Oregon State University Utility Pole Research Cooperative (UPRC)

Department of Wood Science & Engineering
Oregon Wood Innovation Center
37th Annual Report
2017

By:
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COOPERATORS

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
Lonza
Nisus
Osmose Utilities Services, Inc.
Pacific Gas and Electric
PacifiCorp
Poles Inc.
Portland General Electric Company
Puget Sound Energy Services
Rio Tinto Minerals
Salt River Project
Snohomish County Public Utility District
McFarland-Cascade (Stella-Jones Inc.)
The Pentachlorophenol Working Group
Timber Products Inspection
Western Wood Preservers Institute
Wood Care Systems
Xcel Energy

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EXECUTIVE SUMMARY

The Coop continues to make progress on all five of its primary objectives. Progress will be summarized by Objective.

Under **Objective I**, we continue to evaluate long-term performance of numerous remedial treatments. Field assessment of dazomet plus copper compounds indicate residual levels of methylisothiocyanate were extremely low, but detectable 20-years after treatment. Laboratory tests of boron movement are continuing as part of our efforts to better characterize the movement of this element out of wood following application of boron rods.

Under **Objective II**, we continue to assess methods for preventing development of internal decay above groundline. We are assessing pre-treatment with boron prior to over-treatment with pentachlorophenol or copper naphthenate, or dual treatment with boron and ammoniacal copper zinc arsenate. Boron is present at the center of many poles but the levels remain lower than expected one year after treatment. It is unclear how much boron will actually be necessary to prevent fungal attack in these applications. A field trial of fused boron rods to arrest decay around voids above-ground in transmission poles in Oregon was assessed five years after treatment. Boron levels were very low and decay fungi were isolated from areas around the voids in a number of poles. The results suggest boron treatments were less mobile and less effective than expected.

Under **Objective III**, we are exploring a number of actions to improve pole performance. Tests to evaluate the effects of edge distance in through boring patterns on pole flexural properties are nearly complete. Holes were drilled 1, 2, or 3 inches inward from the edge of the pole, and poles were subjected to a flexural test to failure. Finite element models suggested edge distance would not affect flexural properties and the full-scale tests confirmed these results. We will follow up with models to determine if they can accurately predict other factors. This might reduce the need to perform extensive full-scale tests when contemplating changes to pole configuration.

Long term tests on the effects of end-plates on cross arm checking were evaluated and continue to show that plated arms develop fewer deep checks. One non-plated end of an arm has developed an extensive split that would require replacement while the opposite end of the arm with the plate has no evidence of a split. Numerous capping trials continue to show the benefits of using water shedding caps. Moisture contents in poles with caps are markedly lower than those in pole without caps, and would limit the possibility of decay fungi establishing and impacting pole-top integrity. A newer test has been established to evaluate pole top configurations but this test has yet to show any differences in moisture content between the top designs.

No new fire retardant systems were evaluated this past year, but the fire test methodology was adapted to produce heating from all around the pole to more accurately simulate a real fire. Testing to validate this approach will be undertaken this coming year with the goal of generating a sufficient body of performance data to support the development of a standard procedure.

Small scale tests to evaluate the effects of time-after-treatment on corrosion of galvanized fasteners in ACZA-treated poles showed time-after-treatment had no noticeable effect on corrosion. There were differences in corrosion between galvanized bolts inserted in pre-drilled vs field-drilled holes, but the differences were minor. The results suggest no need to delay installing attachments to poles treated with this preservative system.

Field trials of Douglas-fir sapwood stakes treated with copper naphthenate or pentachlorophenol in varying solvents were evaluated after 32-months of ground-contact exposure in Western Oregon. Stakes in the forest site were experiencing more decay than those in the drier field site. Decay was apparent in non-treated controls and was beginning to become evident in stakes treated with solvents alone. Pentachlorophenol-treated stakes were generally performing well, as were copper naphthenate stakes treated using petroleum-based diesel. There was a trend toward increasing decay with increasing levels of biodiesel as the carrier. Results support laboratory trials that showed biodiesel addition was detrimental to copper naphthenate performance.

Under **Objective IV**, field trials of various liner systems to protect poles against fungal attack and limit preservative movement continue to show moisture levels remain slightly elevated in poles with barriers, but the levels are not as high as expected. Soil sampling is also underway to assess the ability of these barriers to limit chemical migration into the surrounding soil.

Under **Objective V**, copper naphthenate-treated western redcedar stakes continue to perform well and illustrate the performance attributes of this system. Field inspections of poles treated with copper naphthenate in either petroleum or biodiesel showed slightly more soft rot fungal attack in the outer zones of poles treated using biodiesel as the solvent, but the differences were negligible. These poles were inspected to provide a baseline for performance and will continue to be monitored to ensure the presence of biodiesel does not adversely affect performance.

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, OR test site. Three steeply angled holes were drilled into each pole beginning at groundline and moving upward 150 mm and around 120º. The holes received either 160 g of powdered dazomet, 107 g of dazomet rod plus 100 g of copper naphthenate (2% as Cu), 160 g of dazomet rod alone, 160 g of dazomet rod amended with 100 g of copper naphthenate, 160 g of dazomet rod amended with 100 g of water, or 490 g of metam sodium. Pre-measured aliquots of amendments were placed into treatment holes on top of the fumigants. Each treatment was replicated on five poles.

Chemical distribution was assessed 1, 2, 3, 5, 7, 8, 10, 12 and 15 years after treatment by removing increment cores from three equidistant locations around each pole (0.3, 0.8 or 1.3 m above groundline). The outer treated zone of each core was discarded, and the remaining inner and outer 25 mm 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. Performance of Dazomet With or Without Copper-based Accelerants

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

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

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

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

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

As with our other tests, the threshold for MITC is considered to be 20 ug or more of MITC/oven dried gram of wood. MITC levels tended to be greater in the inner zones, reflecting the tendency of the treatment holes to encourage chemical movement to the pole center (Table I-2). MITC was present at levels above the threshold in the 0.3 m above groundline zone. While MITC was detected above this area, it was rarely above threshold. For example, MITC levels 1.3 or 2.3 m above groundline in poles with no supplemental copper were only above the threshold 6-years after treatment.

For this reason, the results will be discussed from the perspective of protection around this lowest sampling point above the original treatment site. MITC levels in poles receiving no supplemental treatment reached threshold level 0.3 m above ground 1 year after treatment (Figure I-1). MITC levels 0.3 m above groundline increased slightly over the next 4 years in these poles, but stabilized at levels well above the threshold by 4 years after treatment. MITC levels in these poles declined to just at or below the threshold after 8 years and below that level after 10 years. Levels were again above the threshold 12 and 15 years after treatment, but only at 0.3 m above groundline. The presence of protective levels in these poles is consistent with previous tests showing that dazomet continues to release low levels of MITC for prolonged periods.

MITC levels 0.3 m above groundline one year after treatment were 2 to 5 times higher when copper sulfate was added to the dazomet and these levels continued to remain elevated over the next 4 years (Figure I-2). MITC was also detectable 1.3 and 2.3 m above groundline 4 years after treatment at levels above threshold. Chemical levels remained elevated 5 years after treatment, but then declined to levels just above the threshold 8 years after chemical application. Threshold levels were only present at four sampling locations 10 years after treatment, although all of these were in copper amended poles. These results clearly support the application of copper sulfate at the time of dazomet treatment to increase initial release rate. Results at 12 years indicated that threshold levels were only present 0.3 m above groundline, while MITC was either barely detectable or not detectable at higher locations. MITC levels in these same zones had declined below threshold at 15 years, but were above the threshold in the inner zone 2.3 m above groundline. These results indicate that any protective effect of dazomet had been lost and that retreatment would be advisable.

MITC levels in pole sections 1 year after receiving copper naphthenate appeared to experience less of an initial boost in release rate than poles receiving copper sulfate; however, chemical levels rose sharply 2 years after treatment and have remained elevated and similar to those for the copper sulfate treatment (Figure I-3). MITC was also detectable 1.3 and 2.3 m above groundline, but was only just approaching the threshold 1.3 m above groundline in the inner assay zone. These results indicate that copper naphthenate enhanced dazomet decomposition to MITC, but the levels were slightly lower than those found for copper sulfate. Despite the lower levels, copper naphthenate does appear to be useful for encouraging MITC production to more rapidly eliminate decay fungi established in the wood. As with copper sulfate, MITC levels declined at the 12 year sampling, but were still above the threshold 0.3 m above groundline and remained so at the 15 year sampling point. MITC levels above this zone were well below the threshold.

MITC levels at the 20 year point were generally low, with threshold values only present in the inner zones of cores removed from sites 0.3 m below groundline. The results indicate that any residual MITC has dissipated from the wood. These poles will now be used to evaluate the benefits of retreatment using the same treatment holes. Retreatment will occur during the Fall of 2017.

Isolation of decay fungi from the inner zones of the poles 1 year after treatment were limited except from poles treated with dazomet amended with copper compounds (Table I-3). While decay fungi were isolated 0.3 m above groundline from poles receiving dazomet plus copper naphthenate at the 1 year point, no fungi have been isolated from this zone since and no decay fungi were isolated from 0.3 m above groundline from any poles receiving dazomet alone or dazomet plus copper sulfate. Fungi continue to be periodically isolated from the above ground zones of these poles, but the isolations have been sporadic and suggest that isolated fungal colonies were present in the above ground pole zones (Table I-3). We suspect fungi present after 1 year were probably present at the time of treatment. The relatively low levels of chemical 1.3 and 2.3 m above groundline likely limited the potential for control in these zones. Decay fungi were isolated at various locations along the poles at 1.3 m and 2.3 m above the groundline, but there was no consistent pattern. These results suggest treatment patterns and the zone of protection are more limited with controlled-release formulations than with liquid formulations applied at much higher doses. As a result, some adaptation of treatment patterns may be necessary where fungal control is desired above the groundline; however, one advantage of these treatments over liquids is the ability to more safely apply the chemical above groundline.

Table I-2. Residual MITC in Douglas-fir pole sections 1 to 20 years after treatment with dazomet and copper sulfate or copper naphthenate.

Copper Treatment	Year Sampled	Residual MITC (ug/g oven dried wood)[a]					
		0.3 m		1.3 m		2.3 m	
		inner	outer	inner	outer	inner	outer
None	1	**21 (14)**	18 (37)	0 (0)	0 (0)	0 (0)	3 (8)
	2	**72 (47)**	**36 (33)**	0 (0)	0 (0)	0 (0)	0 (0)
	3	**57 (27)**	**32 (42)**	0 (0)	0 (0)	0 (0)	0 (0)
	4	**50 (41)**	**32 (32)**	6 (5)	6 (5)	0 (0)	0 (0)
	5	**67 (31)**	9 (8)	12 (4)	10 (29)	0 (0)	0 (0)
	8	**21 (26)**	16 (21)	**22 (24)**	17 (28)	**21 (23)**	**26 (39)**
	10	10 (13)	6 (12)	19 (34)	12 (21)	13 (22)	4 (6)
	12	**35 (38)**	**20 (22)**	4 (5)	1 (4)	2 (6)	0 (0)
	15	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	20	**33 (24)**	6 (12)	0 (0)	0 (0)	0 (0)	0 (0)
20 g $CuSO_4$	1	**103 (78)**	**55 (86)**	4 (6)	0 (0)	0 (0)	0 (0)
	2	**101 (36)**	**32 (17)**	7 (7)	3 (7)	0 (0)	0 (0)
	3	**78 (25)**	**29 (17)**	7 (7)	5 (8)	0 (0)	0 (0)
	4	**95 (61)**	**40 (20)**	**20 (21)**	**21 (27)**	**25 (35)**	**23 (33)**
	5	**87 (12)**	**21 (6)**	18 (15)	3 (6)	7 (10)	0 (0)
	8	**35 (43)**	14 (20)	**26 (29)**	12 (21)	**29 (36)**	**24 (40)**
	10	16 (24)	7 (9)	**28 (41)**	5 (8)	**30 (46)**	4 (6)
	12	**40 (16)**	**21 (16)**	13 (6)	1 (2)	4 (6)	0 (0)
	15	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	20	**31 (47)**	3 (10)	0 (0)	0 (0)	0 (0)	0 (0)
20 g Cu Naph	1	**34 (19)**	**43 (54)**	0 (0)	0 (0)	2 (5)	6 (19)
	2	**94 (45)**	**94 (64)**	6 (7)	5 (11)	0 (0)	0 (0)
	3	**110 (29)**	**59 (46)**	7 (7)	4 (8)	0 (0)	0 (0)
	4	**89 (33)**	**73 (24)**	18 (9)	9 (7)	1 (2)	0 (0)
	5	**102 (18)**	**41 (39)**	**23 (7)**	1 (2)	2 (3)	0 (0)
	8	**27 (26)**	**22 (23)**	**26 (35)**	**20 (24)**	**26 (26)**	**38 (55)**
	10	19 (28)	11 (13)	**24 (37)**	4 (9)	**28 (43)**	9 (18)
	12	**57 (17)**	**29 (14)**	8 (30)	2 (4)	3 (6)	0 (0)
	15	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	20	**42 (50)**	10 (16)	0 (0)	0 (0)	0 (0)	0 (0)

[a] Values in bold type represent MITC levels at or above the threshold for protection against fungal attack. Values represent means of 15 analyses, while figures in parentheses represent one standard deviation.

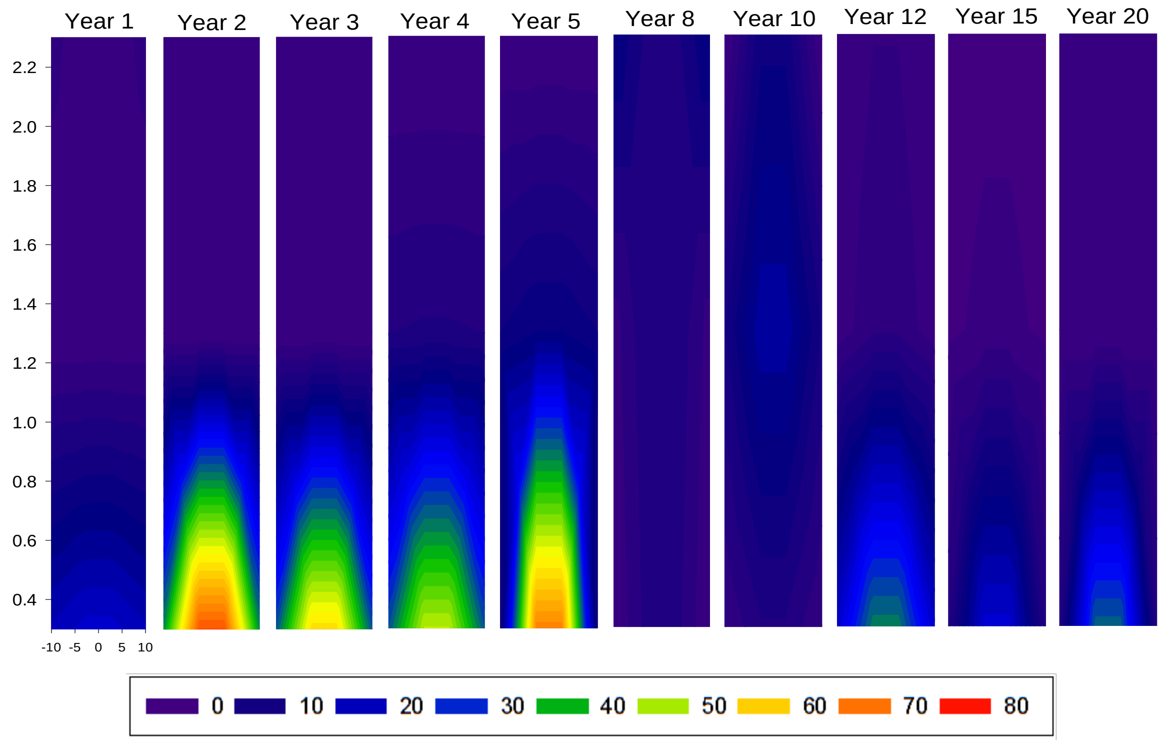

Figure I-1. Distribution of residual MITC in Douglas-fir pole sections 1 to 20 years after treatment with 200 g of dazomet. Dark blue indicates MITC levels below the threshold. Light blue and all other colors indicate MITC levels above that level.

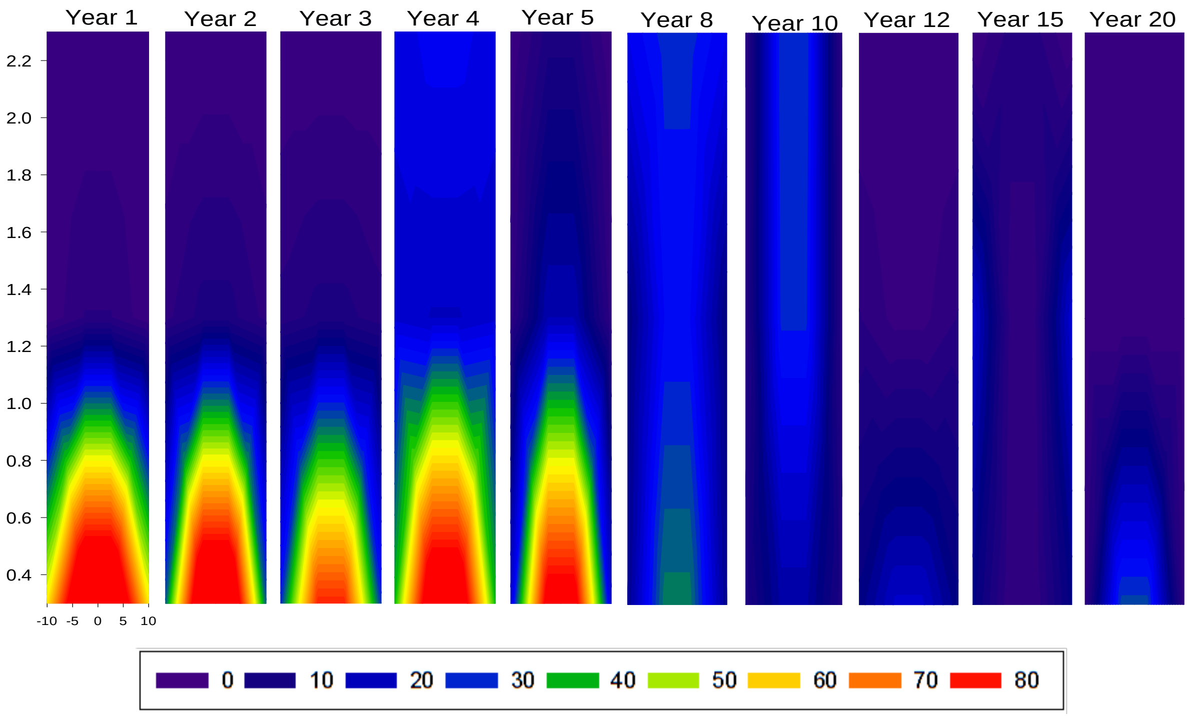

Figure I-2. Distribution of residual MITC in Douglas-fir pole sections 1 to 20 years after treatment with 200 g of dazomet plus 20 g of copper sulfate. Dark blue indicates MITC levels below the threshold. Light blue and all other colors indicate MITC levels above that level.

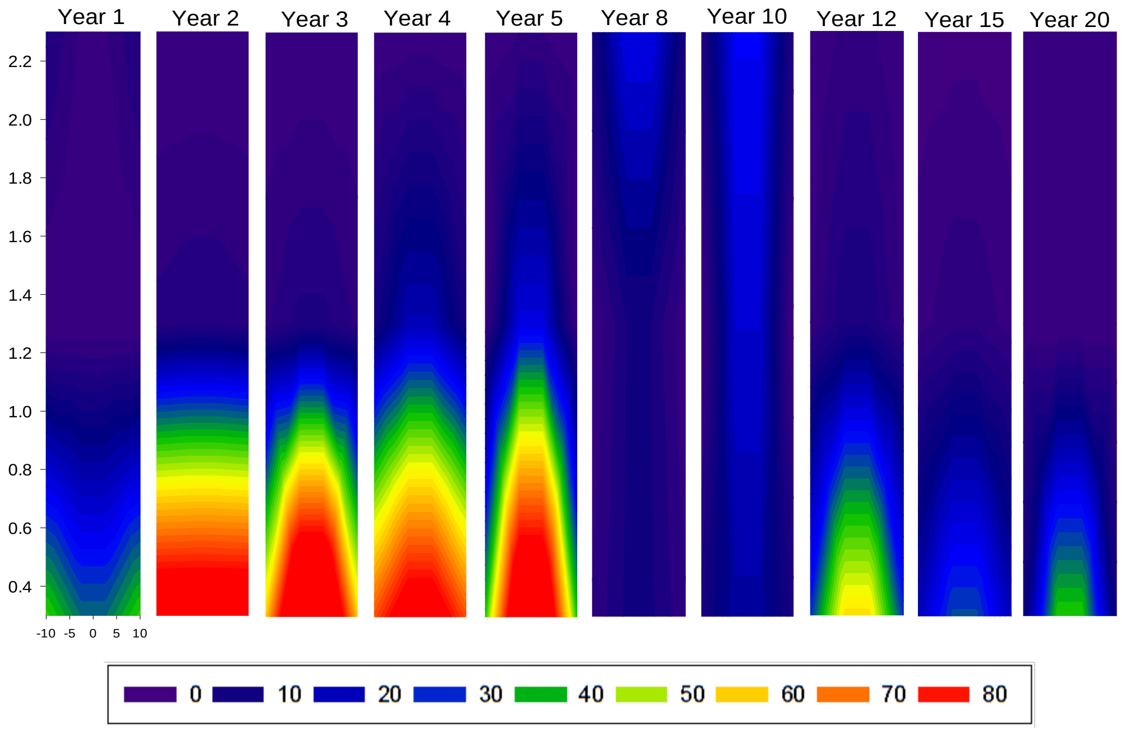

Figure I-3. Distribution of residual MITC in Douglas-fir pole sections 1 to 20 years after treatment with 200 g of dazomet plus 20 g of copper naphthenate. Dark blue indicates MITC levels below the threshold. Light blue and all other colors indicate MITC levels above that level.

Table I-3. Percentage of increment cores containing decay fungi $^{\text{non-decay fungi}}$ 1 to 20 years after treatment with dazomet with or without copper sulfate or copper naphthenate.

Copper Treatment	Year Samples	Isolation Frequency (%)[a]		
		0.3 m	1.3 m	2.3 m
None	1	0^{11}	0^{11}	0^{11}
	2	0^{0}	0^{33}	0^{33}
	3	0^{0}	0^{33}	0^{0}
	4	0^{11}	0^{33}	0^{56}
	5	0^{0}	0^{0}	0^{100}
	8	0^{0}	0^{11}	0^{56}
	10	0^{0}	0^{33}	0^{0}
	12	0^{0}	11^{0}	0^{22}
	15	0^{0}	22^{0}	0^{11}
	20	33^{11}	33^{22}	33^{44}
20 g $CuSO_4$	1	0^{11}	22^{33}	0^{44}
	2	0^{0}	44^{56}	0^{33}
	3	0^{0}	11^{11}	0^{33}
	4	0^{11}	22^{33}	11^{33}
	5	0^{0}	0^{67}	0^{89}
	8	0^{0}	0^{22}	0^{44}
	10	0^{0}	11^{44}	0^{11}
	12	0^{0}	0^{0}	0^{33}
	15	0^{11}	0^{44}	0^{0}
	20	0^{0}	11^{56}	0^{56}
20 g CuNaph	1	33^{33}	0^{22}	0^{44}
	2	0^{0}	0^{0}	0^{67}
	3	0^{0}	0^{0}	0^{22}
	4	0^{0}	0^{0}	0^{67}
	5	0^{0}	11^{11}	0^{78}
	8	0^{11}	0^{0}	0^{33}
	10	0^{0}	0^{11}	0^{44}
	12	0^{0}	0^{11}	0^{22}
	15	0^{0}	0^{22}	0^{0}
	20	0^{22}	0^{33}	0^{56}

B. Performance of Water Diffusible Preservatives as Internal Treatments

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

Boron has a long history of use as an initial treatment of freshly sawn lumber to prevent infestations by various species of powder post beetles in both Europe and New Zealand. This chemical has also been used more recently for treatment of lumber in Hawaii to limit attack by the Formosan subterranean termite. Boron is attractive as a preservative because it has exceptionally low toxicity to non-target organisms, especially humans, and because it has the ability to diffuse through wet wood. In principle a decaying utility pole should be wet, particularly near groundline, and moisture can be a vehicle for boron to move from the point of application to points of decay. Boron is available for remedial treatments in a number of forms, but the most popular are fused borate rods which come as pure boron or boron 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

This test has been completed.

2. Performance of Copper Amended Fused Boron Rods

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

This test will not be sampled again until 2018.

3. Diffusion of Boron Through Preservative Treated Wood

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

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-4).

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

Figure I-4. Photograph of five of the diffusion apparatuses 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.

Last year, we reported on tests that included radially oriented specimens with and without diesel treatment. The experiment was monitored on a regular basis for over 100 days. Boron movement was initially limited in both treated and control samples, but concentrations in control samples increased at a much more rapid rate after 40 days of exposure (Figure I-5). Concentrations on the receiving ends of control samples have continued to increase at a much faster rate than treated samples.

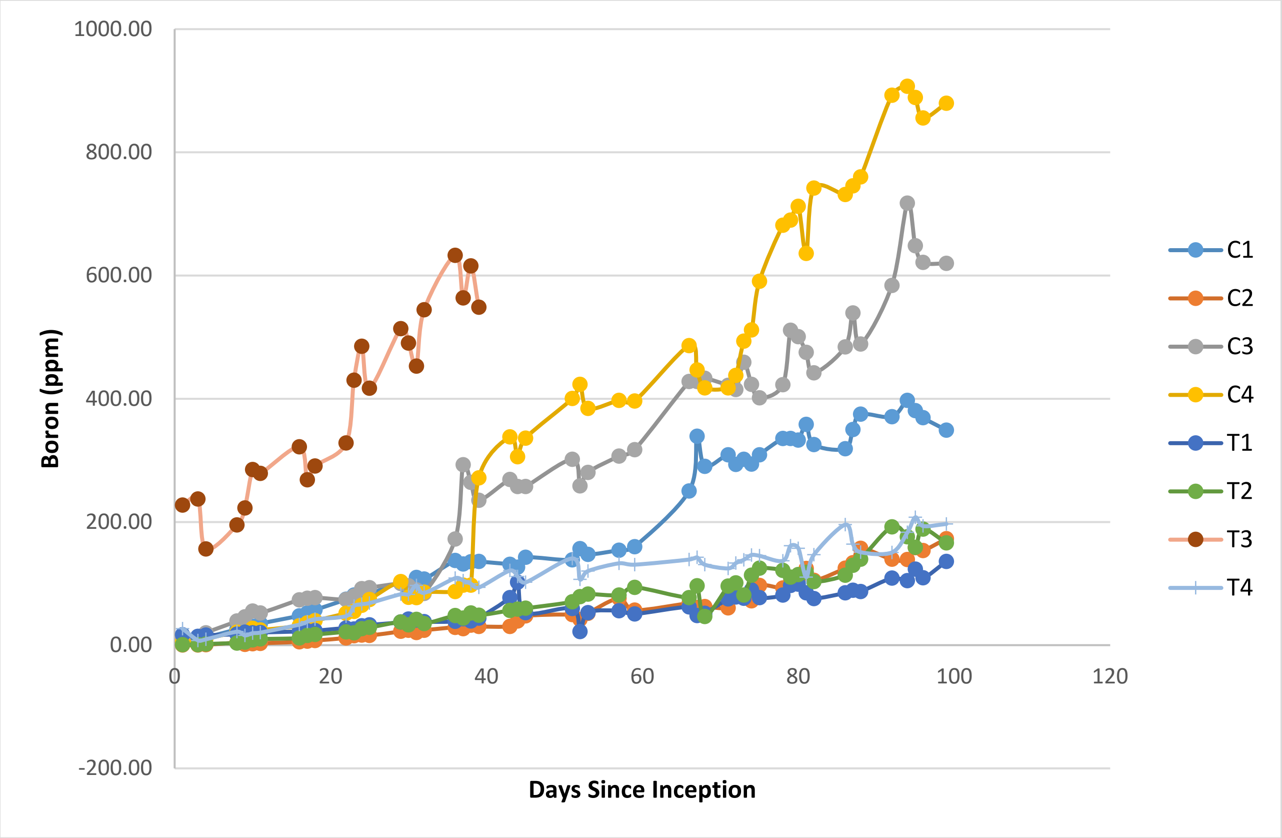

Figure I-5. Boron concentrations on the receiving end of diffusion tests using radially oriented Douglas-fir sapwood with or without a biodiesel treatment where C= no treatment and T= diesel treated samples. The T-3 sample developed a leak and was dropped from the test.

The most recent test was run for 156 days before leaks developed and the test was terminated (Figure I-6). The trends observed in the current tests were similar to those observed in the earlier trials. Boron movement was generally slower through the treated samples, although the results were more variable than previous trials. Concentrations in the receiving end of samples with non-treated wood appeared to be reaching a steady state, while those in holders with treated samples were still increasing.

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 creosote helps retain boron in railroad tie interiors for decades after treatment, even when ties are installed in track. Our test site is far wetter than the conditions a tie would be exposed to in a track on a well-drained ballast. This diffusion test suggests boron losses are slowed by preservative treated shells, even when continuously exposed to liquid water. 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.

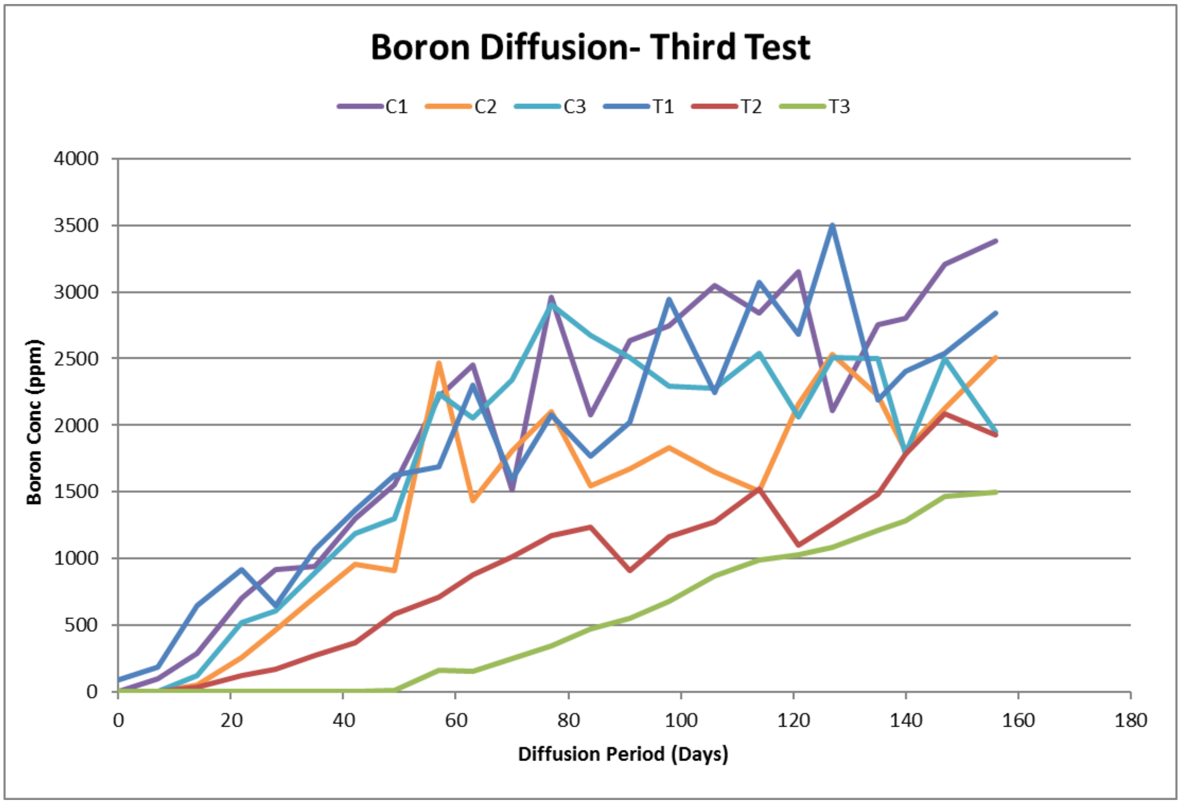

Figure I-6. Boron concentrations vs time on the receiving end of diffusion tests using radially oriented Douglas-fir sapwood with (T samples) or without a biodiesel treatment (C samples).

