5/40	APS	CuBor	Soft rot
WP	gas	1984	5/40	APS	CuRap 20	
WP	gas	1981	5/40	APS	CuRap 20	
WP	gas	1981	5/40	APS	MP400-EXT	
WP	gas	1972	5/40	APS	Osmose EP	Soft rot
WP	gas	1972	5/40	APS	COP-R-PLASTIC II	
WP	gas	1972	5/40	APS	Bioguard	Soft rot
WP	gas	1983	5/40	APS	CuRap 20	
WP	gas	1983	5/40	APS	CuRap 20	
WP	gas	1984	5/40	APS	CuBor	Decay
WP	gas	1984	5/40	APS	COP-R-PLASTIC II	
DF	gas	1984	5/40	APS	Bioguard	
DF	gas	1962	5/35	APS	MP400-EXT	mold
DF	creosote	1962	5/35	APS	Osmose EP	Soft rot
WP	gas	1984	5/40	APS	CuBor	
WP	gas	1984	5/40	APS	COP-R-PLASTIC II	
WP	gas	1984	5/40	APS	Bioguard	
DF	creosote	1962	5/35	APS	CuRap 20	Decay and mold
DF	creosote	1962	5/35	APS	COP-R-PLASTIC II	Decay and mold
DF	creosote	1962	5/35	APS	MP400-EXT	Soft rot
DF	creosote	1962	5/35	APS	Control	
WRC	creosote		4/35	APS	Bioguard	
WRC	creosote		4/35	APS	CuBor	mold
WRC	penta	1987	5/40	APS	Control	Non-decay
WRC	penta	1987	5/40	APS	Osmose EP	
WRC	penta	1987	5/40	APS	MP400-EXT	Decay and soft rot
WP	creosote	1989	5/40	APS	Osmose EP	mold
WP	gas	1986	5/40	APS	MP400-EXT	
WP	gas	1986	5/40	APS	COP-R-PLASTIC II	

Table IV-2 cont. Characteristics of poles receiving external preservative treatments in the Phoenix, Arizona area. APS = Arizona Public Service, SRP = Salt River Project.

Species	Primary Treatment	Year	Class/Length	Site	Treatment	Fungal isolations[b] (before treatment)
WP	gas	1986	5/40	APS	CuBor	
DF	gas	1986	5/40	APS	CuRap 20	
DF	penta	1992	4/40	APS	Bioguard	
DF	creosote	1992	4/40	APS	Control	
DF	gas	1986		APS	Control	
WP	gas	1986	5/40	APS	Control	
DF	penta	2006	1/45	SRP	MP400-EXT	
DF	penta	2002	3/45	SRP	CuBor	
DF	penta	2002	3/45	SRP	COP-R-PLASTIC II	
DF	penta	2001	3/45	SRP	Bioguard	
DF	penta	2002	4/40	SRP	Osmose EP	
DF	penta	2002	4/40	SRP	CuRap 20	
DF	penta	2002	4/40	SRP	MP400-EXT	
DF	penta	2002	4/40	SRP	CuBor	
DF	penta	2001	4/40	SRP	COP-R-PLASTIC II	
DF	penta	2001	4/40	SRP	Bioguard	
DF	penta	2000	4/40	SRP	Osmose EP	
DF	penta	1999	3/45	SRP	Control	
DF	penta	1999	3/45	SRP	CuRap 20	
DF	penta	1999	3/45	SRP	MP400-EXT	Soft rot
DF	penta	1999	3/45	SRP	Control	
DF	penta	1999	3/45	SRP	CuBor	
DF	penta	1999	3/45	SRP	COP-R-PLASTIC II	
DF	penta	1999	3/45	SRP	Bioguard	
DF	penta	1999	3/45	SRP	Osmose EP	
DF	penta	1999	3/45	SRP	CuRap 20	
DF	penta	1999	3/40	SRP	MP400-EXT	
DF	penta	2001	4/40	SRP	Control	
DF	penta	2001	4/40	SRP	CuBor	
DF	penta	1998	1/45	SRP	COP-R-PLASTIC II	
DF	penta	1998	1/40	SRP	Bioguard	
DF	penta	1998	4/40	SRP	Osmose EP	
DF	penta		4/40	SRP	Control	Soft rot
DF	penta	2002	1/40	SRP	CuRap 20	
DF	penta	2002	4/40	SRP	MP400-EXT	
DF	penta	2002	3/45	SRP	Control	

Table IV-2 cont. Characteristics of poles receiving external preservative treatments in the Phoenix, Arizona area. APS = Arizona Public Service, SRP = Salt River Project.

Species	Primary Treatment	Year	Class/Length	Site	Treatment	Fungal isolations[b] (before treatment)
DF	penta	2002	3/45	SRP	CuBor	
DF	penta	2002	3/45	SRP	COP-R-PLASTIC II	
DF	penta	2002	3/45	SRP	Bioguard	
DF	penta	2002	3/45	SRP	Osmose EP	
DF	penta	2000	3/45	SRP	CuRap 20	
DF	penta	2002	3/45	SRP	MP400-EXT	
DF	penta	2004	3/45	SRP	CuBor	
DF	penta	2001	3/45	SRP	COP-R-PLASTIC II	
DF	penta	2006	3/45	SRP	Bioguard	
DF	penta			SRP	Control	
DF	penta			SRP	Osmose EP	
DF	penta	2002	3/40	SRP	CuRap 20	
DF	penta	2002	4/40	SRP	Bioguard Tri-Bor EP	
DF	penta	2007	4/40	SRP	Bioguard Tri-Bor EP	
DF	penta	2008	4/40	SRP	Bioguard Tri-Bor EP	
DF	penta	2009	4/40	SRP	Bioguard Tri-Bor EP	
DF	penta	2007	4/40	SRP	Bioguard Tri-Bor EP	
DF	penta	2005	4/40	SRP	Bioguard Tri-Bor EP	
DF	penta	2004	3/45	APS	Bioguard Tri-Bor EP	
DF	penta	2008	2/50	APS	Bioguard Tri-Bor EP	
DF	penta	2008	2/50	APS	Bioguard Tri-Bor EP	
DF	penta	2007	3/45	APS	Bioguard Tri-Bor EP	
DF	penta			APS	Bioguard Tri-Bor EP	
DF	penta	2006	3/45	APS	Bioguard Tri-Bor EP	

Table IV-3. Material properties of the pastes tested in the Arizona field trial.

Paste	lb/gal	Active Ingredient	% Active
Cu-Bor	10.1	copper hydroxide (2% metallic Cu) sodium tetraborate decahydrate	3.1 43.5
CuRap 20	10.1	copper naphthenate (2% metallic Cu) sodium tetraborate decahydrate	18.2 40.0
COP-R-PLASTIC II	12.4	sodium fluoride copper naphthenate (2% metallic Cu)	44.4 17.7
MP400-EXT	10.6	sodium tetraborate decahydrate copper-8 quinolinolate (micronized) tebuconazole bifenthrin	43.7 0.3 0.2 0.04
Osmose experimental paste	10.8	unknown (copper carbonate)	
Bioguard paste	11.0	boric acid sodium fluoride	40.8 22.5
Bioguard Tri-Bor experimental paste	11.0	boric acid Borax 5 mol (Neobor) Boroguard ZB (zinc borate hydrate)	10 40 5

spectroscopy (XRF) or inductively-coupled plasma mass spectroscopy (ICP). Supplemental analysis of wood for boron by ICP was well correlated with Azomethine-H analyses. We initially analyzed both cores and shavings for copper and boron in order to determine whether the two sampling methods produced similar values but in recent years have determined that collecting shavings is unnecessary. Also, bifenthrin and tebuconazole were not analyzed since results have been variable over the course of this test. We have experienced considerable interference from other materials in the treated shell. As a result, we have omitted these analyses from further consideration and will only discuss copper and boron data.

Figure IV-1. Poles in the APS system after excavation showing evidence of animal gnawing on the barrier bandage.

Fluoride levels in poles treated with either Bioguard or COP-R-PLASTIC II (CRP II) 17 months after treatment were both above threshold for protection against internal fungal attack in the outer 13 mm (0.15% wt/wt), and declined with distance from the surface (Table IV-4). Fluoride levels were near threshold in APS poles in the 13-25 mm assay zone 17 months after treatment, but were below threshold further inward. Fluoride levels in Bioguard treated poles were slightly higher in the outer assay zone in APS poles but lower in SRP poles, although differences were not large. Levels further inward were below threshold in poles from both utilities, suggesting that fluoride in Bioguard was not contributing markedly to performance. Fluoride has the ability to migrate into wood with moisture and eventually, as previous test results suggest, should become evenly distributed within pole cross sections. Data from Arizona suggests that this process is occurring more slowly in dry conditions.

In addition to different fluoride treatment levels, there appeared to be differences in levels by utility. Bioguard treatments were higher in APS poles (Table IV-4). It is unclear why such differences might develop, although initial treatment and species may contribute. SRP poles were all Douglas-fir penta in oil while APS poles were pine, western redcedar and Douglas-fir variously treated with creosote and penta in both oil and liquefied petroleum gas. It is possible that carriers influenced movement, although it is unclear why they might do so differentially. Fluoride is no longer used in paste systems in the U.S. As a result, we have discontinued monitoring this component.

Two different thresholds were used for assessing concentration. The higher threshold (0.275% BAE) was used in the 0-13 mm assay zone since this zone was subjected to more aggressive leaching as well as possible soft rot. Wood in this zone must be protected from soil inhabiting fungi adjacent to poles; these fungi are also harder to control. The lower threshold (0.1% BAE) was used in interior zones because this wood has a lower risk of fungal attack, typically from basidiomycetes more sensitive to boron (Table IV-5).

Table IV-4. Fluoride levels in poles of various species 17 or 30 months after application of Bioguard or COP-R-PLASTIC II.[1]

Treatment	Months	Utility	Fluoride Levels (% wt/wt)			
			Distance from the surface (mm)			
			(0-13)	(13-25)	(25-50)	(50-75)
Bioguard	17	APS	0.47	0.13	0.04	0.03
		SRP	0.26	0.09	0.02	0.01
	30	APS	**0.63**	0.07	0.00	0.00
		SRP	0.17	0.07	0.03	0.01
COP-R-PLASTIC II	17	APS	0.19	0.01	0.00	0.00
		SRP	0.25	0.09	0.00	0.00
	30	APS	Not Sampled			
		SRP				

[1]Numbers in bold are above the toxic threshold of 0.50% F for the outer zone and 0.15 for the three inner zones.

Boron levels in poles treated with six different preservative pastes were at or above threshold for protection against external fungal attack in the outer 25 mm, 17 months after application (Figure IV-2, 3). Boron levels were below threshold in this zone in SRP poles 30 months after application of CuRap 20, but above that level for APS poles. Boron levels in SRP poles 13-25 mm inward were above threshold, using the lower threshold target. Similar to fluoride, chemical levels differed between utilities. It is unclear why, but initial pole treatment is likely a factor. Boron levels at 50 mm declined, but were still above threshold for protection against internal fungal attack for most treatments. This suggests that boron is moving short distances into poles, but not as deeply as it might in wet climates. Boron levels at 50-75 mm appear to be limited. Expectations for boron movement in this environment may need to shift, although lack of deep boron migration in a pole 0-450 mm belowground suggests limited moisture availability for diffusion. Reduced moisture levels also suggests less of a need for preservatives. It is important to remember that moisture regimes in poles in this region are elevated further below groundline. The ability to deliver protective levels of chemicals into this zone warrants further effort.

Boron levels 56 months after treatment generally declined, but still tended to be highest near the surface and declined further inward. Boron levels were above threshold in outer zones of poles receiving CuRap 20, TriBor, and Bioguard, but were more variable with other treatments and between utilities. Boron levels tended to be higher in APS poles. Boron levels also tended to remain low further inward from the surface. This finding differs slightly from results found in poles in wet areas where boron levels tend to become more uniform with depth over time. This may reflect the lower moisture contents in wood in poles at these sites and suggests that these treatments will perform differently under dry climate conditions.

Boron levels in outer zones were higher in APS than SRP poles, except for the Osmose Experimental Paste 17, 30, and 56 months after treatment (Table IV-5; Figure IV-3). It is unclear why this occurred, but the differences suggest initial preservative treatment may influence performance of supplemental treatments. We attempted to examine the role wood species played in boron distribution; however, samples were combined by treatment for copper analysis which made this task impossible, except for poles treated with Bioguard paste. Results suggest that field performance of external preservatives in dry climates differs with initial treatment, although all boron in all the paste systems effectively moved into the outer 50 mm of wood.

Copper was present in five of the external preservative pastes tested. For this test, a minimum protective threshold of 0.15% (wt/wt) was assumed. As noted in previous reports, there are no data on effects of multiple component systems to the threshold of individual constituents; we have used the threshold for each component assuming that there was no interaction. Data presented in Objective I support this premise for boron and copper. Copper analyses obtained from cores and shavings were similar for both CRP II and Cu-Bor, but results were lower in shavings from the outer 6 mm of poles treated with CuRap 20 after 17 and 30 months. It is unclear why this occurred since results were similar in inner pole zones receiving this treatment. Given the general agreement between results, we elected to compare cores only. Copper was present above threshold in outer pole zones receiving Cu-Bor and CuRap 20 after 17 and 30 months; CRP II was not inspected in this cycle, but was above threshold at 17 months (Table IV-6, Figure IV-4). Copper levels declined in outer pole zones treated with CuRap 20 and CuBor 17, 30, or 56 months after treatment. This is consistent with previous field trials of copper based treatments (Figure IV-4). Copper levels again were below threshold in the next zone inward for all treatments, which is also consistent with previous field trials (Figure IV-5). Copper is added to external preservative barriers to protect against renewed fungal attack. It is not expected to move into wood beyond the outer zone.

Copper values for MP400 EXT and Osmose Experimental Paste were modified from the 2014 Annual Report to express copper on an oxide basis- rather than elemental copper.

This was done for consistency between pastes and resulted in a slight rise in copper levels 17 months after treatment. Copper concentration for these pastes were determined by nitric acid digestion and ICP analysis. This was necessary because these pastes contain low levels of copper.

Low levels of copper were detected in the outer zone of poles treated with MP400-EXT or Osmose Experimental Paste (Figure IV-6). Copper levels in poles treated with MP-400 EXT were below threshold at all three sampling points, while they were above threshold in the outer zone of the experimental formulation.

Table IV-5. Boron levels at selected distances from the wood surface in Douglas-fir, western redcedar or pine poles 17, 30, or 56 months after treatment with CuBor, CuRap 20, Bioguard, TriBor, MP400, or Osmose Exp. Paste with data combined for species.

