Cooperators

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Arch Chemical, Inc.
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New York State Electric and Gas
Osmose Wood Preserving, Inc.
Pacific Corp.
Pacific Gas and Electric
Portland General Electric Company
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Objective I

DEVELOP SAFER CHEMICALS FOR CONTROLLING INTERNAL DECAY OF WOOD POLES

The development of decay in utility poles in service remains an important cause of reduced service life. Internal decay can occur in virtually all species, but it is most important in species with thin sapwood, such as Douglas-fir and lodgepole pine. While preservative treatment of these species produces an excellent barrier against fungal attack, checks that develop as the poles season in service provide avenues into the untreated wood inside. Left untreated, this decay can weaken the pole, rendering it prone to failure during wind, ice or other storm events.

The development of methods for arresting and preventing internal decay was the original reason for Oregon State University to become involved with Bonneville Power Administration, Pacific Power and Portland General Electric. These efforts have resulted in the widespread use of through boring and radial drilling of new poles to limit the potential for decay development as well as the development of fumigants for arresting decay once it has begun. Collectively, these advancements have saved countless millions by reducing the need to replace poles and decreasing the risk of catastrophic failure leading to litigation.

While the developments of through boring and fumigants have dramatically extended the service life of poles (one utility once estimated that its Douglas-fir poles had average service lives of 12 to 20 years- they now expect 70 to 100 years), there is a continuing need to improve upon the internal treatments to make them safer and more effective, while minimizing their potential impacts on the environment.

A. Develop Improved Fumigants for Control of Internal Decay

While there are a variety of methods for internal decay control used around the world, fumigants remain the most widely used systems for arresting internal decay in North America. Initially, two fumigants were registered for wood, metam sodium (32.1 % sodium n-methyldithiocarbamate) and chloropicrin (96 % trichloronitromethane). Of these, chloropicrin was the most effective, but both systems were prone to spills and carried the risk of worker contact. UPRC Research identified two alternatives, solid methylisothiocyanate (MITC) and basamid. Both chemicals were solid at room temperature, reducing the risk of spills and simplifying cleanup of any spills that did occur. MITC was commercialized as MITC-FUME, while basamid has been labeled as Ultra-Fume. An important part of the development process for these systems have been continued performance evaluation to determine when retreatment is necessary and to identify any characteristics that might affect performance.

1. <u>MITC movement from MITC-FUME ampules in Douglas-fir pole sections stored under varying conditions:</u>

Eighteen Douglas-fir pole sections (250 mm in diameter by 750 mm long) were end-coated with an elastomeric paint to retard drying. One half of the sections were seasoned to approximately 25 % moisture content, while the others were used while their moisture levels were above the fiber saturation point (> 24 % DF). A single 205 mm long hole (19 mm in diameter) was drilled at a 45 degree angle into the center of each pole section and single MITC-FUME ampule containing 29 g of MITC was inserted in the hole, open end downward. The holes were plugged with cork stoppers. Sets of 3 poles at each moisture content were stored at 5 C, outdoors at ambient temperatures, or at 32 C and 90 % relative humidity. At periodic internals, the ampules were removed and weighed to assess chemical loss over time.