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 during test inception at our Corvallis test site (Table I-4).

Table I-4. 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 (poles treated with diffusible rods) and four (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 120°. 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. 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.

This test was not sampled in 2016, but will be sampled during the 2017-2018 cycle.

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OBJECTIVE II

IDENTIFY CHEMICALS FOR PROTECTING EXPOSED WOOD SURFACES IN POLES

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

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

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

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

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

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

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

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

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

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

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

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

1. **Boron pre-treatment followed by copper naphthenate pressure treatment of Douglas-fir poles**

Freshly peeled Douglas-fir pole sections (2.4 m long by 250-300 mm in diameter) were pressure treated with a 7% solution (BAE) of DOT, then six increment cores were removed from two sides near the middle of each pole. Cores were divided into 25 mm segments from surface to pith and combined by depth for each pole. Combined cores were ground to pass a 20 mesh screen before extraction in hot water and boron analysis according to AWPA Standard A2, Method 16. No AWPA borate retention is specified for 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.

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

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

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.

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 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.

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

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

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

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

Boron levels in the outer 25 mm of poles one year after treatment had declined (Figure II-2, 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 revealed that the interior pole moisture content at groundline tends to be above 30% most of the year, but only reaches that level above groundline near the end of winter. Elevated moisture contents are expected to help boron diffuse and distribute evenly. Declines suggest 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 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.

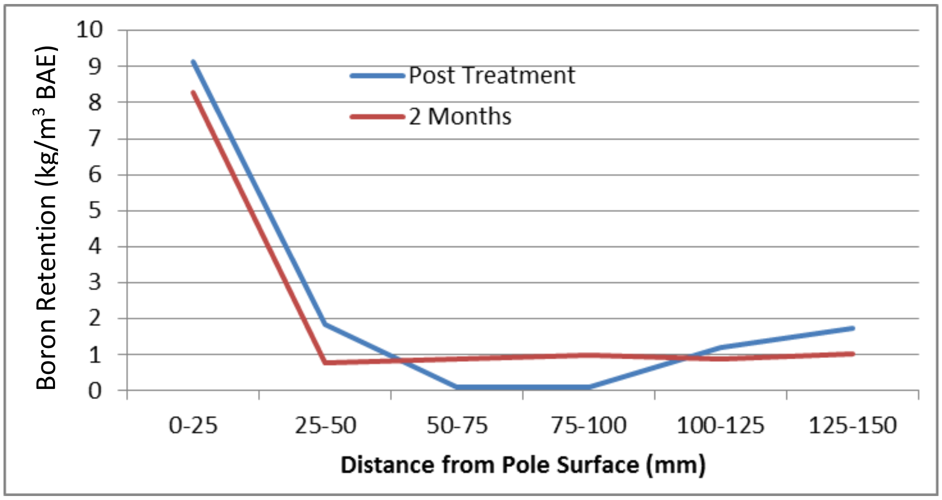

Figure II-1. Boron retentions in 25 mm increments inward from the surface in Douglas-fir poles immediately after pressure treatment with disodium octaborate tetrahydrate and again 2 months later.

Boron levels in poles 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 some boron was leaching from poles in soil contact (Figure II-2). Levels further inward remained similar to those found after one year. These results suggest boron lost from the outer 25 mm zone is not moving to a substantial extent inward to help increase boron levels in those zones.

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

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

These results differ from those found with railroad ties, where boron remains at elevated levels for many years after initial treatment followed by a creosote over-treatment. However, there are several important differences in this test. First, ties are typically installed over well-drained ballast which should reduce the potential for excessive wetting that leads to boron loss. In addition, overall boron levels in these poles were much lower than those typically placed into an air-seasoning tie. This occurred because the poles were pressure treated with a treatment solution that was intended for lumber 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.

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

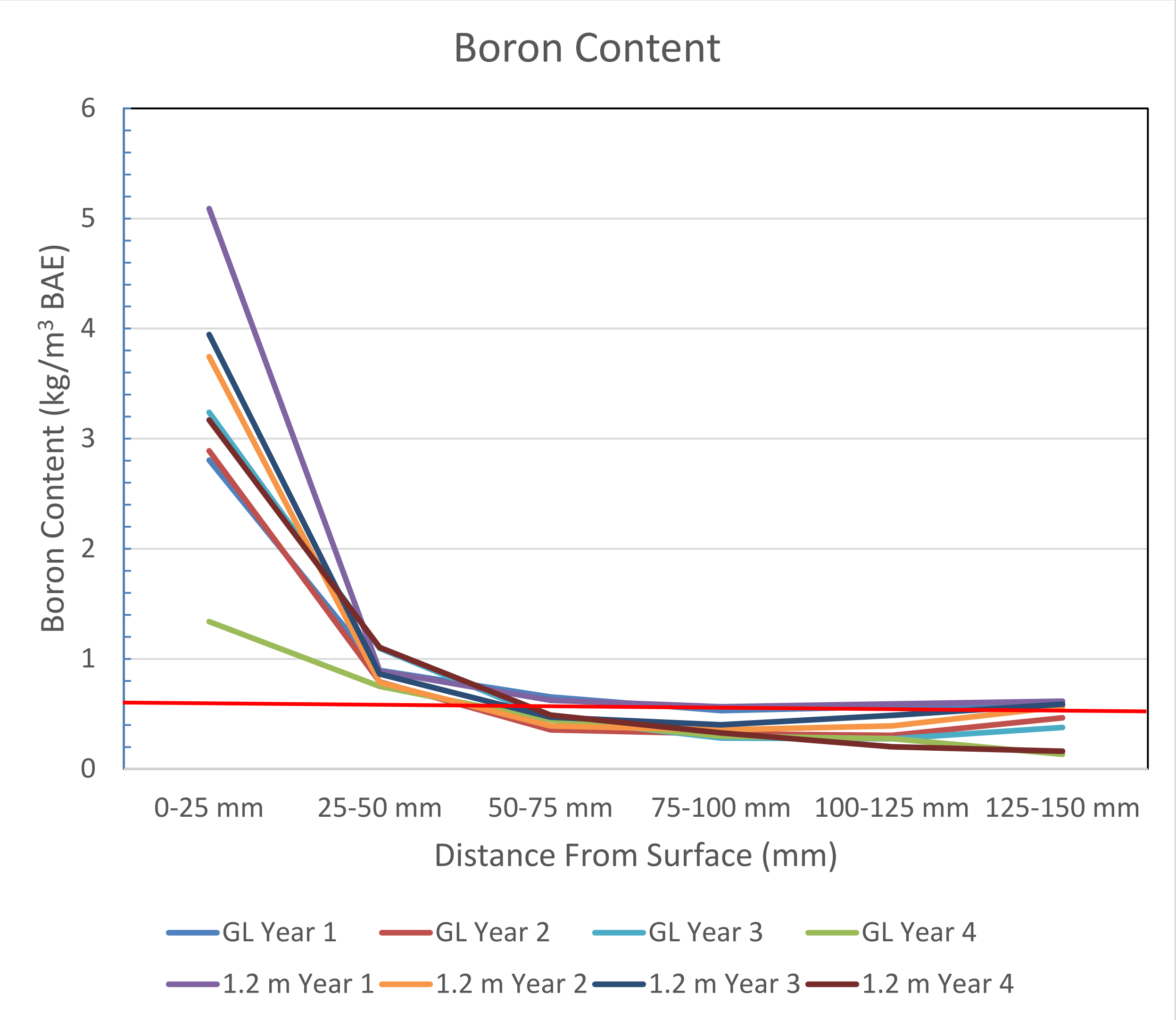

Figure II-2. Boron content at 25 mm increments from Douglas-fir pole surface 1-4 years after pre-treatment with disodium octaborate tetrahydrate followed by either kiln drying or Boulton seasoning and copper naphthenate treatment. Red line indicates 0.6 kg/m^3 BAE.

Table II-6. Boron content in increment cores removed from groundline or 1.2 m above groundline of Douglas-fir poles 1-4 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/m³ 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)
759	Boulton Year 4	**0.82**	**3.63**	**0.86**	**1.60**	**0.83**	0.53	0.46	0.18	0.48	0.21	0.31	0.07
760		**0.80**	**2.18**	**0.63**	**1.41**	0.58	**1.03**	0.50	**0.64**	0.43	0.31	0.35	0.09
762		0.31	**3.71**	0.21	**0.61**	0.00	0.06	0.00	0.03	0.00	0.00	0.00	0.00
763		**2.67**	**3.52**	**0.78**	**3.55**	0.03	0.40	0.06	0.23	0.09	0.16	0.00	0.58
764		**1.68**	**2.51**	**1.17**	**1.27**	**0.71**	**1.13**	**0.80**	0.50	**0.89**	0.34	0.16	0.22
Mean (SD)		**1.26** **(0.82)**	**3.11** **(0.64)**	**0.73** **(0.31)**	**1.69** **(0.99)**	0.43 (0.35)	**0.63** **(0.40)**	0.36 (0.30)	0.32 (0.22)	0.38 (0.32)	0.20 (0.12)	0.17 (0.15)	0.19 (0.21)
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)**
766	Kiln Year 4	**0.66**	**1.79**	0.62	0.27	0.35	**0.19**	0.17	0.17	0.03	0.00	**0.00**	0.00
767		**1.33**	**2.66**	**0.30**	0.34	0.23	0.17	0.12	0.08	0.08	0.04	0.07	0.01
770		**2.03**	**3.25**	**1.56**	**1.01**	**0.94**	**0.95**	0.52	**0.91**	**0.48**	**0.61**	**0.39**	**0.56**
788		**1.10**	**3.85**	**0.69**	**0.39**	0.17	0.24	0.08	**0.38**	0.05	**0.19**	0.05	**0.06**
789		**1.97**	**4.60**	0.70	**0.58**	0.61	0.21	0.26	0.16	0.20	0.14	0.00	0.00
Mean (SD)		**1.42** **(0.52)**	**3.23** **(0.96)**	**0.77** **(0.42)**	**0.52** **(0.27)**	0.46 (0.28)	0.35 (0.30)	0.23 (0.16)	0.34 (0.30)	0.17 (0.17)	0.20 (0.22)	0.10 (0.15)	**0.13** **(0.22)**

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

2. Effect of boron pre-treatment on performance of Douglas-fir poles treated with pentachlorophenol, copper naphthenate, or ammoniacal copper zinc arsenate

As noted, the initial trial to evaluate the potential for pre-treatment with borates produced somewhat anomalous results. There were several delays in processing that might have affected the outcome. In order to develop better data, additional poles were obtained 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. Twelve poles were tagged and 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 commercially treated to the AWPA UC4 retention with copper naphthenate (1.44 kg/m^3) or pentachlorophenol (9.6 kg/m^3). The remaining six pole sections were impregnated with a DOT/ammoniacal copper zinc arsenate solution. Following treatment, increment cores were taken at 300 mm increments along the length of the poles. These cores were divided into 25 mm long segments and the 8 segments from a given depth were combined for each pole. These segments were oven dried, ground to pass a 20 mesh screen, and hot water extracted. The hot water extract was analyzed for boron using the Azomethine H method. Initial preservative retention was determined by taking additional cores. The outer 6 mm of each core was discarded, then the next 19 mm of increment core was retained. These segments were ground to pass a 20 mesh screen and analyzed by x-ray fluorescence. We experienced some interference with the ACZA samples in our XRF unit. Instead, these samples were microwave digested and analyzed by ion-coupled plasma spectroscopy for copper, zinc, arsenic, and boron.

Average boron levels were elevated at all depths in the ACZA treated poles, although there was some variation in distribution within each pole (Table II-7). For example, boron levels ranged from the limit of detection (0.04 kg/m^3 BAE) to 7.64 kg/m^3 BAE in the second 25 mm inward from the surface. Variations in chemical distribution are to be expected in wood, but the range suggests that further work will be needed in the process to deliver more consistent treatment.

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

Table II-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)**

The poles were sampled one year after installation by removing increment cores from three locations around each pole at groundline and 1.2 m above groundline. Each core was divided into 25 mm long segments. Core segments from a given location on each pole were combined and ground to pass a 20 mesh screen. The resulting ground wood was hot water extracted and analyzed for boron via the azomethine H method. Results were expressed on a kg/m^3 boric acid equivalent (% BAE) where the threshold for fungal protection is considered to be equal to, or greater than 0.6 kg/m^3 BAE.

Boron levels at groundline and 1.2 m above groundline did not differ markedly from each other (Table II-8). The 1.2 m height was selected to determine if proximity to the soil resulted in accelerated boron loss near the surface. This did not appear to be the case. Boron levels in the poles were above the threshold in the outer 50 mm at both groundline and 1.2 m above groundline, but levels declined sharply further inward. There was a slight gradient with distance inward beyond the outer 50 mm, but the differences were slight and there was little evidence of substantial movement inward from the surface (Figure II-3). The results would appear to differ substantially from the results immediately after treatment; however, these results must be interpreted carefully. Boron levels were generally low in the freshly treated poles except in a few poles per treatment. These outliers tended to push the averages upward so that the poles looked better treated. It is important to stress that the results do not necessarily mean that boron is not performing a function. The research on railway ties showed that trace amounts of boron protected the wood for over 20 years after treatment and we would expect the results to be similar in utility poles. While higher boron loadings would be preferable, it does not take much boron to inhibit the germination of fungal spores. We will continue to monitor these poles to determine how boron redistributes in the interior of the poles.

Table II-8. Boron levels at 25 mm increments inward from the surface at groundline and 1.2 m above groundline in Douglas-fir poles one year after dual treatment with boron plus ACZA, copper naphthenate, or pentachlorophenol.

Primary Treatment	Depth (mm)	Boron content (kg/m^3 BAE)[a]	
		Groundline	1.2 m
ACZA	0-25	**3.74 (2.33)**	**2.83 (1.47)**
	25-50	**0.65 (0.39)**	**0.63 (0.61)**
	50-75	0.50 (0.43)	0.23 (0.22)
	75-100	0.42 (0.27)	0.35 (0.31)
	100-125	0.45 (0.25)	0.46 (0.45)
	125-150	0.51 (0.52)	0.47 (0.42)
Cu Naphthenate	0-25	**2.27 (1.61)**	**4.47 (2.62)**
	25-50	0.41 (0.32)	**0.75 (0.47)**
	50-75	0.24 (0.18)	0.48 (0.33)
	75-100	0.30 (0.30)	0.20 (0.10)
	100-125	0.37 (0.38)	0.23 (0.13)
	125-150	0.31 (0.41)	0.16 (0.12)
Pentachlorophenol	0-25	**3.81 (2.91)**	**2.38 (0.97)**
	25-50	**1.11 (1.04)**	**0.90 (0.46)**
	50-75	0.53 (0.55)	0.55 (0.35)
	75-100	0.41 (0.43)	0.39 (0.17)
	100-125	0.48 (0.45)	0.42 (0.25)
	125-150	0.29 (0.20)	0.25 (0.20)

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

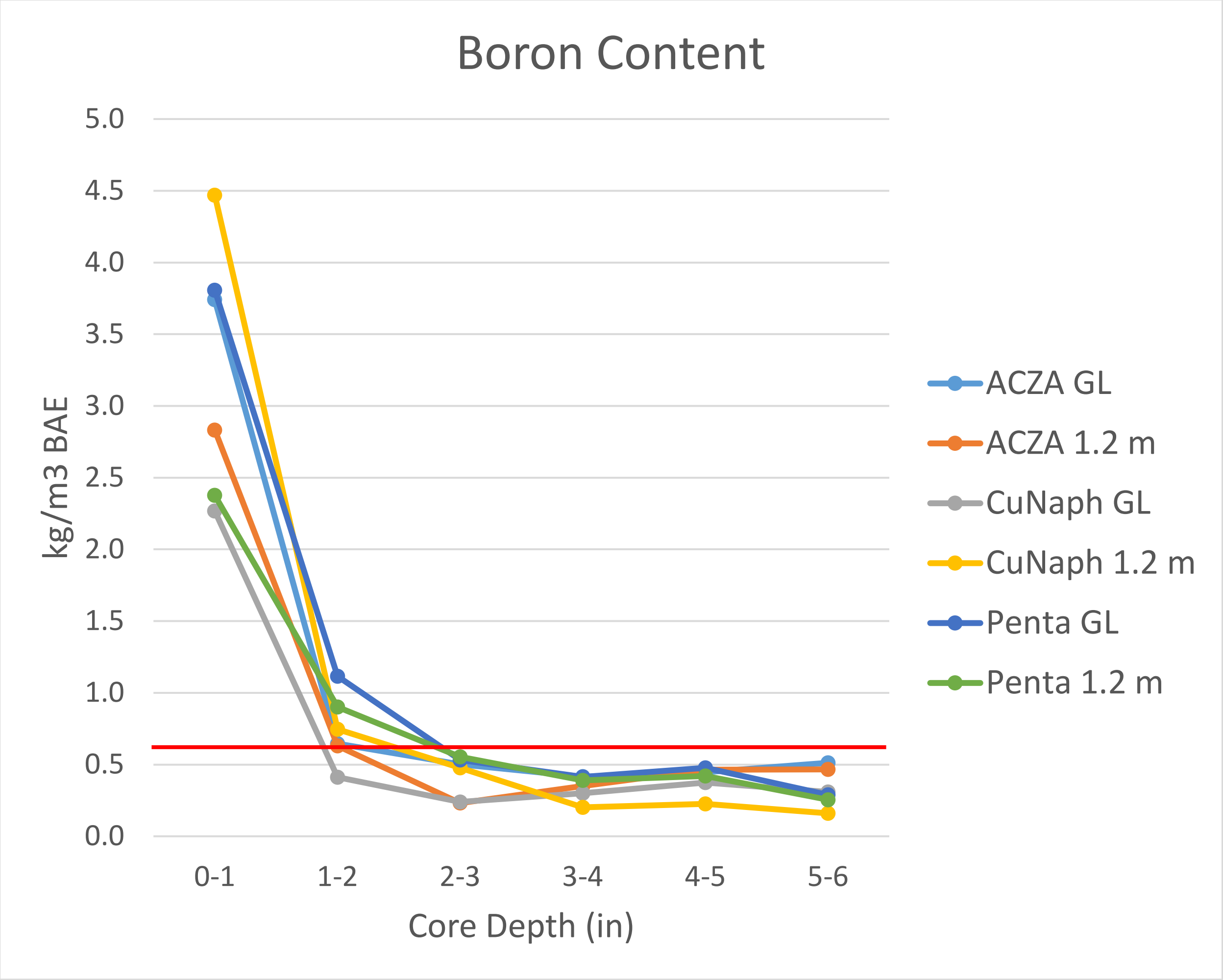

Figure II-3. Boron levels in Douglas-fir poles subjected to either a boron pre-treatment followed by over-treatment with copper naphthenate or pentachlorophenol, or an ACZA/boron pressure treatment. Red line indicates 0.6 kg/m^3 BAE.

B. Assessment of Fused Borate Rods for Arresting Above-Ground Decay in Douglas-fir transmission poles:

The outer preservative treated shell on Douglas-fir poles provides excellent protection against fungal attack provided that no checks or splits develop that penetrate beyond the original depth of treatment. These checks allow moisture and fungal spores to enter the non-treated heartwood to initiate internal decay. Internal decay is easily prevented through practices such as through boring at groundline to produce internal preservative treated zones that resist fungal attack.

Through boring in the groundline zone of Douglas-fir utility poles is standard practice for many utilities, especially in the western United States; however, this process has little or no effect on the potential for decay to develop as checks open throughout the pole. The potential for decay development above groundline in older poles is dependent on a number of factors including treatment quality, the degree to which a pole dries once in service, and the prevalence of wind-driven rain. The Pacific Northwest has mild, very dry summers followed by cool, wet winters. Areas along the coast are especially prone to strong, wind driven rain that can penetrate into checks that open in seasoned poles, creating conditions suitable for decay.

Concerns about the risk of internal decay above ground in older poles led OSU to undertake a cooperative project with Portland General Electric to inspect a series of 30 to 50 year old distribution poles in the area around Salem, Oregon. In these tests, line crews removed increment cores from locations beginning approximately 20 feet above groundline, near the underbuilt communication lines, and finally near the energized line (usually near the cross-arm). Cores were assessed for the presence of fungal attack and then cultured to determine if viable decay fungi were present. The results were surprising in that, while some decay was present, the incidence was extremely low. Decay at the top of the pole due to the absence of a water-shedding cap was viewed as the highest risk for these poles, which were mostly Class 3 or 4 and 30 to 40 feet long. Continuing discussions about the risk of above ground decay, coupled with additional evaluations of Class 2 Douglas-fir transmission poles that contained extensive above ground decay after having only been in service for approximately 25 years, led to further discussion about the need to sample transmission poles in the PGE system.

Five lines located in Western Oregon were chosen for inspection. The lines were located in the Coast Range where wind-driven rain was more likely, the Willamette Valley where rain is frequent in the winter, and in the eastern Cascades to a drier area that still received some winter rain. Four lines contained poles treated with pentachlorophenol and one contained creosote-treated poles. The poles in the lines ranged from 17 to 59 years old. The inspections differed slightly depending on line configuration, but all included line personnel sounding the pole as they climbed upward so that they could detect severely decay poles. Line configurations inspected included poles with wishbone-type crossarms, poles with stand-alone insulators, and H-frames (Figure II-4). A total of 1025 increment cores were sampled.

The line crews also removed 3-7 increment cores from locations along the pole length. These cores were placed into plastic drinking straws that were returned to OSU for culturing on malt extract agar. Cores were observed for fungal growth. The fungi were examined for characteristics typical of Basidiomycetes, a group that includes many important wood decay fungi.

Initial preservative treatment varied widely in the 1025 cores sampled, ranging from 4 to 165 mm in depth. The American Wood Protection Association Standards specify a minimum of depth of 75 mm in cores removed from groundline along with 85% of the sapwood, but does not specify a penetration depth further up the pole. The vast majority of cores met penetration requirements and average penetration for the lines ranged from 43 to 64 mm (Table II-9).

Woodpeckers were detected in 10 of 183 poles inspected (Table II-10). The highest prevalence of woodpecker attack was found in poles in the Beaver to Alston line with 20% of inspected poles having some evidence of attack. This line is located in the Coast Range where woodpeckers are more abundant. Woodpeckers can be quite destructive in localized areas and there evidence suggests woodpecker attack is increasing. The high incidence of attack on this line suggests the need for more vigilant patrols on specific lines prone to attack coupled with rapid repair of holes to limit the potential for moisture and fungal ingress in the exposed, untreated wood.

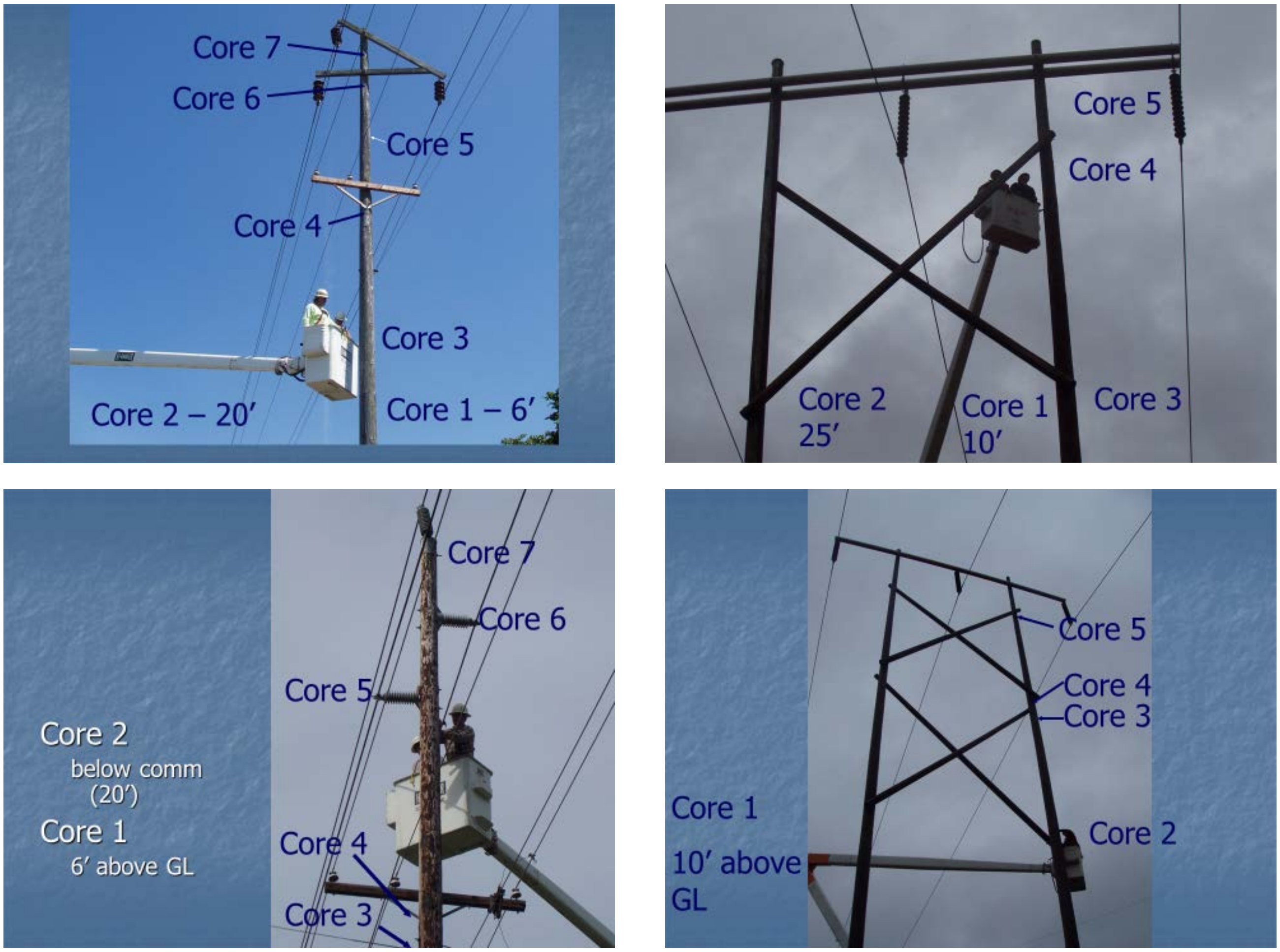

Figure II-4. Locations of increment cores removed from above ground zones of Douglas-fir transmission poles with various configurations.

Twenty of the 183 poles inspected contained a decay pocket above ground, as determined by sounding or coring. While this did not represent a high level of decay, it was indicative of a larger problem than found during inspections of smaller diameter poles. Discovering decay pockets in 20% of poles in the Cascade Mountain line was significant because this transmission line connects Portland to a large hydro-generating station across the Cascades.

Culturing revealed 22 of the 183 poles contained viable decay fungi (Table II-11). Culturing results were comparable to those found via sounding and coring. In both cases, sampling indicated decay fungal presence well above ground in poles at sites not traditionally inspected.

Table II-9. Treatment characteristics of increment cores removed from above the groundline zone of Douglas-fir transmission poles inspected in the PGE system.

Line	Location	Age (Yr.)	# Poles	Penetration (mm)	
				Range	Average
Beaver-Alston	Coast Range	37	44	10-115	46
Silverton-Mt. Angel	Willamette Valley	37	33	10-165	64
Scotts Mills-Mollala	Willamette Valley	27-57	33	4-157	55
Dayton-Yamhill	Coast Range	59	34	5-132	46
Bethel-Round Butte	Cascades	45	39	15-144	43

Table II-10. Incidence of woodpecker voids, decay pockets, or viable fungi in the above ground zone of Douglas-fir transmission poles in the PGE system.

Line	Age (Yr.)	# Poles	Defect Detected		
			Woodpeckers	Decay voids	Decay fungus
Beaver-Alston	37	44	7	0	3
Silverton-Mt. Angel	37	33	2	3	3
Scotts Mills-Mollala	27-57	33	0	3	2
Dayton-Yamhill	59	34	1	5	3
Bethel-Round Butte	45	39	0	9	11

The incidence of decay above ground in critical transmission lines in the PGE system led to a discussion about possible treatment alternatives. While a few poles merited replacement, the presence of internal decay above ground in a percentage of the poles encouraged a full scale climbing inspection program using PGE line crews. At the same time, it was considered pointless to perform an inspection without applying a remedial treatment to arrest decay pockets that were detected.

There are relatively few options for internal treatment above ground. The two most likely candidates would be MITC-FUME, available in aluminum tubes, or fused borate rods activated by the addition of water. The choices were further narrowed because the company wanted to avoid using anything classified as a restricted use pesticide since it would entail extra training that would increase operational costs. A full-scale inspection was performed on all transmission poles in the PGE system and fused borate rods were applied to holes drilled above and below identified voids. Poles without voids received no supplemental treatment. It was assumed that poles with decay had moisture contents above the level required for decay fungal growth at some time of the year and that this moisture would facilitate boron movement form rods into surrounding wood where it would affect established decay fungi. However, there were also concerns that the moisture around the treatment holes might not be adequate for movement.

It has been over 5 years since treatment. This past year, we were fortunate to be able to work with a contractor crew inspecting poles that had been identified as having decay pockets above ground in the first inspection. As in the first inspection, the line crews performed the inspection and relayed increment cores to the ground. Cores were removed from sites above and below the voids at three locations around each pole. The cores were removed, placed into straws and returned to OSU. The inner and outer zones of each core were separated and a small amount of wood near the middle of the core was retained for culturing. The inner and outer zones for a given pole location were combined and ground to pass a 20 mesh screen. The ground wood was extracted in hot water and this extract was analyzed for boron content using the Azomethine H method.

Only fifteen poles have been inspected to date. There have been a number of difficulties in the inspections. First, a number of poles that were reported to have voids and been treated, have, in fact, not received prior treatment. In addition, because only poles that had voids were treated, the poles that need to be inspected are widely scattered within the system. This has made collection slower than would be expected if all poles in a single line had received treatment.