Treatment	Months	Utility	Boron Concentration (% wt/wt BAE)			
			Distance from the surface (mm)			
			(0-13)	(13-25)	(25-50)	(50-75)
Cu-Bor	17	APS	**1.03**	**0.20**	0.04	0.01
		SRP	**0.53**	**0.41**	**0.14**	0.02
	30	APS	**0.48**	**0.16**	0.05	0.02
		SRP	**0.69**	**0.14**	0.08	0.02
	56	APS	0.12	**0.35**	**0.41**	**0.36**
		SRP	0.05	**0.27**	**0.41**	**0.17**
CuRap 20	17	APS	**2.53**	**0.80**	**0.14**	0.03
		SRP	**1.09**	**0.49**	**0.14**	0.05
	30	APS	**1.01**	**0.68**	**0.45**	**0.23**
		SRP	0.16	**0.16**	0.09	0.03
	56	APS	**1.05**	**0.33**	**0.32**	**0.21**
		SRP	**1.14**	**1.85**	**1.54**	**0.32**
Bioguard	17	APS	**2.31**	**0.78**	**0.31**	**0.13**
		SRP	**0.87**	**0.63**	**0.26**	0.09
	30	APS	**3.29**	**0.89**	0.07	0.01
		SRP	**0.46**	**0.39**	**0.22**	**0.10**
	56	APS	**1.77**	**1.93**	**1.00**	**0.58**
		SRP	**0.81**	**0.64**	**0.43**	**0.17**
TriBor	17	APS	**2.23**	**1.02**	**0.17**	0.02
		SRP	**1.65**	**0.61**	**0.19**	0.07
	30	APS	**1.68**	**1.16**	**0.32**	0.02
		SRP	**1.32**	**0.76**	**0.30**	0.08
	56	APS	**2.10**	**1.37**	**0.87**	**1.54**
		SRP	**1.22**	**0.68**	**0.45**	**0.86**
MP400-EXT	17	APS	**2.04**	**0.66**	**0.18**	**0.11**
		SRP	**1.02**	**0.47**	**0.15**	0.03
	30	APS	**1.26**	**0.68**	**0.20**	0.05
		SRP	**0.35**	**0.29**	**0.14**	0.04
	56	APS	**0.84**	**0.62**	**0.35**	**0.21**
		SRP	0.19	**0.16**	**0.12**	0.07
Osmose Exp	17	APS	**1.08**	**0.15**	0.02	0.01
		SRP	**1.15**	**0.46**	**0.15**	0.02
	30	APS	**0.62**	**0.56**	**0.23**	0.06
		SRP	**0.36**	**0.38**	**0.23**	0.08
	56	APS	**1.71**	**1.04**	**0.76**	**0.17**
		SRP	**0.28**	**0.27**	**0.17**	**0.10**

[1]Numbers in bold are above the toxic threshold of 0.275% BAE for the outer zone or 0.10 for the three inner zones.

Table IV-5. Boron levels at selected distances from the wood surface in Douglas-fir, western redcedar or pine poles 17, 30, or 56 months after treatment with CuBor, CuRap 20, Bioguard, TriBor, MP400, or Osmose Exp. Paste with data combined for species.

Treatment	Months	Utility	Boron Concentration (% wt/wt BAE) Distance from the surface (mm)			
			(0-13)	(13-25)	(25-50)	(50-75)
Cu-Bor	17	APS	**1.03**	**0.20**	0.04	0.01
		SRP	**0.53**	**0.41**	**0.14**	0.02
	30	APS	**0.48**	**0.16**	0.05	0.02
		SRP	**0.69**	**0.14**	0.08	0.02
	56	APS	0.12	**0.35**	**0.41**	**0.36**
		SRP	0.05	**0.27**	**0.41**	**0.17**
CuRap 20	17	APS	**2.53**	**0.80**	**0.14**	0.03
		SRP	**1.09**	**0.49**	**0.14**	0.05
	30	APS	**1.01**	**0.68**	**0.45**	**0.23**
		SRP	0.16	**0.16**	0.09	0.03
	56	APS	**1.05**	**0.33**	**0.32**	**0.21**
		SRP	**1.14**	**1.85**	**1.54**	**0.32**
Bioguard	17	APS	**2.31**	**0.78**	**0.31**	**0.13**
		SRP	**0.87**	**0.63**	**0.26**	0.09
	30	APS	**3.29**	**0.89**	0.07	0.01
		SRP	**0.46**	**0.39**	**0.22**	**0.10**
	56	APS	**1.77**	**1.93**	**1.00**	**0.58**
		SRP	**0.81**	**0.64**	**0.43**	**0.17**
TriBor	17	APS	**2.23**	**1.02**	**0.17**	0.02
		SRP	**1.65**	**0.61**	**0.19**	0.07
	30	APS	**1.68**	**1.16**	**0.32**	0.02
		SRP	**1.32**	**0.76**	**0.30**	0.08
	56	APS	**2.10**	**1.37**	**0.87**	**1.54**
		SRP	**1.22**	**0.68**	**0.45**	**0.86**
MP400-EXT	17	APS	**2.04**	**0.66**	**0.18**	**0.11**
		SRP	**1.02**	**0.47**	**0.15**	0.03
	30	APS	**1.26**	**0.68**	**0.20**	0.05
		SRP	**0.35**	**0.29**	**0.14**	0.04
	56	APS	**0.84**	**0.62**	**0.35**	**0.21**
		SRP	0.19	**0.16**	**0.12**	0.07
Osmose Exp	17	APS	**1.08**	**0.15**	0.02	0.01
		SRP	**1.15**	**0.46**	**0.15**	0.02
	30	APS	**0.62**	**0.56**	**0.23**	0.06
		SRP	**0.36**	**0.38**	**0.23**	0.08
	56	APS	**1.71**	**1.04**	**0.76**	**0.17**
		SRP	**0.28**	**0.27**	**0.17**	**0.10**

[1]Numbers in bold are above the toxic threshold of 0.275% BAE for the outer zone or 0.10 for the three inner zones.

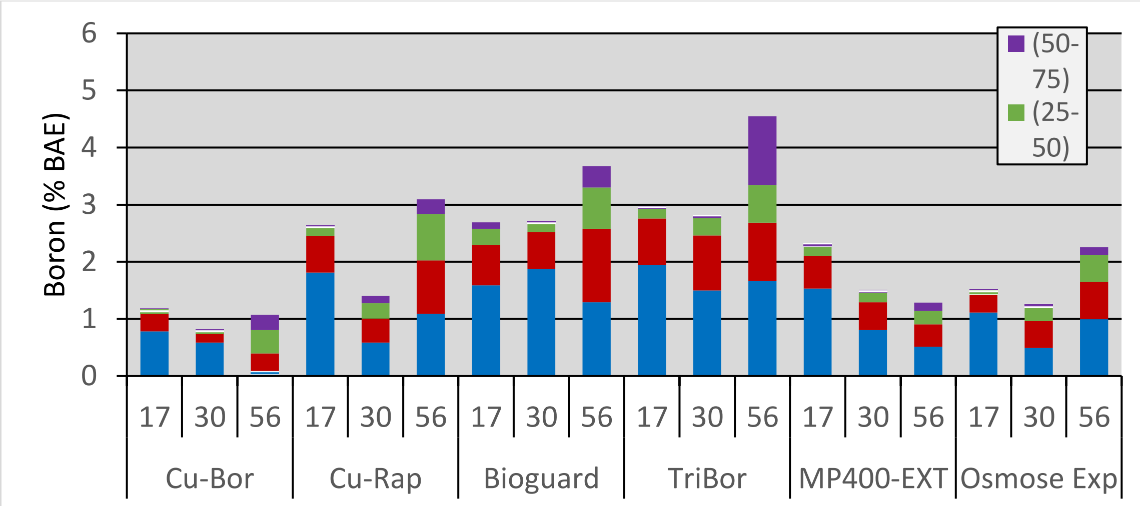

Figure IV-2. Total boron measured in the outer 75 mm of poles 17, 30 or 56 months after treatment with selected boron-containing pastes. Solid bars are above the toxic threshold of 0.275% BAE for the outer zone or 0.10 for the three inner zones.

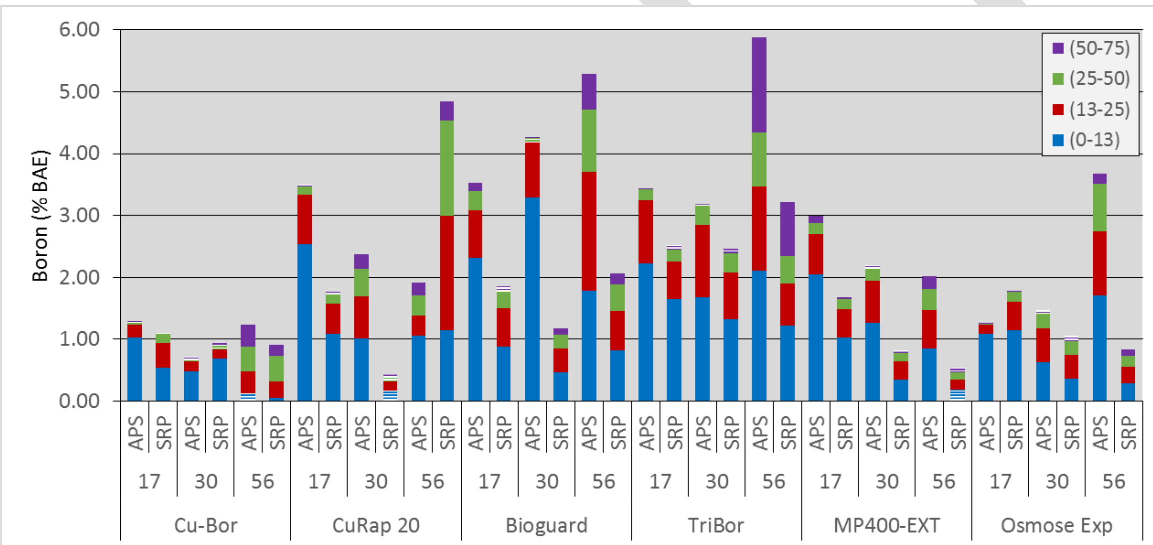

Figure IV-3. Boron content in the outer 75 mm of poles of various species segregated by utility 17, 30, or 56 months after application of various boron-containing pastes. Solid bars are above the toxic threshold of 0.275% BAE for the outer zone or 0.10 for the three inner zone.

These results bear some explanation. MP400-EXT utilizes a micronized oxine copper component that is suspended rather than solubilized. Oxine copper is far more effective than copper naphthenate. Thus, the threshold may be higher than required. There is some evidence that, while this approach works well with southern pine, copper does not penetrate less permeable woods such as Douglas-fir. Therefore, copper penetration into the wood may be limited. Ultimately, this may not affect overall preservative performance because copper is only one component and in combination with bifenthrin and tebuconazole provides a surface barrier against renewed fungal attack. Boron is expected to migrate deeper into wood and arrest any existing fungal attack. Further evaluations will be required to determine if this premise is correct. Unlike boron, where the initial treatment influenced subsequent distribution, there were no consistent differences in copper levels among treatments by utility (Figure IV-7). The lack of difference may reflect shallow overall penetration of copper compared with more mobile boron.

Table IV-6. Copper levels at selected distances from the wood surface in poles of various species 17, 30, and 56 months after application of copper containing preservative pastes. Separated by utility.[1]

Treatment	Months	Copper Levels (% wt/wt as CuO) Distance from the surface (mm)					
		Utility	(0-6)	(6-13)	(13-25)	(25-50)	(50-75)
Cu-Bor	17	APS	**0.31**	0.00	0.00	0.00	0.00
		SRP	**0.35**	0.03	0.01	0.00	0.00
	30	APS	**0.46**	0.04	0.01	0.00	0.00
		SRP	**0.30**	0.03	0.01	0.00	0.00
	56	APS	**0.22**	0.01	0.00	0.00	0.00
		SRP	0.13	0.03	0.01	0.00	0.00
CuRap 20	17	APS	**0.98**	0.03	0.01	0.00	0.00
		SRP	**0.65**	0.05	0.01	0.00	0.00
	30	APS	**0.55**	0.10	0.01	0.00	0.00
		SRP	**0.28**	0.03	0.01	0.00	0.00
	56	APS	**0.21**	**0.22**	0.02	0.00	0.00
		SRP	**0.16**	0.04	0.01	0.00	0.00
MP400-EXT	17	APS	0.01*	0.01*	0.00	0.00	0.00
		SRP	0.01*	0.00	0.00	0.00	0.00
	30	APS	0.00	0.00	0.00	0.00	0.00
		SRP	0.01	0.00	0.00	0.00	0.00
	56	APS	0.00	0.00	0.00	0.00	0.00
		SRP	0.00	0.00	0.00	0.00	0.00
Osmose Exp	17	APS	**0.04***	0.00	0.00	0.00	0.00
		SRP	**0.10***	0.00	0.00	0.00	0.00
	30	APS	**0.09**	0.01	0.00	0.00	0.00
		SRP	**0.14**	0.01	0.00	0.00	0.00
	56	APS	**0.08**	0.01	0.00	0.00	0.00
		SRP	**0.06**	**0.06**	0.01	0.00	0.00
COP-R-PLASTIC II[2]	17	APS	**0.49**	0.07	0.01	0.00	0.00
		SRP	**0.64**	0.14	0.01	0.00	0.00
	30	APS	Not Sampled				
		SRP					
	56	APS	**0.16**	**0.15**	0.03	0.00	0.00
		SRP	**0.15**	0.04	0.01	0.00	0.00

1. Numbers in bold are above the toxic threshold of 0.15% Cu.
2. COP-R-PLASTIC II was not sampled at 30 months.
* Numbers were corrected from the 2012 report to account for CuO, rather than Cu, concentration.

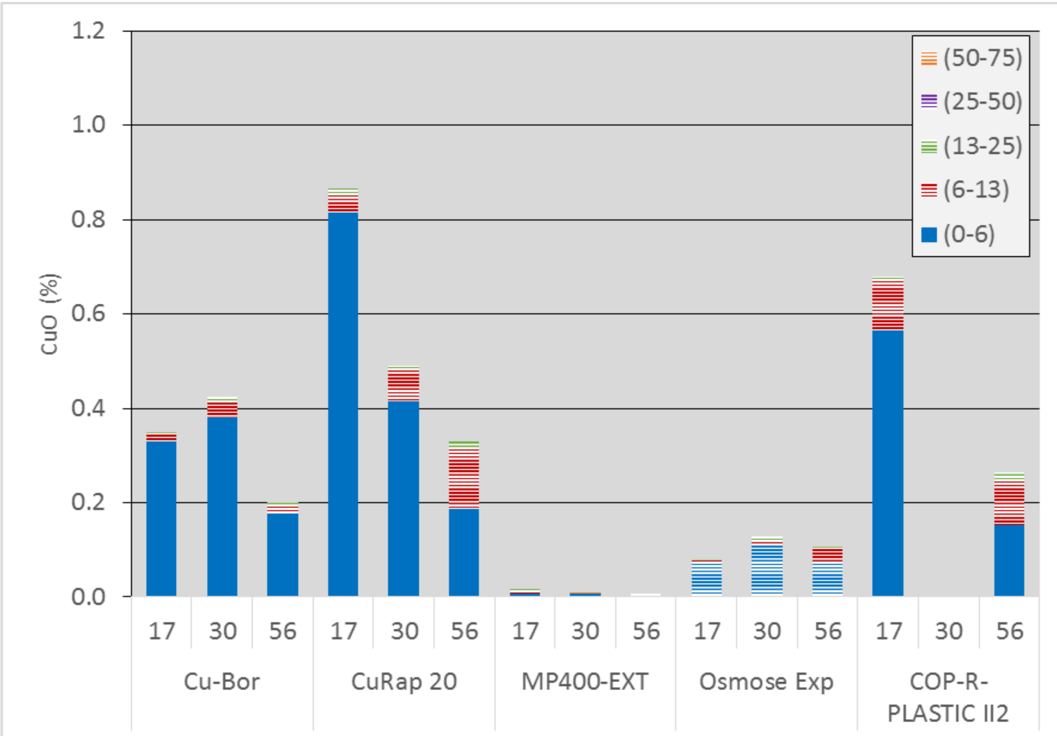

Figure IV-4. Stacked bar graph showing total copper levels in the outer 75 mm of poles 17, 30, or 56 months after application of copper containing preservative pastes. Note that most copper is in the outer assay zone.