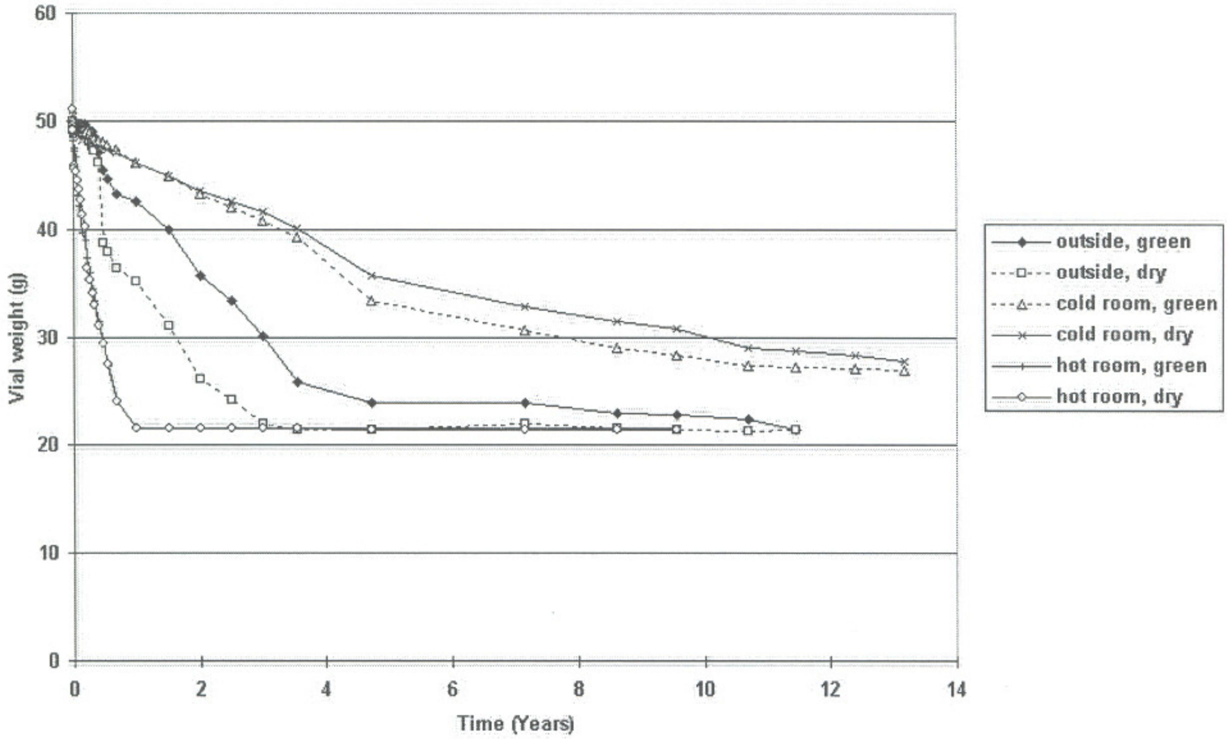
Ampules in pole sections under hot humid conditions rapidly lost chemical and were virtually empty within one year after treatment (Figure I-1). There appeared to be little or no difference in rate of chemical loss in green versus seasoned poles. Ampules stored outside required nearly 4 to 8 years to lose chemical, depending on whether the poles were treated in the green or dry condition. Ampules in dry poles tended to lose chemical more rapidly, although the reasons for these differences remain unknown. Ampules stored at 5 C lost chemical very slowly and still retained approximately 25 % of the original chemical 13 years after treatment. MITC sublimes at room temperature (goes directly from a solid to a gas), but the rate of sublimation slows markedly at lower temperatures. Clearly, poles in cooler climates will lose chemical more slowly than those exposed under warmer conditions. This characteristic has some performance advantages since more chemical will be released under warmer conditions that are also likely to favor rapid decay development. Conversely, less chemical is released during cooler periods when fungal activity is likely to be diminished. The down side to this characteristic is that chemical remains in the ampules for many years. There are, however, a number of studies showing that the amount of chemical remaining in the ampules poses a minimal risk to line crews as well as the general public.

2. Residual MITC in MITC-FUME ampules in Douglas-fir transmission poles in eastern and western Washington:

As noted in Section I-A-1, some utilities remain concerned about the length of time that MITC remains in MITC-FUME ampules following application. To provide additional information on this subject, western redcedar transmission poles in the Bonneville Power Administration system were selected for evaluation. The poles were located in lines near Pasco, Washington and Snohomish, WA. The former line is located in the drier part of the state where rainfall totals rarely exceed 325 mm per year, while the Snohomish site averages 1125 mm of rainfall per year.

The ampules were installed, 3 to a pole (except for one larger pole that received four ampules), through steeply drilled holes drilled beginning at groundline then around the pole 120 degrees and upward 150 mm. The holes were plugged with removable plastic plugs. Ampule weights were assessed 6, 12, 18, 24, 28 and 34 months after treatment. The individual ampules weighed at each time point were not the same.

Figure I-1 Residual MITC in glass ampules installed in green and dry Douglas-fir pole sections exposed at 5 C, ambient conditions or 32 C for 13 years.