Decay fungi were isolated from 8 of the 15 poles sampled and several decay fungi were isolate from 3 of these poles (Table II-11). Only three species were identified; among these were *Antrodia xantha*, a common fungus in Douglas-fir heartwood. Fungi that resembled *Trametes versicolor* and *Phanerochaete gigantea* were also isolated, but not confirmed. The presence of viable decay fungi in more than half of the poles sampled suggests that the boron is not moving at effective levels into the area around the voids.

Limited examination of treatment holes suggested the rods had generally dissolved and moved into the wood, although there were cases where there was no evidence of breakdown. This variation would be expected since placement of treatment holes will be critical for ensuring sufficient moisture presence in the wood to facilitate rod dissolution.

Boron levels varied widely among poles and within areas around the same void. Boron levels were above threshold for internal protection (0.134% BAE) in 12 of the 70 samples analyzed, suggesting the need for additional chemical. Boron levels were lower in samples from the outside of poles with levels above threshold in 2 of the 42 samples. Boron levels were above threshold in 10 of 29 samples removed from the inside of the poles which is consistent with previous reports showing higher levels of remedial treatment tend to develop towards the pole center. Boron levels in cores removed from the area around the void were above threshold in three of 7 cores in the inner zone, but not over threshold in the outer zone. Cores were removed from this area because we wanted to determine if boron was moving from the upper application point to the zone around the void. Previous fumigant studies suggested they were capable of moving either through or around voids to arrest decay below the damaged area. The results with boron rods suggest some ability to move into this decayed zone.

Moisture availability is critical for both breakdown of fused borate rods and subsequent boron diffusion. The environment in which these rods were applied is likely to have highly variability in moisture levels both seasonally and by pole position. Moisture pockets that can aid in rod breakdown can be quite localized, making it difficult to ensure a treatment hole will appropriately intersect a moisture pocket. The variability in boron levels found in this limited sample illustrate that difficulty. While it is possible boron has already diffused out of the pole, previous boron rod tests at groundline indicate boron remains in the wood for long periods, even under high moisture regimes. The results suggest boron provides variable protection to above ground pole zones.

Table II-11. Incidence of decay fungi and residual boron levels (as % boric acid equivalent) in increment cores removed from areas around voids above the ground in Douglas-fir poles 5 years after treatment with fused borate rods.

Pole #	Decay Fungus Isolated	Boric Acid Equivalent (%)[a]					
		Outer Zone			Inner		
		Above	Below	Middle	Above	Below	Middle
418	-	0.03	0.02	0.03	**0.31**	**0.17**	0.02
421	+	0.02	0.01	0.10	0.03	0.08	0.02
424	++	0.11	**0.15**	*	0.11	**0.36**	*
724	-	0.01	0.11	0.03	0.01	**0.18**	0.01
797	+	0.01	0.01	-	0.01	**0.15**	**0.16**
1058	-	-	-	*	0.01	**0.19**	*
1307	++	-	0.04	0.07	0.07	0.12	**0.28**
1960	-	0.01	-	*	**0.27**	0.01	*
3268	+++	0.01	0.01	0.07	0.02	0.06	**0.17**
7861	-	-	0.05	-	-	0.08	0.05
13181	-	0.02	**0.44**	*	0.01	0.01	*
461	++++++	0.07	0.01	0.02	*	*	*
505	+	0.04	0.03	0.02	*	*	*
512	+	0.01	0.01	0.02	*	*	*
538	-	0.02	0.01	0.01	*	*	*

[a] Values represent single analyses for each location. (-) denotes boron below detection limit, bold font denotes boron levels above the threshold for internal fungal control and (*) denotes that no sample could be obtained for this location.

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OBJECTIVE III

EVALUATE PROPERTIES AND DEVELOP IMPROVED SPECIFICATIONS FOR WOOD POLES

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

A. Effects of Through-Boring on Preservative Treatment and Strength of Douglas-fir Poles

There are over 150 million wood poles supporting the wires that make up the electric grid in the United States (Mankowski et al. 2002). These poles are largely composed of three wood species: southern pine, western redcedar, and Douglas-fir. Wood is a biological material that is susceptible to degradation from a variety of agents. As a result, most poles are artificially impregnated with preservatives to extend their service-life.

The wood species used for wood poles have different performance attributes. Southern pine is the most commonly used species; it has a thick band of very treatable sapwood surrounding a small, untreatable heartwood core. Once treated, the thick shell of treated wood provides good protection for the untreated core. Western redcedar has a thin shell of sapwood surrounding a naturally durable heartwood core. This species was initially used without supplemental treatment, but the thin sapwood shell is now impregnated with preservative.

The expansion of the burgeoning electrical distribution system after the Second World War led to shortages of western redcedar and the use of Douglas-fir as a substitute. There were a number of problems with this substitution. This species has a thin band of treatable sapwood surrounding a moderately durable heartwood core that poses a protection challenge. The thin layer of preservative treatment can be compromised by checks while in service. Furthermore, poles were not being sufficiently heated during the treatment process, allowing decay fungi already present in the wood to continue to degrade the poles once they were placed in service. The poles were often not properly seasoned prior to treatment, leading to skips in the preservative barrier. These wet poles also continued to season in service. As they did, deep checks opened that often penetrated beyond the depth of the original preservative treatment. These checks created pathways for fungi and insects to enter and degrade the moderately durable heartwood.

A 1959 survey of 74 pressure-treated poles that had been service for an average of 11 years in Portland, Oregon found that 19% of the poles had decay pockets, while a separate survey by the Bonneville Power Administration (BPA) found decay rates closer to 50% (Merz 1959). These surveys led to a cooperative effort by BPA, Pacific Power, and Portland General Electric Co. (PGE) to identify solutions to what was viewed as a very large, emerging problem. Among the developments from this process were the identification of fumigants for the internal treatment of poles in order to arrest decay and the requirement that poles be heated for a sufficient time period to kill any fungi present inside the wood. In addition, there were efforts to develop improved methods for achieving more complete treatment of Douglas-fir heartwood. Among the processes developed were deep incising, radial drilling, and through boring prior to preservative impregnation.

Incising is the practice of driving sharpened metal teeth into the wood to a specific depth (usually 0.40 to 0.75 inches). The process exposes more end-grain to preservative penetration, improving the depth and uniformity of treatment. Deep incising substitutes 5- to 6-inch-long teeth to produce much deeper penetration. Radial drilling involves drilling 0.25-inch diameter holes to a depth of 3 to 5 inches into the wood in a pattern that produces nearly complete preservative penetration of the bored area.

Through-boring was developed by George Merz of PGE, and it has increased the service life of Douglas-fir poles to 60 to 70 years (Morrell 2011). Through boring involves drilling 0.50 to 0.56 inch diameter holes into the pole at a slight angle completely through the pole in the groundline area (Figure III-1). While all three practices were and continue to be used, through boring has become the most widely adopted. At first, only local PNW utilities employed through boring for their Douglas-fir poles, but the practice slowly spread across the country for pre-treatment of large Douglas-fir transmission poles, ultimately leading to its inclusion in the American National Standards Institute Standard ANSI 05.1 (ANSI 2017).

Conceptually, drilling holes in the critical groundline region of a pole creates concern among engineers, and there were a limited number of tests to evaluate the potential effects of these groundline treatments on the flexural properties of poles. Brown and Davidson (1961) tested the bending strength of Class 4, 40-foot poles with several variations of groundline boring. The poles were drilled before treatment with one of either two different radial drilling patterns or two Merz through-bored patterns. The poles were set in the ground to a normal depth (about 6 feet) and tested full length in cantilever loading. They found that the breaking strengths of the poles with varying Merz patterns were 91% to 96% of those for the untreated controls. Radial drilling to a depth of 4 inches from the surface or to the pole center resulted in breaking strengths that were 73% to 76% of the controls.

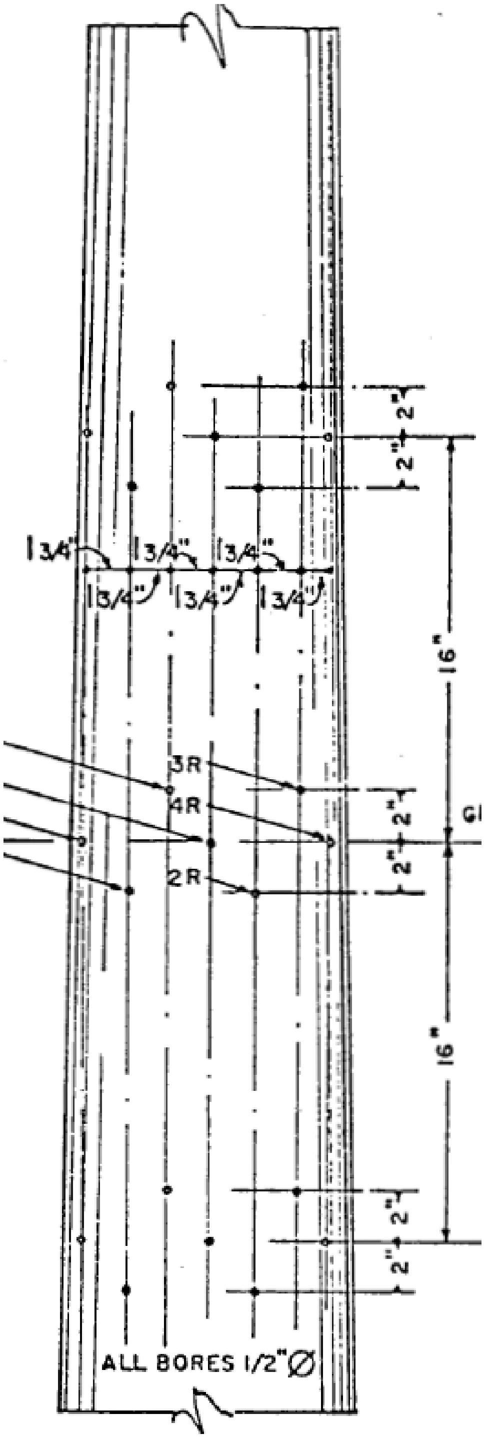


Figure III-1. The Merz through-boring pattern developed in 1959 (Merz 1959).

Graham et al. (1969) tested shorter Douglas-fir pole sections that had been deep incised, through bored, or radially drilled, and found minimal effects for deep incising, but 16% to 24% losses in modulus of rupture (MOR) for poles with various boring patterns. These poles were tested in bending, but it is unclear if the results bear directly on the properties of a full-length pole tested in cantilever loading, which is more reflective of in-service loads. These limited test data largely formed the basis for supporting the use of through boring and radial drilling in utility specifications.

In 2002, the effects of through boring on lodgepole pine were investigated; this species has similar durability and treatment characteristics as Douglas-fir (2002 Annual Report). The pole sections were small (average diameter was 4.77 inches) with 0.25-inch diameter holes drilled 0.5 inch from the edge, at a spacing of 1.97 inches (50 mm) or 5.91 inches (150 mm) horizontally and 2.95 inches (75 mm) longitudinally. The poles were tested in four-point bending, both parallel and perpendicular to the holes. Modulus of elasticity (MOE) was found to be 88% of that found for non-through-bored controls; MOR was found to be 90% to 96% of the control when poles were tested parallel to the holes and 70% to 82% when tested perpendicular to the holes. The results indicated that through boring could negatively affect the flexural properties of smaller diameter poles, and that the effect was directional.

A number of studies showed that through-boring largely eliminated decay in the drilled region and markedly extended pole service life (Newbill 1993, Morrell and Schneider 1994). While there were periodic concerns about losses in flexural properties, the trade-off in terms of improved treatment at the ground line was believed to largely offset any strength losses. However, periodic pole failures of through-bored poles subjected to overloads such as strong winds or ice generally occurred in the through-bored zone, leading engineers to question the potential effects of this practice on strength. In addition, there were a number of patterns used by utilities, making it difficult for wood treaters to standardize practices.

Kent (2003) used loss of section modulus from through boring to estimate possible strength effects, and estimated a maximum 17.5% to 23.5% reduction in strength. These calculations did not take into account stress concentrations, and he recommended modeling and testing to determine the actual effects.

In order to address the issues highlighted by Kent (2003), Elkins (2005) undertook a large-scale test to determine the effects of through boring on pole properties. Elkins began with finite-element modeling to study stress concentrations around through-bored holes. The goal was to determine the sizes of and distances between holes that would minimize stress concentrations. These data, along with prior studies, identified minimum distances needed to result in full preservative penetration in a through-bored zone, which were then used to develop an optimum boring pattern. The effects of through boring on flexural properties were then evaluated, using four different hole sizes on Class 4, 40-foot pole sections. One hundred and thirty-two poles were tested in four-point bending in a configuration developed in Australia (Crews et al. 2004). The results indicated that through boring had no significant effect on flexural properties when the holes were less than or equal to 0.5 inches in diameter. These results, along with a follow-up test evaluating the effects of the orientation of the load direction (parallel or perpendicular to the holes) were used to support the inclusion of through boring in the ANSI 05.1 standard, using a standard pattern, 0.5-inch diameter holes and a reduction in properties of 5%, in order to account for the directional effects.

While through boring continues to be used and adopted by utilities, there are still lingering concerns about its possible effects on pole properties. One particular area of concern is the distance from a through-boring hole to the edge of a pole. Elkins (2005) examined this factor using finite-element modeling and used test data to arrive at a minimum 2-inch edge distance. However, some utilities have chosen to use larger edge distances. This practice moves the holes farther into the pole and increases the likelihood of unpreserved wood between the surface and hole. This is important because the potentially affected area is located close to the surface, where most of the bending strength of a pole lies. There appear to be no data supporting the larger edge distance, and there is concern among treaters that this practice will make it more difficult to obtain acceptable treatment. In order to address this issue, the following study was undertaken.

Before we discuss the current test, it is helpful to review the previous data that has examined hole diameter, orientation of the holes in relation to load direction and, finally, compared through boring with radial drilling or deep incising to provide some perspective concerning the amount of data that has been accumulated on this subject.

Over the past decade, we have undertaken a series of full scale bending tests to assess the effects of various methods for improving treatment in the groundline zone on flexural properties. Three tests have been completed. In the first, 139 Class 4 forty-foot long Douglas-fir poles were tested. Poles were left non-bored, or received 0.25, 0.5, 0.75, or 1.00 diameter holes at groundline. These data showed that through boring had no significant negative effects on flexural properties when the holes were 0.50 inches in diameter or less, and the data were used to support the inclusion of through boring in the ANSI 05.1 Standard. The committee reviewing the data asked for additional testing to assess the impact of loading perpendicular to the through boring hole direction. A second test was performed in which poles with the same through boring pattern used in the initial test along with poles that were radial drilled or deep incised were tested to failure. These tests showed no significant difference in Modulus of rupture at groundline

(MOR-GL) between the three treatments; however, MOR-GL was much lower than that found in the original trials. The poles in the second study were obtained from a widely dispersed pole population, while those in the first test were obtained from a narrow geographic area in southern Oregon. In addition, the lack of non-bored controls in this test made it difficult to compare the two trials. These concerns led us to test poles with no groundline boring along with poles that were radial drilled or through-bored. Through-bored poles were tested with the load applied perpendicular or parallel to the holes.

In all three tests, freshly peeled, green Class 4-40 foot long poles were obtained and randomly allocated to a given treatment. The poles were immediately placed under sprinklers to maintain a green condition. This is important because ANSI tests are performed in the green condition to avoid the need for moisture content corrections. The boring pattern was applied from 2 feet above ground to 4 feet below the theoretical groundline (6 feet from the butt in this case).

In addition to the through-bored poles, additional poles were either deep-incised or radial-drilled to a depth of 3.5 inches in the same zone. Each treatment was replicated on 27-30 poles. The poles in the first two tests were supplied as 40 foot sections, but each pole was cut into a 20 foot long section for testing. The poles in the third test were supplied in 20 foot lengths. Pole circumference was measured at the butt, the theoretical groundline (10% of pole length plus 2 feet), 20 feet, and at the tip.

The poles were tested in a modified 4-point bending method that forced the maximum bending stress to be in the region containing either the groundline preparation treatment or the inspection holes while maintaining a nearly constant moment in the high moment zone so that the bending moment at failure could be accurately calculated (Figure III-1). The test setup was a modification of that described by Crews et al. (2004).

The poles were tested as simply supported beams with two-point loads applied near the assumed groundline. The end bearing points allow the pole to rotate as well as move longitudinally. Wood saddles were used at the bearing points, as well as the points of loading. The u-shaped saddles measured 11-in. in length, and were made out of Douglas-fir so the point of contact between the two materials was of similar hardness.

Poles were shortened to a convenient length such that they had a reasonable span-depth ratio and were not shear critical. With those criteria, the poles were tested on four point bending where the length for the test specimen (L) was 144 inches with a minimum 1-ft overhang on each end (Figure III-2).

Figure III-2. Photograph showing a pole in the test set-up.

A 200-kip capacity hydraulic actuator mounted on a steel portal frame attached to the laboratory strong floor was used to apply the load to the poles. The load was displacement-controlled and the rate of loading was 0.01 in./sec. This rate was estimated from the D1036 (ASTM 2004). An external load cell attached to the rod end of the actuator measured the force as it was applied to the pole. Deflection and force data were compiled continuously at 1 Hz during the test using National Instruments LabVIEW 6.1, operated through a personal computer.

The poles were loaded to failure, defined as the point at which the pole could not continue to take increasing load. After failure, each pole was evaluated and the location of failure was recorded. Photographs were taken of each failure and notes were made of any significant features that might have contributed to failure. A single cross section was cut near the failure zone and weighed before being oven-dried and reweighed. The difference between initial and final weight was used to determine wood moisture content. The dry section was then used to determine the number of annual rings in the outer 2 inches as well as the total number of rings in the cross section. The section modulus was determined at the point of failure from the butt and groundline circumference data taken assuming a constant taper and uniform circular cross-section.

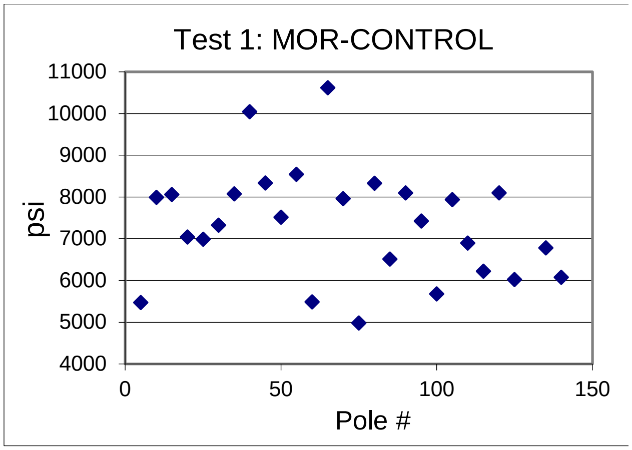
The maximum load was used to calculate the moment at failure assuming a prismatic member. The section modulus used as input for the MOR values was the section of the pole at the failure location. All section modulus calculations were based on the gross pole section.

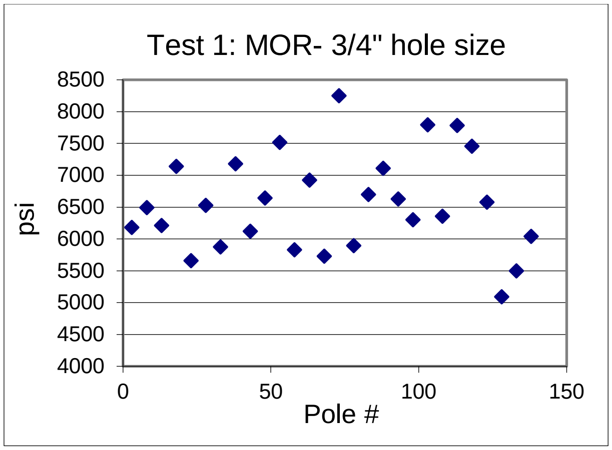
Modulus of elasticity (MOE) values were estimated from the load-displacement data in a range of approximately 10 to 30 percent of maximum load to ensure the data were from the linear portion of the curve. *P* is the load applied at the point of measured deflection (kips); Δ and *d* (in.) are the displacement and diameter, respectively, measured at the failure point.

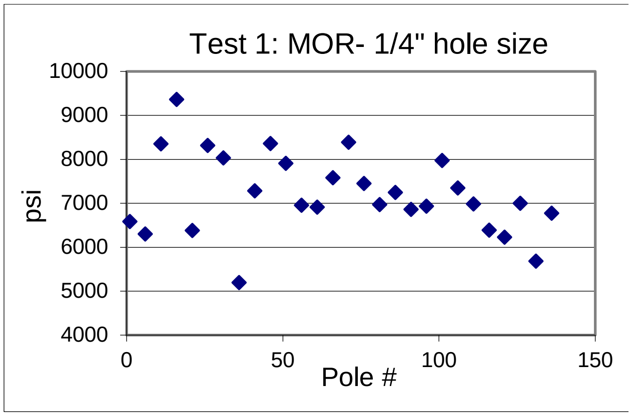
$$MOE\ (ksi) = \frac{14236P}{\Delta d^4}$$

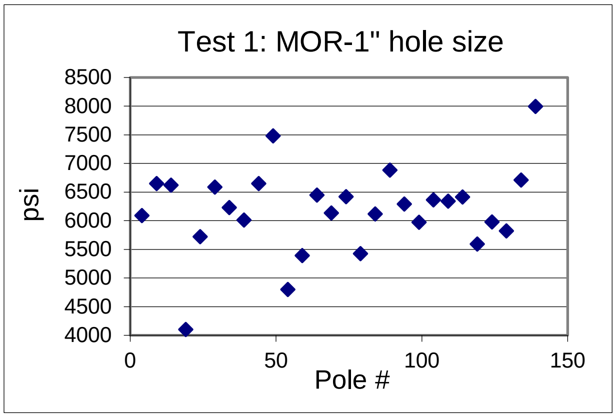
Table III-1. Wood characteristics and flexural properties of Douglas-fir poles with various groundline boring treatments.

Test	Treatment	Reps	Circumference (inches)		Modulus of Rupture- GL (psi)			Ring Count	
			Butt	Tip	Mean	Range	COV (%)	Outer 2 in.	Total
1	None	27	36.46	32.21	7353 (1332)	5328-10425	18	18.2	33.9
	0.25 in TB	28	36.70	31.90	7207 (913)	4887-9350	13	15.8	30.9
	0.50 in TB	28	35.87	31.71	6860 (774)	5445-8385	11	17.2	32.6
	0.75 in TB	28	36.14	31.96	6554 (766)	5026-8041	12	16.5	31.8
	1.00 in TB	28	36.78	31.82	6187 (746)	5328-7963	12	17.0	32.9
2	Radial drill	30	37.27	27.21	6177 (677)	5070-8248	11		
	TB- Perp	31	39.91	27.05	5736 (669)	4399-7063	12		
	Deep incise	31	37.31	27.07	6520 (894)	5055-9160	14		
3	Control	31	39.4	34.7	6575 (1011)	4597-9026	15	18.3	32.5
	TB parallel	32	40.5	35.9	5132 (879)	2578-6879	17	19.0	36.7
	TB-perp	32	40.6	35.1	5449 (879)	3750-6952	16	21.6	35.4
	Radial drill	30	41.1	35.4	5816 (1422)	3550-7805	24	19.4	35.0









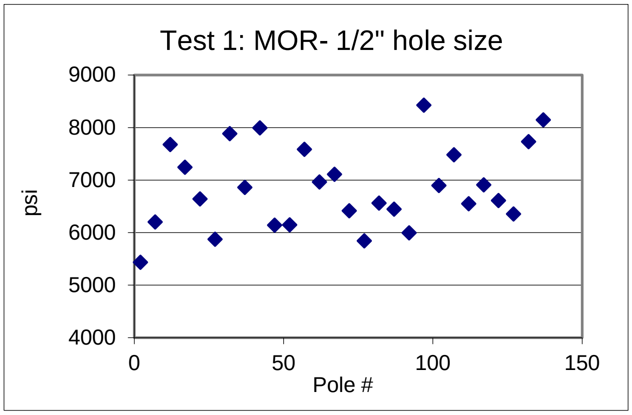


Figure III-3. MOR-GL distribution in Douglas-fir poles with or without 0.25, 0.50, 0.75, or 1.00 inch diameter through boring holes in the groundline region.

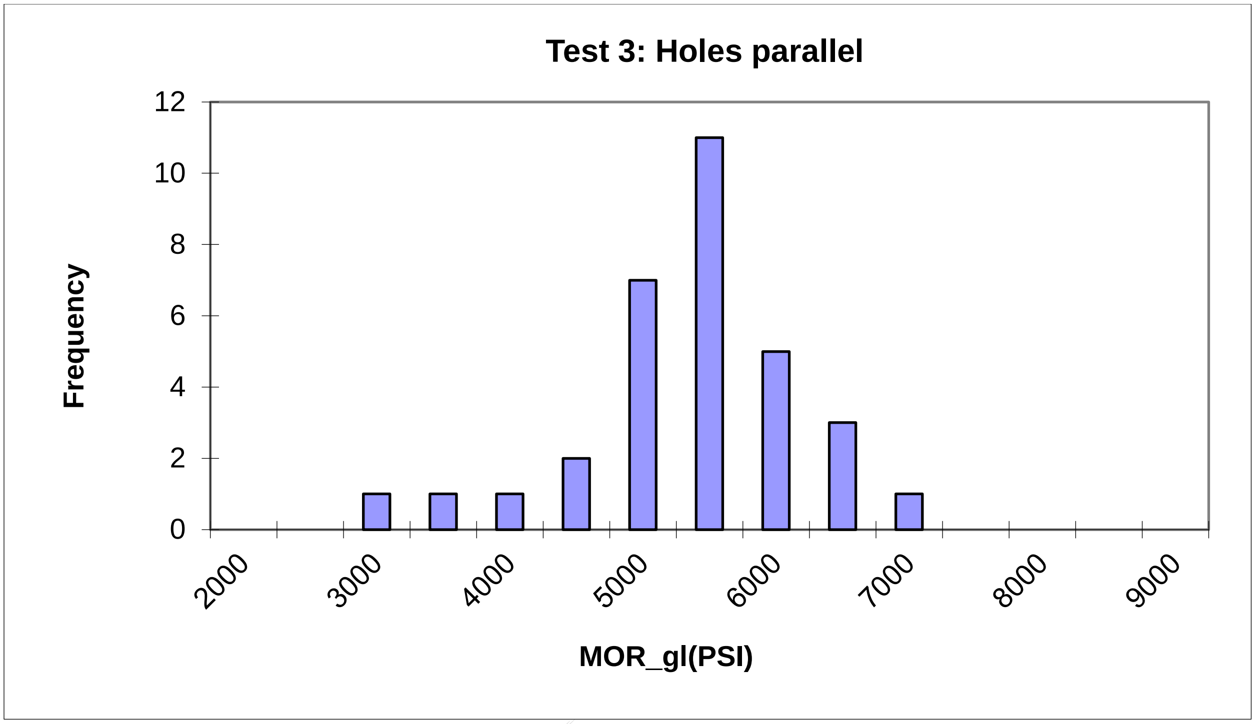


Figure III-4. MOR-GL distribution for Douglas-fir poles tested with the holes parallel to the loading direction in Test # 3.

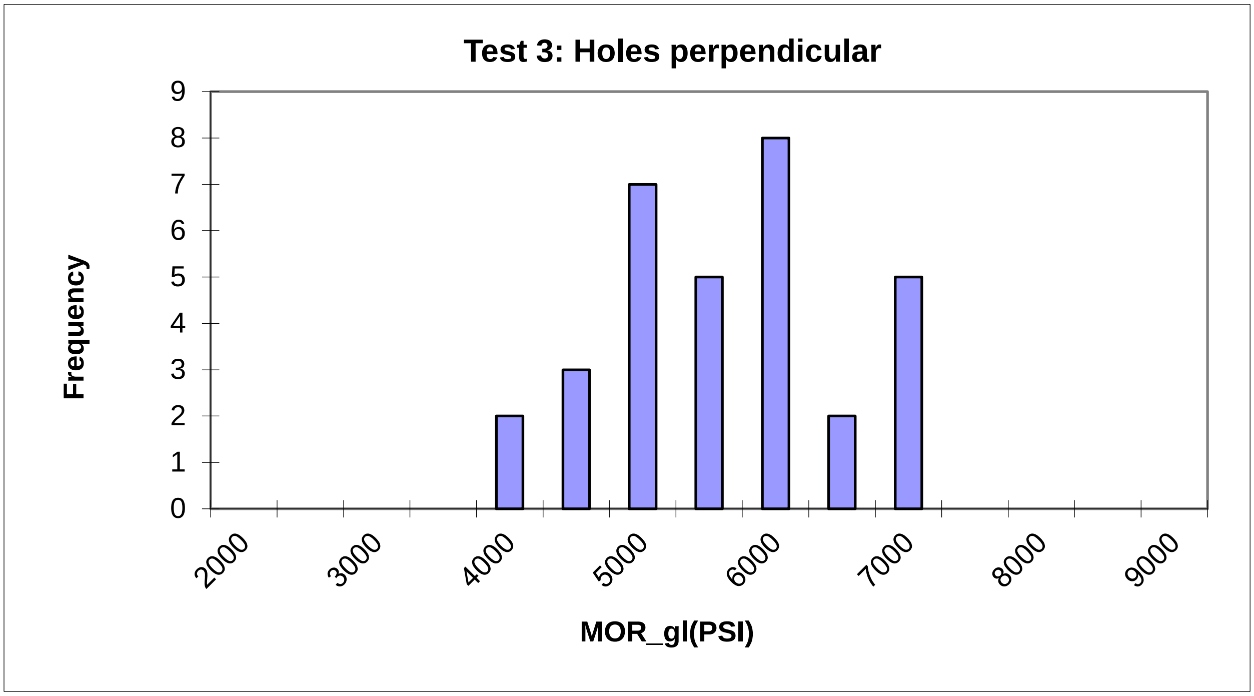


Figure III-5. MOR-GL distribution for Douglas-fir poles tested with the holes perpendicular to the loading direction in Test # 3.