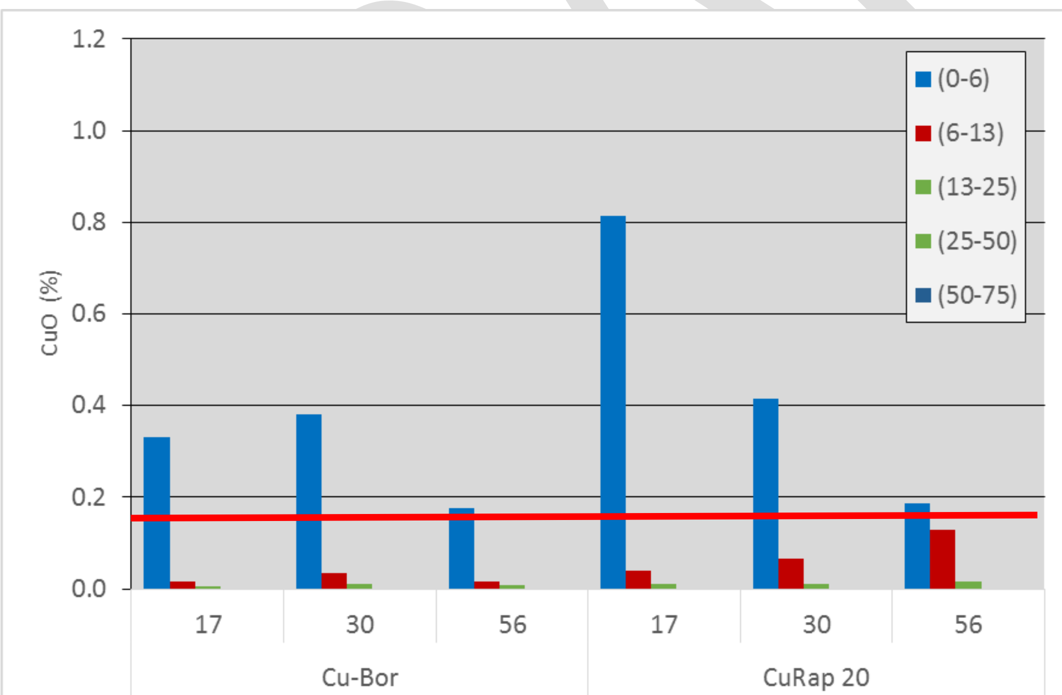

Figure IV-5. Copper levels at selected distances from the surface of poles 17, 30, or 56 months after application of either CuBor or CuRap 20. The horizontal line indicates the presumed protective threshold for the form of copper in these systems.

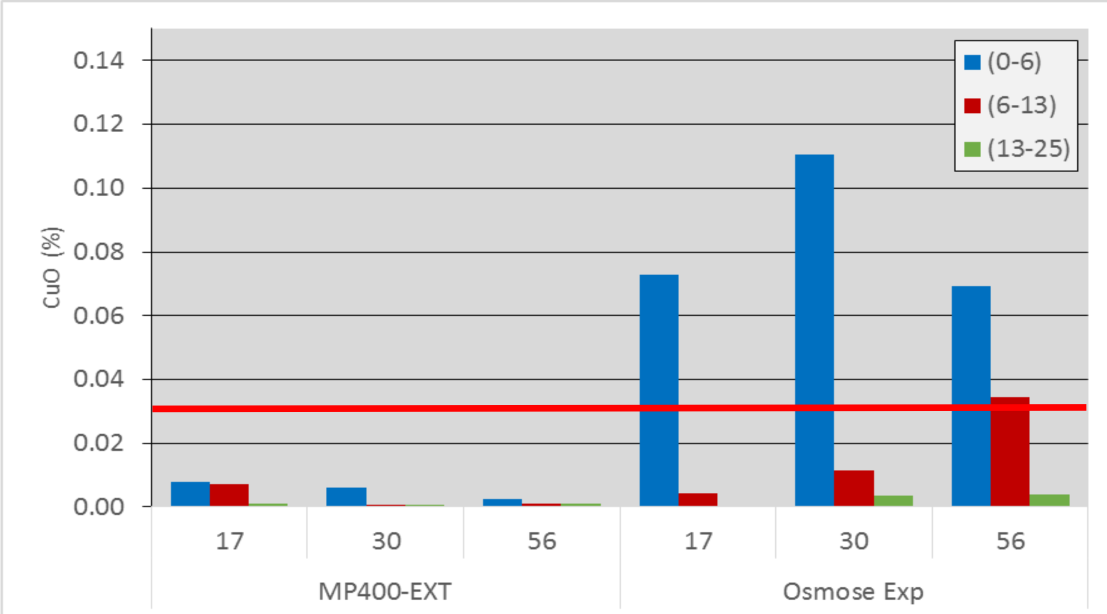

Figure IV-6. Copper levels at selected distances from the surface of poles 17, 30, or 56 months after application of either MP-400-EXT or Osmose Experimental paste. The horizontal line indicates the presumed protective threshold for the form of copper in these systems.

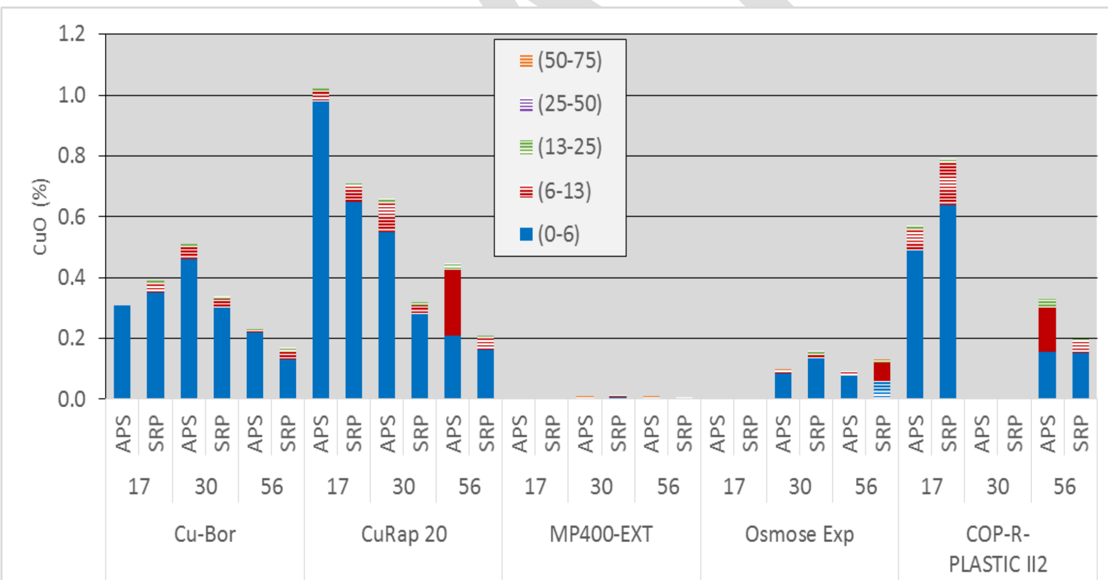

Figure IV-7. Copper levels in poles 17, 30, or 56 months after treatment with selected copper containing preservative pastes segregated by treatment and utility.

These results suggest that copper, tebuconazole and bifenthrin form a barrier near the wood surface (0-13 mm), while boron diffuses more deeply into the wood. This pattern is similar to other multi-component external preservative barriers and indicates that this system should perform well as an external preservative paste.

C. Effect of External Barriers on Pole Performance

Preservative treatment is a remarkably effective barrier against biological attack, but these same chemicals can be susceptible to migration into the surrounding soil. A number of studies documenting chemical migration have shown migration to occur a short distance around a treated structure and that levels present do not pose a hazard in terms of environmental impact or disposal. Despite these data, some utilities have explored the use of external barriers to contain any migrating preservative. These barriers, while not necessary in terms of environmental issues, may have a secondary benefit in terms of both retaining the original chemical and limiting the entry of moisture and fungi.

The potential for barriers to limit moisture uptake in poles has been assessed in a trial where pole sections with two different barriers were installed in either soil or water. Poles were kept indoors and not subjected to overhead watering. Results showed that considerable moisture wicked up poles and moisture contents at groundline were suitable for decay. 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 2 years of installation. These poles were moved to our test site and set such that the tops of the barriers extend 150 mm above the soil level. These pole sections were then sampled for wood moisture content (MC) at groundline, 150 mm above groundline and 300 mm above groundline immediately after installation and 2 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 liner and set into the ground at Peavy Arboretum (Figure IV-8). The poles were sampled prior to installation to determine chemical penetration and retention and baseline MC. Five poles received a Biotrans liner that extended 150 mm above groundline; five received a Biotrans liner that extended 300 mm above groundline and eleven poles were left without liners.

The poles were sampled over 77 months after installation by removing three increment cores from a single location 150 mm below groundline but were not sampled this past year. They will be examined in 2017.

Figure IV-8. Example of a Biotrans liner at the Peavy Arboretum test site.

D. Potential for using borate mixtures as groundline preservative pastes

(This section is a portion of Mr. Selim Uysal's MSc thesis- which was supported by the Turkish government)

External decay is typically controlled by application of supplemental preservative pastes that arrest existing fungal attack and limit other fungi from entering wood. Preservative pastes provide protection for a limited period and are re-applied on a 10 to 15 year retreatment cycle. Most pastes contain a copper-based fungicide along with a co-biocide. Copper compounds include copper naphthenate, copper hydroxide and oxine copper. These compounds have limited mobility in wood and are primarily designed to provide surface protection against renewed fungal attack. Themost common co-biocides are borates; usually sodium octaborate tetrahydrate or sodium tetraborate decahydrate. Both compounds have high degrees of water solubility and can easily move for 3 to 25 mm inward from the wood surface, inhibiting activity of fungi already established within wood. One alternative to copper is to develop pastes made solely from borates. While current boron pastes have high water solubility, other borates are less soluble in water and might make good surface barriers (Table IV-7). For example, zinc borate is widely used as a component in composite wood panels and wood plastic composites because of its ability to slowly release boron but is not currently registered for remedial treatment applications. Combinations of borates with differing degrees of water solubility might allow for a controlled release system whereby more soluble borates rapidly released boric acid that moved into wood to arrest existing fungal attack, while less soluble borates slowly release boric acid to provide continued protection.

The potential for using this approach was explored with a small block paste test. Douglas-fir sapwood lumber [(nominal 2 by 4 inch (50 by 100 mm)] was obtained locally and cut into 37.5 by 87.5 by 150 mm long pieces. A 37.5 mm diameter by 5 mm deep hole was drilled in the middle of one wide face of each block (Figure IV-9). Blocks were oven dried at 50°C and weighed (nearest 0.01 g) before being immersed in tap water in a pressure treatment vessel. The vessel was subjected to a 30-minute vacuum at 20 mm (Hg), then the pressure was raised to 80 psi and held for 1 hour. The pressure was released, and the blocks were wiped dry of excess water and weighed. Blocks were assigned to be conditioned to either 40% or 60% MC (as determined by the oven-dry weight). If blocks were over their assigned MC they were air-dried and periodically weighed until they reached the desired target weight. A 40-mm square of duct tape was placed over the hole and the blocks were dipped in molten paraffin to retard moisture loss and stored in plastic bags at 5°C for 2-3 weeks to allow moisture to become more evenly distributed.

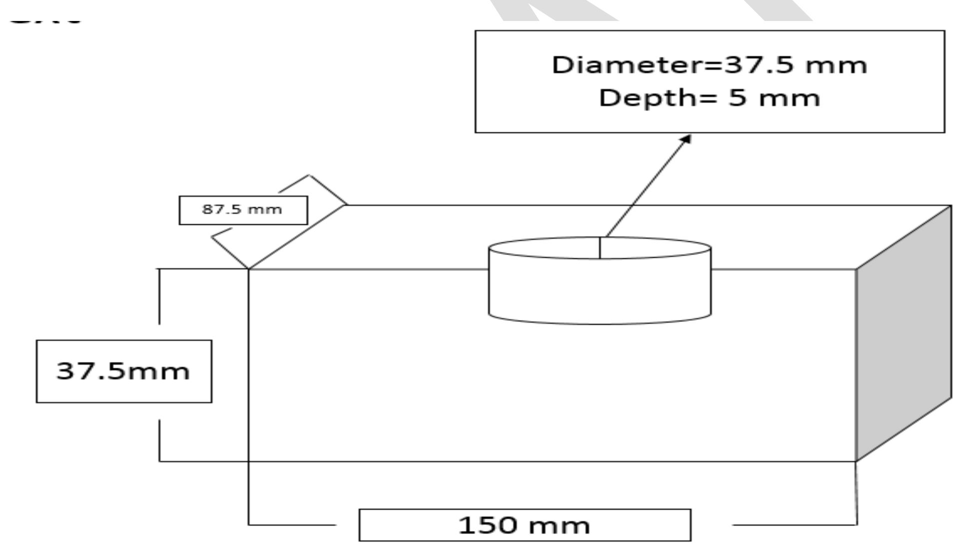

Figure IV-9. Diagram showing a test block with a drilled hole for paste application.

Paste Preparation: Pastes were prepared by combining a given mixture of boron compounds (totaling 47.8%) with 17.4% Bentonite clay, 28.1% ethanol (95%), and (6.7%) water (w/w basis). Pastes were thoroughly mixed before being applied. A block was weighed, the duct tape was removed, and 8 g of a given paste was added to the drilled hole. The duct tape was replaced, the blocks were placed in the bags, and incubated at 5°C for 3 or 6 weeks.

Treatment compounds evaluated included sodium octaborate tetrahydrate (DOT), sodium tetraborate decahydrate, sodium tetraborate pentahydrate, zinc borate, and di-calcium hexaborate pentahydrate (Table IV-7). Only DOT and sodium tetraborate decahydrate are EPA registered for use as remedial paste treatments. Pastes were formulated using 100% of a given compound, as well as mixtures containing [3:1], [1:1], or [1:3] of that compound with one of the other compounds (Table IV-8). A total of 51 paste combinations were examined and every combination had six replicates for both target MC.

Table IV-7. Characteristics of boron compounds evaluated as potential groundline paste components.

Trade Name	Source	Chemical name	Elemental boron content (%)	Water solubility @ 25ºC
TIMBOR	Rio Tinto Minerals (Boron, CA)	Sodium octaborate tetrahydrate	67	~20 %
Borax Decahdyrate	Etimine USA INC (Pittsburg, PA)	Sodium tetraborate decahydrate	36.47	5.8%
Etibor48	Etimine USA INC (Pittsburg, PA)	Sodium tetraborate pentahydrate	47.80-49	4.4%
Ulexite	Etimine USA INC (Pittsburg, PA)	Sodium-calcium pentaborate octahydrate	37	7.6g/l
Colemanite	Etimine USA INC (Pittsburg, PA)	Di-calcium hexaborate pentahydrate	40	0.81g/l
Borogard ZB	Rio Tinto Minerals (Boron, CA)	Zinc borate	48.05%	<0.28%

Table IV-8. Combinations of boron compounds used to formulate pastes for application to Douglas-fir sapwood blocks.