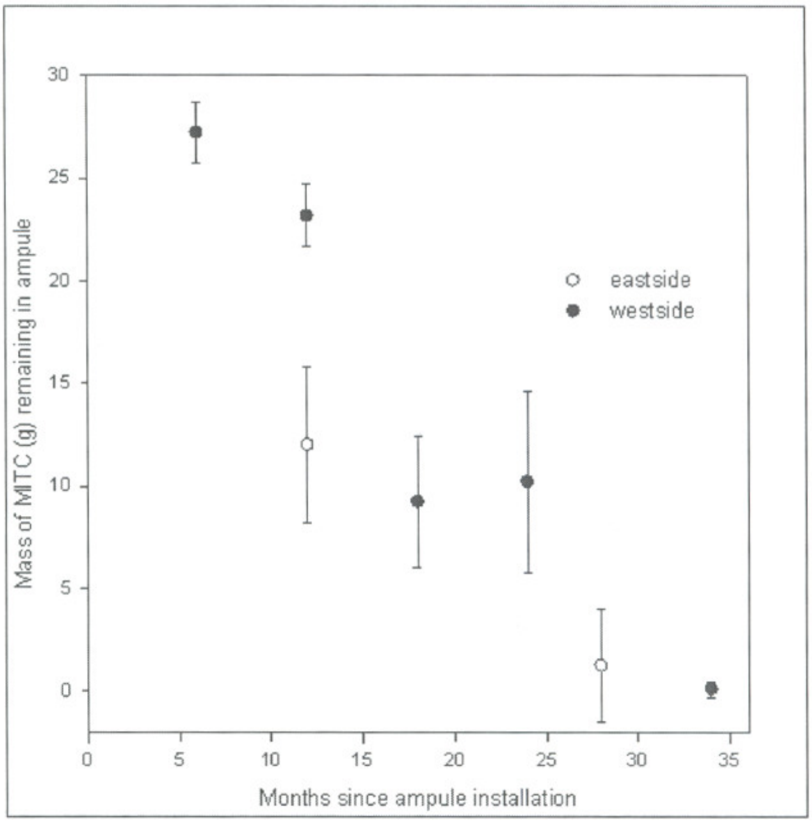
Ampule weights varied little 6 months after application, with all but one ampule retaining over 25 g of the original 29 g dosage (Figure I-2). Ampule weights became more variable 12 months after application. Two ampules contained only 5 g or less of chemical at the 12 month point. Ampule weight losses were generally much lower in poles exposed in Snohomish, reflecting the cooler, wetter conditions at this site. Ampule weights continued to decline at both sites 18 to 24 months after treatment, with the Pasco ampules losing chemical more rapidly. All of the ampules at this site contained less than 15 g of MITC 28 months after application and more than half contained less than 5 g.

These results appear to follow those found in the ambient pole sections exposed at Corvallis, with slightly higher release rates occurring at warmer temperatures. It is clear that MITC will remain in some ampules for at least 2 to 3 years after treatment. As a result, alerting line personnel to the potential for the presence of this chemical in poles being removed from service is advisable as is planning for ampule removal in the event the poles are given away to the general public.

3. Effect of copper sulfate on performance of Basamid in Douglas-fir transmission poles:

The poles treated with metam sodium or basamid and copper sulfate in 1993 were not sampled this past year. They are scheduled to be sampled in 2003.

Figure I-2 Residual MITC in MITC-FUME ampules 6 to 34 months after application to Western Redacedar poles in Pasco (eastside) or Snohomish, WA. (westside).



4. <u>Use of copper naphthenate to enhance performance of basamid in Douglas-fir poles</u>:

Our preliminary field data clearly showed that copper sulfate accelerated the decomposition of basamid to produce MITC, but this chemical is not generally used by utility personnel. One alternative to copper sulfate is 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 soap, to enhance decomposition in comparison with the copper salt.

Douglas-fir pole sections (250-300 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 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 g of basamid was equally distributed among the 3 holes. One set of 3 poles received no additional treatment, 3 poles received 20 g of copper sulfate, and 3 received 20 g of 2 % copper naphthenate in mineral spirits. The holes were plugged with tight fitting wood dowels.

Chemical distribution was assessed 1, 2, 3 and 4 years after treatment by removing increment cores from three equidistant points around each pole at sites 0,.3, 1.3, and 2.3 m above the groundline. The outer and inner 25 mm of each core were placed into 5 ml of ethyl acetate, extracted for 24 hour at room temperature, then the resulting extract was analyzed for residual MITC by gas chromatography. MITC levels were quantified by comparison with standards of known concentration. The increment core segment was then oven-dried and weighed so that the MITC content could be expressed on an MITC per oven dried weight 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 many important wood decayers.

Evaluations of previously collected data suggest that the MITC threshold for fungal protection in Douglas-fir poles is approximately 20 ug/oven dried g of wood. MITC levels in poles receiving no supplemental treatment barely reached the threshold level 0.3 m above ground 1 year after treatment (Table I-1). MITC levels increased slightly over the next 4 years in these poles, but appear to have stabilized at levels well above the threshold. Chemical levels above this zone were extremely low, suggesting that the treatment effect was confined to a very narrow zone around the application point.