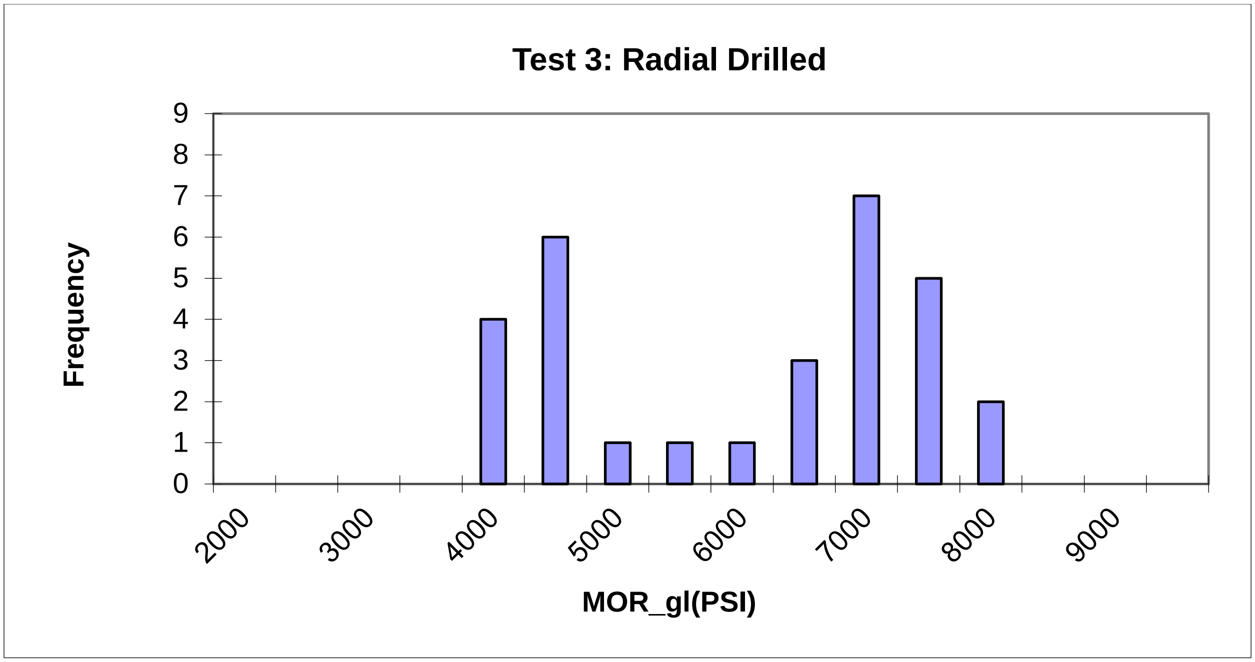


Figure III-6. MOR-GL distribution for radial drilled Douglas-fir poles tested to failure in bending in Test # 3.

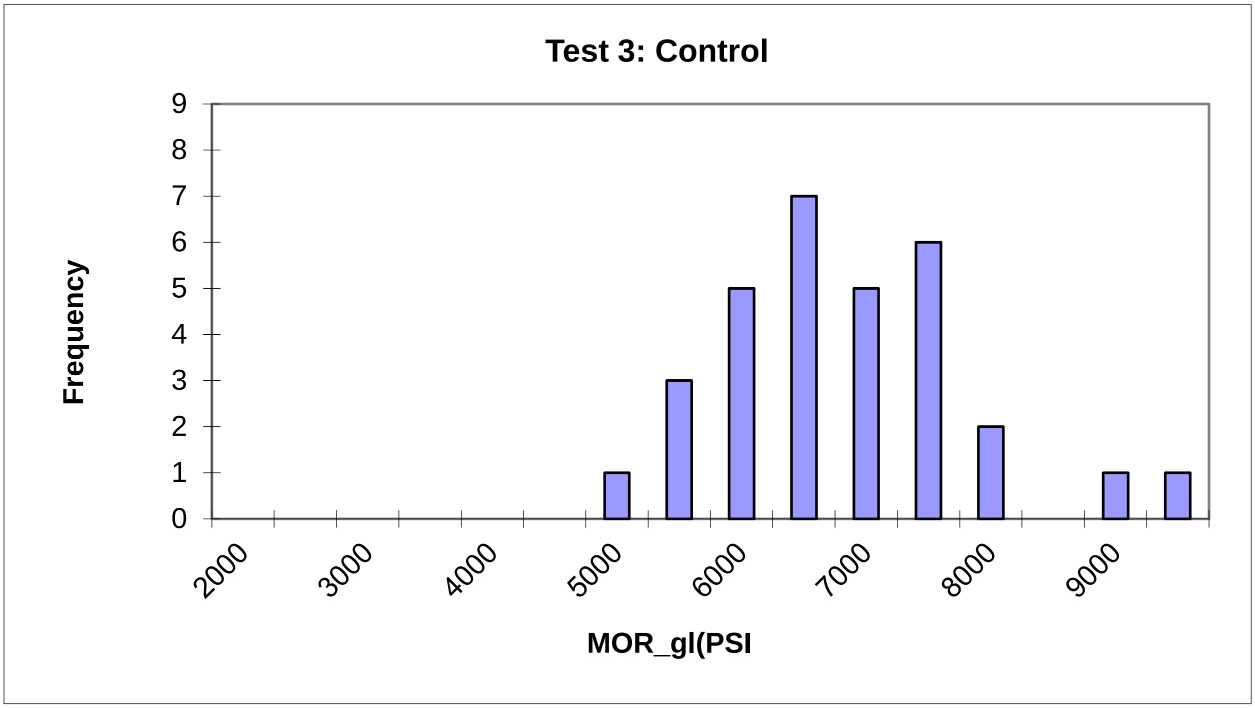


Figure III-7. MOR-GL distribution in Douglas-fir poles subjected to full scale flexural testing to failure from Test # 3.

In Test # 1, MOR gradually declined with increasing hole size, while the presence of holes appeared to reduce the variability in MOR at GL (Table III-1, Figure III-3). It was suggested that reduced variance was due to the holes acting as consistently located stress points in place of more randomly positioned knots. Statistical analysis of the data indicated that MOR did not differ significantly from the control for 0.25 and 0.5 in diameter holes. These tests led to the decision to use 0.5 inch diameter holes in the proposed through boring pattern.

In test # 2, poles were through bored, radial drilled or deep incised in the groundline zone prior to testing (Table III-1). The lack of a through boring effect in Test # 1 led us to only test through bored poles perpendicular to grain direction in order to answer the questions raised by the ASC committee. We included the other groundline preparation techniques because we were also interested in seeing these included in ANSI 05.1. We, regrettably, chose not to include controls.

t-Tests comparing radial drilling, deep incising, and through boring showed that MOR at groundline was significantly lower in through bored poles tested with the holes perpendicular to the loading direction than in poles that were either radial drilled or deep incised. Deep incised poles had a greater tendency to fail in shear; however, this did not appear to affect overall flexural properties of the poles.

The flexural properties of all poles in Test # 2 were lower than those from Test # 1. We later learned that the poles had been obtained from a much wider geographic area. In addition, the poles were slightly larger. While the larger size should not adversely affect MOR at GL for poles of these dimensions, the sourcing might be an issue. The lack of controls also made it difficult to determine if the lower flexural values were due to natural variations in wood properties or to a through boring effect.

Test # 3 was initiated to resolve the questions raised by the ANSI committee and resolve the issues raised in Test # 2. Poles were through bored either parallel or perpendicular to load direction, were radial drilled or were left as non-bored controls. T-tests showed that MOR at GL for poles receiving all three groundline boring treatments differed significantly from MOR-Gl for the non-bored poles (Figures III-4 to 7). As with Test # 2, MOR values were much lower than those found in Test # 1, although the pole sample had a similar geographic origin. In addition, the ring counts in both the outer 2 inches and the entire cross section were similar and all moisture contents were at or above the fiber saturation point (Table III-1). The results differ markedly from the MOR at GL values for the through bored poles tested with the holes parallel to load direction from Test # 1. Variability in wood properties is a given; however, the test populations were sufficient to allow for separation of treatment differences. The one major difference in wood characteristics between Tests 1 and 2 was the circumference at GL. Poles in the first test had average butt circumferences of 35.9 to 36.8, while those from Test # 3 had averages circumferences ranging from 39.4 to 41.1 inches. The minimum circumference for a Class 4 forty foot long Douglas-fir pole is 36.5 inches similar to the measurements for the poles in the first population. The circumferences in the Test # 3 sample were closer to a Class 3. It is unclear how this might affect groundline boring, since MOR is based upon actual groundline circumference and any differences due to size would have been considered in the calculations.

The results gave us two conflicting data sets. Test # 1 showed no significant effect of holes up to 0.5 inches in diameter, while test # 2 showed a significant effect of through boring regardless of whether the holes were oriented parallel or perpendicular to line direction.

The data were provided to the ASC committee suggested that a strength reduction factor be applied to through bored poles. As a result, the ASC committee approved the inclusion of through boring in the most recent ANSI 05.1 Standard with a 5% reduction in MOR to account for possible effects of orientation of through bored holes perpendicular to the maximum stress in line.

The resulting standard has generally been accepted by utilities using through boring; however, there have been some exceptions. One question that has arisen among some users is the effects of placing holes within 2 inches of the edge of a pole. While the Elkins modeling and the full scale testing suggested that the 2 inch edge distance was more than adequate for reducing any possible effects on pole flexural properties, at least one utility has elected to use a deeper edge distance of 3 inches. This conservative approach has two effects. First, it can reduce the number of holes drilled in a given area of the pole, thereby decreasing the amount of longitudinal area open to preservative flow. This can reduce the potential for producing thorough preservative distribution in the through bored zone. In addition, moving the hole inward by 1 inch will generally place the hole in heartwood, creating the potential for reduced preservative flow in the inner sapwood zone.

Forty-eight poles were obtained from a treating facility located in Arbuckle, California and shipped to Oregon State University (OSU) in Corvallis. The poles were a mix of Class 1 40-foot, Class 2 35-foot, and Class 4 40-foot, and the butts were cut into 20-foot sections. The poles had been obtained from an area near Lebanon, Oregon and had been air seasoned prior to arrival.

Typically, through-boring holes are drilled parallel to the reference face, or the face of greatest curvature. This is important, as the greatest wind loads will bear perpendicularly against the pole. Many of the poles were heavily checked in one direction, however; and this face was marked as the reference face. Orienting the pole according to the largest check minimized the creation of a shear plane.

A drilling apparatus was created (Figures III-8 to 9) to allow accurate drilling for holes at a constant edge distance. Holes were drilled at 1, 2, or 3 inches (25, 50, or 75 mm) inward from the pole edge (Figure III-10). Holes were drilled in both the tension and compression faces at the defined edge distance. The Merz pattern (1959) additionally has holes in the center (crossed circles in Figure III-10); however, these holes were not drilled in the test poles because the stress they add is negligible compared to holes nearer to the edge. Additional holes also increased the probability that these holes would interact with knots, causing failure due to the interaction. This would obfuscate the role of edge distance on flexural properties.

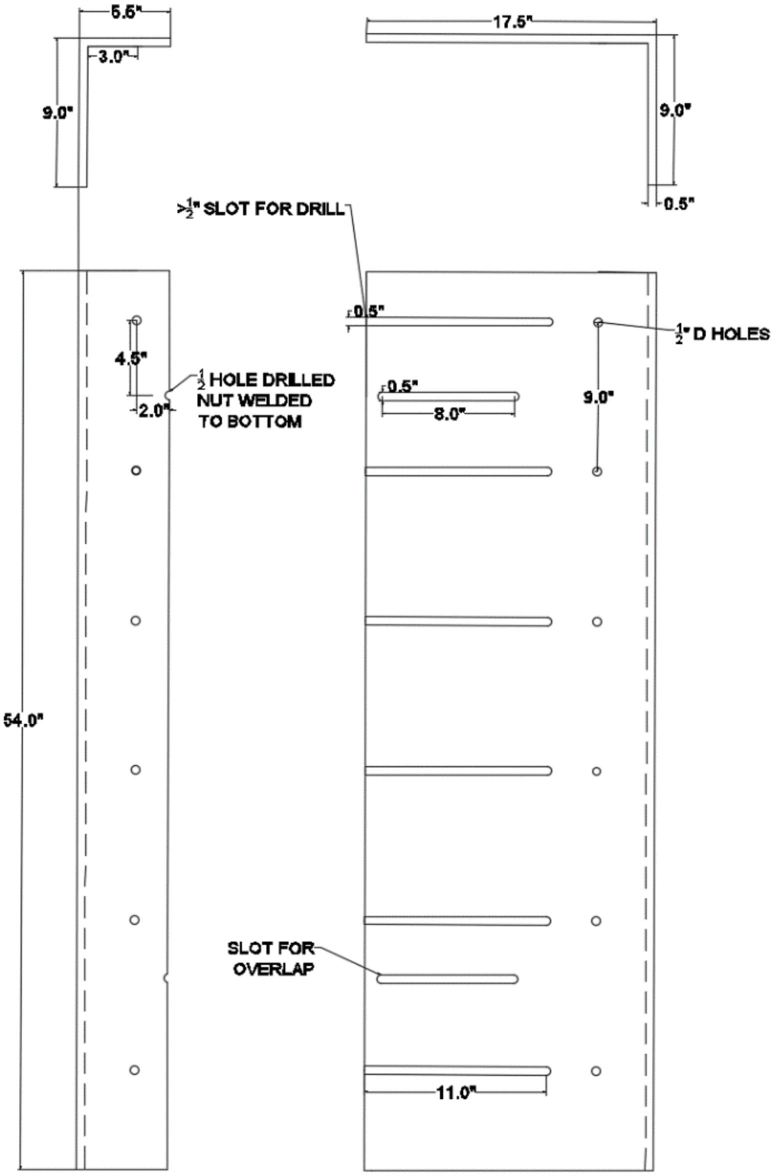


Figure III-8. Diagram of drilling rig created for drilling holes at a constant edge distance for any size of pole.

Figure III-9. Drilling apparatus created for the drilling of holes at a constant edge distance. The plate can slide in and out to fit any pole size. Blocks cut to 1 and 2 inches are placed in the interior edges to drill at different edge distances. Holes are drilled downward through the pipes.

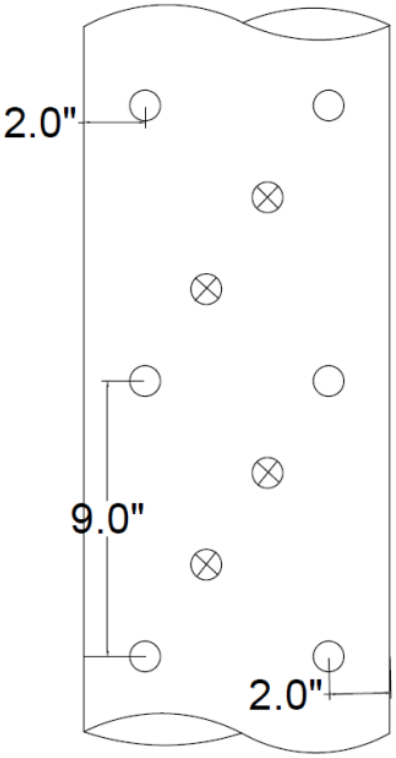


Figure III-10. Example of a hole pattern used to through bore Douglas-fir poles. Holes with an "x" were not drilled.

Twelve holes were drilled at 9-inch (225 mm) intervals along the pole length, from 36 to 96 inches (900 to 2400 mm) above the butt, following the Merz (1959) pattern, as defined in ANSI Standard 05.1 (2017). Six holes were drilled parallel to the tension face, and the other six were drilled on the compression face of each pole.

The initial moisture content (MC) of the poles ranged from 14% to 28%, as measured from the outer 1.5 inch (38.1 mm). Due to the range of MC and moisture's influence on mechanical properties, the poles were kiln dried at OSU. This option was chosen over wetting all poles above the FSP, due to time limits. Generally poles are used green and will dry below the FSP in service.

The poles were dried in three charges each containing sixteen poles. The first charge of 16 poles was subjected to a dry-bulb temperature of 160° F for 48 hours, with no steam applied, resulting in severely checked poles with an MC of 8% in the outer inch. The poles form this charger were conditioned to 14% before testing. The second and third batches of poles were first dried at a dry bulb temperature of 120°F with a wet bulb depression of 15°F for 2 hours. Temperature was then increased to 140°F with a depression of 15°F for 72 hours. The average MC was 14% to 16% in the outer inch of the poles.

Test Apparatus: The poles were tested using a method first developed by Crews et al. (2004), and adopted by Elkins (2005). The test is an asymmetric, unequally loaded four-point bending test. The load is biased 1:5 to the bottom end (Figure III-11). The asymmetric and unequal loading conditions create a nearly constant moment across the groundline, mimicking the stress at the groundline observed in the field. The 1:5 ratio is created by the cylinder pushing asymmetrically on a beam, and by lever arms producing the 1:5 ratio. The moment in this test is not constant, and shear is present. Rounding of the loads was done for ease of construction of the beam lever arm. This test setup has advantages over the three-point bending test, as it stresses the entire groundline region rather than a small section directly beneath the load. This nearly constant moment will affect both natural and manufactured stress concentrations, with the cause of failure being easily traced at the point of origin, which should be the highest stress concentration present in the loaded section.

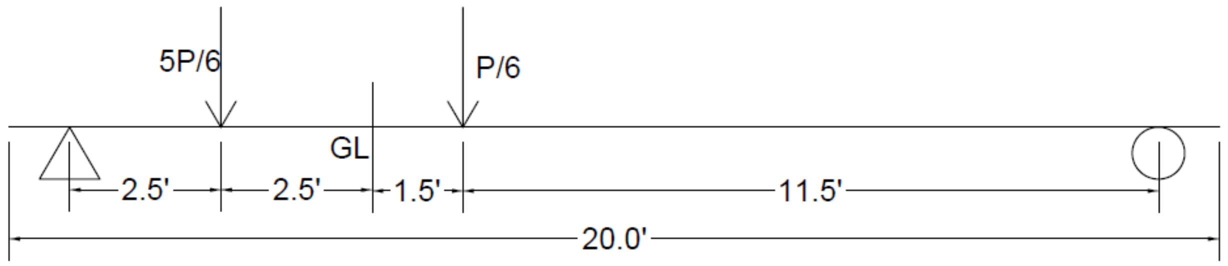


Figure III-11. Diagram illustrating the support position and loading direction.

The supports were Douglas-fir saddles, with rotation allowed. This configuration allowed the pole tests to be modeled as a simply supported beam. The use of Douglas-fir for both the supports and the load heads minimized stress concentrations and limited material bearing. The test was not shear critical; the length was calculated to produce a depth-to-length ratio greater than 14.

The poles were grouped so that poles subjected to each treatment (i.e. edge distance) had a constant average diameter and standard deviation. Additionally, all poles in Charge 1 were distributed across all groups, to keep variability caused by drying stresses constant through all groups. This was done for Charge 2 and Charge 3 as well.

The poles were weighed, and the diameters at the tip, bottom, and the loading locations were measured. Multiple diameters were measured, since taper was not constant across the pole length. Knot maps were created for each pole, noting the longitudinal location and size of every knot >0.5 inches in diameter near the groundline. The minimum diameter was defined by ANSI 05.1, as contributing to the maximum number of knots per 300-mm-long section. The circumferential distance was defined by the arc distance from a straight line on the compression face.

These parameters were needed create the finite element model for each pole. The largest checks and their distance, width, and arc position were reported. The checks were not included in the finite model nor were other defects such as splits, crushing, and sweep. The edge distances of the through-bored poles were measured, with both ends of the holes being measured, to give the average through-bored distance. Additionally, the average edge distance of at least two holes was measured on both the tension and compression faces in every pole.

Some poles were too large for the load heads, and supports had to be cut to fit. This was done by using an angle grinder to remove material at the location. Pole diameter, length of pole, locations and edge distances of through-bored holes, knot maps, and test MOE data were all input into the finite element model. These data were used to predict failure location, the failure load, and mode of failure and the results were compared to the experimental results.

Each pole was loaded with the through-bored holes perpendicular to the applied load. Each pole was loaded in four-point bending at a rate of 6.25 mm/min, with a 250 kip hydraulic actuator attached to a steel moment frame bolted to a concrete reaction floor. Linear variable differential transformers (LVDTs) measured the displacement at each support caused by compression of the saddles. The settlement from both ends was averaged and subtracted from the total deflection. Additionally, a potentiometer measured deflection at a point 9.5 feet from the butt; which was calculated as the point where the greatest deflection occurred. Load, the two deflection measurements, and support settlement were recorded continuously at a rate of 5 Hz.

Failure was defined as the point when the maximum strength capacity of the pole was reached. The test was stopped after a loss of 15% of strength (post peak) or after a catastrophic failure. The ultimate mode of failure was recorded for each pole, in addition to any previous failures. Modes of recorded failure included tension, hole shear, compression, or end-shear failure. The failure area was photographed for each pole segment. Possible causes of failure, such as knot, knot cluster, hole, or check were noted for each pole. The diameter of the failure location was determined from the known taper, and was used for the section modulus and edge distance calculations.

A 50-mm-thick disk was cut near the failure zone of each pole. The disks were weighed, oven dried at 102° C, and weighed again to determine MC (oven dry basis). Thickness and diameter of each disk were measured. Disks with large voids or holes were cut into a half or quarter for measurement. The oven-dry volume and mass for each disk were found by using the above method. These data were used to calculate specific gravity. The number of annual rings and number of rings in the outer 2 inches of the pole were counted, and heartwood diameter was measured.

The MOR was calculated by using the section modulus of the through-bored region and the maximum moment. This was done to remain consistent with the method used in previous papers. The section modulus was calculated using a gross section, rather than subtracting the areas removed from through-bored holes. Many poles did not fail at a section with through-bored holes, negating the need to account for this lost volume. The effect of grinding larger members only changed MOR by 1% to 2%. The post-grinding MOR was not used, as many sections did not fail at a section with removed material.

The MOE was derived by using equations for a tapered beam and superposition of two loads. The recorded MOE was used for to evaluate elastic properties in the finite element models and to examine correlations between MOE and MOR.

Sample Size Determination: Sample size was determined by using a power-based calculation, typically used for hypothesis testing (Cornish 2006). Both power-based and precision-based samples were considered, but power calculations compare two groups directly to each other. δ was the smallest detectable difference, s was the standard deviation, and α and β represented the tests significance and power, respectively. The Elkins (2005) data were used to determine standard deviation by multiplying MOR and the coefficient of variation for a 50-mm diameter hole. δ was estimated so that a 15% difference in the sample MOR would be detected. These analyses indicated that 12 samples were sufficient for each group.

$$n = f(a, B) * \frac{2s^2}{\delta^2}$$

$$\alpha = .05$$

$$\beta = .1$$

$$f(\alpha, \beta) = 10.5$$

$$n = f(a, B) * \frac{2s^2}{\delta^2} = 11.29 \rightarrow 12$$

Poles were grouped by hole treatment (Table III-2). Mean values and standard deviations are presented graphically (Figure III-12). A t-test was used to compare the means of two groups. The mean MOR for different edge distances were not significantly different from each other (α = 0.05), but there was a significant trend of decreasing strength with decreasing edge distance with the three-inch group similar to the control.

The variation (COV) in each group was similar. This differed from the results reported by Elkins (2005), who found that the control group had the greatest variation and that variation decreased in groups with smaller holes, and cited the defense hole theory as the reason. She cited the defense hole theory for these effects since holes should alleviate stresses by redirecting the stress field. Elkins (2005) used the full Merz (1959) pattern for drilling, and the additional holes could have redistributed stress differently.

Table III-2. Effect of hole edge distance on average MOR of Douglas-fir poles subjected to flexural tests.[a]

Hole edge distance (inches)	Average MOR (psi)	Std. Dev.	Coefficient of variation (%)	Difference from control (%)
Control	6228.5	(999.0)	16.0	n/a
1	5831.0	(1163.1)	19.9	6.4%
2	5894.6	(1198.9)	20.3	5.4%
3	6301.5	(1275.9)	20.2	-1.2%

[a] Values represent means of 12 poles per drilling group and 11 in the control. One pole was excluded from the control group due to a testing error. Figures in parentheses represent one standard deviation.

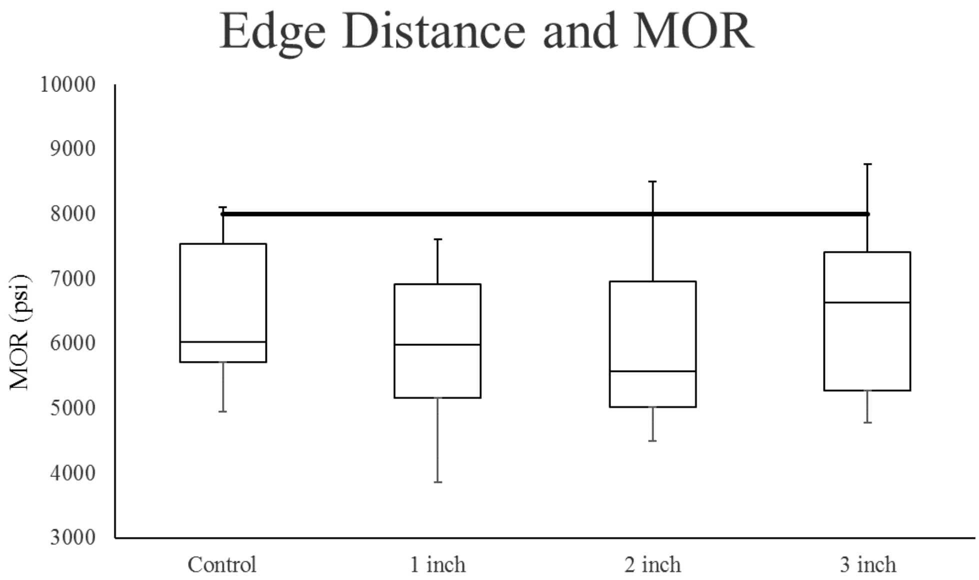


Figure III-12. Box and whisker plot showing the distribution of MOR for the three edge distances and the control group. The middle line in each group represents the median. The black line represents the ANSI 05.1 fiber stress standard of 8000 psi for Douglas-fir poles (ANSI 2017).

The average MOR for the poles was 6060 psi for all specimens (Figure III-12). This value is below the ANSI specification of 8000 psi for green poles. Elkins (2005) used the same bending apparatus and found the mean MOR of green poles to be 7350 psi for the poles without through boring, and 6860 psi for the poles with 0.5-inch diameter through-bored holes. Elkins (2005) used an edge distance of 2 inches. Her results for this edge distance were significantly greater than the results for the 2-inch edge group tested here. Morrell et al. (2011) found the mean MOR to be 5750 psi for 0.5-inch diameter through-bored poles at an edge distance of 2 inches.

Although not statistically significant, the difference in strength between poles without holes and those with 0.5-inch diameter holes was 5.5% for the 2-inch edge distance, compared with 6.5% for Elkins (2005). This reduction was also noted in poles with a 1-inch edge distance. Elkins (2005) found no significant differences in strength between poles with 0.5-inch through-bored holes and the control group (α =.05).

Kiln Cycle: The poles were grouped by kiln cycle (Table III-3). There were significant differences in moisture content (α = 0.05) between poles from different kiln cycles. However, MC was poorly correlated to MOR (R^2 = 0.05) and varied by only a few percent. Despite differences in MC from poles in the third charge, mean MOR did not differ significantly, although from the first charge had a higher MOR. This effect may be due to pole size, as the first charge contained smaller poles than the other charges.

Table III-3. Effect of kiln charge on MOR of Douglas-fir poles with edge distance groups equally distributed to each.

Kiln cycle	Average MOR (psi)	Coefficient of variation (%)	Moisture content (%)
1	6588.4 (935.3)	14.2	14.6
2	5998.7 (1224.6)	20.4	14.8
3	6014.4 (1228.2)	20.4	16.2

MOE has generally been well-correlated with MOR (R^2 = 0.45-0.72) in previous pole tests using the same test method (Elkins 2005, Clauson et al. 2017). R^2 values for the current set of data were around 0.4. One possible reason for the lower correlations was the high frequency of end shear as a failure mode. MOR is a measure of bending strength, and the presence of shear failures obscures the effects of bending strength. The R^2 values improve to 0.67 when the end-shear specimens are removed from the data. It is unclear why end–sear was so prevalent in the current test since it was a minor cause of failure in the previous studies, although the presence of deep checks may have facilitated this failure mode.

Effect of Pole Circumference: Although not typically correlated with MOR, pole size seemed to be a factor in the current study. Previous tests showed poor correlations (R^2 = 0.08-0.15) between diameter and MOR (Elkins 2005, Clauson et al. 2017). MOR in the current study was negatively correlated with pole circumference (Figure III-13).

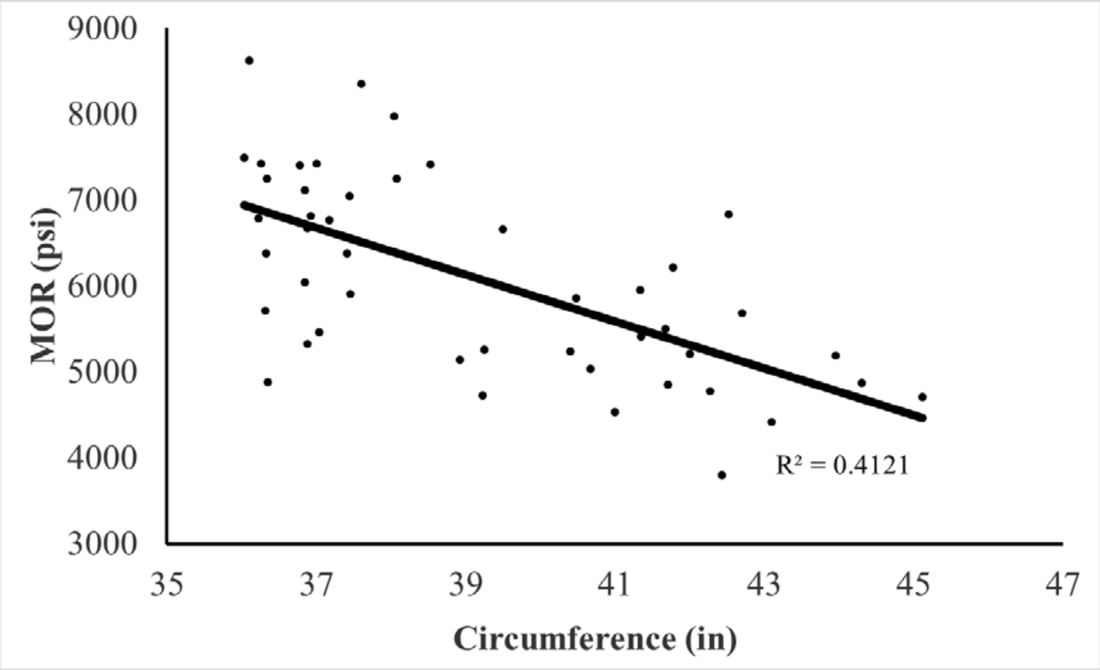


Figure III-13. Relationship between pole circumference and MOR of Douglas-fir poles with and without through boring.

The size dependency of MOR differed between groups. Figure III-14 displays the normalized edge distance (c/e) and MOR: for the 1-inch edge distance ($R^2 = 0.34$), for the 2-inch edge distance ($R^2 = 0.27$), and for the 3-inch edge distance ($R^2 = 0.75$) (Figure III-14). Although not displayed, the $R^2 = 0.41$ for the controls.

Stress concentration theory predicts that a smaller c/e ratio causes increased stress. Following that prediction, an initial hypothesis for the current study was that c/e would affect MOR. However, c/e and MOR were poorly correlated for all through-bored holes ($R^2 = 0.08$). Therefore, c/e and, consequently, edge distance did not affect MOR in the current study.

Poles from the first kiln charge (Table III-2) had a larger mean strength than those from the other two charges, while diameter was significantly smaller ($p = .003$) than poles in the other two charges. Smaller diameter poles could have lost less strength from kiln drying.