Boron compounds	**Boron compounds' amount percentages used in paste mixtures**															
Timbor	100	75	50	25	75	50	25	75	50	25	75	50	25	75	50	25
Etibor48		25	50	75												
Colemanite					25	50	75									
Borax Decahydrate								25	50	75						
Ulexite											25	50	75			
Zinc Borate														25	50	75
Etibor48	100	75	50	25	75	50	25	75	50	25	75	50	25			
Colemanite		25	50	75												
Borax Decahydrate					25	50	75									
Ulexite								25	50	75						
Zinc Borate											25	50	75			
Colemanite	100	75	50	25	75	50	25	75	50	25						
Borax Decahydrate		25	50	75												
Ulexite					25	50	75									
Zinc Borate								25	50	75						
Borax Decahydrate	100	75	50	25	75	50	25									
Ulexite		25	50	75												
Zinc Borate					25	50	75									
Ulexite	100	75	50	25												
Zinc Borate		25	50	75												
Zinc Borate	100															

Boron Assessment **:** Blocks were incubated at 5°C for 3 or 6 weeks. Three blocks from each treatment were sampled at both time points. Duct tape and paste were removed from the drilled hole. Wood around each drilled hole was cut away and the resulting block was cut into zones: 0–6, 6–13, and 13–25 mm from the surface of the drilled hole (Figure IV-10). Wood from a given zone was oven dried before being ground to pass a 20-mesh screen.

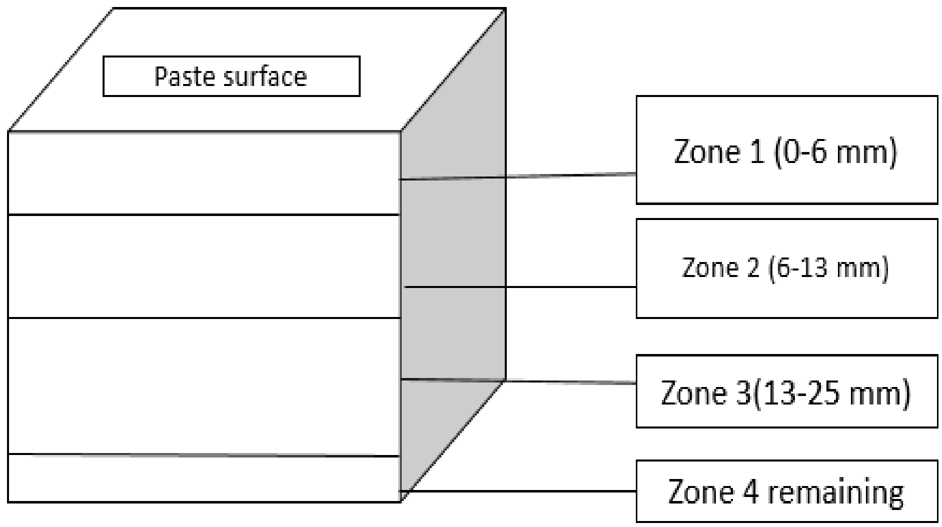

Figure IV-10. Diagram showing the cutting pattern for examining boron content in Douglas-fir blocks 3 or 6 weeks after the application of various boron pastes.

Ground wood (0.5–1.0 g) was placed into a beaker with 100 ml of deionized water (DI). Beakers were heated for 30 minutes at 100°C, cooled and filtered. Wood was washed three times with distilled water, then the original filtrate and rinses were combined in a flask. Additional DI water was added to bring the total volume to 250 mL. The flask was agitated to ensure boron was evenly distributed, and a 4 mL aliquot was placed into a sample vial. Although three assay zones were prepared, analysis was limited to the outer two zones. The third zone was held in reserve in case boron levels in the outer two zones indicated the need for further analysis.

Boron content was determined using the Azomethine H-Carminic acid method, as described in American Wood Protection Association Standard A65-11 (AWPA, 2012).

Data Analysis: The data were subjected to an analysis of variance (ANOVA) to examine the effects of wood MC or incubation period on boron content. Mean boron concentrations in the blocks were examined by treatment group, moisture content, and incubation time using a Tukey's honest significant difference (HSD) test ($\alpha = 0.05$).

Results and Discussion: Boron levels in the blocks was examined by time after treatment and distance from the surface. The threshold for protection against fungal attack differs depending on whether the wood is inside a larger beam subjected to internal decay or exposed on the surface. The threshold for protection against internal fungal attack is about 0.15 % BAE, while the threshold for external protection is 0.50 % BAE (Freitag and Morrell, 2005; Williams and Amburgey, 1987). For this discussion we use the higher concentration as the target threshold. Also, for this discussion, we will primarily concentrate on the 6 week data and use only the outer two zones because boron movement inward was exceedingly low and variable.

Boron levels in the outer 6 mm were at or above 0.5 % BAE in all single treatments 3 weeks after application (Figure IV-11). Boron levels were slightly higher in 60% MC blocks than those at 40% MC, although differences were small. Boron levels were highest in blocks receiving DOT, which also has the highest water solubility of the borates tested; however, boron levels in the remaining treatments were similar despite a nearly 20 fold difference in water solubility between sodium tetraborate decahydrate and zinc borate (Table IV-7). Boron levels increased slightly with an additional 3 weeks of incubation and, with the exception of DOT (Timbor) treated blocks, concentrations became less variable (Figure IV-12). Once again, boron levels were slightly higher in blocks at 60% moisture content in four of the six treatments.

Boron levels in blocks treated with various borate combinations followed trends similar to those found with single paste formulations (Figure IV-13-18). In general, the presence of DOT, in any paste, resulted in increased boron levels in the outer zone of blocks regardless of the ratio used or wood MC. All other borate combinations and singular pastes resulted in similar boron levels. While this consistency is understandable based on these compounds decreased water solubilities, it indicates that any mixture must include DOT if it is to initially release a sufficient quantity of boron that can diffuse into wood.

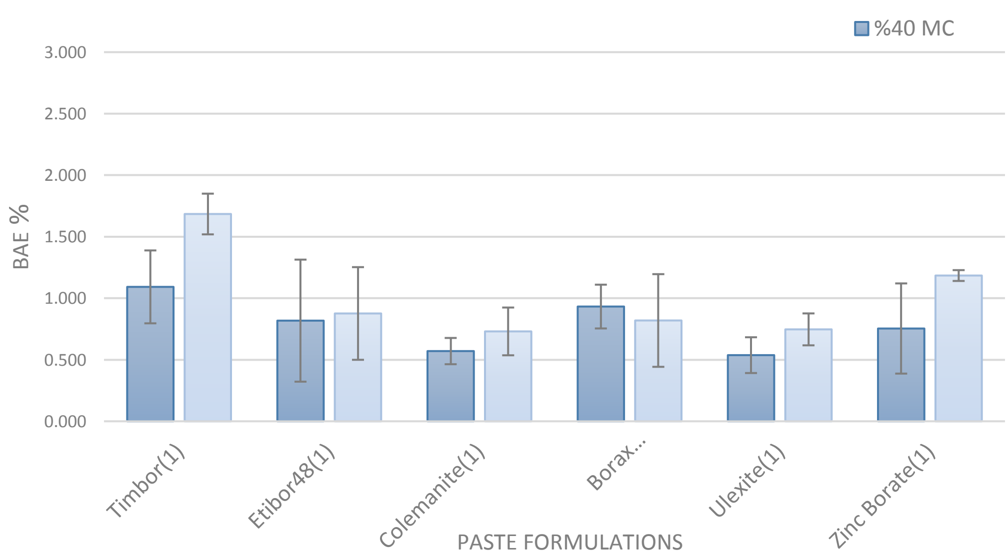

Figure IV-11. Boron levels in the outer 0–6 mm from the treated surface in Douglas-fir sapwood *blocks conditioned to 40% or 60% MC and treated with one of six different paste formulations and incubated for 3 weeks (BAE = boric acid equivalent).*

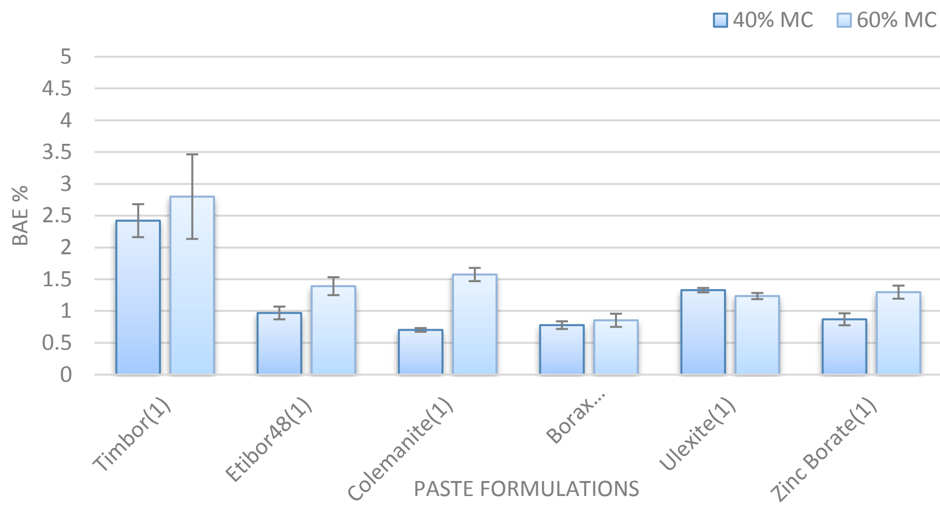

Figure IV-12. Boron levels 0–6 mm from the surface in Douglas-fir sapwood blocks conditioned to 40% or 60% MC and then treated with one of six different paste formulations and incubated for 6 weeks (BAE = boric acid equivalent).

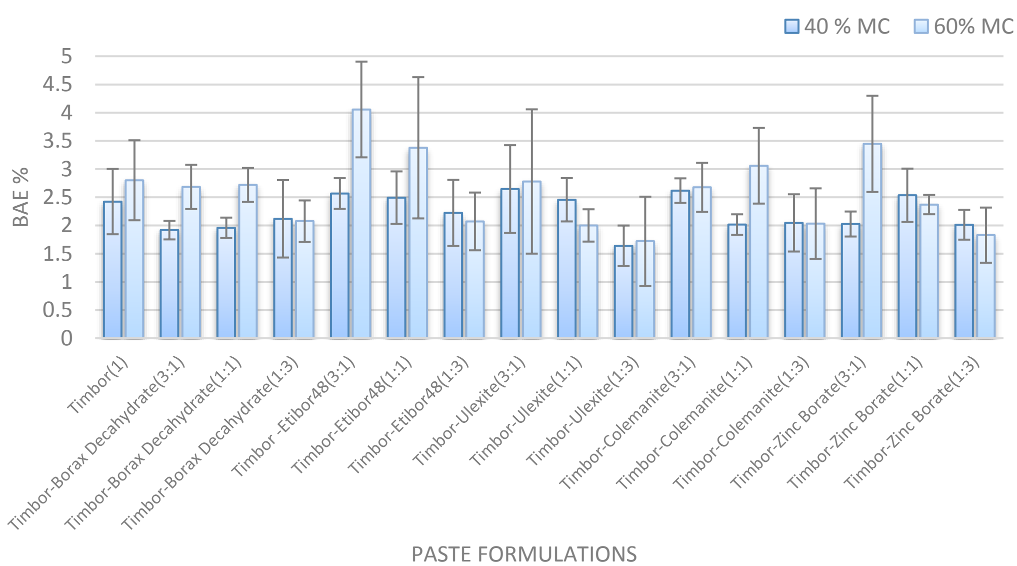

Figure IV-13. Boron levels 0–6 mm from the surface in Douglas-fir blocks conditioned to 40% or 60% MC and then treated with Timbor in 16 different paste formulations and incubated for 6 weeks (BAE = boric acid equivalent).

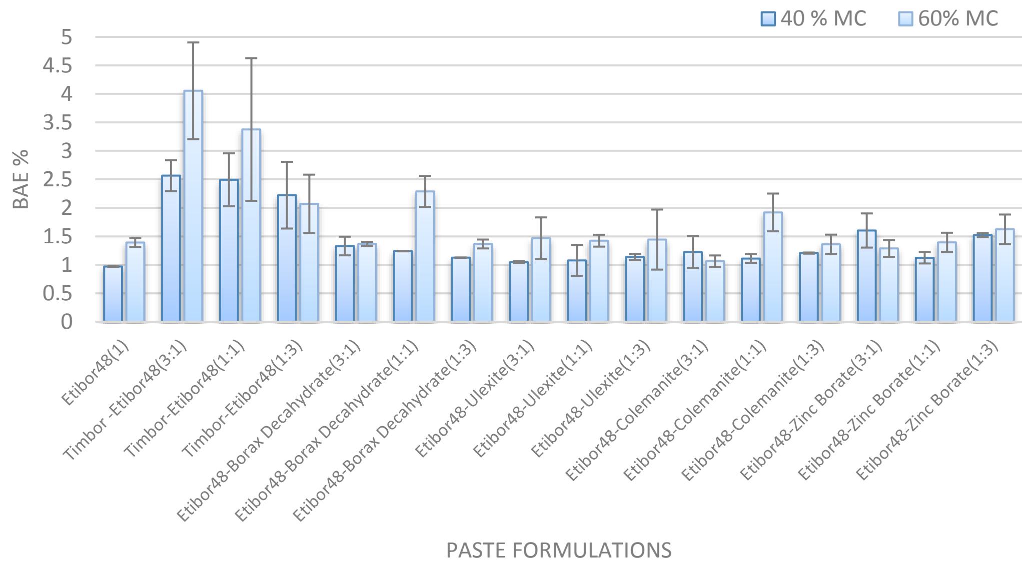

Figure IV-14. Boron levels 0–6 mm from the surface in Douglas-fir blocks conditioned to 40% or 60% MC and then treated with Etibor48 in 16 different paste formulations and incubated for 6 weeks (BAE = boric acid equivalent).

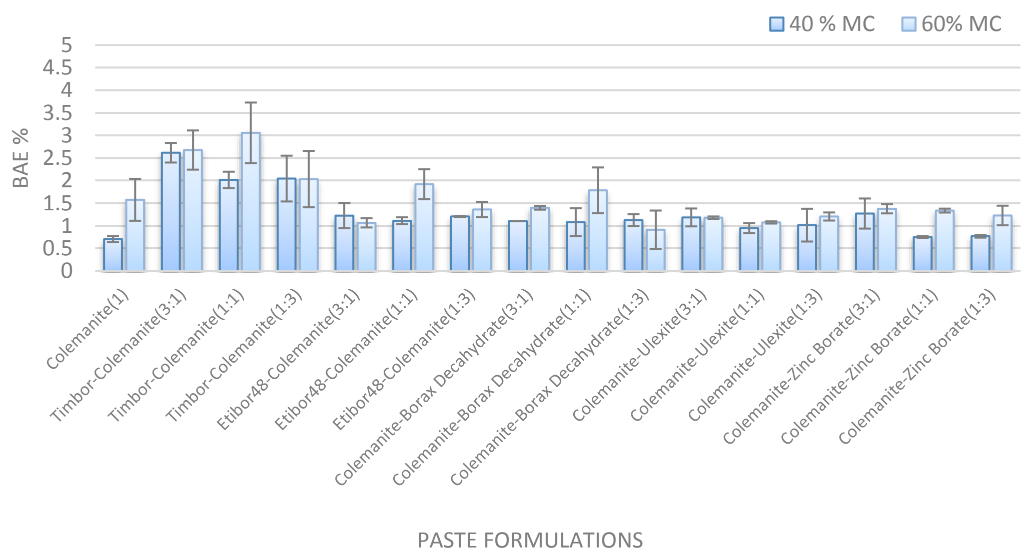

Figure IV-15. Boron levels 0–6 mm from the surface in Douglas-fir blocks conditioned to 40% or 60% MC and then treated with Colemanite in 16 different paste formulations and incubated for 6 weeks (BAE = boric acid equivalent).