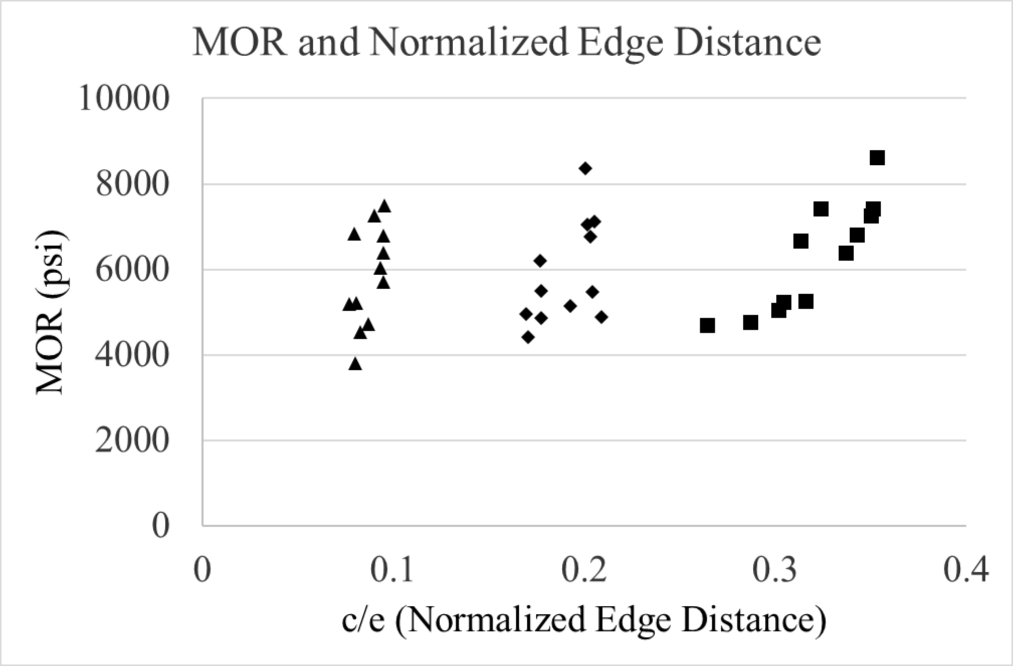


Figure III-14. Normalized edge distance (c/e) and MOR, where c is the edge distance and e is diameter minus the edge distance. Normalizing edge distance is a method of graphically separating groups. Three distinct groups, representing: 1-inch, 2-inch and 3-inch drilling distances are shown from left to right.

Statistical Analysis Of Above Variables: T-tests confirmed neither edge distance nor kiln cycle significantly affected pole properties. Data were then subjected to an analysis of covariance (ANCOVA). ANCOVA was preferred over an analysis of variance (ANOVA) because it allows the inclusion of pole diameter and MOE as covariates. Assumptions of

ANCOVA are homogeneity of variance, parallel regression slopes for each independent variable, and normality. Homogeneity in variance was tested by using Levene's test, which showed no difference in variance between groups. MOR distribution appeared to be bimodal (Figure III-15), which would violate the assumptions used in the Student's t-test and ANCOVA. A Shapiro- Wilk normality test did not detect departures of normality (p =0.185). The regression slopes for each group were roughly parallel.

The ANCOVA used a linear model, with the factors of kiln cycle and edge distance, and the covariates of diameter or MOE. No significant differences were found for kiln cycle and edge distance (p = 0.54), but diameter and MOE had a significant effect (p = 0.001). The Kruskal-Wallace test assesses whether a non-normal distribution would change the significance of any factors (Ramsey and Schafer 2012). The Kruskal-Wallace test did not reveal any variables with a significant effect on the MOR.

An experimental assumption was that COV would be approximately 13% and differences between groups would be 15%. Group variance ranged from 14% to 20%. The sources of variance were kiln-drying and the fact that the poles were tested when the wood was below the fiber saturation point. The greater-than-expected variance showed that the power of the statistical tests performed was lower than expected.

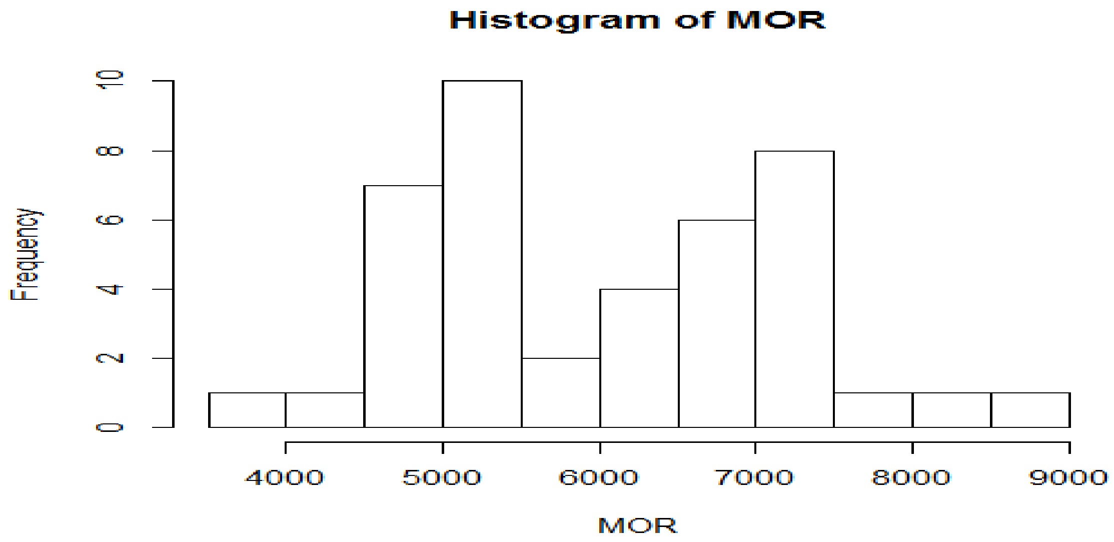


Figure III-15. Distribution of MOR values of Douglas-fir poles with and without through-bored holes.

Moisture Content: Moisture contents (MC) of the kiln-dried poles ranged from 8% to 16% in the outer inch, as measured with a Delmhorst RDM-3 resistance-type moisture meter. MC was measured after testing using the oven-dry method, averaged 15.2% with a range of 11% to 19% (Table III-2). Moisture contents of poles from the third charge differed significantly different from those in the first and second charges (p = .003 and p = .047). The second and third kiln charges were removed when the outer inch reached 15% MC, while the first was subjected to a much longer drying cycle with a wide wet bulb/dry bulb depression due to human error. Although the second and third charges underwent the same drying cycle, the second charge was not removed from the dry kiln immediately, allowing the residual heat in the dry kiln to continue to dry the wood. This would tend to make moisture levels nearer to the surface similar to those in the first group. The potential effects of kiln charge on flexural properties were minimized by equally distributing poles from each charge to each edge distance group.

Weight and Specific Gravity: The average pole weight was 518 lb, with a range of 388 to 694 lb. The wide range reflects the fact that pole diameter varied by 3 inches. The specific gravity of the measured poles averaged 0.51, which is consistent with the reported value for oven-dried Douglas-fir of 0.5 (USDA, 2010).

Circumference: The poles were a mixture of Class 4, 40-foot, Class 2, 35-foot, and Class 1, 40-foot. The average circumference of the poles was 40.8 inches at the butt and 35.3 inches at the tip. The average circumference at the groundline was 39.22 inches. The pole circumferences were not normally distributed (Figure III-16). The supplier chose poles that had a circumference greater than 36 inches; and three different classes of poles were present. Previous pole studies have not shown strength differences between classes for distribution poles; however, the poles were sorted so that average diameter was equal for each edge distance group, in order to limit possible size effects. The poles were then visually assessed for knot checks, knots, and other defects to ensure that they met the ANSI 05.1 requirements.

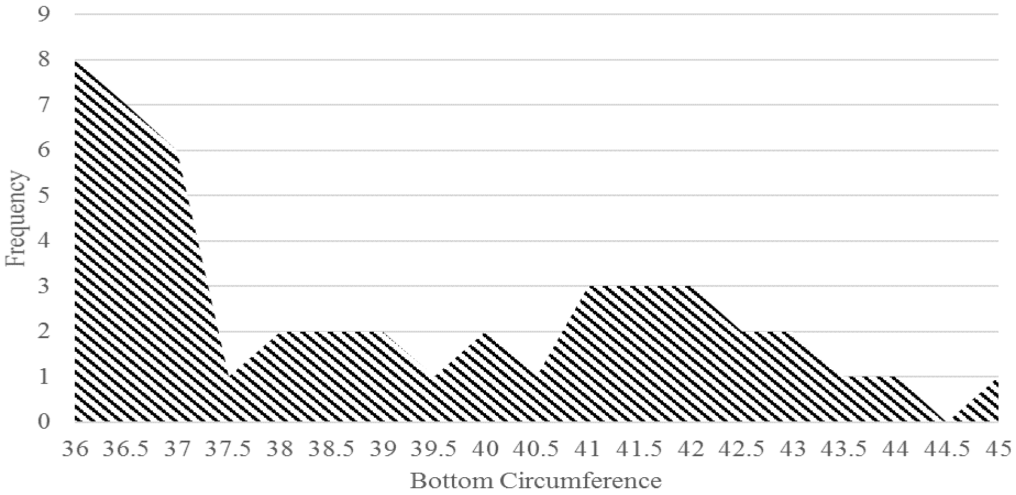


Figure III-16. Distribution of circumferences for 48 Douglas-fir poles used to evaluate the effects of edge distance of through bored holes on pole flexural properties.

Ring Count: The average pole age was 45 years, with a range of 23 to 77 years. The number of growth rings in the outer 2 inches averaged 19, with all poles having a minimum of 10 rings in that zone. All poles met the ANSI requirement for a minimum of 5 rings per inch in the outer 2 inches.

*Failure Modes***:** Ultimate failures were separated into three groups: tensile, end shear, and compression. Most tensile failures occurred around a knot or hole. Some tensile failures were attributable to slope of grain. End shear is a shear failure at the end of the pole. Compression failures occurred near the top of knots and holes, but were not the ultimate cause of failure.

Most failures occurred at knot clusters. The same result observed by Elkins (2005). This observation suggests that the largest stress concentrations remain at knots. The weakest failed modes failed under compression and end shear. Only three specimens failed in compression, making statistical comparisons impossible. End shear strength was lower (Table 5-3), but the differences were not significant. End shear caused the ultimate failure in 35% of all poles, but was present in 68.8% of poles (Figure III-17). Penultimate end shear failures release energy and change material properties such as MOE.

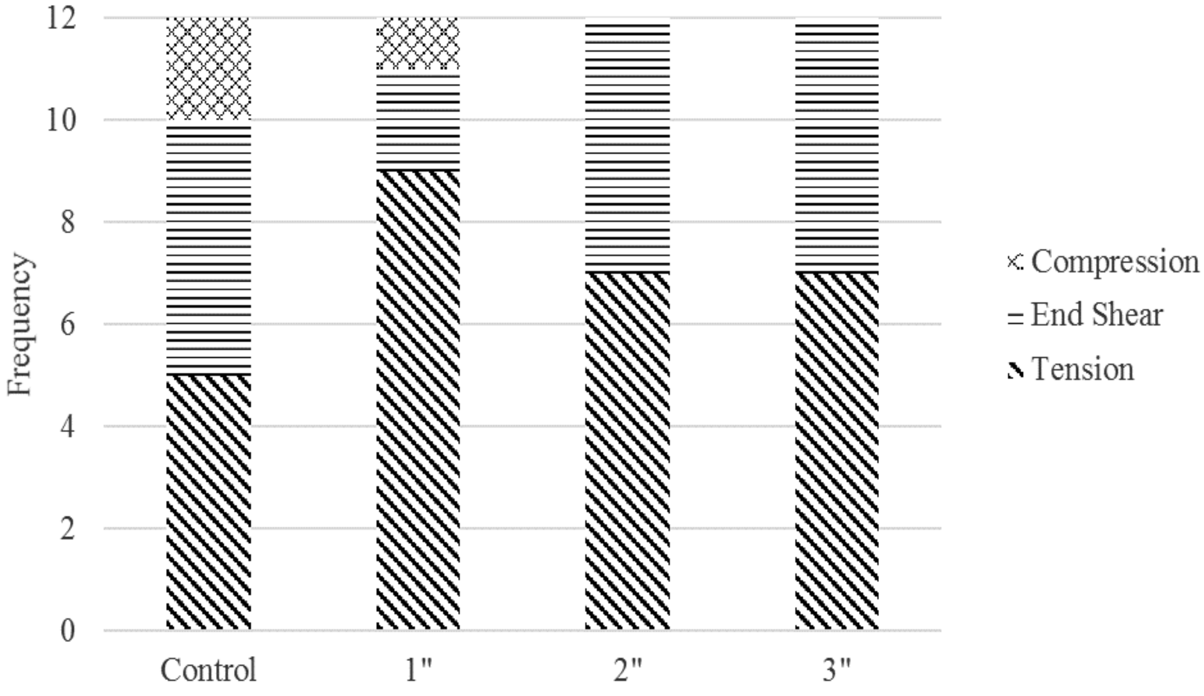


Figure III-17. Frequency of ultimate failure modes for each edge distance group.

Many poles in the control group failed in end shear or compression, suggesting that holes cause more tensile failures to occur. The highest average MOR should be associated with tensile failures, making it beneficial to force the pole to break in tension. The majority of failures in the one inch group were tensile failures, whereas the failure modes were more mixed in the two and three inch group. Drilling holes closer to the edge was associated with more tensile failures, but may also reduce the poles strength as seen in Table III-4. Although the failure patterns in the two and three-inch group are similar the three inch group is stronger (Table III-4). This is due to some holes in the two-inch group causing failure compared to none in the three–inch group. Drilling at a two or three inch group seems to be optimal, with a three-inch group causing no strength loss.

Table III-4. Failure modes observed in poles without through bored holes or with through bored holes drilled 1, 2, or 3 inches inward from the edge.

Failure Mode	Average MOR (psi)	Coefficient of Variation
Tension	6252.9 (1282.6)	0.205
End shear	5867.0 (881.6)	0.150
Compression	5423.9 (374.5)	0.069

The comparison between the finite element model data and the actual flexural tests are still underway; however a number of preliminary observations can be made:

Flexural properties of the current pole population are lower than those observed in previous tests. We believe that the lower MOR values reflect the effects of drying and checking. NSI tests are usually conducted on poles in the green or wet condition. This minimizes the effects of drying checks and other drying induced defects. The presence of checks, while not reported to cause losses in properties, may have had other effects on failure modes under the test conditions. It is important to remember that this test differs from a typical cantilever loading and this change may have enhanced any checking effects.

Edge distance, however, had no significant effect on pole flexural properties at the current two inch edge distance. Moving the edge distance inward on the poles didn’t result in any improvement in pole properties. These results would argue for the decreased edge distance as a means for producing better preservative treatment.

Further analyses are underway to determine how well the ANSYS finite element modeling was able to predict both MOR and failure mode with the ultimate goal of reducing the need for the extensive pole testing required for answering seemingly simple questions about the effects of pre-treatment boring or incising on pole properties.

B. Effect of End Plates on Checking of Douglas-fir Cross arms

The environmental conditions in crossarms present a much lower risk of decay than would be found at groundline; however, the arms are subjected to much wider fluctuations in wood moisture content than poles. Arms expand as they wet and shrink when they dry. This repeated cyclic moisture behavior can lead to mechanical damage and the development of deep checks, which can lead to splits that cause bolts and other hardware to loosen and fail. The incidence of splits in crossarms is generally low, but the cost of repairs can be significant. Thus, the development of methods to limit crossarm splitting would be economical in many utility systems.

One approach to limit splitting is end-plating. End-plates have long been used for railroad ties and many rail lines routinely plate all ties. End-plates might provide similar benefits for crossarms; however, there is little data on the merits of these plates for this application. In order to develop these data, we established a test of end-plates on crossarms by exposing arms to repeated wetting and drying. These tests were run for 13 wet/dry cycles and the results were presented in the 2011 Annual Report. The results showed that end-plated arms experienced much lower checking frequency and the checks that were present were narrower. These results should translate into a reduced risk of decay in service, thereby producing longer arm life.

At the end of these tests, the arms were placed aboveground at our Peavy Arboretum test site for further weathering. We expected the arms to continue to wet and dry, albeit at a slower rate than the accelerated tests. This past year, we assessed the arms earlier in the wet season and then, most recently, near the end of our dry summer. The earlier data are presented to provide context for the newer results.

Thirteen pentachlorophenol treated Douglas-fir crossarm sections (87.5 mm by 112.5 mm by 1.2 m long) were end-plated on both ends then cut in half to create 26 test pieces, each with one plated end and one non-plated end (Figure III-17). The objective was to compare checking with/without plates on comparable wood samples. Plates were developed by Brooks Manufacturing (Bellingham, WA). The arms were initially examined for the presence of checks. The arms were then immersed in water for 30 days before being removed and assessed for check development. The total number of checks longer than 2.5 cm on each face was recorded, and the check of the widest width on each face was measured. Arm sections were air dried and measurements were made again. The arms were returned to the dipping tank for an additional 30 days before the cycle was repeated. Arms were air-dried in the first cycle and kiln-dried for the remaining 12 cycles.

The differences in degree of checking between the arms were slight for the first few drying cycles and checking was slightly greater in end-plated arms early in the test (Table III-5). Continued moisture cycling, however, gradually showed that check width and frequency both became larger on the arm end without the end-plate. Check width reached a maximum between 12 and 13 wet/dry cycles, while checking frequency continued to slowly increase on the plated ends of the arms. The results suggest that both the frequency and size of checks can be limited by end-plating. These results parallel those found with end-plating on railway sleepers. In the case of the sleepers, the need for anti-splitting devices is much greater because of the tendency of many hardwood species to split as they season; however, the principle is the same. These plates would be especially useful in very dry areas or in those subjected to extreme wet/dry cycles. In both cases, the build-up of internal stress can lead to deep check development that can compromise crossarm connectors.

Table III-5. Number and width of checks on penta-treated Douglas-fir crossarm sections with and without end plates over repeated wet and dry cycles.

Number of Wet/Dry Cycles	Check Frequency (#/arm) [1]		Maximum check width (mm)	
	No Endplate	Endplate	No Endplate	Endplate
1	0.5	0.1	0.8	0.8
2	1.0	0.5	1.1	1.4
3	0.2	0.2	1.0	1.3
4	1.0	1.0	1.2	1.1
5	0.6	0.8	3.0	1.5
6	2.0	0.4	2.5	2.0
7	2.2	2.0	3.6	2.1
8	2.0	1.4	7.0	2.2
9	3.1	2.2	6.6	3.4
10	3.8	2.2	5.9	2.6
11	3.4	2.3	7.0	3.0
12	3.6	2.4	7.9	2.2
13	3.5	2.8	9.2	3.7

[1] Values represent means of 25 arms per treatment.

Check frequency was lower on the plated ends of arms exposed outside compared with the levels found at the end of the 13 wet/dry cycles (Table III-6). This difference may have occurred because the arms were oven-dried and near zero percent moisture content at the end of the laboratory phase of this test, while they had reached an equilibrium moisture content on the outdoor test racks. Thus, there would have been some wood swelling that could obscure small checks that were counted in the original study. Check frequency was still much greater on the arm ends without the plates illustrating the potential benefits of plating.

Maximum number of checks were also lower on the arms following outdoor exposure. Once again, the arms would be at a slightly higher moisture content and the corresponding moisture associated wood expansion could account for some of this reduction. Arms with plates had much narrower checks than those without plates. One arm in particular had a very wide split on the non-plated end, but no evidence of the split on the plated end (Figure III-18). The presence of this split illustrates the potential benefits of using some type of end-plating device. While this damage only occurred in one arm, the utility would have to determine if the cost for replacing this arm in service or the potential costs of an outage outweighed the costs of adding plates to the other arms. It would also be important to factor in the potential for the plates to limit the development of deep checks that penetrated beyond the depth of the original treatment and allowed entry by decay fungi that could reduce arm life.

We will continue to monitor these arms as they age in service.

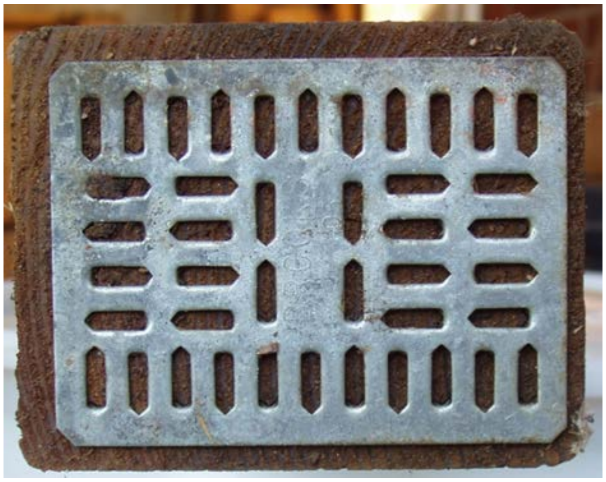


Figure III-17. Example of an end-plate on a penta treated Douglas-fir crossarm.

Table III-6. Check frequency and width on the ends of Douglas-fir crossarms with and without a metal end-plate following 58 months of aboveground exposure at the Peavy Arboretum test site.

Sampling Date	Check Frequency (#/arm) [1]		Maximum check width (mm)	
	Endplate	No Endplate	Endplate	No Endplate
October 2012	3.5	2.8	9.2	3.7
October 2016	0.63 (0.81)	2.25 (1.27)	0.81 (1.00)	2.03 (1.86)
August 2017	0.08 (0.28)	2.25 (0.97)	0.17 (0.55)	1.80 (1.46)

[1]Values represent means of 25 arms per treatment.

Figure III-18. Example of the opposite ends of a single arm showing a plated end with minimal checking and the opposite non-plated end with a severe split.

C. Effect of Capping on Pole Moisture Content

Extensive application of remedial treatments at groundline have markedly improved the service life of wood poles across North America. Controlling decay at groundline, however, has little influence on fungal activity further up the pole. Although fungi invade at a much slower rate above ground, they will eventually begin to affect pole performance above groundline. One area where this becomes evident in older poles is at the top. While many utility specifications call for a water shedding cap to be applied to the top of poles, others leave pole tops with a cover.

Preservative treatment does tend to penetrate through the end of the pole for distances ranging from 150 to 450 mm depending on the species. Logic would suggest that this degree of preservative penetration should prevent fungi from entering the untreated wood beneath; however, checks and splits that develop as the pole seasons can extend beyond this preservative treatment allowing fungi and moisture to enter. The result will be decay that extends downward into the energized zone, necessitating early replacement. Remedial treatment of this type of damage is difficult and the best approach is prevention through the application of a water shedding cap.

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

Effect of conventional capping on moisture content: Ten Douglas-fir poles that had been removed from service were cut into 2.5 m lengths and set in the ground to a depth of 0.6 m. The poles were cut so that the top was at least 150 mm away from any pre-existing bolt hole. The original bolt holes 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.

Cap effect 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-7). The cores were processed as described above. Moisture contents were initially higher in capped poles, but have since declined to a range of 13 to 18% over the 113 months since installation. The moisture level generally considered necessary for fungal attack is 28-30%. Thus, wood in the area beneath the caps is well below the level required for fungal growth. Moisture contents of poles without caps were initially lower than the capped poles, but levels have steadily increased over time. Moisture contents were very high after 90 months of exposure and there was some decay evident in cores. Sampling of poles at 113 months showed that moisture levels near the pole centers averaged 29.5% while those closer to the surface averaged 21.5%. The higher moisture levels in the center are consistent with previous results. The caps remained sound and free of damage that might allow moisture to intrude into the wood (Figure III-19). The results clearly show the benefits of capping in terms of reducing internal moisture content. Ultimately, reducing the time when conditions are suitable for fungal growth should translate into improved performance

Figure III-19. Example of the condition of water-shedding caps at the start of exposure and after 113 months of exposure in Corvallis, OR.

Table III-7. 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
113	July	29.5	21.5	18.1	16.3

Use of Polyurea Caps for Limiting moisture intrusion on Douglas-fir pole tops: Polyurea barriers have proven to be durable on crossarm sections in sub-tropical exposures in Hilo, Hawaii. 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-20). 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-8). The poles, installed in the spring of 2011, were sampled after 4, 12, 16, 24, 38 and 61 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.

The caps remain sound and free of damage 5 years after installation (Figure III-21). Moisture contents of non-coated

Figure III-20. Example of a polyurea capped pole top.

Table III-8. 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
61	July	29.5	21.5	20.4	14.7

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

Figure III-21. Condition of polyurea coatings on the tops of Douglas-fir pole sections after 61 months of exposure in Corvallis, OR.

D. Effect of pole top configuration on moisture uptake in poles

In previous tests, we have explored the benefits of capping poles at the time of installation to retard moisture uptake and limit the potential for pole top decay. These tests have shown dramatic differences in moisture content between poles with and without caps. One other 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 0.9 m long sections which were allocated to four different treatment groups. Two groups were left with their tops cut perpendicular to the length. The tops of one set of pole sections were cut at 30 degree angles while the final set was cut with two sloping sides coming to a point (Figure III-22).

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-22. Examples of the different pole top roofing patterns assessed for their ability to resist moisture ingress.

The samples all generally lost weight over the first 5 months of exposure. These losses reflected the absence of substantial rainfall during this period coupled with volatilization of residual solvent (Table III-9). The samples all gained substantial amounts of weight over the next 5 months regardless of the capping configuration. Weights remained steady for the next 4 months, even through our normally dry summer. This lack of difference between capped and non-capped specimens is perplexing since previous tests have shown distinct differences with cap presence. Further tests are planned to determine the cause of this anomaly.

Table III- 9. Mass changes of Douglas-fir pole sections with different top configurations as determined by weighing over a 15 moth exposure period in western Oregon.

Exposure Time (Months)	Average Moisture Content (%)[a]			
	Flat	Flat/capped	Sloped	Double Slope
5	-3.06 (2.05)	-0.05 (2.18)	-4.99 (2.87)	-3.95 (1.93)
11	55.58 (4.69)	57.86 (2.47)	54.18 (4.54)	56.94 (3.64)
12	52.86 (3.95)	55.88 (3.66)	49.69 (4.83)	52.18 (5.24)
15	47.22 (3.28)	54.86 (2.51)	46.31 (5.97)	49.17 (2.64)

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

E. Effect of Time after Treatment on Corrosion of Metal Fasteners in ACZA Treated Wood

Ammonia tends to swell wood, dissolve materials on cell pits, and improve the ability to impregnate refractory woods such as Douglas-fir. Ammoniacal copper arsenate (ACA) and later ammoniacal copper zinc arsenate (ACZA) were both developed with ammonia to solubilize the copper and improve treatment of Douglas-fir with water based solutions. However, the presence of ammonia in treating solutions has a well-known effect on corrosion of iron fasteners. The normal recommendation to limit corrosion in woods treated with ammonia based systems is to use either stainless steel or hot-dipped galvanized fasteners, but some utilities are still concerned about how long after treatment they should wait before installing hardware. In order to address this question, we set up the following trial.

Thirty eight Douglas-fir pole sections (0.9 m long by 200 mm in diameter) were obtained. One 13 mm diameter hole was drilled into each pole section approximately 300 mm from one end. Sixteen pole sections were commercially impregnated with ACZA to a target retention of 9.6 kg/m^3 (oxide basis), 16 sections were treated to the same retention with ACZA plus disodium octaborate tetrahydrate (DOT) (4 kg/m^3), and three sections were left without treatment. An additional 13 mm diameter hole was drilled into each pole 300 mm from the opposite end of the pole. The 16 poles in a treatment group were allocated to four groups of four poles each. Hot-dip galvanized metal bolts that had previously been weighed (nearest 0.01 g) were inserted into the holes in four poles from each treatment group (ACZA or ACZA/DOT). Additional sets of poles from each treatment group received galvanized bolts 2, 4, and 8 weeks after treatment to assess the benefits of delayed installation on fastener behavior. Galvanized bolts were also inserted in the non-treated control poles at the same time the first bolts were inserted into the ACZA or ACZA/DOT treated poles.

The pole sections were stored upright on pallets off the ground in an area that had good air circulation that would be similar to air conditions around a pole in the field. The effects of pre-vs post treatment drilling and installation time after treatment on fasteners was assessed by removing the bolts 10, 14, 36, 52, 137, and 209 weeks after installation (Table III-10). A wire brush was used to remove any corrosion and each bolt was weighed. Mass loss was calculated on the basis of the original bolt weight and was used as the measure of corrosion over time.

There was little evidence of corrosion on any of the bolts over the course of the study. In fact, most bolts experienced slight weight gains over the first 52 weeks after treatment. Mass losses became evident in some bolts that were inserted in holes drilled prior to ACZA treatment, but the mass loses were generally small 36 weeks after installation and rose slightly with time. No mass losses were observed on bolts inserted into holes drilled after ACZA treatment for the first 137 weeks. The results suggest that higher treatment levels in the heartwood of the poles encouraged slightly higher rates of corrosion. Mass losses remained slightly higher at 209 weeks for bolts that were inserted in pre-bored holes in ACZA treated poles. Mass losses were observed in bolts 52 weeks after installation in both pre-and post-treatment bored holes for the ACZA/DOT treated poles. These differences disappeared at 137 weeks, illustrating how small they were at this point. Mass losses were more evident 209 weeks after installation, but the differences were higher for bolts inserted in holes drilled after treatment. It is unclear why mass losses differed between bolts in the ACZA and ACZA/DOT treatments. Although borates were added primarily to enhance protection of the heartwood from internal decay in the poles, they should also help buffer the solution, thereby reducing corrosion. It is not clear that this occurred.

The poles will continue to be periodically monitored. At present, it appears that time after treatment had little or no effect on the risk of corrosion in the bolts nor did it matter whether the hole was pre-drilled prior to or after treatment. In general, we recommend pre-drilling since it creates a well-treated hole that can reduce the risk of decay developing above the ground. These results support a neutral effect on metal integrity using this process.

Table III-10. Effect of ammoniacal copper zinc arsenate (ACZA) with or without disodium octaborate tetrahydrate (DOT) treatment on corrosion rates of galvanized bolts inserted into holes bored before or after treatment as measured by mass loss.

Treatment		Bolt Hole	Time Delay (wks.)	Average Bolt Mass Losses Over Time (%)[a]					
ACZA	DOT			10 Wk	14 Wk	36 Wk	52 Wk	137 Wk	209 Wk
Yes	No	After	0	+0.072 (0.017)	+0.124 (0.014)	+0.120 (0.040)	+0.49 (0.018)	+0.117 (0.057)	0.403 (0.269)
			2	+0.064 (0.009)	+0.102 (0.024)	+0.090 (0.020)	+0.030 (0.068	+0.097 (0.098)	0.475 (0.496)
			4	+0.039 (0.013)	+0.117 (0.027)	+0.09 (0.0064)	0.016 (0.109)	+0.119 (0.295)	1.313 (0.404)
			8	0	+0.100 (0.032)	+0.146 (0.030)	+0.055 (0.056)	+0.116 (0.143)	0.825 (0.430)
		Before	0	+0.191 (0.044)	+0.079 (0.065)	0.032 (0.074)	0.097 (0.083)	0.060 (0.103)	0.611 (0.199)
			2	+0.123 (0.033)	+0.090 (0.014)	0.073 (0.130)	0.157 (0.159)	0.125 (0.183)	0.707 (0.520)
			4	+0.085 (0.035)	+0.033 (0.047)	0.067 (0.047)	0.132 (0.067)	0.029 (0.096)	1.106 (0.433)
			8	+0.109 (0.053)	+0.108 (0.073)	0.074 (0.151)	0.189 (0.234)	0.035 (0.054)	0.980 (0.892)
Yes	Yes	After	0	0	+0.019 (0.076)	+0.009 (0.127)	0.213 (0.216)	0.192 (0.489)	2.016 (0.723)
			2	+0.036 (0.017)	+0.090 (0.017)	+0.104 (0.021)	0.002 (0.041)	+0.242 (0.084)	1.305 (0.750)
			4	+0.017 (0.009)	+0.085 (0.020)	+0.091 (0.028)	0.048 (0.112)	+0.055 (0.099)	1.783 (1.393)
			8	0.553 (1.123)	+0.092 (0.023)	+0.070 (0.013)	0.028 (0.089)	+0.117 (0.133)	1.168 (0.723)
		Before	0	0.029 (0.037)	+0.001 (0.043)	+0.021 (0.030)	0.102 (0.143)	0.180 (0.146)	1.480 (1.466)
			2	0.007 (0.064)	+0.014 (0.074)	+0.035 (0.076)	0.037 (0.106)	+0.019 (0.171)	0.673 (0.455)
			4	0.013 (0.032)	+0.010 (0.041)	+0.028 90.012)	0.022 (0.060)	+0.157 (0.177)	0.957 (1.048)
			8	+0.012 (0.013)	+0.037 (0.012)	+0.048 (0.023)	+0.031 (0.020)	+0.093 (0.063)	0.060 (0.106)
No	No	After	0	+0.034	+0.094	+0.056	+0.029	+0.024	0.046
			4	0.002	+0.080	+0.073	+0.051	+0.073	+0.061
			8	0.002	+0.073	+0.080	+0.046	+0.056	+0.058
		Before	0	+0.002	+0.061	+0.075	+0.044	+0.075	+0.032
			4	+0.005	+0.061	+0.051	+0.034	+0.090	+0.058
			8	0.005	+0.065	+0.070	+0.036	+0.075	+0.024

[a] Values represent means of 4 replicates per treatment, while figures in parentheses represent one standard deviation. Pluses represent weight gains.

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

Over the past 7 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 proper solution concentration. This required oils that had sufficient penta solvency, which 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 diluted with diesel oil; however, this solvent mixture had strong odors and the volatile diesel made it difficult to utilize Boulton seasoning (boiling in oil under vacuum to season prior to treatment).

One solution to the problem was the inclusion of biodiesel in the blended oil. Biodiesel 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.

Samples were weighed prior to treatment and subjected to 30 psi of initial air pressure. Treatment solution was pumped into the vessel and pressure was raised to 150 psi and held for at least 2 hours. Pressure was released and a 2 to 4 hour vacuum was drawn to relieve internal pressure and recover residual preservative. Stakes continued to lose solvent after treatment and were allowed to stabilize for 2 weeks before being re-weighed to determine net solution uptake (Figure III-23). The net weight gain was used to estimate 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.

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

Figure III-23. Stakes drying under cover after treatment with copper naphthenate (bottom) or penta (top).

Stakes in the open field setting tended to have lower degree of fungal attack than those in the wooded area (Tables III-11, III-12). 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 after 22 months of exposure, 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.

Stakes in the open field site were generally in good condition 32 months after installation, with ratings above 9.0, indicating that there was little evidence of advanced decay. Stakes in the forest setting tended to experience far more decay. The non-treated controls showed evidence of advanced decay (Rating = 5.5) and average ratings for many of the samples treated with solvent alone or solvent plus the lower preservative retention showed evidence of decay. Stakes treated with copper naphthenate in petroleum diesel/biodiesel blends showed increased decay with increasing levels of biodiesel with the most decay in the stakes treated using 100% biodiesel (Figure III-24). Although the test is still in the early stages, the results support the laboratory trials showing the negative effects of using biodiesel in combination with this preservative. It is important to note that stakes treated with copper naphthenate in petroleum based biodiesel are performing well. The status of our biodiesel field trials in 2017 are shown in Figure III-25.

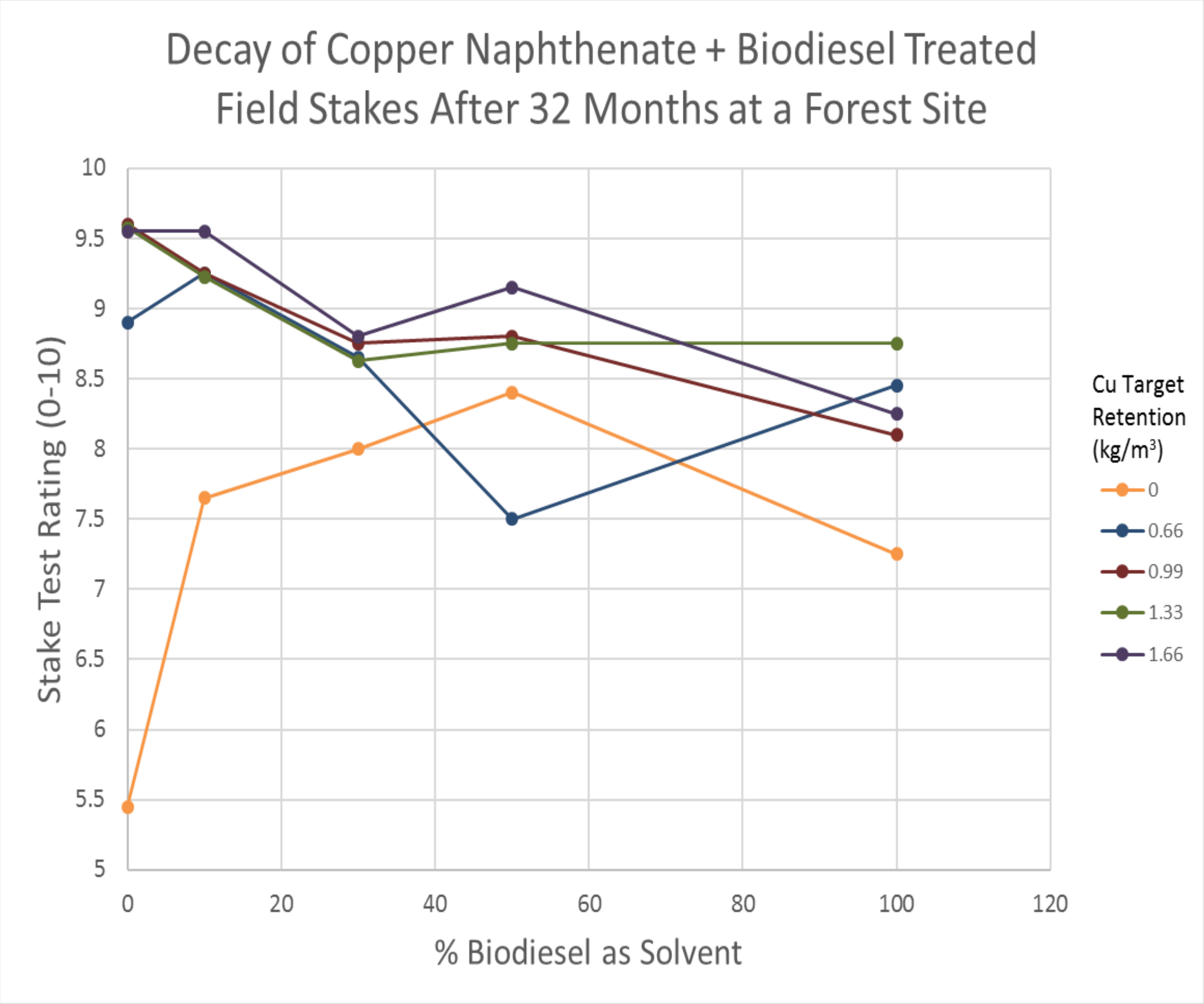


Figure III-24. Average ratings of Douglas-fir sapwood stakes in the forest site treated with copper naphthenate in mixtures of petroleum and bio-based diesel after 32 months of exposure in soil showing the relationship between increased biodiesel content and increased decay.

Table III-11. Condition of Douglas-fir sapwood stakes treated with penta or copper naphthenate in various solvents and exposed for 32 months in a meadow site near Corvallis, Oregon.

Field Stake Assessment (Fall 2016)									
Treatment				Target Retentions (kg/m^3)					
Pentachlorophenol Carrier	Biodiesel %	Months	**Water (UTC)**	**0**	**2.4**	**4.8**	**7.2**	**9.6**	**Total**
Water (UTC)	-----	22	9.90 (0.3)						
		32	9.3 (1.3)						
Diesel	0	22		10.00 (0.0)	10.00 (0.0)	10.00 (0.0)	9.90 (0.2)	10.00 (0.0)	9.98
		32		9.75 (0.6)	9.85 (0.5)	9.8 (0.6)	9.55 (0.8)	10 (0.0)	9.79
	30	22		9.90 (0.2)	10.00 (0.0)	9.95 (0.2)	9.95 (0.2)	9.98 (0.1)	9.96
		32		9.35 (1.2)	9.85 (0.5)	9.95 (0.2)	9.7 (0.5)	9.68 (0.7)	9.71
	50	22		9.70 (0.9)	9.95 (0.2)	9.95 (0.2)	10.00 (0.0)	10.00 (0.0)	9.93
		32		9.25 (1.5)	9.65 (0.8)	9.75 (0.6)	9.75 (0.0)	9.9 (0.3)	9.66
	70	22		9.95 (0.2)	9.98 (0.1)	10.00 (0.0)			9.98
		32		9.65 (0.5)	9.9 (0.3)	10 (0.0)			9.85
Aromatic Oil	0	22		10.00 (0.0)	10.00 (0.0)	9.90 (0.3)	10.00 (0.0)	10.00 (0.0)	9.98
		32		10 (0.0)	9.9 (0.3)	9.9 (0.3)	10 (0.2)	9.93 (0.2)	9.95
Naphthenic Oil	30	22		10.00 (0.0)	9.95 (0.2)	9.95 (0.2)	9.95 (0.2)	9.98 (0.1)	9.97
		32		9.35 (0.9)	9.85 (0.3)	9.95 (0.2)	9.95 (0.5)	9.9 (0.3)	9.80
Paraffinic Oil	30	22		9.95 (0.2)	10.00 (0.0)	10.00 (0.0)	10.00 (0.0)	10.00 (0.0)	9.99
		32		9.3 (1.5)	9.4 (1.0)	9.9 (0.3)	9.7 (0.3)	9.9 (0.3)	9.64
FPRL Oil	0	22		9.95 (0.2)	9.90 (0.2)	10.00 (0.0)	10.00 (0.0)	9.98 (0.1)	9.97
		32		9.7 (0.7)	9.55 (0.6)	9.9 (0.3)	9.9 (0.6)	9.83 (0.6)	9.78
Ketone Bottoms	0	22		9.90 (0.2)	9.90 (0.3)	9.95 (0.2)	10.00 (0.0)	9.95 (0.2)	9.94
		32		9.45 (1.0)	9.75 (0.5)	9.9 (0.3)	9.95 (0.0)	9.8 (0.5)	9.77
Copper Naphthenate Carrier	Biodiesel %			**0**	**0.66**	**0.99**	**1.33**	**1.66**	
Diesel	0	22			10.00 (0.0)	10.00 (0.0)	9.98 (0.1)	10.00 (0.0)	9.99
		32			10 (0.0)	9.8 (0.5)	9.85 (0.5)	10 (0.0)	9.91
	10	22		9.90 (0.2)	10.00 (0.0)	9.90 (0.2)	9.98 (0.1)	10.00 (0.0)	9.96
		32		9.9 (0.3)	10 (0.0)	9.8 (0.3)	9.85 (0.8)	10 (0.0)	9.91
	30	22			9.85 (0.3)	10.00 (0.0)	9.93 (0.2)	9.90 (0.3)	9.92
		32			9.3 (1.2)	9.85 (0.3)	9.6 (0.7)	9.95 (0.2)	9.68
	50	22			9.90 (0.3)	9.90 (0.2)	9.88 (0.3)	10.00 (0.0)	9.91
		32			9.75 (0.6)	9.4 (0.7)	9.58 (0.3)	9.8 (0.5)	9.63
	100	22		9.95 (0.2)	9.95 (0.2)	9.60 (0.9)	9.98 (0.1)	9.95 (0.2)	9.90
		32		9.5 (1.1)	9.75 (0.8)	8.95 (1.4)	9.88 (0.0)	9.5 (1.1)	9.52

Values represent means of 10 stakes per treatment. Figures in parentheses represent one standard deviation. Ratings for non-treated controls averaged 9.90 (0.30) and 9.30 (1.3), respectively, after 22 and 32 months of exposure. Copper naphthenate values are as Cu metal.

Table III-12. Condition of Douglas-fir sapwood stakes treated with penta or copper naphthenate in various solvents and exposed for 32 months in a forest site near Corvallis, Oregon.

Forest Stake Assessment (Fall 2016)									
Treatment				Target Retentions (kg/m^3)					
Pentachlorophenol Carrier	Biodiesel %	Months	**Water (UTC)**	**0**	**2.4**	**4.8**	**7.2**	**9.6**	**Total**
Water (UTC)	-----	22	8.00 (2.0)						
		32	5.5 (2.2)						
Diesel	0	22		8.70 (1.5)	9.20 (0.9)	9.65 (0.3)	9.95 (0.2)	9.88 (0.4)	9.54
		32		8.4 (2.0)	8.3 (1.8)	9.2 (0.8)	9.7 (0.6)	9.8 (0.6)	9.05
	30	22		9.05 (1.0)	9.50 (0.4)	9.80 (0.3)	9.95 (0.2)	9.65 (0.5)	9.60
		32		8 (1.1)	9 (0.9)	9.5 (0.5)	9.8 (0.3)	9.2 (1.2)	9.09
	50	22		8.95 (1.0)	9.35 (0.7)	9.45 (0.6)	9.75 (0.4)	9.73 (0.5)	9.49
		32		8.4 (1.2)	8.8 (1.3)	8.8 (1.0)	9.3 (0.7)	9.5 (0.6)	8.96
	70	22		8.75 (1.0)	9.83 (0.5)	9.75 (0.5)			9.58
		32		7.5 (1.4)	9.6 (0.9)	9.8 (0.5)			8.93
Aromatic Oil	0	22		9.80 (0.3)	9.85 (0.3)	9.95 (0.2)	9.85 (0.5)	9.93 (0.2)	9.88
		32		9.5 (0.7)	9.7 (0.5)	9.9 (0.3)	10 (0.0)	9.8 (0.4)	9.78
Naphthenic Oil	30	22		9.45 (0.7)	9.70 (0.5)	9.85 (0.2)	9.90 (0.3)	9.90 (0.3)	9.78
		32		7.8 (1.8)	9.3 (1.0)	9.6 (0.5)	9.8 (0.5)	9.7 (0.8)	9.23
Paraffinic Oil	30	22		9.35 (0.7)	9.30 (1.3)	9.95 (0.2)	9.90 (0.2)	9.70 (0.6)	9.65
		32		8.7 (1.4)	8.5 (2.2)	9.6 (0.8)	9.8 (0.4)	9.5 (0.9)	9.17
FPRL Oil	0	22		9.25 (0.4)	9.60 (0.5)	9.95 (0.2)	9.70 (0.7)	9.98 (0.1)	9.74
		32		8.3 (1.1)	9.1 (1.0)	8.7 (1.1)	9.3 (1.2)	9.9 (0.4)	9.05
Ketone Bottoms	0	22		9.25 (0.8)	9.70 (0.5)	9.90 (0.2)	9.40 (0.7)	9.95 (0.2)	9.69
		32		8.4 (1.1)	9.1 (1.0)	9.7 (0.7)	9.2 (0.9)	9.9 (0.5)	9.22
Copper Naphthenate Carrier	Biodiesel %			**0**	**0.66**	**0.99**	**1.33**	**1.66**	
Diesel	0	22			9.80 (0.3)	9.85 (0.3)	9.88 (0.3)	9.75 (0.4)	9.83
		32			8.9 (1.1)	9.6 (0.7)	9.6 (0.7)	9.6 (0.8)	9.41
	10	22		8.85 (1.0)	9.75 (0.5)	9.65 (0.3)	9.68 (0.5)	9.85 (0.2)	9.58
		32		7.7 (1.4)	9.3 (0.9)	9.3 (0.8)	9.2 (1.0)	9.6 (0.4)	8.99
	30	22			9.55 (0.4)	9.25 (0.7)	9.63 (0.5)	9.35 (0.6)	9.48
		32			8.7 (1.3)	8.8 (0.7)	8.6 (1.7)	8.8 (0.5)	8.71
	50	22			8.70 (0.9)	9.40 (0.7)	9.23 (0.8)	9.55 (0.6)	9.22
		32			7.5 (1.5)	8.8 (1.3)	8.8 (1.0)	9.2 (1.0)	8.55
	100	22		8.60 (1.6)	8.60 (1.2)	8.85 (1.1)	9.35 (0.7)	8.95 (1.2)	8.95
		32		7.3 (2.4)	8.5 (1.4)	8.1 (1.9)	8.8 (1.2)	8.3 (1.5)	8.16

Values represent means of 10 stakes per treatment. Figures in parentheses represent one standard deviation.
Ratings for the non-treated control averages 8.0 (2.0) and 5.5 (2.2), respectively after 22 and 32 months of exposure. Copper naphthenate values are as Cu metal.

Figure III-25. Composite photo showing a control stake at the field site, the forest site, and the field site in early September 2017.

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OBJECTIVE IV

PERFORMANCE OF EXTERNAL GROUNDLINE PRESERVATIVE SYSTEMS

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

For many years, pastes incorporated a diverse chemical mixture including pentachlorophenol, potassium dichromate, creosote, fluoride, and an array of insecticides. In the 1980s, the U.S. Environmental Protection Agency 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 of this objective is to assess laboratory and field performance of external preservative systems to protect belowground portions of wood poles.

A. Previous External Groundline Treatment Tests

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

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.	

B. Effect of External Barriers on Pole Performance

Preservative treatment is a remarkably effective barrier against biological attack, but these chemicals can migrate into surrounding soil. A number of studies documenting chemical migration have shown movement occurring for short distances around treated structures. Generally, the levels present do not pose environmental or disposal hazards. Despite these data, some utilities have explored external barriers to contain migrating preservative. These barriers, while not necessary in terms of environmental issues, may have secondary benefits of both retaining the original chemical and limiting moisture and fungal entry.

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

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

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

Moisture contents below groundline have generally been above 30% for the entire 95 months of the test, regardless of whether a barrier was present (Table IV-2). This value is considered to be the general fiber saturation point for Douglas-fir and is considered to the point where fungal decay can begin to occur. The results indicate wood conditions below ground are almost always suitable for fungal attack at this site.

Moisture contents in non-lined poles tended to be slightly lower than those for the barrier-treated poles near the surface, but were similar further into the pole. The absence of a barrier on the surface should allow for more moisture fluctuation at the site, which is characterized by very wet winters, where the water table rises to just below the surface, and summers with very little rainfall.

Originally, there was concern that the barriers would restrict moisture loss and result in extremely high moisture contents below ground. That has not happened, at least immediately adjacent to the groundline zone.

Ultimately, we might also expect the barriers to produce differences in external preservative performance; however, Douglas-fir is not prone to external decay so any differences in performance will likely take decades to emerge.

Figure IV-1. Example of a Biotrans liner on a Douglas-fir pole.

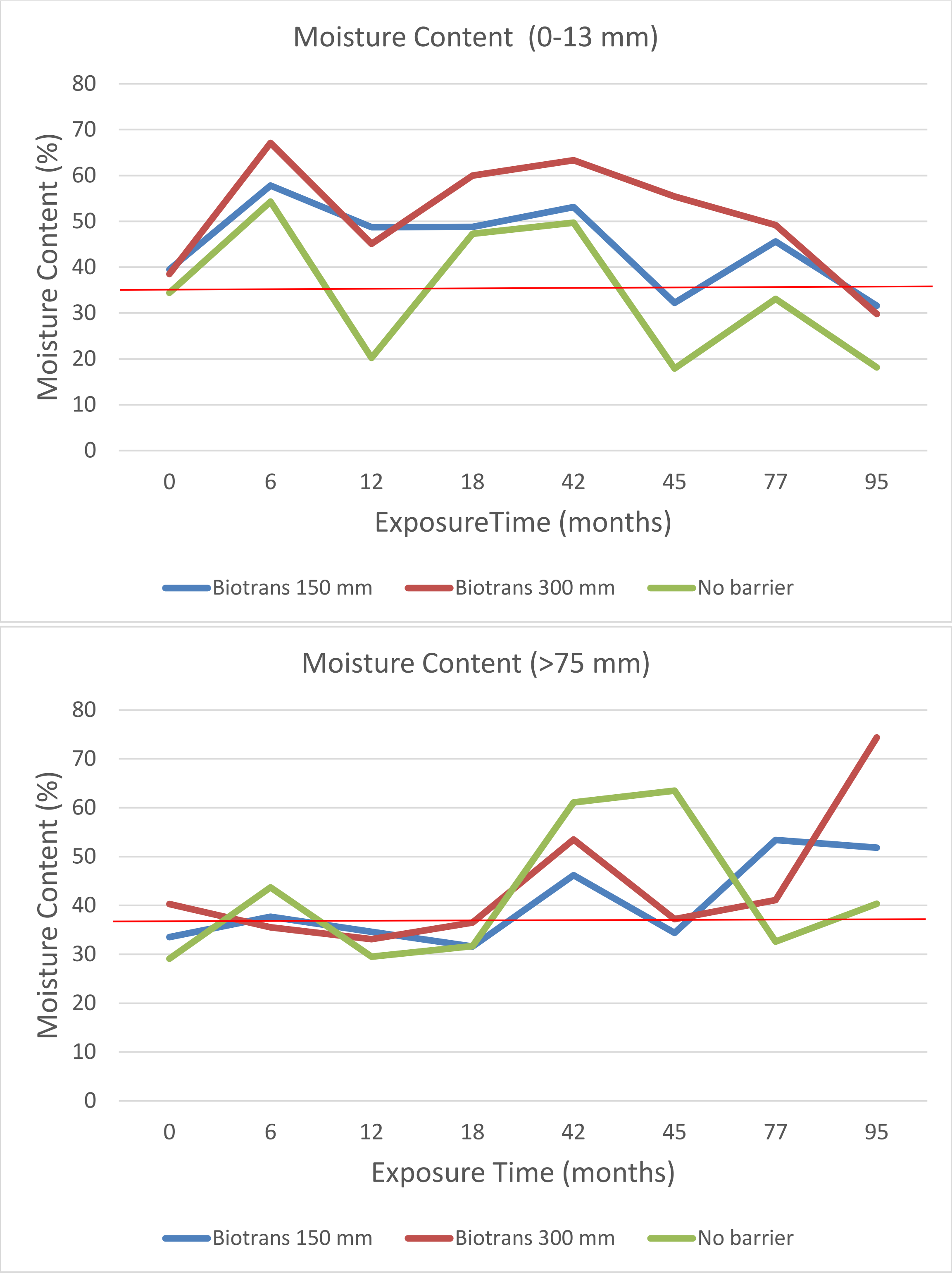


Figure IV-2 Moisture contents in the outer 13 mm of the pole or >75 mm from the surface of Douglas-fir poles with or without a Biotrans liner system installed so that the top was 150 or 300 mm above the soil level.

Table IV-2. Moisture contents of increment cores removed 150 mm below groundline in Douglas-fir poles with/without a Biotrans wrap so that the top is 150 mm or 300 m above the soil level.

Barrier	Months After Installation	Moisture Content (%)[a]			
		0-13	13-25	25-50	50-75
150 mm above GL	0	39.5 (10.0	35.1 (7.4)	34.0 (11.8)	33.5 (10.5)
	6	57.8 (19.0	48.1 (10.5)	37.6 (2.6)	37.7 (5.5)
	12	48.7 (13.9	35.6 (10.3)	35.7 (14.6)	34.6 (16.1)
	18	48.8 (11.9	40.6 (11.2)	34.7 (5.3)	31.6 (4.7)
	42	53.1 (31.1	42.7 (15.8)	47.6 (26.2)	46.2 (26.6)
	45	32.2 (11.1	28.7 (4.1)	32.3 (10.1)	34.4 (6.6)
	77	45.6 (25.2	41.3 (28.6)	66.3 (65.8)	53.4 (32.5)
	95	31.6 (14.6)	43.8 (27.3)	45.2 (31.7)	51.8 (42.5)
300 mm above GL	0	38.5 (7.7)	32.2 (3.9)	32.2 (8.1)	40.3 (24.3)
	6	67.1 (18.3)	49.5 (5.7)	38.8 (3.0)	35.5 (3.2)
	12	45.1 (20.7)	34.6 (9.8)	33.3 (7.0)	33.1 (6.7)
	18	60.0 (14.6)	40.1 (6.3)	37.4 (5.0)	36.5 (5.6)
	42	63.3 (23.2)	47.4 (31.3)	45.8 (26.1)	53.5 (35.2)
	45	55.4 (18.6)	36.7 (9.0)	37.0 (5.6)	37.2 (5.9)
	77	49.2 (20.3)	36.8 (10.4)	35.9 (18.8)	41.1 (18.2)
	95	29.8 (15.9)	36.8 (13.0)	42.5 (19.6)	74.4 (90.1)
No Liner	0	34.4 (3.5)	28.9 (2.7)	27.2 (3.2)	29.1 (3.3)
	6	54.3 (14.9)	47.1 (7.4)	42.1 (7.9)	43.7 (10.8)
	12	20.2 (4.9)	28.7 (15.7)	28.8 (8.3)	29.5 (4.3)
	18	47.3 (15.0)	34.7 (6.1)	31.5 (3.6)	31.7 (5.4)
	42	49.7 (23.3)	45.4 (25.7)	62.6 (55.6)	61.1 (59.1)
	45	17.9 (9.4)	24.7 (8.6)	39.9 (19.6)	63.5 (18.6)
	77	33.1 (12.2)	29.3 (17.2)	38.0 (20.4)	32.6 (19.7)
	95	18.1 (4.3)	25.6 (4.1)	30.2 (8.8)	40.3 (23.8)

[a] Values represent means of 5 replicates per time/treatment combination while figures in parentheses represent one standard deviation

C. Ability of Field Liner Systems to control Wood Moisture Content and Limit Preservative Migration

Liner systems for utility poles were originally developed in South Africa to help improve the performance of poorly performing poles in the now ESKOM system. The systems have been employed by U.S. utilities for almost 20 years wherever utilities have concerns about the potential risk of preservative migration from treated wood. While these systems have been reported to improve overall treatment performance, there are few data on the effects of these systems on preservative migration. In the Fall of 2010, we installed a field test of poles with and without liners to address the following objectives:

1. Assess the ability of external barriers to prevent preservative migration from poles in soil contact.
2. Determine the impact of external barriers on wood moisture contents above and below the barrier over time.

Douglas-fir pole sections (250-300 mm in diameter by 3.1 m long) were treated to a target retention of 9.6 kg/m^3 with pentachlorophenol, while southern pine pole sections of the same dimensions were treated with CCA to a retention of 9.6 kg/m^3 or penta to a retention of 7.2 kg/m^3. Additional non-treated poles were included in the test as controls. Prior to setting, the pole sections were sampled using an increment borer to determine initial preservative penetration. A sufficient number of cores were removed to determine retention per pole section. The pole sections were set to a depth of 0.9 m with or without field liners. Poles with liners were set so that the liner was 150 mm above groundline. One half of the poles will be used for monitoring potential migration of preservative components into the surrounding soil, and the other half will be used for measuring wood moisture content (MC) above and below the barrier.

Wood MC was assessed at the time of installation, 14, 22, 33, 60, and 83 months afterward. At each time point, increment cores were removed from one side of each pole beginning 150 mm below groundline, at groundline, 300 mm, and 900 mm above groundline. Each increment core was divided into four zones (0-25 mm, 25-50 mm, 50-75 mm, 75 mm-pith). Each core section was placed into a tared glass vial which was sealed and returned to the lab where the cores were weighed, oven dried, and reweighed to determine MC. The sampling holes were plugged with wood plugs and the liner repaired. These results will be used to develop MC profiles over time for lined and non-lined poles.

Moisture contents of the penta-treated Douglas-fir poles were below 30% at all four sampling locations and ranged from 9.7% in the outer zone of the lined poles to 26.7% in the inner zones of the non-lined poles at the time of installation (Table IV-3). Non-treated southern pine poles without liners followed similar trends. Moisture contents of penta-treated southern pine poles tended to be higher than Douglas-fir poles, ranging from 22.3% in the outer zone to 54.3% in the inner zone. Initial MC differences between penta-treated pine and Douglas-fir may reflect differences in post-treatment drying processes. The pine poles were kiln-dried, while the Douglas-fir poles were dried using a combination of air seasoning and Boultonizing (boiling in oil under vacuum) prior to pressure treatment. The kiln process used for southern pine is fairly aggressive and can be manipulated to dry the outer shell. Air-seasoning and Boultonizing tend to produce a more uniformly seasoned pole. This is less important in pine, which will tend to have a deeper zone of treatment that is more forgiving of post-treatment check development. It is essential for Douglas-fir, because deep checks that develop after treatment will invariably expose non-treated wood to fungal attack and, eventually, internal decay.

Table IV-3. Moisture contents at the time of installation at selected distances from the surface in Douglas-fir and southern pine poles with various treatments with or without a field liner.

Species	Treatment	Liner	Moisture Content (%)			
			0-25 mm	25-50 mm	50-75 mm	>75 mm
Douglas-fir	Penta	+	10	19	25	26
		-	11	19	25	27
Southern Pine	CCA	+	37	59	84	81
		-	29	44	42	60
	None	-	13	20	26	26
	Penta	+	22	38	41	42
		-	24	38	40	54

Moisture contents of CCA treated southern pine were well above those found in the penta-treated poles, reflecting the introduction of large amounts of water in the treating process. Moisture contents in the inner zone were over 80% at the time of installation.

Although there were sometimes large differences in MC between species and treatments, there were no differences between lined and non-lined poles with the same treatment.

Moisture contents of the poles 14 months after installation varied with initial treatment and wood species (Table IV-4; Figures IV-3-5). This sampling occurred at the end of our long, dry season and the results reflect that prolonged drying. Moisture contents for both non-treated and penta-treated Douglas-fir poles were below 35% and most were below 20%. Moisture contents were slightly higher near the groundline, but conditions were generally not suitable for fungal growth. There also appeared to be no difference in moisture contents for penta-treated Douglas-fir poles with and without a liner.