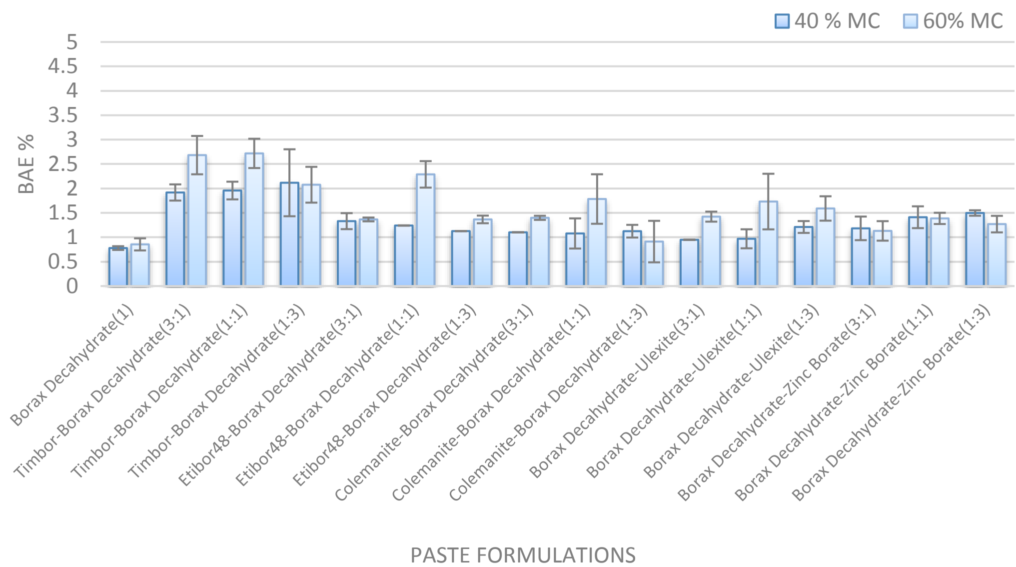

Figure IV-16. Boron levels 0–6 mm from the surface in Douglas-fir blocks conditioned to 40% or 60% MC and then treated with Borax Decahydrate in 16 different paste formulations and incubated for 6 weeks (BAE = boric acid equivalent).

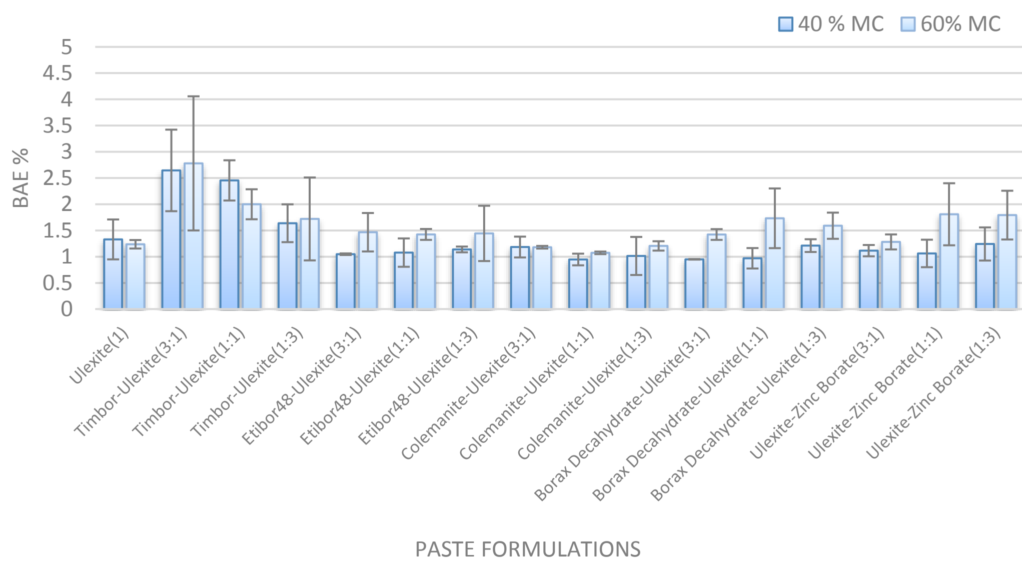

Figure IV-17. Boron levels 0–6 mm from the surface in Douglas-fir blocks conditioned to 40% or 60% MC and then treated with Ulexite in 16 different paste formulations and incubated for 6 weeks (BAE = boric acid equivalent).

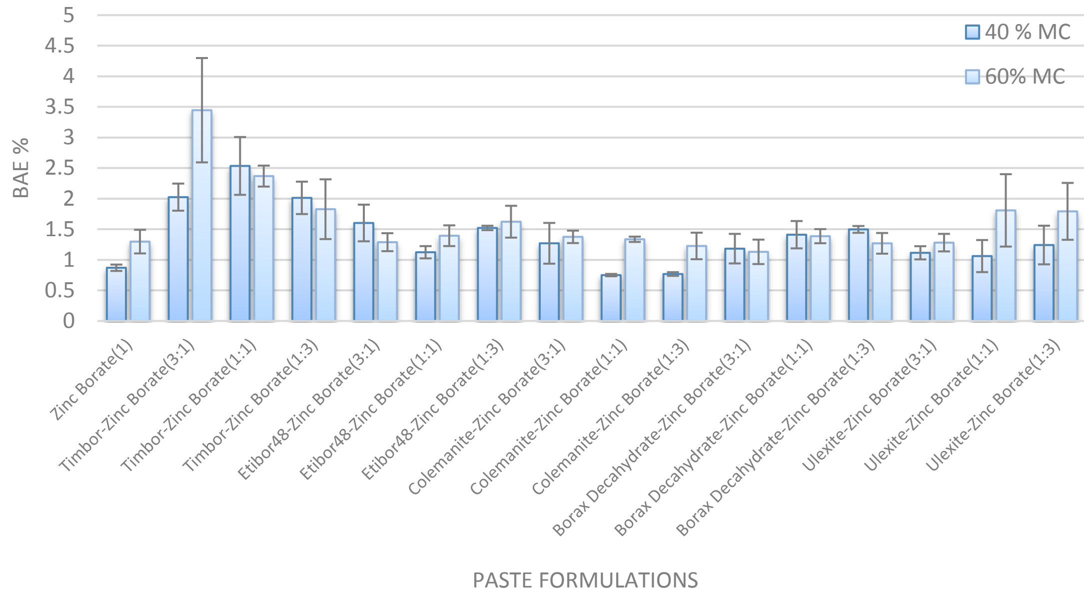

Figure 1IV-18. Boron levels 0–6 mm from the surface in Douglas-fir blocks conditioned to 40% or 60% MC and then treated with zinc borate in 16 different paste formulations and incubated for 6 weeks (BAE = boric acid equivalent).

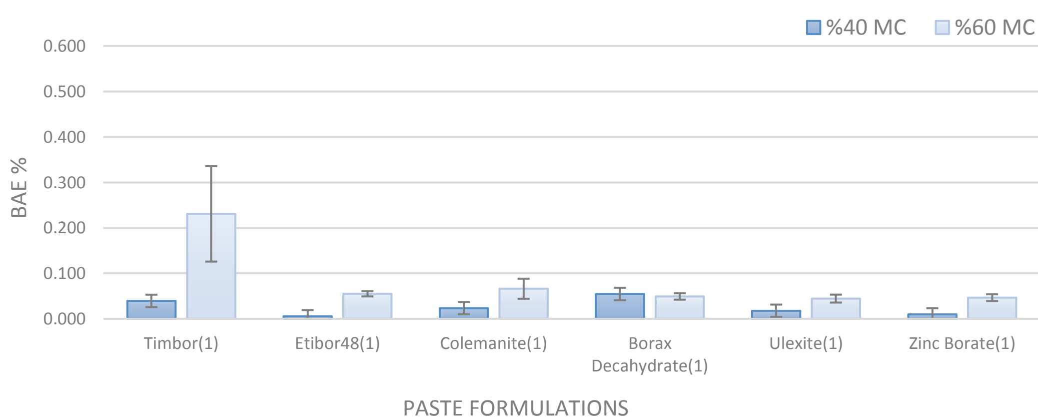

Figure IV-19. Boron levels 6–13 mm from the surface in Douglas-fir sapwood blocks conditioned to 40% or 60% MC and treated with one of six different paste formulations and incubated for 3 weeks (BAE = boric acid equivalent).

Boron levels 6-13 mm inward tended to be much lower than those found in the outer zone 3 weeks after application of single component pastes, reflecting the relatively short diffusion period (Figure IV-19). Boron levels were higher in blocks at 60% MC, but differences were only substantial for those receiving DOT. The remainder were well below 0.5% BAE and only 60% MC blocks treated with DOT alone reached the 0.15% BAE threshold for protection against internal decay. Results suggest that boron is not diffusing at substantial levels inward from the wood surface. Incubating blocks for an additional 3 weeks was associated with increased boron levels in all treatments (Figure IV-19). Blocks at 60% MC treated with DOT were above threshold for external protection, while those at 40% MC remained below that level but above the internal decay threshold. Boron levels in the remaining treatments were all well below threshold for protection against external decay, but approached the level for internal protection.

The trends observed with single borate pastes were also observed in the combination systems (Figure IV- 20-26). Boron levels in the inner zone tended to be higher in blocks at 60% MC. Systems that included DOT also tended to have higher levels of boron in the same zone, illustrating the importance of including the more water soluble component in any mixture. All remaining borate combinations resulted in much lower boron levels 6-13 mm from the wood surface. Higher moisture levels tended to improve boron movement, but the effects were slight. The inability of the alternative borate systems to produce high amounts of boron release could be viewed as a negative aspect; however, one of the reasons for including these borates would be to produce a low level of continuous release over time. The high water solubility of DOT should result in relatively rapid boric acid release. Some of this boric acid will move into the wood, but the remainder has the potential to move down along the pole surface and into the surrounding soil. Systems with lower water solubility have the potential to slowly release boric acid that can move into the wood to replenish boron over time. The combination of a rapid release via DOT coupled with a slower release from other compounds could provide a prolonged inhibition of fungal attack.

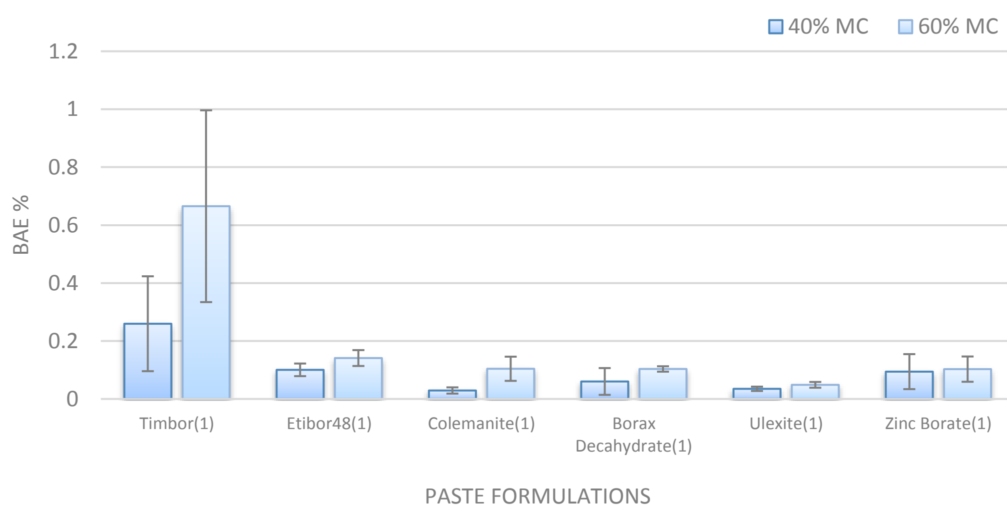

Figure IV-20. Boron levels 6–13 mm from the surface in Douglas-fir sapwood blocks conditioned to 40% or 60% MC and then treated with one of six different paste formulations and incubated for 6 weeks (BAE = boric acid equivalent).

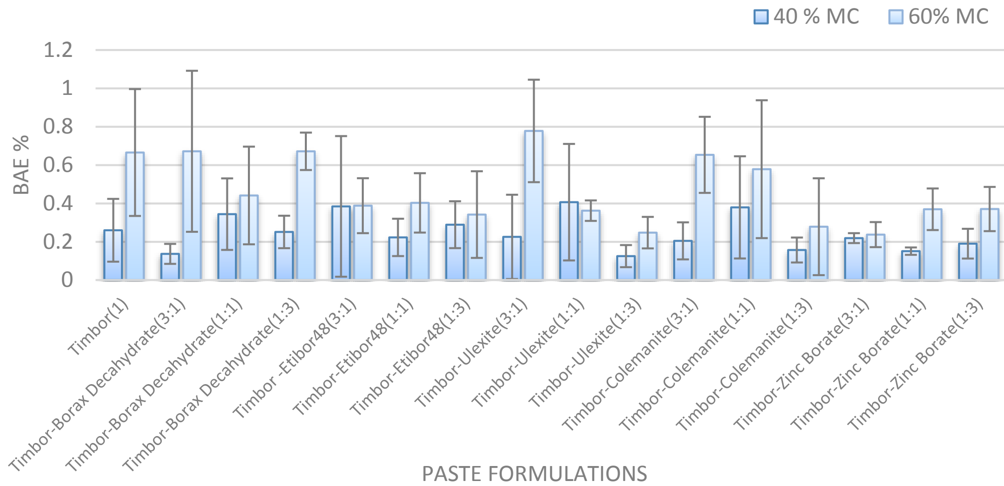

Figure IV-21. Boron levels 6–13 mm from the surface in Douglas-fir blocks conditioned to 40% or 60% MC and then treated with Timbor in 16 different paste formulations and incubated for 6 weeks (BAE = boric acid equivalent).

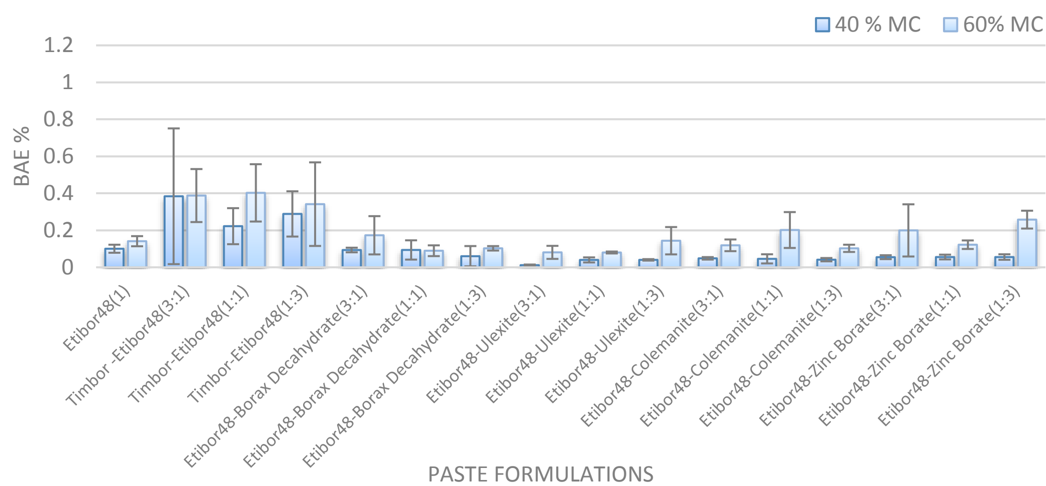

Figure IV-22. Boron levels 6–13 mm from the surface in Douglas-fir blocks conditioned to 40% or 60% MC and then treated with Etibor48 in 16 different paste formulations and incubated for 6 weeks (BAE = boric acid equivalent).

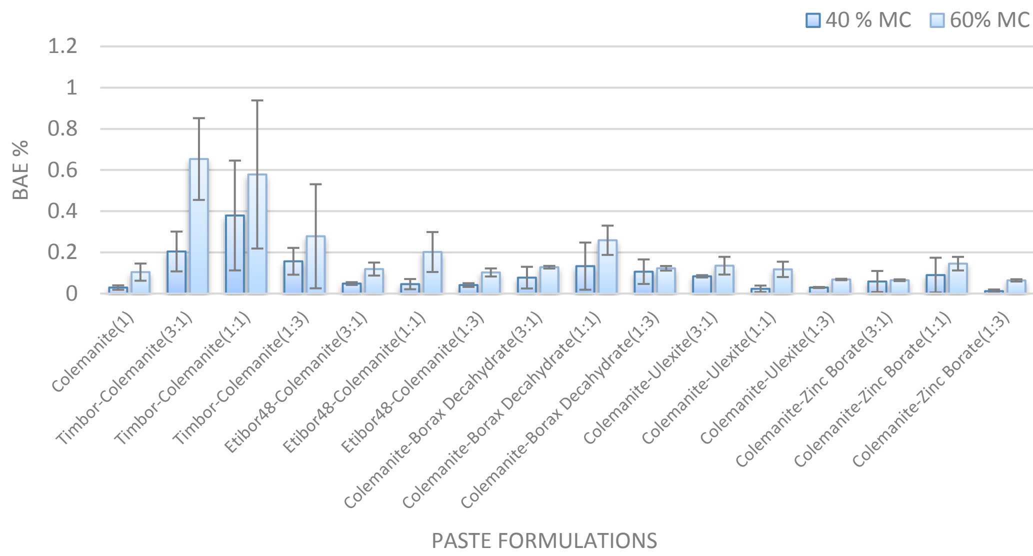

Figure IV-23. Boron levels 6–13 mm from the surface in Douglas-fir blocks conditioned to 40% or 60% MC and then treated with Colemanite in 16 different paste formulations and incubated for 6 weeks (BAE = boric acid equivalent).

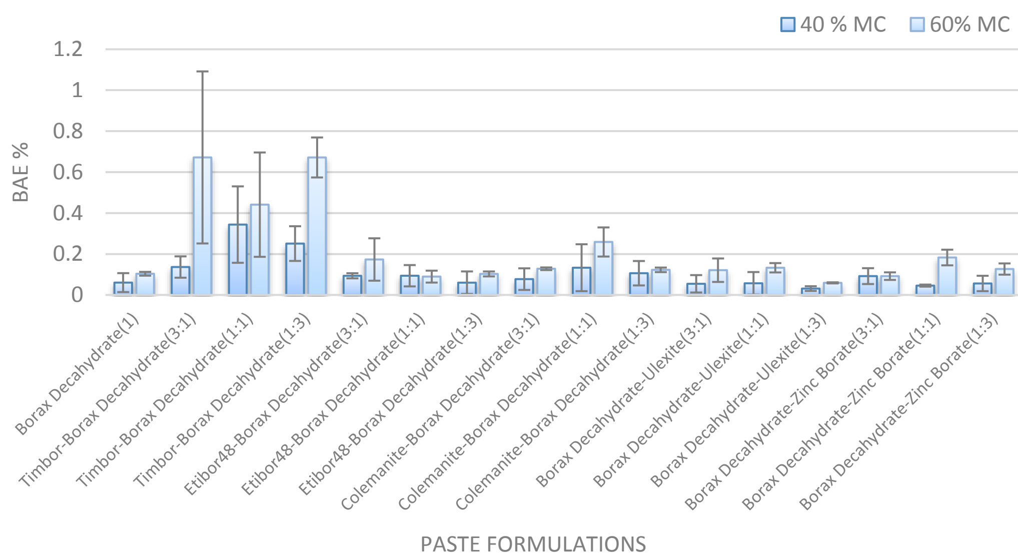

Figure IV-24. Boron levels 6–13 mm from the surface in Douglas-fir blocks conditioned to 40% or 60% MC and treated with Borax Decahydrate in 16 different paste formulations and incubated for 6 weeks (BAE = boric acid equivalent).

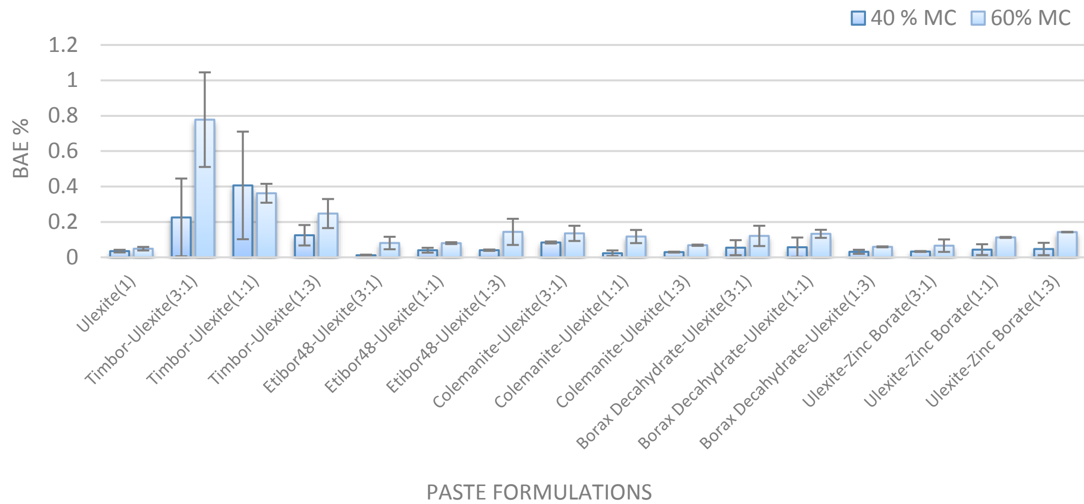

Figure IV-25. Boron levels 6–13 mm from the surface in Douglas-fir blocks conditioned to 40% or 60% MC and then treated with Ulexite in 16 different paste formulations and incubated for 6 weeks (BAE = boric acid equivalent).

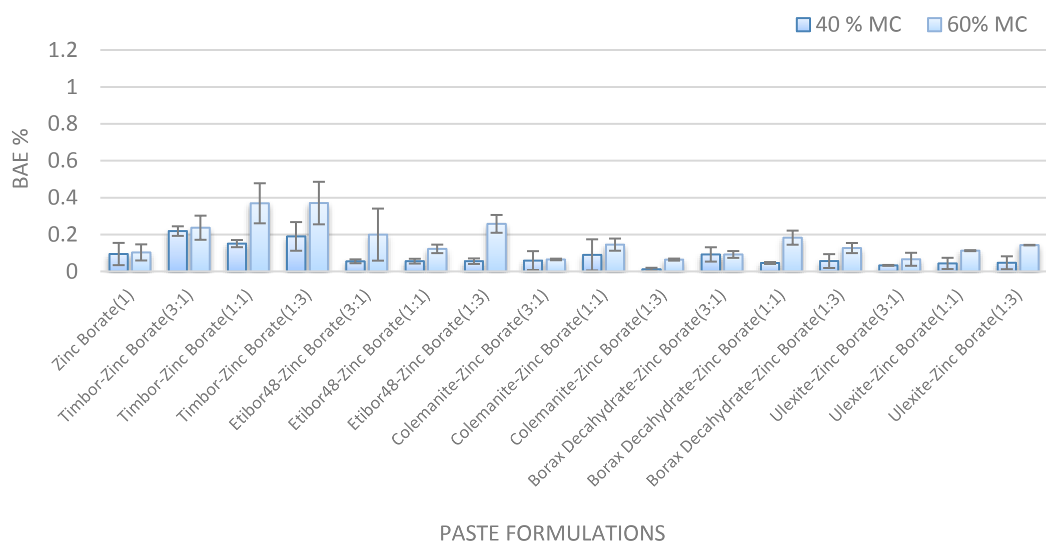

Figure IV-26. Boron levels 6–13 mm from the surface in Douglas-fir blocks conditioned to 40% or 60% MC and then treated with zinc borate in 16 different paste formulations and incubated for 6 weeks (BAE = boric acid equivalent).

Conclusions: The use of less water soluble pastes resulted in reduced boron movement into Douglas-fir sapwood blocks. While more boron moved at higher wood MC the effect was not sufficient enough to protect wood from fungal attack. Incorporating DOT in a paste formulation was essential for developing sufficient quantities of boron in wood.

Note: This section represents a portion of the MS Thesis of Selim Uysal.

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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, but commercial use for treating 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 the specification as an alternative treatment.

Copper naphthenate has a history of successful use on southern pine. 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 reasonable protection in a variety of field stake tests, but there are relatively little long term-data on western wood species. To help develop this information, the following test was established.

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.

Stakes were conditioned to 13% 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, 2). All freshly sawn stakes treated with copper naphthenate to retentions of 4.0 kg/m^3 continue to provide excellent protection after 314 months, while the conditions of stakes treated to the two lower retentions continued to decline over the past 2 years. Stakes treated to the two lowest retentions have declined to a rating near 5.0, suggesting that fungal decay significantly degraded the wood. Ratings for the intermediate retention were just above 6.0, indicating treatment efficacy loss.

Weathered stakes have consistently exhibited greater degrees of damage at a given treatment level and their condition continues to slowly decline. The three lowest retentions had ratings below 3.0 indicating they are no longer serviceable (Figure V-2). The condition of stakes treated to these three retentions continue to decline. The conditions of stakes treated to the two higher retentions also declined slightly in the past year. Ratings for the highest retention are approaching 5.0, while those for the next highest retention have declined to below 4. Clearly, prior surface degradation from both microbial activity and UV light sharply reduced performance of the weathered material.

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 the performance characteristics of weathered retreated material will differ substantially from those of 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. As a result, retreatment of western redcedar still appears feasible for avoiding pole disposal and maximizing 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 contributes little to overall material properties and its treatment serves little practical purpose. Removal of this more permeable and weaker wood would effectively reduce the pole class, but might result in a better performing pole. Resulting treatments on shaved poles might be shallower, but non-treated wood beneath is 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.

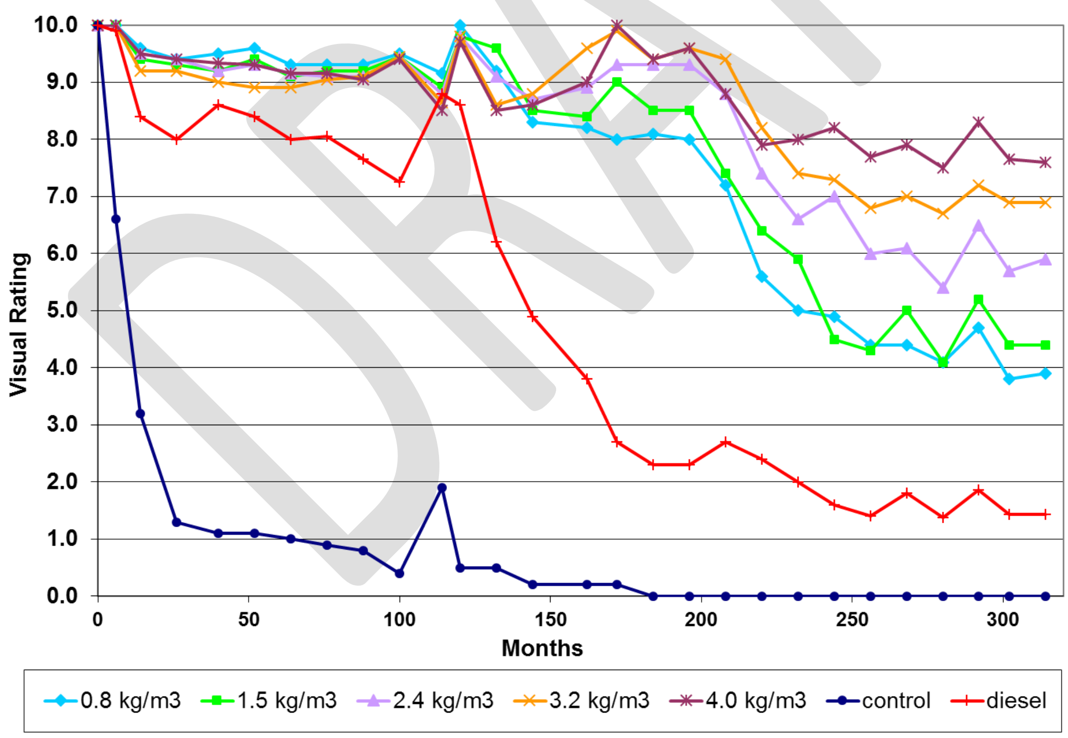

Figure V-1. Condition of freshly sawn western redcedar sapwood stakes treated with selected retentions of copper naphthenate in diesel oil and exposed in a soil bed for 314 months.