Non-treated southern pine poles tended to have higher moisture contents at groundline than Douglas-fir. Pine is more permeable and susceptible to fungal attack and the higher moisture contents could reflect both the greater tendency of this species to absorb water and the potential for fungal colonization to further enhance permeability. Moisture contents of penta-treated southern pine poles were higher than those for Douglas-fir at or below groundline and ranged from 28% to 45%. Moisture contents 300 and 900 mm above groundline were lower than those at groundline but still higher than those for Douglas-fir. There appeared to be no consistent differences in moisture contents between poles with and without barriers. Moisture contents for CCA-treated southern pine were higher than those found with penta-treated poles of the same species, reflecting the tendency of this treatment to increase hygroscopicity of the wood, but there were no noticeable differences in moisture contents between poles with and without barriers.

Sampling of poles 22 months after installation at the end of the wet season indicated that trends, with regard to wood treatment and species, were the same as those found after 14 months (Table IV-5; Figures IV-3-5). Moisture contents were much higher than those found at 14 months with levels in the inner zones of non-treated southern pine poles exceeding 100% below groundline. This test site has poor drainage and tends to collect water during the wet season. This creates ideal conditions for moisture uptake. In addition, regular rainfall creates ample opportunity for water to run down the pole in checks to the pole base where it can be more slowly absorbed by the wood. Over time, we might expect moisture contents in poles with the field liners to increase because of the limited opportunities for drying. However, there appear to be few consistent differences in moisture contents between poles with and without field liners.

Moisture contents in poles 33 months after installation were lower than those found at 14 or 22 months (Table IV-6, Figures IV-3-5). Wood moisture contents tended to be over the fiber saturation point at or below groundline, but levels dropped off sharply above that zone. There appeared to be little difference in MC with or without a barrier for the same treatment and species combination. Once again, moisture levels tended to be higher in southern pine poles, regardless of treatment, possibly reflecting the more permeable nature of this wood species. There appeared to be little difference in MC with preservative treatment on pine.

Moisture contents 60 months after installation tended to be much higher than those found in previous inspections (Table IV-7; Figure IV-3-5). This was interesting because rainfall that year was slightly below average, suggesting that wood moisture levels might be lower than normal. Moisture levels at several locations were over 100% in CCA and penta-treated southern pine poles. They were, also, over this level in many of the non-treated pine poles, but this reflects the presence of advanced decay that has left the wood spongy and more likely to absorb water. Moisture levels tended to be above 30% MC well above the groundline, particularly in pine poles. As in previous assessments, moisture levels tended to be lower in Douglas-fir poles, although the differences were sometimes slight. Furthermore, there were few consistent differences in moisture levels in poles receiving the same initial preservative treatment with or without a barrier wrap. These results suggest that the barriers are not appreciably altering the wood moisture relationships in the groundline zone.

Moisture contents in poles 83 months after barrier installation tended to be slightly lower than those found at 60 months even though the sampling was performed at the same time of year (Table IV-8, Figures IV-3-5). However, the period prior to sampling was characterized by above average temperatures and no measurable rainfall and these factors may have accelerated summer drying. Moisture contents below ground and at groundline tended to be higher in lined poles of either species. This is consistent with previous results and indicates that the barriers slow drying. Southern pine poles treated with penta tended to have higher moisture contents than Douglas-fir poles treated with the same preservative. CCA-treated southern pine poles had lower moisture contents than either southern pine or Douglas-fir poles treated with penta. The oil-treated shell should restrict drying to some extent. Moisture contents of penta-treated southern pine poles tended to be at or above the fiber saturation point (30%) 300 mm above the groundline while moisture contents of CCA-treated poles of the same species, as well as all of the Douglas-fir poles, were well below that level. The results indicate that the barriers alter moisture behavior in the poles, although it is unclear how these elevated moisture levels will affect performance in the more deeply-treated southern pine.

Table IV-4. Moisture contents 14 months after installation at selected distances from the surface along the pole length in Douglas-fir and southern pine poles with various treatments with/without a field liner.

Species/ Treatment	Lined	Wood Moisture Content (%)															
		-150 mm				Groundline				+300 mm				+900 mm			
		0-25	25-50	50-75	>75	0-25	25-50	50-75	>75	0-25	25-50	50-75	>75	0-25	25-50	50-75	>75
DF (None)	-	**33**	**31**	28	**34**	24	20	26	**32**	17	17	22	24	16	20	22	25
DF-Penta	+	23	26	**31**	29	17	22	24	26	12	17	21	22	12	18	21	21
	-	24	29	**33**	**33**	16	24	26	28	14	19	21	21	13	17	21	22
Pine-CCA	+	**37**	**44**	**59**	**72**	29	**39**	**45**	**54**	20	24	**32**	**46**	19	23	27	**31**
	-	**33**	**46**	**46**	**52**	**31**	**50**	**48**	**49**	23	**32**	**31**	**34**	19	24	**35**	29
Pine (None)	-	**35**	**70**	**65**	**41**	**45**	**34**	**47**	**33**	20	19	23	24	17	16	28	18
Pine-Penta	+	**45**	**40**	**40**	**41**	**31**	**37**	**40**	**39**	22	29	**35**	**35**	22	26	**34**	**37**
	-	**43**	**49**	**44**	**44**	28	**34**	**37**	**40**	21	25	**31**	**32**	22	26	30	**31**

Table IV-5. Moisture contents 22 months after installation at selected distances from the surface along the pole length in Douglas-fir and southern pine poles with various treatments with/without a field liner.

Species/ Treatment	Lined	Wood Moisture Content (%)															
		-150 mm				Groundline				+300 mm				+900 mm			
		0-25	25-50	50-75	>75	0-25	25-50	50-75	>75	0-25	25-50	50-75	>75	0-25	25-50	50-75	>75
DF (None)	-	**33**	26	27	30	27	26	27	28	14	16	19	21	14	17	19	20
DF-Penta	+	30	**35**	**38**	**34**	**23**	**34**	**40**	**34**	15	26	28	27	18	26	28	26
	-	**35**	**46**	**50**	**42**	**26**	**43**	**42**	**33**	18	28	30	29	18	26	**37**	31
Pine-CCA	+	**53**	**59**	**72**	**77**	**37**	**49**	**57**	**68**	29	**32**	**33**	**35**	22	26	27	40
	-	**52**	**64**	**76**	**64**	**50**	**61**	**81**	**61**	30	**41**	**48**	**40**	23	**32**	**35**	30
Pine (None)	-	**59**	**72**	**104**	**86**	**68**	**68**	**60**	**44**	17	17	20	21	13	16	18	20
Pine-Penta	+	**59**	**52**	**49**	**46**	**44**	**50**	**54**	**50**	24	**41**	**45**	**43**	24	**36**	**37**	**37**
	-	**58**	**47**	**43**	**46**	**56**	**48**	**36**	**38**	20	29	**34**	**39**	21	**31**	**33**	**35**

Table IV-6. Moisture contents 33 months after installation at selected distances from the surface along the pole length in Douglas-fir and southern pine poles with various treatments with/without a field liner.

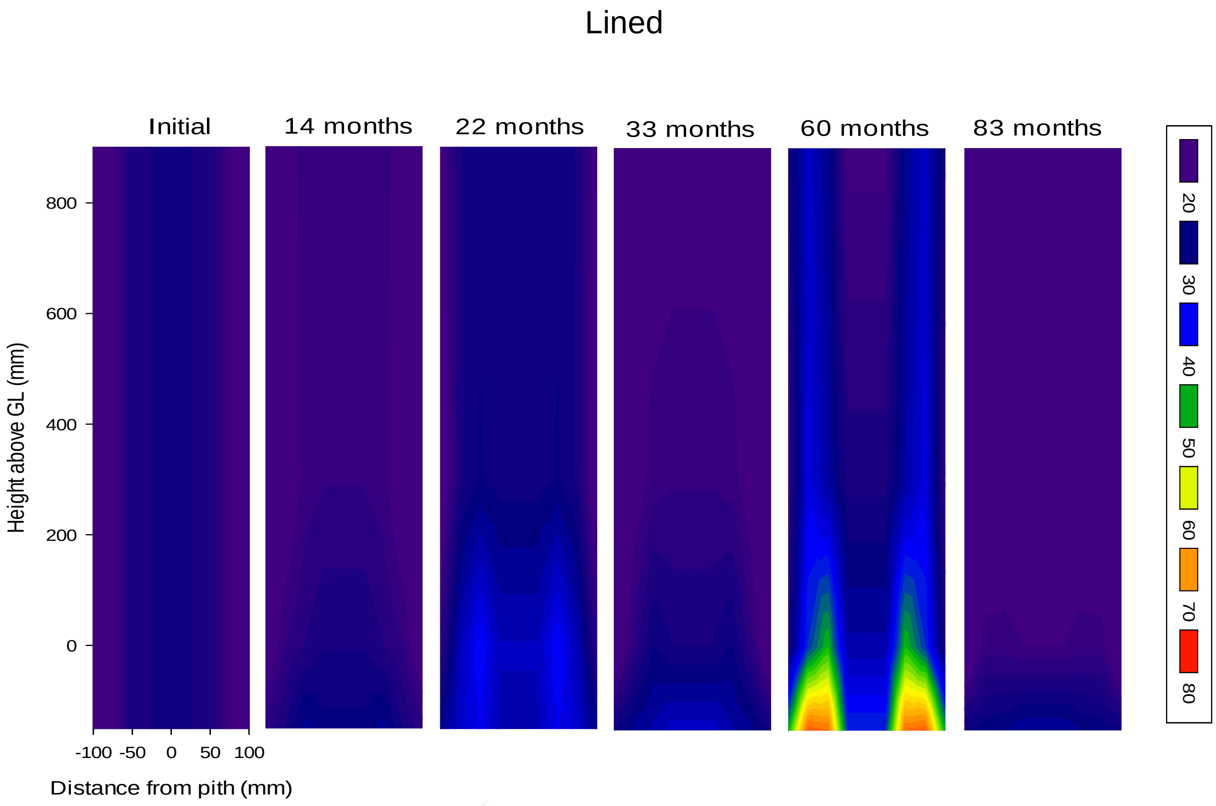
Species/ Treatment	Lined	Wood Moisture Content (%)															
		-150 mm				Groundline				+300 mm				+900 mm			
		0-25	25-50	50-75	>75	0-25	25-50	50-75	>75	0-25	25-50	50-75	>75	0-25	25-50	50-75	>75
DF (None)	-	**36**	**33**	29	30	24	25	26	26	14	17	19	20	12	16	18	17
DF-Penta	+	27	**31**	**32**	**35**	14	23	28	26	11	18	21	22	12	17	18	18
	-	25	30	**35**	**36**	18	25	29	**31**	11	19	21	23	11	18	20	20
Pine-CCA	+	**47**	**59**	**62**	**72**	24	**38**	**54**	**75**	13	19	24	27	12	16	17	16
	-	**36**	**50**	**63**	**64**	26	**36**	**42**	**48**	15	22	29	29	13	17	18	17
Pine (None)	-	**75**	**74**	**86**	**76**	**42**	**51**	**50**	**48**	15	20	27	24	14	18	22	21
Pine-Penta	+	**61**	**56**	**50**	**50**	29	**53**	**61**	**71**	18	**32**	**40**	**40**	22	29	**32**	**31**
	-	**64**	**55**	**49**	**50**	30	**41**	**39**	**40**	19	28	**32**	**36**	18	27	**31**	**35**

Table IV-7. Moisture contents 60 months after installation at selected distances from the surface along the pole length in Douglas-fir and southern pine poles with various treatments with/without a field liner.

Species/ Treatment	Lined	Wood Moisture Content (%)															
		-150 mm				Groundline				+300 mm				+900 mm			
		0-25	25-50	50-75	>75	0-25	25-50	50-75	>75	0-25	25-50	50-75	>75	0-25	25-50	50-75	>75
DF (None)	-	**52**	**76**	**63**	**40**	22	**48**	**43**	**34**	16	26	30	30	27	28	**45**	23
DF-Penta	+	**49**	**73**	**72**	**42**	26	**42**	**50**	**33**	22	**37**	**32**	25	26	**35**	30	19
	-	29	**53**	**76**	**84**	22	**39**	**57**	**37**	21	**38**	**50**	23	23	19	**42**	22
Pine-CCA	+	**86**	**122**	**124**	**116**	**34**	**47**	**67**	**76**	27	**40**	**42**	**32**	**36**	**37**	**34**	21
	-	**54**	**66**	**65**	**61**	**31**	**52**	**50**	**44**	**31**	**38**	**35**	**26**	**31**	**39**	**45**	19
Pine (None)	-	**99**	**85**	**133**	**131**	**50**	**54**	**72**	**63**	**32**	24	**54**	29	**33**	**32**	**35**	23
Pine-Penta	+	**105**	**97**	**105**	**73**	23	**48**	**71**	**78**	**24**	**42**	**44**	**48**	24	**42**	**43**	30
	-	**65**	**103**	**82**	**60**	**43**	**50**	**67**	**43**	**34**	**52**	**59**	**33**	**33**	**50**	**56**	**40**

Table IV-8. Moisture contents 83 months after installation at selected distances from the surface along the pole length in Douglas-fir and southern pine poles with various treatments with/without a field liner.

Species/ Treatment	Lined	Wood Moisture Content (%)															
		-150 mm				Groundline				+300 mm				+900 mm			
		0-25	25-50	50-75	>75	0-25	25-50	50-75	>75	0-25	25-50	50-75	>75	0-25	25-50	50-75	>75
DF (None)	-	40	23	26	24	17	16	24	20	26	25	22	26	13	15	17	18
DF-Penta	+	28	29	30	32	13	21	21	20	11	15	17	16	11	13	14	14
	-	19	21	23	22	15	16	18	18	12	12	13	12	10	12	12	12
Pine-CCA	+	28	30	38	37	21	24	31	34	11	12	13	14	11	11	11	12
	-	18	20	21	22	13	17	16	16	9	12	13	11	11	11	11	12
Pine (None)	-	38	42	46	43	45	39	47	49	15	38	34	29	9	13	13	9
Pine-Penta	+	48	46	45	45	28	39	40	45	21	31	39	32	17	24	35	28
	-	36	38	33	36	35	33	36	37	16	24	26	26	15	23	22	17



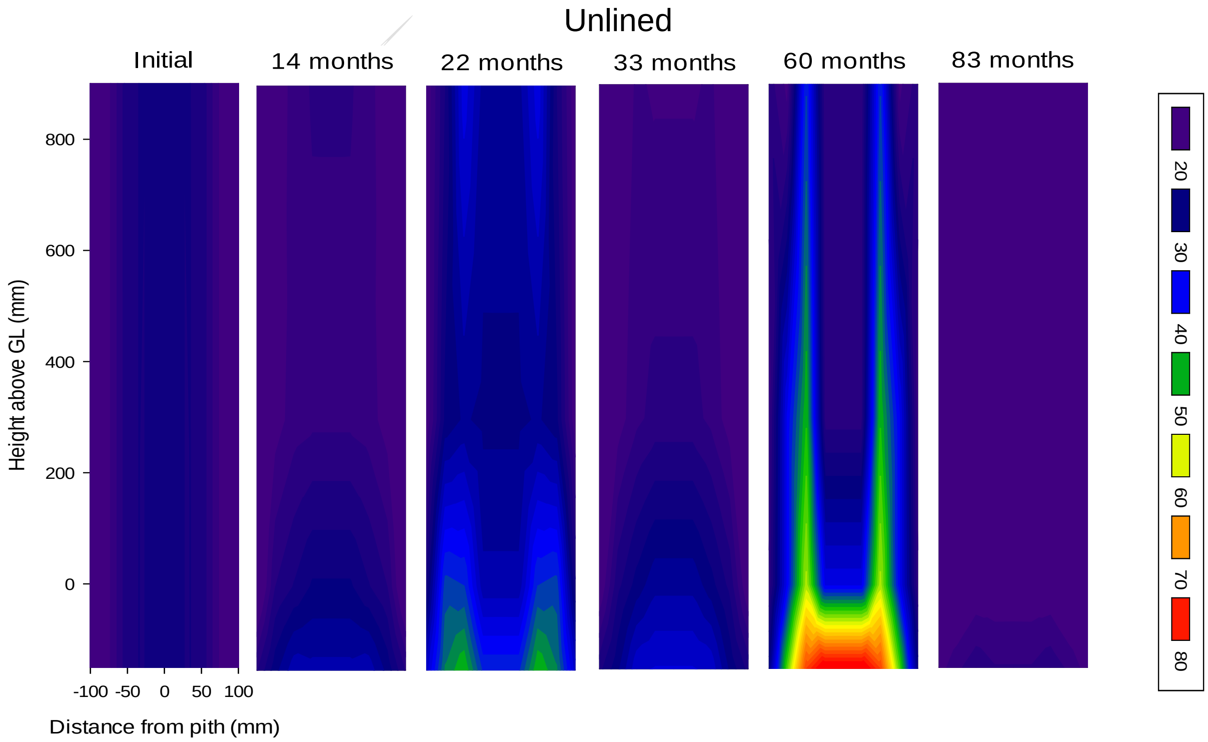


Figure IV- 3. Moisture contents in penta-treated Douglas-fir poles with or without a field liner after 0, 14, 22, 33, or 60 months in the ground at the Peavy Arboretum test site. These charts are extrapolated from data in Tables IV-4 to IV-8.

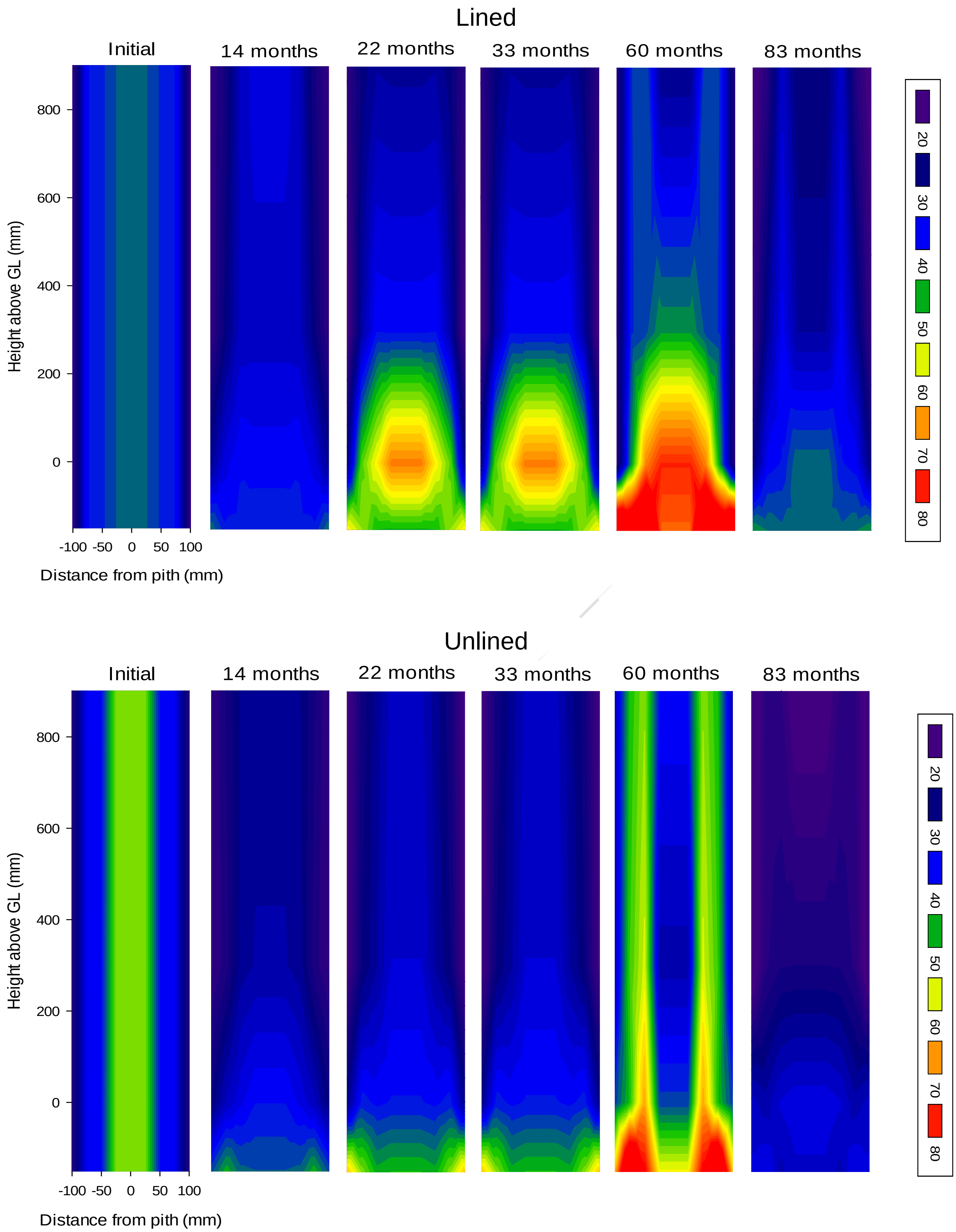


Figure IV- 4. Moisture contents in penta-treated southern pine poles with or without a field liner after 0, 14, 22, 33, or 60 months in the ground at the Peavy Arboretum test site. These charts are extrapolated from data in Tables IV-4 to IV-8.

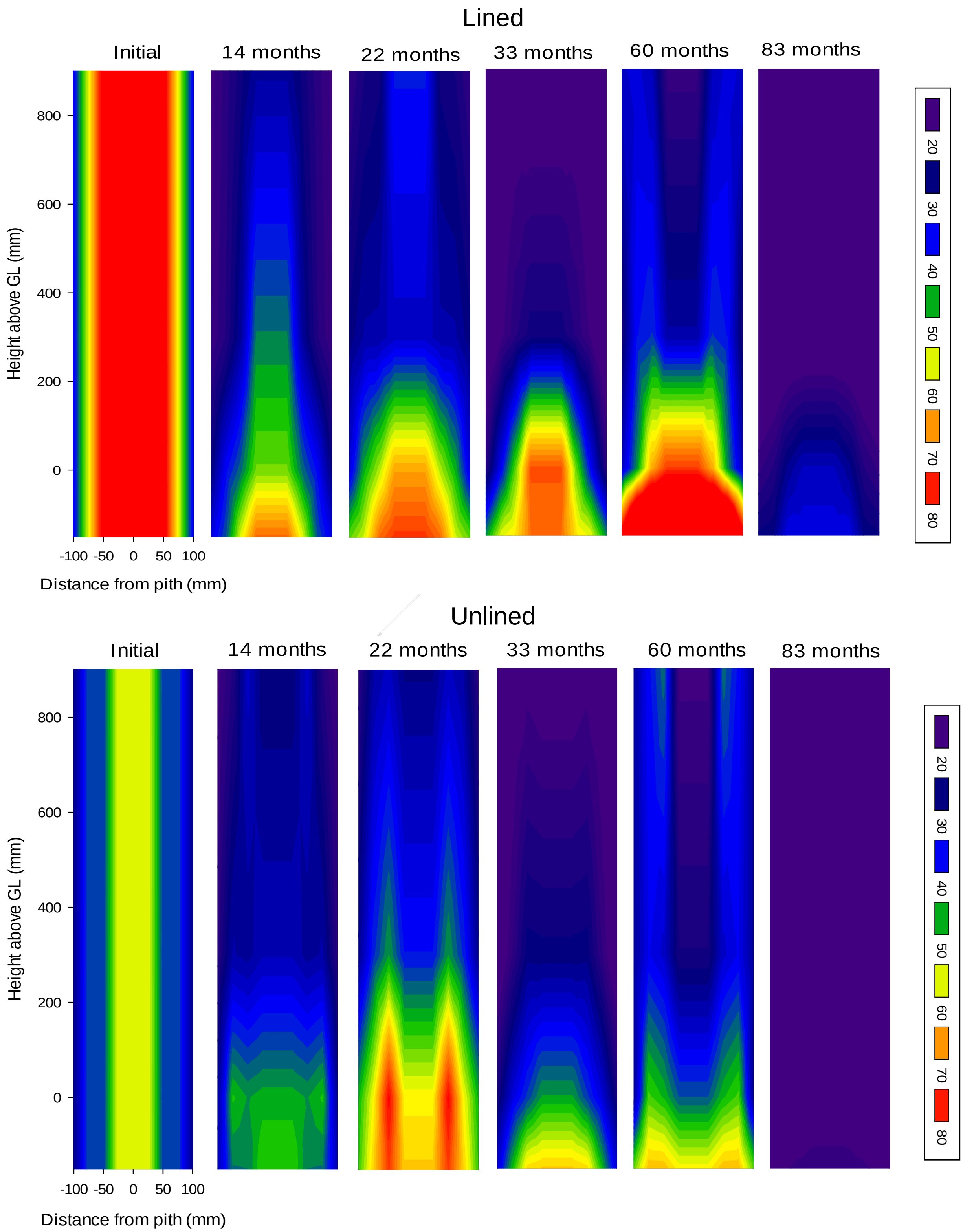


Figure IV- 5. Moisture contents in CCA-treated southern pine poles with or without a field liner after 0, 14, 22, 33, or 60 months in the ground at the Peavy Arboretum test site. These charts are extrapolated from data in Tables IV-4 to IV-8.

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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 their specifications 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). Non-treated stakes failed within 180 months while stakes treated with diesel have average ratings of approximately 1.5. All freshly sawn stakes treated with copper naphthenate to retentions of 4.0 kg/m^3 continue to provide excellent protection after 324 months, while the conditions of stakes treated to the two lower retentions declined between 300 and 314 months and then did not change over the last year. Stakes treated to the two lowest retentions have declined to a rating near 4.0, suggesting that fungal decay significantly degraded the wood. Ratings for the intermediate retention were just above 6.0, indicating treatment efficacy loss.

Decay in the stakes cut from freshly sawn lumber tended to be at the bottom of the stakes- giving the samples an hour glass shape from the groundline to the tip (Figure V-3). This suggests that conditions were more suitable for decay deeper in the soil.

Weathered stakes have consistently exhibited greater degrees of damage at a given treatment level; their condition continues to slowly decline. The three lowest retentions had ratings below 3.0 indicating they were no longer serviceable (Figure V-2). The condition of stakes treated to these three retentions continues to decline at a slow rate. 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 performance characteristics of weathered, retreated material will differ substantially from freshly sawn material. The effects of these differences on overall performance may be minimal. Even if the outer, weathered wood were to degrade over time, this zone is relatively shallow on western redcedar and would not markedly affect overall pole properties.

Copper naphthenate should continue to protect weathered western redcedar sapwood above-ground; allowing utility personnel to safely climb these poles. Any slight decrease in aboveground protection would probably take decades to emerge. 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 and gaps in the treatment barrier would only expose durable heartwood.

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

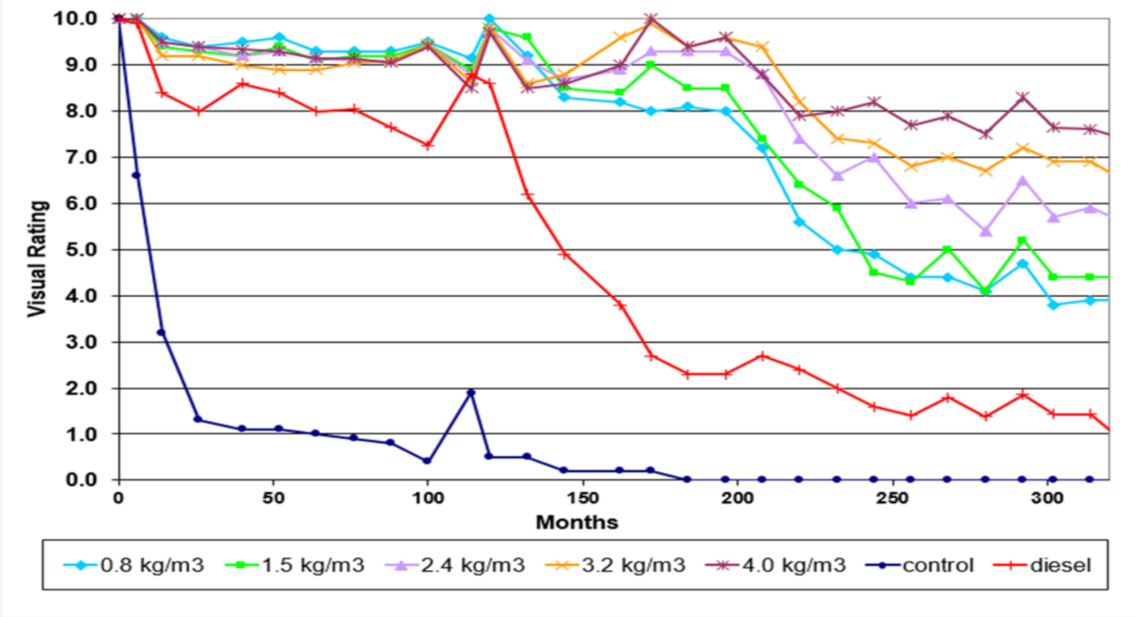

Figure V-1. Condition of freshly sawn western redcedar sapwood stakes treated with selected retentions of copper naphthenate in diesel oil and exposed in a soil bed for 324 months.

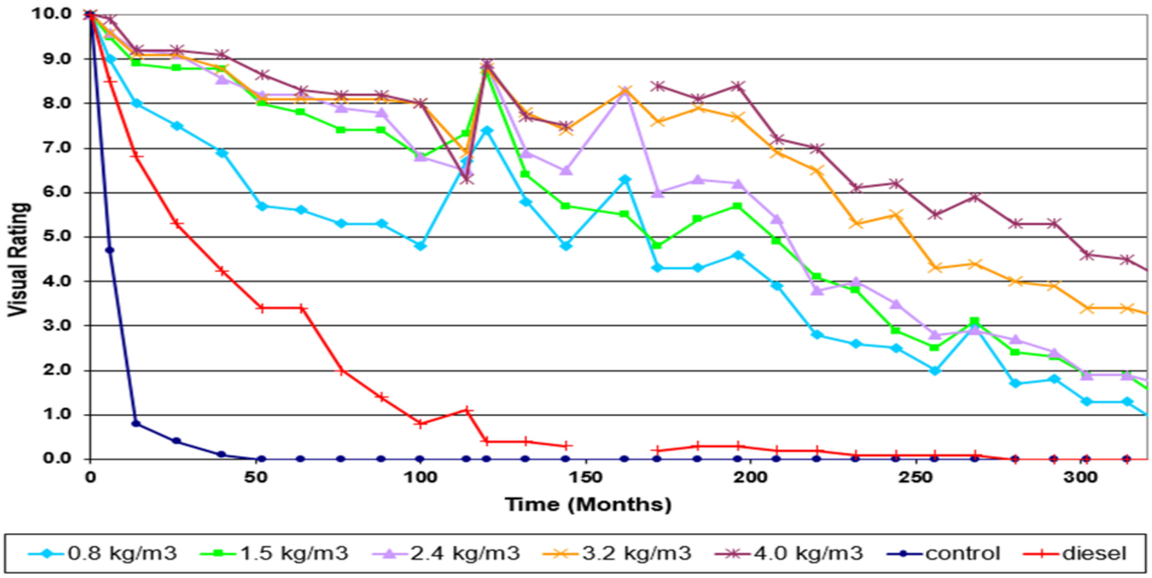

Figure V-2. Condition of weathered western redcedar sapwood stakes treated with selected retentions of copper naphthenate in diesel oil and exposed in a soil bed for 324 months.