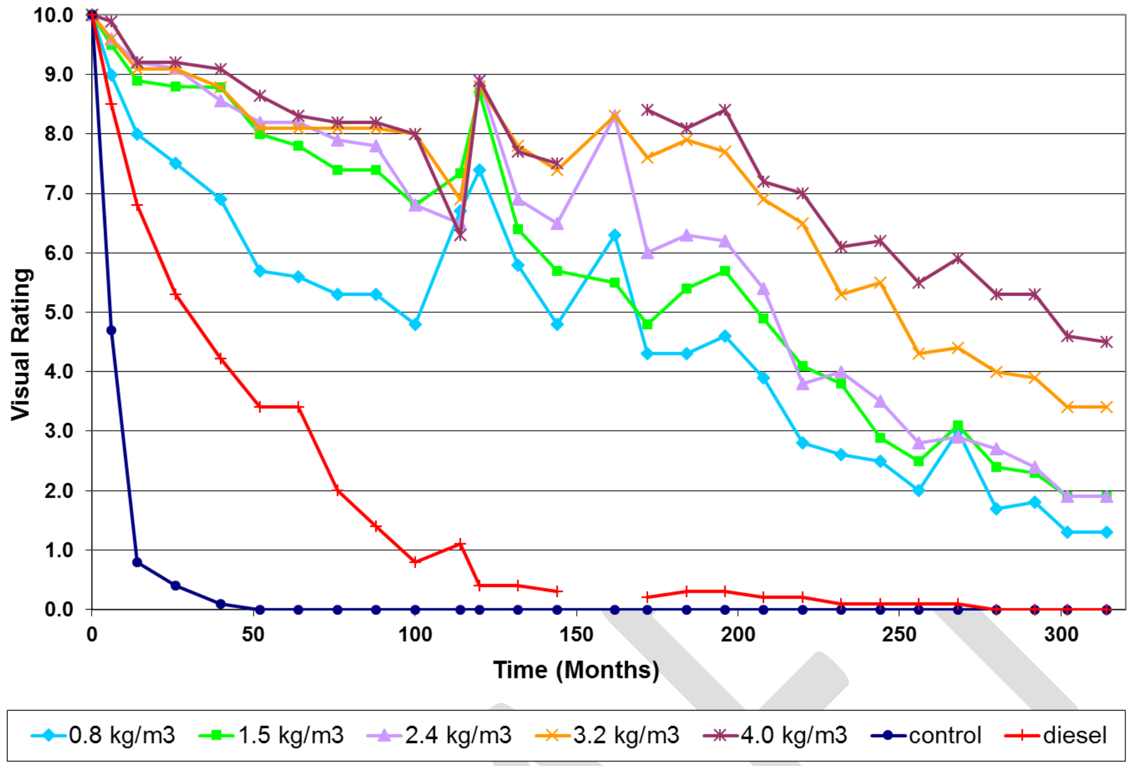

Figure V-2. Condition of weathered western redcedar sapwood stakes treated with selected retentions of copper naphthenate in diesel oil and exposed in a soil bed for 314 months.

B. Condition of Douglas-fir poles Treated with Copper Naphthenate in Diesel or Biodiesel Blends

As noted, copper naphthenate has provided excellent performance when dissolved in diesel as a solvent; however, there have been concerns about the performance of this system when dispersed in solvents containing biodiesel. As a part of our evaluation of copper naphthenate performance, we had previously inspected 65 copper naphthenate treated Douglas-fir poles in the Puget Sound area. These poles had been treated with various combinations of biodiesel and conventional diesel solvents. The intent of these inspections was to assess preservative retention and determine if surface decay was developing more rapidly. These poles would then be monitored over the next decade to detect any early issues associated with the use of biodiesel. This past year we added an additional population of poles into this data base (Table V-1). The poles were inspected just below groundline by probing the wood surface for the presence of softened wood, then removing increment cores from 3 locations around each pole 150 mm below and 100 mm above groundline. The outer 6 mm of each core was removed for assessing the presence of soft rot, then the zone from 6 to 25 mm from the surface was removed and core zones from a given location on each pole were combined before being ground to pass a 20 mesh screen. The resulting sawdust was analyzed for copper by x-ray fluorescence spectroscopy. The remainder of each core was plated on malt extract agar and observed for the growth of decay fungi as previously described. The outer segments will be digested into individual wood fibers and these fibers were examined for evidence of fungal attack as either cell wall thinning or diamond shaped cavities. Cavities and cell wall thinning are evidence of fungal soft rot attack which is the primary cause of surface decay on utility poles. We have seen some evidence of soft rot attack during previous investigations.

No decay fungi were isolated from any of the core samples. This is not surprising since the poles had only been in service for 6 years. Non–decay fungi, including a number of dark pigmented fungi were isolated from poles, particularly from the samples obtained from below groundline. Some of these fungi are known to cause a surface decay or soft rot and it is these fungi we are concerned about if copper naphthenate efficacy has been reduced by biodiesel solvent use.

Preservative penetration was generally above the minimum for treatment of Douglas-fir (19 mm) although cores from 12 poles failed to meet that level. In most cases, only one of 6 cores taken from a pole failed to meet the requirement, suggesting overall pole quality was acceptable. A total of 20 cores failed to meet the 19 mm penetration requirement, representing 5% of the 390 cores evaluated. These results indicate sufficient treatment quality.

The required retention for treatment of Douglas-fir with copper naphthenate is 1.52 kg/m^3 as Cu for Use Category 4B. It is difficult to directly translate this value to individual pole retention because poles are normally assayed in batches where cores from individual poles are combined, ground, and analyzed for preservative content. Thus, some poles may have retentions above the minimum and others below, but the average will meet the minimum. The minimum is then set so the majority of wood samples have retentions well above a minimum protective threshold of preservative.

However, for the purposes of comparison, we can examine individual retentions as a means for assessing overall treatment levels. We used a target retention of 1.50 kg/m^3 (as Cu). There were 37 poles treated with copper naphthenate in biodiesel and 27 poles treated using biodiesel as a solvent. Six of 27 poles treated with regular diesel failed to meet the AWPA Standard. As noted earlier, this sampling method differs from the normal process because individual poles were assayed, while the normal assay uses a batch analysis. Biodiesel treated poles had higher retentions with 19 of the 37 poles failing to achieve the 1.5 kg/m^3 target. Retentions in biodiesel treated poles ranged from 0.66 to 2.44 kg/m^3, while those for diesel treated poles ranged from 1.02 to 3.55 kg/m^3 (Table V-1). The results indicate that the copper naphthenate in diesel treated poles were better treated than those with biodiesel.

Overall results indicate preservative penetration was acceptable; however, preservative retention was lower on poles treated using biodiesel as the solvent. The original reason for establishing this trial was to determine if biodiesel poles were at a higher risk of developing premature decay and to establish a baseline for future assessments. While no evidence of advanced surface decay was noted on the poles 6 years after treatment, the low retentions on many poles suggest the need for continued monitoring.

Only one possible decay fungus was isolated from any of the poles sampled, but numerous non-decay fungi were isolated. A total of 19 taxa were isolated from the poles, but only 11 have been positively identified (Table V-2). Of these, four are known to cause soft rot damage. These fungi are generally present at very low levels in the fungal population, suggesting the risk of soft rot development remains low. The most common fungus identified (*Amorphotheca resinae*) is a weak soft rotter and is more common on creosote-treated poles, where it is known to degrade creosote components.

No fungi were isolated from 16 of the 37 copper naphthenate poles treated using biodiesel as a solvent, while fungi were isolated from all but one of the 27 poles treated using regular diesel as the solvent (Table V-2). Fungi were isolated from 59 of the 222 cores removed from biodiesel poles and 24 of these were dark pigmented. Fungi were isolated from 115 of the156 cores removed from poles treated with copper naphthenate in petroleum based diesel and 60 of these were dematiaceous. The ratios of dematiaceous fungi to all fungi isolated were similar for poles treated using biodiesel and diesel (40.6 vs 52.2 %), but the fungal frequency in biodiesel treated poles was much lower.

Table V-1. Characteristics of copper naphthenate treated poles sampled in the Puget Sound Energy and Snohomish PUD systems.

Utility Pole Identification	Height (Ft)	Class	Treatment Type	Year	Height (in)	Preservative Penetration (mm)	Fungi/ Plate	Dematiaceous Fungi /Plate	CuNap (kg/m³ as Cu)
SK-C 4/6 2	86	H-6	CuNap in Biodiesel	2009	-6	**31**	1	1	0.74
					-6	**27**	1	1	
					-6	**39**	1	1	
					4	**25**	1	1	
					4	**33**	1	0	
					4	**35**	0	0	
SK-C 4/5 3	86	H-6	CuNap in Biodiesel	2009	-6	**49**	1	1	1.14
					-6	**51**	1	1	
					-6	**50**	0	0	
					4	**20**	1	0	
					4	**35**	1	1	
					4	**30**	1	0	
SK-C 4/4	86	H-6	CuNap in Biodiesel	2009	-6	**32**	1	1	1.22
					-6	**41**	1	1	
					-6	**39**	0	0	
					4	**47**	1	1	
					4	**37**	1	1	
					4	**45**	0	0	
SK-C 4/3	86	H-6	CuNap in Biodiesel	2009	-6	**35**	1	0	1.39
					-6	**47**	0	0	
					-6	**35**	0	0	
					4	**55**	1	0	
					4	**19**	1	0	
					4	**40**	1	0	

Table V-1 (cont.). Characteristics of copper naphthenate treated poles sampled in the Puget Sound Energy and Snohomish PUD systems.

Utility Pole Identification	Height (Ft)	Class	Treatment Type	Year	Height (in)	Preservative Penetration (mm)	Fungi/ Plate	Dematiaceous Fungi /Plate	CuNap (kg/m^3 as Cu)
SK-C 4/2	86	H-6	CuNap in Biodiesel	2009	-6	18	1	0	**1.88**
					-6	16	0	0	
					-6	**45**	0	0	
					4	15	1	0	
					4	11	0	0	
					4	**46**	0	0	
SK-C 4/1	86	H-6	CuNap in Biodiesel	2009	-6	**64**	1	1	**1.57**
					-6	**62**	0	0	
					-6	**40**	0	0	
					4	**33**	1	0	
					4	**39**	0	0	
					4	**50**	0	0	
SC-BW 6/8	86	H-6	CuNap in Biodiesel	2009	-6	**53**	0	0	1.18
					-6	**47**	0	0	
					-6	**29**	0	0	
					4	**24**	0	0	
					4	**29**	0	0	
					4	**26**	0	0	
SK-C 3/12	86	H-6	CuNap in Biodiesel	2009	-6	**40**	1	0	0.66
					-6	**42**	1	0	
					-6	**45**	2	0	
					4	16	1	0	
					4	**26**	1	0	
					4	**33**	0	0	

Table V-1 (Cont). Characteristics of copper naphthenate treated poles sampled in the Puget Sound Energy and Snohomish PUD systems.

Utility Pole Identification	Height (Ft)	Class	Treatment Type	Year	Height (in)	Preservative Penetration (mm)	Fungi/ Plate	Dematiaceous Fungi /Plate	CuNap (kg/m^3 as Cu)
SK-C 3/11	86	H-6	CuNap in Biodiesel	2009	-6	**39**	1	0	**2.44**
					-6	**35**	0	0	
					-6	**40**	0	0	
					4	**40**	1	0	
					4	**24**	0	0	
					4	**32**	0	0	
SK-C 3/10	86	H-6	CuNap in Biodiesel	2009	-6	**40**	1	1	0.54
					-6	**35**	0	0	
					-6	**35**	0	0	
					4	**20**	1	1	
					4	**35**	2	1	
					4	15	1	1	
SK-C 3/9	86	H-6	CuNap in Biodiesel	2009	-6	**35**	1	0	0.72
					-6	**20**	0	0	
					-6	**20**	0	0	
					4	**30**	1	0	
					4	15	0	0	
					4	**25**	0	0	
SK-C 3/8	86	H-6	CuNap in Biodiesel	2009	-6	**40**	2	1	1.02
					-6	**40**	0	0	
					-6	**30**	0	0	
					4	**35**	1	1	
					4	**25**	0	0	
					4	**35**	0	0	

Table V-1 (Cont.). Characteristics of copper naphthenate treated poles sampled in the Puget Sound Energy and Snohomish PUD systems.

Utility Pole Identification	Height (Ft)	Class	Treatment Type	Year	Height (in)	Preservative Penetration (mm)	Fungi/ Plate	Dematiaceous Fungi /Plate	CuNap (kg/m^3 as Cu)
W to E intersection of 52nd and 22nd heading on 22nd	45	CL2	CuNap in Petrodiesel	2009	-6	**60**	1	1	**2.22**
					-6	**50**	1	1	
					-6	**50**	1	0	
					4	**40**	0	0	
					4	**40**	0	0	
					4	**40**	0	0	
229282	50	CL1	CuNap in Petrodiesel	2009	-6	**35**	1	1	**1.96**
					-6	**30**	2	1	
					-6	**35**	2	1	
					4	**30**	0	0	
					4	**30**	0	0	
					4	**35**	0	0	
229283	50	CL1	CuNap in Petrodiesel	2009	-6	**50**	1	1	**2.57**
					-6	**55**	1	1	
					-6	**50**	0	0	
					4	**40**	1	0	
					4	**35**	1	0	
					4	**25**	1	0	
229284	50	CL1	CuNap in Petrodiesel	2009	-6	12	2	0	1.02
					-6	**20**	0	0	
					-6	**23**	0	0	
					4	**27**	0	0	
					4	**24**	0	0	
					4	**26**	0	0	

Table V-1 (Cont.). Characteristics of copper naphthenate treated poles sampled in the Puget Sound Energy and Snohomish PUD systems.

Utility Pole Identification	Height (Ft)	Class	Treatment Type	Year	Height (in)	Preservative Penetration (mm)	Fungi/ Plate	Dematiaceous Fungi /Plate	CuNap (kg/m^3 as Cu)
229285	50	H-2	CuNap in Petrodiesel	2009	-6	**30**	1	1	**2.08**
					-6	**35**	3	2	
					-6	**30**	3	2	
					4	**25**	1	0	
					4	**35**	1	0	
					4	**30**	1	0	
229286	60	H-4	CuNap in Petrodiesel	2009	-6	**35**	1	0	1.47
					-6	**35**	1	0	
					-6	**30**	1	0	
					4	**25**	0	0	
					4	**25**	0	0	
					4	**40**	0	0	
229287	50	CL1	CuNap in Petrodiesel	2009	-6	**19**	3	1	**2.16**
					-6	**23**	1	0	
					-6	**35**	1	0	
					4	**30**	2	1	
					4	**27**	1	0	
					4	**23**	1	0	
229288	50	CL1	CuNap in Petrodiesel	2009	-6	**42**	2	0	**1.92**
					-6	**40**	1	0	
					-6	**41**	1	0	
					4	**39**	1	0	
					4	**32**	1	0	
					4	**33**	1	0	

Table V-1 (Cont.). Characteristics of copper naphthenate treated poles sampled in the Puget Sound Energy and Snohomish PUD systems.

Utility Pole Identification	Height (Ft)	Class	Treatment Type	Year	Height (in)	Preservative Penetration (mm)	Fungi/ Plate	Dematiaceous Fungi /Plate	CuNap (kg/m^3 as Cu)
229289	50	CL1	CuNap in Petrodiesel	2009	-6	**45**	0	0	**2.64**
					-6	**40**	0	0	
					-6	**42**	0	0	
					4	**35**	1	0	
					4	**36**	0	0	
					4	**38**	0	0	
229290	45	CL2	CuNap in Petrodiesel	2009	-6	**35**	1	0	**2.50**
					-6	**34**	0	0	
					-6	**36**	0	0	
					4	**27**	1	0	
					4	**27**	1	0	
					4	**37**	0	0	
229291	50	CL1	CuNap in Petrodiesel	2009	-6	**43**	1	1	**1.63**
					-6	**51**	1	1	
					-6	**55**	1	1	
					4	**32**	1	0	
					4	**35**	1	0	
					4	**37**	0	0	
229292	50	CL1	CuNap in Petrodiesel	2009	-6	**55**	1	1	1.22
					-6	**55**	1	0	
					-6	**70**	1	1	
					4	**35**	1	1	
					4	**30**	1	1	
					4	**30**	0	0	

Table V-1 (Cont.). Characteristics of copper naphthenate treated poles sampled in the Puget Sound Energy and Snohomish PUD systems.

Utility Pole Identification	Height (Ft)	Class	Treatment Type	Year	Height (in)	Preservative Penetration (mm)	Fungi/ Plate	Dematiaceous Fungi /Plate	CuNap (kg/m ^{3} as Cu)
161885	45	CL2	CuNap in Petrodiesel	2003	-6	**45**	1	1	**3.55**
					-6	**45**	1	1	
					-6	**45**	1	1	
					4	**30**	1	1	
					4	**25**	1	1	
					4	**25**	0	0	
161884	35	CL2	CuNap in Petrodiesel	2003	-6	**30**	1	1	**1.81**
					-6	**30**	2	0	
					-6	**30**	0	0	
					4	**30**	1	0	
					4	**25**	1	0	
					4	**30**	1	1	
161882	45	CL2	CuNap in Petrodiesel	2003	-6	**30**	1	1	**2.77**
					-6	**30**	1	1	
					-6	**30**	1	1	
					4	**25**	1	1	
					4	**25**	1	1	
					4	**20**	1	1	
161880	45	CL2	CuNap in Petrodiesel	2003	-6	**36**	1	1	**1.80**
					-6	**43**	1	1	
					-6	**45**	1	1	
					4	**25**	1	0	
					4	**24**	1	0	
					4	**27**	0	0	

Table V-1 (Cont.). Characteristics of copper naphthenate treated poles sampled in the Puget Sound Energy and Snohomish PUD systems.

Utility Pole Identification	Height (Ft)	Class	Treatment Type	Year	Height (in)	Preservative Penetration (mm)	Fungi/ Plate	Dematiaceous Fungi /Plate	CuNap (kg/m³ as Cu)
161878	45	CL2	CuNap in Petrodiesel	2003	-6	**43**	1	1	**1.54**
					-6	**40**	1	1	
					-6	**39**	1	1	
					4	**35**	1	1	
					4	**30**	1	0	
					4	**25**	1	0	
161877	50	CL1	CuNap in Petrodiesel	2003	-6	**40**	1	1	**1.97**
					-6	**45**	2	1	
					-6	**40**	1	1	
					4	**40**	1	1	
					4	**41**	1	1	
					4	**44**	0	0	
466859157274	75	H2	CuNap in Petrodiesel	2005	-6	**40**	1	1	**1.50**
					-6	**35**	0	0	
					-6	**25**	1	0	
					4	**50**	1	0	
					4	**35**	2	0	
					4	**25**	1	0	
466857157362					-6	**35**	1	1	2.07
					-6	**45**	1	1	
					-6	**40**	1	1	
					4	**40**	1	1	
					4	**40**	1	1	
					4	**40**	1	0	

Table V-1 (Cont.). Characteristics of copper naphthenate treated poles sampled in the Puget Sound Energy and Snohomish PUD systems.

Utility Pole Identification	Height (Ft)	Class	Treatment Type	Year	Height (in)	Preservative Penetration (mm)	Fungi/ Plate	Dematiaceous Fungi /Plate	CuNap (kg/m^3 as Cu)
465347160725	75	H1	CuNap in Petrodiesel	2005	-6	**50**	1	1	1.48
					-6	**55**	2	2	
					-6	**65**	0	0	
					4	**40**	0	0	
					4	**35**	0	0	
					4	**25**	0	0	
465368160727	70	CL1	CuNap in Petrodiesel	2005	-6	**29**	1	0	0.93
					-6	**40**	0	0	
					-6	**31**	0	0	
					4	**41**	0	0	
					4	**49**	0	0	
					4	**32**	0	0	
465389160729	75	CL1	CuNap in Petrodiesel	2005	-6	**35**	0	0	1.10
					-6	**35**	0	0	
					-6	**30**	0	0	
					4	**40**	0	0	
					4	**37**	0	0	
					4	**35**	0	0	
465488160741	70	CL1	CuNap in Petrodiesel	2005	-6	**27**	1	1	**2.76**
					-6	**34**	1	1	
					-6	**35**	0	0	
					4	**46**	0	0	
					4	**47**	0	0	
					4	**40**	0	0	

Table V-1 (Cont.). Characteristics of copper naphthenate treated poles sampled in the Puget Sound Energy and Snohomish PUD systems.

Utility Pole Identification	Height (Ft)	Class	Treatment Type	Year	Height (in)	Preservative Penetration (mm)	Fungi/ Plate	Dematiaceous Fungi /Plate	CuNap (kg/m^3 as Cu)
465703160589	75	H1	CuNap in Petrodiesel	2005	-6	**54**	0	0	**2.06**
					-6	**51**	0	0	
					-6	**37**	0	0	
					4	6	1	1	
					4	**43**	1	0	
					4	**39**	0	0	
465712160407	75	CL1	CuNap in Petrodiesel	2005	-6	**35**	1	1	**2.12**
					-6	**41**	0	0	
					-6	**49**	0	0	
					4	**27**	0	0	
					4	**39**	0	0	
					4	**37**	0	0	
945710160447	80	CL1	CuNap in Petrodiesel	2005	-6	**49**	0	0	**3.57**
					-6	**47**	0	0	
					-6	**45**	0	0	
					4	**35**	0	0	
					4	**47**	0	0	
					4	**37**	0	0	
465709160481	75	CL1	CuNap in Petrodiesel	2005	-6	**40**	1	1	0.82
					-6	**40**	1	1	
					-6	**40**	0	0	
					4	**50**	0	0	
					4	**45**	0	0	
					4	**50**	0	0	

Table V-1 (Cont.). Characteristics of copper naphthenate treated poles sampled in the Puget Sound Energy and Snohomish PUD systems.

Utility Pole Identification	Height (Ft)	Class	Treatment Type	Year	Height (in)	Preservative Penetration (mm)	Fungi/ Plate	Dematiaceous Fungi /Plate	CuNap (kg/m^3 as Cu)
453816157815	80	H1	CuNap in Biodiesel	2008	-6	**35**	0	0	**1.50**
					-6	**39**	0	0	
					-6	**27**	0	0	
					4	**25**	0	0	
					4	**30**	0	0	
					4	**33**	0	0	
453818157786	75	H1	CuNap in Biodiesel	2008	-6	**40**	1	1	**1.65**
					-6	**37**	0	0	
					-6	**35**	0	0	
					4	**27**	0	0	
					4	**29**	0	0	
					4	**36**	0	0	
4538118157758	75	H1	CuNap in Biodiesel	2008	-6	**54**	0	0	1.44
					-6	**56**	0	0	
					-6	**55**	0	0	
					4	**26**	0	0	
					4	**24**	0	0	
					4	**39**	0	0	
453602157724	75	H1	CuNap in Biodiesel	2008	-6	**47**	0	0	1.15
					-6	**41**	0	0	
					-6	**42**	0	0	
					4	**31**	0	0	
					4	**41**	0	0	
					4	**39**	0	0	

Table V-1 (Cont.). Characteristics of copper naphthenate treated poles sampled in the Puget Sound Energy and Snohomish PUD systems.

Utility Pole Identification	Height (Ft)	Class	Treatment Type	Year	Height (in)	Preservative Penetration (mm)	Fungi/ Plate	Dematiaceous Fungi /Plate	CuNap (kg/m^3 as Cu)
453821157691	80	CL1	CuNap in Biodiesel	2008	-6	**29**	0	0	**1.55**
					-6	**39**	0	0	
					-6	**23**	0	0	
					4	**21**	1	1	
					4	**26**	1	1	
					4	**31**	0	0	
453830157900	80	H1	CuNap in Biodiesel	2008	-6	**35**	0	0	1.48
					-6	**30**	0	0	
					-6	**30**	0	0	
					4	**35**	0	0	
					4	**40**	0	0	
					4	**45**	0	0	
453817157958	75	CL1	CuNap in Biodiesel	2008	-6	**60**	0	0	0.80
					-6	**55**	0	0	
					-6	**55**	0	0	
					4	**35**	0	0	
					4	**30**	0	0	
					4	**30**	0	0	
453799157983	75	H1	CuNap in Biodiesel	2008	-6	**75**	0	0	1.61
					-6	**85**	0	0	
					-6	**65**	0	0	
					4	**20**	0	0	
					4	**35**	0	0	
					4	**45**	0	0	

Table V-1 (Cont.). Characteristics of copper naphthenate treated poles sampled in the Puget Sound Energy and Snohomish PUD systems.

Utility Pole Identification	Height (Ft)	Class	Treatment Type	Year	Height (in)	Preservative Penetration (mm)	Fungi/ Plate	Dematiaceous Fungi /Plate	CuNap (kg/m^3 as Cu)
453746157981	70	CL1	CuNap in Biodiesel	2008	-6	**29**	0	0	1.46
					-6	**26**	0	0	
					-6	**33**	0	0	
					4	**21**	0	0	
					4	**23**	0	0	
					4	**26**	0	0	
453862157583	75	CL1	CuNap in Biodiesel	2008	-6	**50**	0	0	1.03
					-6	**71**	0	0	
					-6	**80**	0	0	
					4	18	0	0	
					4	**21**	0	0	
					4	**20**	0	0	
455610156371	75	H1	CuNap in Biodiesel	2008	-6	**29**	0	0	**1.84**
					-6	**34**	0	0	
					-6	**39**	0	0	
					4	**25**	0	0	
					4	**30**	0	0	
					4	**29**	0	0	
455609156411	80	H1	CuNap in Biodiesel	2008	-6	**39**	0	0	**1.53**
					-6	**45**	0	0	
					-6	**40**	0	0	
					4	**20**	0	0	
					4	**45**	0	0	
					4	**51**	0	0	

Table V-1 (Cont.). Characteristics of copper naphthenate treated poles sampled in the Puget Sound Energy and Snohomish PUD systems.

Utility Pole Identification	Height (Ft)	Class	Treatment Type	Year	Height (in)	Preservative Penetration (mm)	Fungi/ Plate	Dematiaceous Fungi /Plate	CuNap (kg/m^3 as Cu)
455366156438	75	CL1	CuNap in Biodiesel	2008	-6	**35**	0	0	**2.74**
					-6	**30**	0	0	
					-6	**35**	0	0	
					4	**25**	0	0	
					4	**30**	0	0	
					4	**30**	0	0	
455336156436	75	CL1	CuNap in Biodiesel	2008	-6	**30**	1	0	**2.14**
					-6	**35**	0	0	
					-6	**30**	0	0	
					4	**25**	0	0	
					4	**20**	0	0	
					4	**25**	0	0	
455242156430	75	H1	CuNap in Biodiesel	2008	-6	**25**	0	0	0.78
					-6	15	0	0	
					-6	**30**	0	0	
					4	**20**	0	0	
					4	18	0	0	
					4	13	0	0	
455017156578	85	H1	CuNap in Biodiesel	2008	-6	**35**	1	0	**2.63**
					-6	**35**	0	0	
					-6	**30**	0	0	
					4	**35**	0	0	
					4	**20**	0	0	
					4	10	0	0	

Table V-1 (Cont.). Characteristics of copper naphthenate treated poles sampled in the Puget Sound Energy and Snohomish PUD systems.

Utility Pole Identification	Height (Ft)	Class	Treatment Type	Year	Height (in)	Preservative Penetration (mm)	Fungi/ Plate	Dematiaceous Fungi /Plate	CuNap (kg/m^3 as Cu)
455050156589	85	H1	CuNap in Biodiesel	2008	-6	**27**	1	1	**1.54**
					-6	**34**	0	0	
					-6	**35**	0	0	
					4	**30**	0	0	
					4	**34**	0	0	
					4	**35**	0	0	
453542157567	70	CL1	CuNap in Biodiesel	2008	-6	**30**	0	0	**1.80**
					-6	**35**	0	0	
					-6	**37**	0	0	
					4	18	0	0	
					4	**39**	0	0	
					4	**35**	0	0	
453543157504	75	CL1	CuNap in Biodiesel	2008	-6	**63**	0	0	**2.46**
					-6	**58**	0	0	
					-6	**60**	0	0	
					4	**45**	0	0	
					4	**27**	0	0	
					4	**35**	0	0	
453544157510	75	CL1	CuNap in Biodiesel	2008	-6	**40**	1	1	1.33
					-6	**30**	0	0	
					-6	**35**	0	0	
					4	**35**	1	0	
					4	**30**	0	0	
					4	**30**	0	0	

Table V-1 (Cont.). Characteristics of copper naphthenate treated poles sampled in the Puget Sound Energy and Snohomish PUD systems.

Utility Pole Identification	Height (Ft)	Class	Treatment Type	Year	Height (in)	Preservative Penetration (mm)	Fungi/ Plate	Dematiaceous Fungi /Plate	CuNap (kg/m^3 as Cu)
318537166857	60	CL1	CuNap in Biodiesel	2008	-6	**25**	2	1	**1.77**
					-6	**50**	1	1	
					-6	**25**	1	0	
					4	**45**	1	0	
					4	**40**	0	0	
					4	**40**	0	0	
318951166858	55	CL1	CuNap in Biodiesel	2008	-6	**25**	0	0	**1.92**
					-6	**30**	0	0	
					-6	**35**	0	0	
					4	**25**	0	0	
					4	**25**	0	0	
					4	**25**	0	0	
318638166856	65	CL1	CuNap in Biodiesel	2008	-6	**60**	1	0	1.29
					-6	**50**	1	0	
					-6	**50**	0	0	
					4	**30**	1	0	
					4	**20**	0	0	
					4	**25**	0	0	
221584167047	80	CL1	CuNap in Biodiesel	2008	-6	**25**	0	0	**1.67**
					-6	**30**	0	0	
					-6	**20**	0	0	
					4	15	0	0	
					4	**20**	0	0	
					4	**20**	0	0	

Table V-1 (Cont.). Characteristics of copper naphthenate treated poles sampled in the Puget Sound Energy and Snohomish PUD systems.

Utility Pole Identification	Height (Ft)	Class	Treatment Type	Year	Height (in)	Preservative Penetration (mm)	Fungi/ Plate	Dematiaceous Fungi /Plate	CuNap (kg/m^3 as Cu)
223772167361	55	CL1	CuNap in Biodiesel	2008	-6	**20**	2	1	0.86
					-6	15	1	0	
					-6	15	0	0	
					4	15	1	0	
					4	**20**	0	0	
					4	15	0	0	

Table V-2. Groups of fungi isolated from Douglas-fir poles treated with copper naphthenate in diesel or biodiesel. Species with an asterisk are known to cause soft rot

Morphogroup	Species	Total Occurrences	% plates
MG1	Amorphotheca resinae*	72	18.5%
MG2	Penicillium sp.	8	2.1%
MG3		2	0.5%
MG4	Paecilomyces sp.	44	11.3%
MG5		1	0.3%
MG6		16	4.1%
MG7	Phialophora fastigiata*	5	1.3%
MG8	Pithomyces chartarum	7	1.8%
MG9	Zygomycete	1	0.3%
MG10	Alternaria sp.*	1	0.3%
MG11		2	0.5%
MG12		1	0.3%
MG13		2	0.5%
MG14	Talaromyces amestolkiae	1	0.3%
MG15	Penicillium sp.	1	0.3%
MG16		2	0.5%
MG17	Mollisia dextrinospora	1	0.3%
MG18		1	0.3%
MG19	Cadophora melinii*	4	1.0%
Decay 1		2	0.5%