Figure V-3. Examples of western redcedar stakes that have failed in test showing a tendency for the wood to decay towards the lower end of the samples.

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. Last 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. We reported on some of the results of this inspection last year, but we have completed the soft rot examinations and report the overall results herein.

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 lower 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 where 24 were dark pigmented. Fungi were isolated from 115 of 156 cores 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.

Soft rot damage was present in 13 of 37 poles treated with copper naphthenate in biodiesel and 8 of 21 poles treated with copper naphthenate in conventional petroleum based diesel. The damage was generally minor in both treatments and it is important to note that the damage was only found in the outer 1 to 2 mm of the pole surface (Table V-3). There are only a limited amount of data on the incidence of soft rot in preservative treated Douglas-fir poles. In 2012, we assessed soft rot presence in pentachlorophenol treated Douglas-fir and found little evidence of substantial attack on poles treated with penta in heavy oil. Soft rot is common on wood exposed to soil contact and its presence can have profound effects on wood properties; however, the levels noted in the current survey would be considered minor. The original purpose of these surveys was to establish a baseline for continued assessment to ensure that poles treated with copper naphthenate in biodiesel do not develop early evidence of surface decay. The similarity between poles treated using petroleum and bio-based diesel suggests that this is not happening, but we will continue to sample poles over time so that we can detect any problems before they pose a risk of pole integrity.

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	*Epicoccum nigrum*	2	0.5%
MG4	*Paecilomyces sp.*	44	11.3%
MG5	unknown	1	0.3%
MG6	*Talaromyces ruber*	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	unknown	2	0.5%
MG12	unknown	1	0.3%
MG13	unknown	2	0.5%
MG14	*Talaromyces amestolkiae*	1	0.3%
MG15	*Penicillium sp.*	1	0.3%
MG16	unknown	2	0.5%
MG17	*Mollisia dextrinospora*	1	0.3%
MG18	unknown	1	0.3%
MG19	*Cadophora melinii**	4	1.0%
Decay 1	*Postia placenta*	2	0.5%

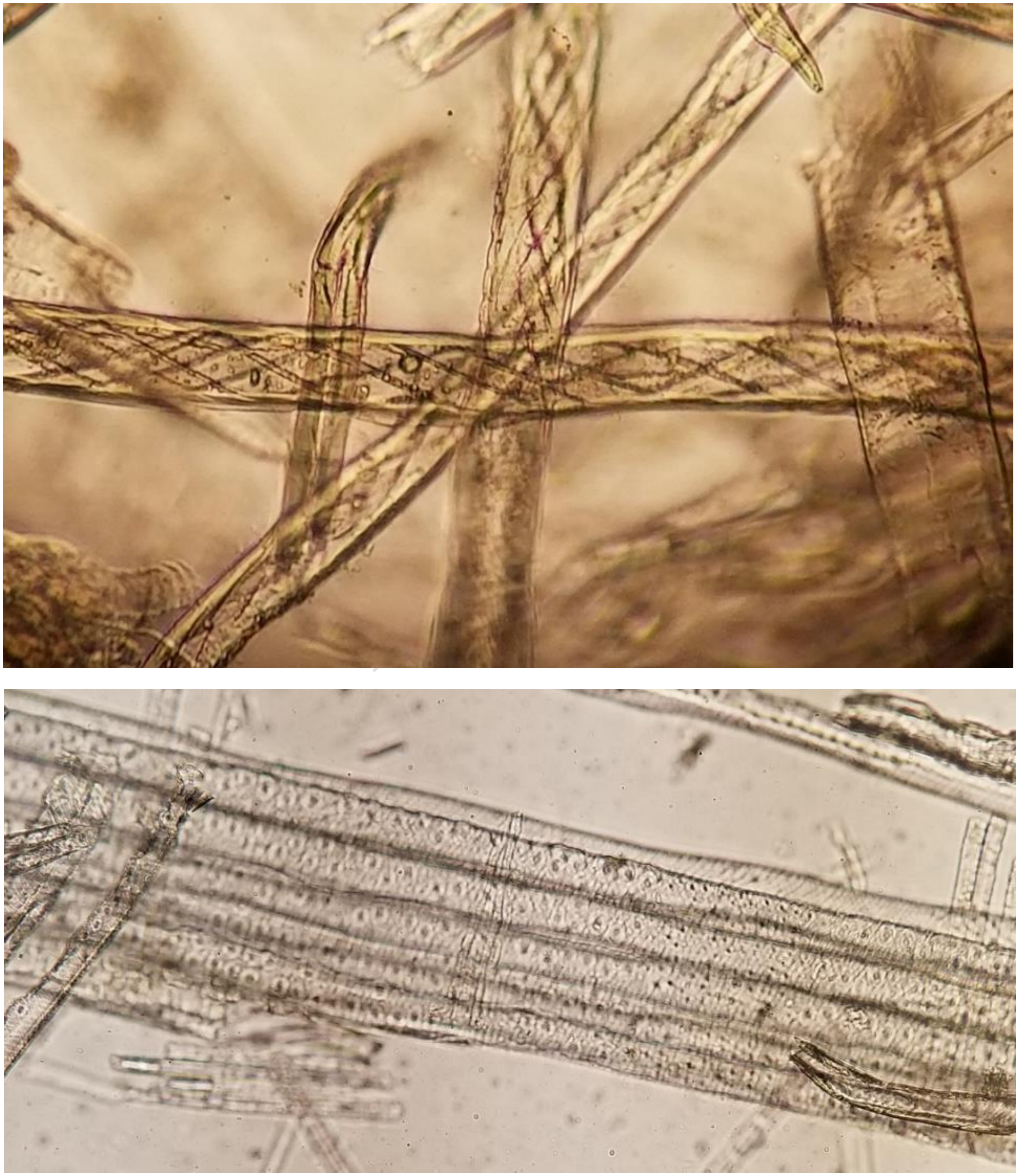

Figure V-3 Examples of Douglas-fir tracheids removed from the outer surfaces of poles showing bordered pits and the spiral thickenings typical of this species (bottom) and diamond-shaped soft rot cavities (top).

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

Data From Annual Report 2016										*Soft Rot Fungal Decay*					
Utility Pole Identification	**OSU Pole ID**	**Height/Class (ft)**	**Solvent**	**Year**	**Height (in)**	**Preservative Penetration (mm)**	**Fungi/ Plate**	**Soft Rot Fungi/Plate**	**CuNap (kg/m^3 as Cu)**	**Height**	**No Visible Decay**	**Mild**	**Common**	**High**	**Cultured Fungi**
SK-C 4/6 2	**SnoPud 1**	**85/H6**	**Biodiesel**	**2009**	**-6**	**31**	**1**	**1**	**0.74**	**-6**				**1**	**Amorphotheca resinae**
					-6	**27**	**1**	**1**							
					-6	**39**	**1**	**1**							
					4	**25**	**1**	**1**		**4**			**1**		**Amorphotheca resinae** **Penicillium sp.**
					4	**33**	**1**	**0**							
					4	**35**	**0**	**0**							
SK-C 4/5 3	**SnoPud 2**	**85/H6**	**Biodiesel**	**2009**	**-6**	**49**	**1**	**1**	**1.14**	**-6**	**1**				**Amorphotheca resinae**
					-6	**51**	**1**	**1**							
					-6	**50**	**0**	**0**							
					4	**20**	**1**	**0**		**4**	**1**				**Amorphotheca resinae** **Paecilomyces sp.**
					4	**35**	**1**	**1**							
					4	**30**	**1**	**0**							
SK-C 4/4	**SnoPud 3**	**85/H6**	**Biodiesel**	**2009**	**-6**	**32**	**1**	**1**	**1.22**	**-6**		**1**			**Amorphotheca resinae**
					-6	**41**	**1**	**1**							
					-6	**39**	**0**	**0**							
					4	**47**	**1**	**1**		**4**	**1**				**Amorphotheca resinae**
					4	**37**	**1**	**1**							
					4	**45**	**0**	**0**							
SK-C 4/3	**SnoPud 4**	**85/H6**	**Biodiesel**	**2009**	**-6**	**35**	**1**	**0**	**1.39**	**-6**		**1**			**Talaromyces ruber**
					-6	**47**	**0**	**0**							
					-6	**35**	**0**	**0**							
					4	**55**	**1**	**0**		**4**			**1**		**Talaromyces ruber** **Paecilomyces sp.**
					4	**19**	**1**	**0**							
					4	**40**	**1**	**0**							
SK-C 4/2	**SnoPud 5**	**85?h6**	**Biodiesel**	**2009**	**-6**	**18**	**1**	**0**	**1.88**	**-6**	**1**				**Talaromyces ruber**
					-6	**16**	**0**	**0**							
					-6	**45**	**0**	**0**							
					4	**15**	**1**	**0**		**4**	**1**				**Talaromyces ruber**
					4	**11**	**0**	**0**							
					4	**46**	**0**	**0**							
SK-C 4/1	**SnoPud 6**	**85/H6**	**Biodiesel**	**2009**	**-6**	**64**	**1**	**1**	**1.57**	**-6**	**1**				**Amorphotheca resinae**
					-6	**62**	**0**	**0**							
					-6	**40**	**0**	**0**							
					4	**33**	**1**	**0**		**4**	**1**				**Talaromyces ruber**
					4	**39**	**0**	**0**							
					4	**50**	**0**	**0**							

SC-BW 6/8	**SnoPud 7**	**85/H6**	**Biodiesel**	**2009**	-6	53	0	0	1.18	-6	1				none
					-6	47	0	0							
					-6	29	0	0							
					4	24	0	0		4	1				none
					4	29	0	0							
					4	26	0	0							
SK-C 3/12	**SnoPud 8**	**85/H6**	**Biodiesel**	**2009**	-6	40	1	0	0.66	-6	1				Talaromyces ruber Paecilomyces sp.
					-6	42	1	0							
					-6	45	2	0							
					4	16	1	0		4	1				Paecilomyces sp.
					4	26	1	0							
					4	33	0	0							
SK-C 3/11	**SnoPud 9**	**85/H6**	**Biodiesel**	**2009**	-6	39	1	0	2.44	-6	1				Paecilomyces sp.
					-6	35	0	0							
					-6	40	0	0							
					4	40	1	0		4	1				Paecilomyces sp.
					4	24	0	0							
					4	32	0	0							
SK-C 3/10	**SnoPud 10**	**85/H6**	**Biodiesel**	**2009**	-6	40	1	1	0.54	-6	1				Amorphotheca resinae
					-6	35	0	0							
					-6	35	0	0							
					4	20	1	1		4	1				Amorphotheca resinae Paecilomyces sp.
					4	35	2	1							
					4	15	1	1							
SK-C 3/9	**SnoPud 11**	**85/H6**	**Biodiesel**	**2009**	-6	35	1	0	0.72	-6			1		Talaromyces ruber
					-6	20	0	0							
					-6	20	0	0							
					4	30	1	0		4	1				Talaromyces ruber
					4	15	0	0							
					4	25	0	0							
SK-C 3/8	**SnoPud 12**	**85/H6**	**Biodiesel**	**2009**	-6	40	2	1	1.02	-6			1		Talaromyces ruber Phialophora fastigiata
					-6	40	0	0							
					-6	30	0	0							
					4	35	1	1		4	1				Unknown MG 18
					4	25	0	0							
					4	35	0	0							
W to E intersection of 52nd and 22nd heading on 22nd	**SnoPud 13**	**45/Cl 2**	**Petrodiesel**	**2009**	-6	60	1	1	2.22	-6	1				Amorphotheca resinae Pithomyces chartarum
					-6	50	1	1							
					-6	50	1	0							
					4	40	0	0		4	1				none
					4	40	0	0							
					4	40	0	0							

229282	**SnoPud 14**	**50/Cl 1**	**Petrodiesel**	**2009**	**-6**	**35**	**1**	**1**	**1.96**	**-6**	**1**				**Amorphotheca resinae** **Paecilomyces sp.**
					-6	**30**	**2**	**1**							
					-6	**35**	**2**	**1**							
					4	**30**	**0**	**0**		**4**	**1**				**none**
					4	**30**	**0**	**0**							
					4	**35**	**0**	**0**							
229283	**SnoPud 15**	**50/Cl 1**	**Petrodiesel**	**2009**	**-6**	**50**	**1**	**1**	**2.57**	**-6**		**1**			**Amorphotheca resinae**
					-6	**55**	**1**	**1**							
					-6	**50**	**0**	**0**							
					4	**40**	**1**	**0**		**4**	**1**				**Paecilomyces sp.** **Zygomycete**
					4	**35**	**1**	**0**							
					4	**25**	**1**	**0**							
229284	**SnoPud 16**	**50/Cl1**	**Petrodiesel**	**2009**	**-6**	**12**	**2**	**0**	**1.02**	**-6**			**1**		**Paecilomyces sp.** **Alternaria sp.**
					-6	**20**	**0**	**0**							
					-6	**23**	**0**	**0**							
					4	**27**	**0**	**0**		**4**	**1**				**none**
					4	**24**	**0**	**0**							
					4	**26**	**0**	**0**							
229285	**SnoPud 17**	**50/H2**	**Petrodiesel**	**2009**	**-6**	**30**	**1**	**1**	**2.08**	**-6**		**1**			**Amorphotheca resinae** **Paecilomyces sp.** **Unknown MG 11**
					-6	**35**	**3**	**2**							
					-6	**30**	**3**	**2**							
					4	**25**	**1**	**0**		**4**	**1**				**Paecilomyces sp.**
					4	**35**	**1**	**0**							
					4	**30**	**1**	**0**							
229286	**SnoPud 18**	**60/H4**	**Petrodiesel**	**2009**	**-6**	**35**	**1**	**0**	**1.47**	**-6**		**1**			**Paecilomyces sp.**
					-6	**35**	**1**	**0**							
					-6	**30**	**1**	**0**							
					4	**25**	**0**	**0**		**4**		**1**			**Paecilomyces sp.**
					4	**25**	**0**	**0**							
					4	**40**	**0**	**0**							
229287	**SnoPud 19**	**50/Cl 1**	**Petrodiesel**	**2009**	**-6**	**19**	**3**	**1**	**2.16**	**-6**	**1**				**Amorphotheca resinae** **Paecilomyces sp.** **Pithomyces chartarum**
					-6	**23**	**1**	**0**							
					-6	**35**	**1**	**0**							
					4	**30**	**2**	**1**		**4**	**1**				**Paecilomyces sp.** **Unknown MG 12**
					4	**27**	**1**	**0**							
					4	**23**	**1**	**0**							
229288	**SnoPud 20**	**50/Cl 1**	**Petrodiesel**	**2009**	**-6**	**42**	**2**	**0**	**1.92**	**-6**	**1**				**Paecilomyces sp.** **Phialophora fastigiata**
					-6	**40**	**1**	**0**							
					-6	**41**	**1**	**0**							
					4	**39**	**1**	**0**		**4**	**1**				**Paecilomyces sp.**
					4	**32**	**1**	**0**							
					4	**33**	**1**	**0**							

229289	SnoPud 21	50/Cl 1	Petrodiesel	2009	-6	45	0	0	2.64	-6	1				none
					-6	40	0	0							
					-6	42	0	0							
					4	35	1	0		4	1				Paecilomyces sp.
					4	36	0	0							
					4	38	0	0							
229290	SnoPud 22	45/Cl 2	Petrodiesel	2009	-6	35	1	0	2.5	-6	1				Penicillium sp.
					-6	34	0	0							
					-6	36	0	0							
					4	27	1	0		4	1				Penicillium sp.
					4	27	1	0							
					4	37	0	0							
229291	SnoPud 23	50/Cl 1	Petrodiesel	2009	-6	43	1	1	1.63	-6	1				Amorphotheca resinae Phialophora fastigiata
					-6	51	1	1							
					-6	55	1	1							
					4	32	1	0		4	1				Penicillium sp. Paecilomyces sp.
					4	35	1	0							
					4	37	0	0							
229292	SnoPud 24	50/Cl 1	Petrodiesel	2009	-6	55	1	1	1.22	-6	1				Amorphotheca resinae Penicillium sp.
					-6	55	1	0							
					-6	70	1	1							
					4	35	1	1		4	1				Amorphotheca resinae
					4	30	1	1							
					4	30	0	0							
161885	SnoPud 25	45/Cl 2	Petrodiesel	2003	-6	45	1	1	3.55	-6	1				Amorphotheca resinae
					-6	45	1	1							
					-6	45	1	1							
					4	30	1	1		4	1				Amorphotheca resinae
					4	25	1	1							
					4	25	0	0							
161884	SnoPud 26	35/Cl 2	Petrodiesel	2003	-6	30	1	1	1.81	-6	1				Pithomyces chartarum Mollisia dextrinospora Cadophora melinii
					-6	30	2	0							
					-6	30	0	0							
					4	30	1	0		4	1				Amorphotheca resinae Cadophora melinii
					4	25	1	0							
					4	30	1	1							
161882	SnoPud 27	45/Cl 2	Petrodiesel	2003	-6	30	1	1	2.77	-6	1				Amorphotheca resinae
					-6	30	1	1							
					-6	30	1	1							
					4	25	1	1		4	1				Amorphotheca resinae Epicoccum nigrum
					4	25	1	1							
					4	20	1	1							

161880	**SnoPud 28**	**45/Cl 2**	**Petrodiesel**	**2003**	-6	36	1	1	**1.8**	**-6**		**1**			**Amorphotheca resinae**
					-6	43	1	1							
					-6	45	1	1							
					4	25	1	0		**4**	**1**				**Paecilomyces sp.** **Cadophora melinii**
					4	24	1	0							
					4	27	0	0							
161878	**SnoPud 29**	**45/Cl 2**	**Petrodiesel**	**2003**	-6	43	1	1	**1.54**	**-6**	**1**				**Amorphotheca resinae**
					-6	40	1	1							
					-6	39	1	1							
					4	35	1	1		**4**	**1**				**Amorphotheca resinae** **Penicillium sp.** **Paecilomyces sp.**
					4	30	1	0							
					4	25	1	0							
161877	**SnoPud 30**	**50/Cl 1**	**Petrodiesel**	**2003**	-6	40	1	1	**1.97**	**-6**			**1**		**Amorphotheca resinae** **Epicoccum nigrum** **Paecilomyces sp.**
					-6	45	2	1							
					-6	40	1	1							
					4	40	1	1		**4**	**1**				**Amorphotheca resinae**
					4	41	1	1							
					4	44	0	0							
466859157274	**PSE 1**	**75/H2**	**Petrodiesel**	**2005**	-6	40	1	1	**1.5**	**-6**				**1**	**Postia placenta** **Amorphotheca resinae** **Unknown MG 16**
					-6	35	0	0							
					-6	25	1	0							
					4	50	1	0		**4**	**1**				**Paecilomyces sp.**
					4	35	2	0							
					4	25	1	0							
466857157362	**PSE 2**				-6	35	1	1	**2.07**	**-6**	**1**				**Amorphotheca resinae**
					-6	45	1	1							
					-6	40	1	1							
					4	40	1	1		**4**	**1**				**Amorphotheca resinae** **Unknown MG 16**
					4	40	1	1							
					4	40	1	0							
465347160725	**PSE 3**	**75/H1**	**Petrodiesel**	**2005**	-6	50	1	1	**1.48**	**-6**		**1**			**Amorphotheca resinae** **Phialophora fastigiata** **Talaromyces amestolkiae**
					-6	55	2	2							
					-6	65	0	0							
					4	40	0	0		**4**	**1**				**none**
					4	35	0	0							
					4	25	0	0							
465368160727	**PSE 4**	**70/Cl 1**	**Petrodiesel**	**2005**	-6	29	1	0	**0.93**	**-6**	**1**				**Penicillium sp.**
					-6	40	0	0							
					-6	31	0	0							
					4	41	0	0		**4**	**1**				**none**
					4	49	0	0							
					4	32	0	0							

465389160729	PSE 5	75/Cl 1	Petrodiesel	2005	-6	35	0	0	1.1	-6	1				none
					-6	35	0	0							
					-6	30	0	0							
					4	40	0	0		4	1				none
					4	37	0	0							
					4	35	0	0							
465488160741	PSE 6	70/Cl 1	Petrodiesel	2005	-6	27	1	1	2.76	-6	1				Amorphotheca resinae
					-6	34	1	1							
					-6	35	0	0							
					4	46	0	0		4	1				none
					4	47	0	0							
					4	40	0	0							
465703160589	PSE 7	75/H1	Petrodiesel	2005	-6	54	0	0	2.06	-6			1		none
					-6	51	0	0							
					-6	37	0	0							
					4	6	1	1		4		1			Amorphotheca resinae Pithomyces chartarum
					4	43	1	0							
					4	39	0	0							
465712160407	PSE 8	75/Cl 1	Petrodiesel	2005	-6	35	1	1	2.12	-6		1			Amorphotheca resinae
					-6	41	0	0							
					-6	49	0	0							
					4	27	0	0		4	1				none
					4	39	0	0							
					4	37	0	0							
945710160447	PSE 9	80/Cl 1	Petrodiesel	2005	-6	49	0	0	3.57	-6	1				none
					-6	47	0	0							
					-6	45	0	0							
					4	35	0	0		4	1				none
					4	47	0	0							
					4	37	0	0							
465709160481	PSE 10	75/Cl 1	Petrodiesel	2005	-6	40	1	1	0.82	-6	1				Amorphotheca resinae
					-6	40	1	1							
					-6	40	0	0							
					4	50	0	0		4	1				none
					4	45	0	0							
					4	50	0	0							
453816157815	PSE 11	80/H1	Biodiesel	2008	-6	35	0	0	1.5	-6	1				none
					-6	39	0	0							
					-6	27	0	0							
					4	25	0	0		4	1				none
					4	30	0	0							
					4	33	0	0							

453818157786	**PSE 12**	**75/H1**	**Biodiesel**	**2008**	**-6**	**40**	**1**	**1**	**1.65**	**-6**	**1**				**Pithomyces chartarum**
					-6	**37**	**0**	**0**							
					-6	**35**	**0**	**0**							
					4	**27**	**0**	**0**		**4**	**1**				**none**
					4	**29**	**0**	**0**							
					4	**36**	**0**	**0**							
4538118157758	**PSE 13**	**75/H1**	**Biodiesel**	**2008**	**-6**	**54**	**0**	**0**	**1.44**	**-6**		**1**			**none**
					-6	**56**	**0**	**0**							
					-6	**55**	**0**	**0**							
					4	**26**	**0**	**0**		**4**	**1**				**none**
					4	**24**	**0**	**0**							
					4	**39**	**0**	**0**							
453602157724	**PSE 14**	**75/H1**	**Biodiesel**	**2008**	**-6**	**47**	**0**	**0**	**1.15**	**-6**	**1**				**none**
					-6	**41**	**0**	**0**							
					-6	**42**	**0**	**0**							
					4	**31**	**0**	**0**		**4**	**1**				**none**
					4	**41**	**0**	**0**							
					4	**39**	**0**	**0**							
453821157691	**PSE 15**	**80/Cl 1**	**Biodiesel**	**2008**	**-6**	**29**	**0**	**0**	**1.55**	**-6**	**1**				**none**
					-6	**39**	**0**	**0**							
					-6	**23**	**0**	**0**							
					4	**21**	**1**	**1**		**4**	**1**				**Unknown MG 13**
					4	**26**	**1**	**1**							
					4	**31**	**0**	**0**							
453830157900	**PSE 16**	**80/H1**	**Biodiesel**	**2008**	**-6**	**35**	**0**	**0**	**1.48**	**-6**	**1**				**none**
					-6	**30**	**0**	**0**							
					-6	**30**	**0**	**0**							
					4	**35**	**0**	**0**		**4**	**1**				**none**
					4	**40**	**0**	**0**							
					4	**45**	**0**	**0**							
453817157958	**PSE 17**	**75/Cl 1**	**Biodiesel**	**2008**	**-6**	**60**	**0**	**0**	**0.8**	**-6**	**1**				**none**
					-6	**55**	**0**	**0**							
					-6	**55**	**0**	**0**							
					4	**35**	**0**	**0**		**4**	**1**				**none**
					4	**30**	**0**	**0**							
					4	**30**	**0**	**0**							
453799157983	**PSE 18**	**75/H1**	**Biodiesel**	**2008**	**-6**	**75**	**0**	**0**	**1.61**	**-6**	**1**				**none**
					-6	**85**	**0**	**0**							
					-6	**65**	**0**	**0**							
					4	**20**	**0**	**0**		**4**	**1**				**none**
					4	**35**	**0**	**0**							
					4	**45**	**0**	**0**							

453746157981	PSE 19	70/Cl 1	Biodiesel	2008	-6	29	0	0	1.46	-6	1				none
					-6	26	0	0							
					-6	33	0	0							
					4	21	0	0		4	1				none
					4	23	0	0							
					4	26	0	0							
453862157583	PSE 20	75/Cl 1	Biodiesel	2008	-6	50	0	0	1.03	-6	1				none
					-6	71	0	0							
					-6	80	0	0							
					4	18	0	0		4	1				none
					4	21	0	0							
					4	20	0	0							
455610156371	PSE 21	75/H1	Biodiesel	2008	-6	29	0	0	1.84	-6	1				none
					-6	34	0	0							
					-6	39	0	0							
					4	25	0	0		4	1				none
					4	30	0	0							
					4	29	0	0							
455609156411	PSE 22	80/H1	Biodiesel	2008	-6	39	0	0	1.53	-6		1			none
					-6	45	0	0							
					-6	40	0	0							
					4	20	0	0		4	1				none
					4	45	0	0							
					4	51	0	0							
455366156438	PSE 23	75/Cl 1	Biodiesel	2008	-6	35	0	0	2.74	-6		1			none
					-6	30	0	0							
					-6	35	0	0							
					4	25	0	0		4	1				none
					4	30	0	0							
					4	30	0	0							
455336156436	PSE 24	75/Cl 1	Biodiesel	2008	-6	30	1	0	2.14	-6	1				Pithomyces chartarum
					-6	35	0	0							
					-6	30	0	0							
					4	25	0	0		4	1				none
					4	20	0	0							
					4	25	0	0							
455242156430	PSE 25	75/H1	Biodiesel	2008	-6	25	0	0	0.78	-6		1			none
					-6	15	0	0							
					-6	30	0	0							
					4	20	0	0		4	1				none
					4	18	0	0							
					4	13	0	0							

455017156578	**PSE 26**	**85/H1**	**Biodiesel**	**2008**	**-6**	**35**	**1**	**0**	**2.63**	**-6**		**1**			**Pithomyces chartarum**
					-6	**35**	**0**	**0**							
					-6	**30**	**0**	**0**							
					4	**35**	**0**	**0**		**4**		**1**			**none**
					4	**20**	**0**	**0**							
					4	**10**	**0**	**0**							
455050156589	**PSE 27**	**85/H1**	**Biodiesel**	**2008**	**-6**	**27**	**1**	**1**	**1.54**	**-6**	**1**				**Amorphotheca resinae**
					-6	**34**	**0**	**0**							
					-6	**35**	**0**	**0**							
					4	**30**	**0**	**0**		**4**	**1**				**none**
					4	**34**	**0**	**0**							
					4	**35**	**0**	**0**							
453542157567	**PSE 28**	**70/Cl 1**	**Biodiesel**	**2008**	**-6**	**30**	**0**	**0**	**1.8**	**-6**	**1**				**none**
					-6	**35**	**0**	**0**							
					-6	**37**	**0**	**0**							
					4	**18**	**0**	**0**		**4**	**1**				**None**
					4	**39**	**0**	**0**							
					4	**35**	**0**	**0**							
453543157504	**PSE 29**	**75/Cl 1**	**Biodiesel**	**2008**	**-6**	**63**	**0**	**0**	**2.46**	**-6**	**1**				**None**
					-6	**58**	**0**	**0**							
					-6	**60**	**0**	**0**							
					4	**45**	**0**	**0**		**4**	**1**				**none**
					4	**27**	**0**	**0**							
					4	**35**	**0**	**0**							
453544157510	**PSE 30**	**75/Cl 1**	**Biodiesel**	**2008**	**-6**	**40**	**1**	**1**	**1.33**	**-6**				**1**	**Amorphotheca resinae**
					-6	**30**	**0**	**0**							
					-6	**35**	**0**	**0**							
					4	**35**	**1**	**0**		**4**		**1**			**Penicillium sp.**
					4	**30**	**0**	**0**							
					4	**30**	**0**	**0**							
318537166857	**PSE 31**	**60/Cl 1**	**Biodiesel**	**2008**	**-6**	**25**	**2**	**1**	**1.77**	**-6**	**1**				**Amorphotheca resinae** **Paecilomyces sp.**
					-6	**50**	**1**	**1**							
					-6	**25**	**1**	**0**							
					4	**45**	**1**	**0**		**4**	**1**				**Unknown MG 7**
					4	**40**	**0**	**0**							
					4	**40**	**0**	**0**							
318951166858	**PSE 32**	**55/Cl 1**	**Biodiesel**	**2008**	**-6**	**25**	**0**	**0**	**1.92**	**-6**	**1**				**none**
					-6	**30**	**0**	**0**							
					-6	**35**	**0**	**0**							
					4	**25**	**0**	**0**		**4**	**1**				**none**
					4	**25**	**0**	**0**							
					4	**25**	**0**	**0**							

318638166856	**PSE 33**	**65/Cl 1**	**Biodiesel**	**2008**	**-6**	**60**	**1**	**0**	**1.29**	**-6**	**1**				**Talaromyces ruber**
					-6	**50**	**1**	**0**							
					-6	**50**	**0**	**0**							
					4	**30**	**1**	**0**		**4**	**1**				**Talaromyces ruber**
					4	**20**	**0**	**0**							
					4	**25**	**0**	**0**							
221584167047	**PSE 34**	**80/Cl 1**	**Biodiesel**	**2008**	**-6**	**25**	**0**	**0**	**1.67**	**-6**			**1**		**none**
					-6	**30**	**0**	**0**							
					-6	**20**	**0**	**0**							
					4	**15**	**0**	**0**		**4**	**1**				**none**
					4	**20**	**0**	**0**							
					4	**20**	**0**	**0**							
223772167361	**PSE 35**	**55/Cl 1**	**Biodiesel**	**2008**	**-6**	**20**	**2**	**1**	**0.86**	**-6**		**1**			**Paecilomyces sp.** **Talaromyces ruber** **Phialophora fastigiata**
					-6	**15**	**1**	**0**							
					-6	**15**	**0**	**0**							
					4	**15**	**1**	**0**		**4**	**1**				**Talaromyces ruber**
					4	**20**	**0**	**0**							
					4	**15**	**0**	**0**							

Table V-3. Frequency of soft rot damage in wood tracheids in the outer 1-2 mm of the pole surface at groundline in Douglas-fir poles treated with copper naphthenate in petroleum or bio-based diesel.

Solvent	Year Installed	Number Sampled	Poles with Differing Levels of Soft Rot[a]			
			None Observed	Low	Medium	High
Biodiesel	2008	25	17	6	1	1
	2009	12	7	2	2	1
Petroleum diesel	2003	6	4	1	1	0
	2005	9	5	2	1	1
	2009	12	8	3	1	0

[a] Where soft rot ratings of low, medium and high signify finding 1, 1 to 5, and >5 tracheids with soft rot cavities per ~100 tracheids examined.