MITC levels 0.3 m above the groundline one year after treatment were 2 to 5 times higher when copper sulfate was added to the basamid and these levels continued to remain elevated over the four year test period (Figure I-3). MITC was also detectable 1.3 and 2.3 m above groundline 4 years after treatment at levels above the threshold. These results clearly supported the application of copper sulfate at the time of basamid treatment to increase the initial release rate.

MITC levels in pole sections receiving copper naphthenate appeared to experience less of an initial boost in release rate than poles receiving copper sulfate following treatment; however, chemical levels rose sharply 2 years after treatment and have remained elevated and similar to those for the copper sulfate treatment. MITC is also detectable 1.3 and 2.3 m above groundline but it is only just approaching the threshold 1.3 above groundline in the inner assay zone. These results indicate that copper naphthenate enhances basamid decomposition to MITC, but the levels are 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 any decay fungi established in the wood.

Table I-1 Residual MITC in Douglas-fir pole sections 1 to 4 years after treatment with 200 g of Basamid supplemented with copper naphthenate or copper sulfate.

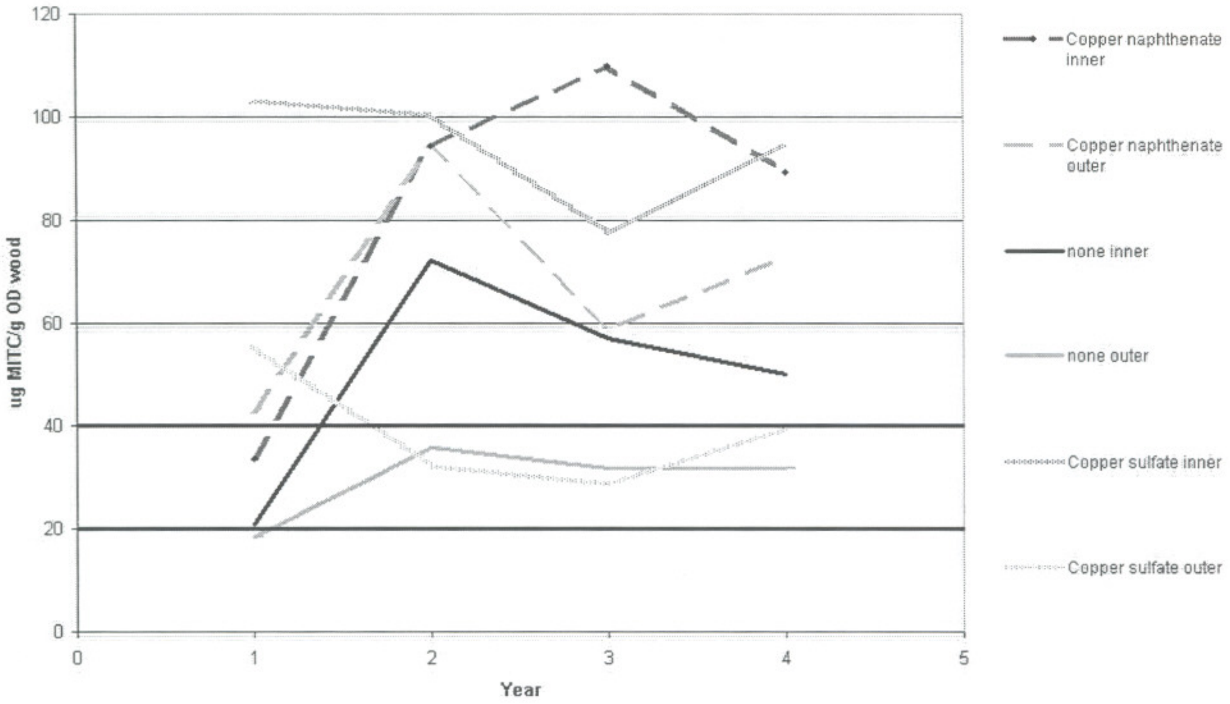
Copper Treatment	Height Meters	Core Section	Residual MITC (ug/g of wood)[a]							
			Year 1		Year 2		Year 3		Year 4	
none	0.3	Inner	21	(14)	72	(47)	57	(27)	50	(41)
		Outer	18	(37)	36	(33)	32	(42)	32	(32)
	1.3	Inner	0	(0)	0	(0)	0	(0)	6	(5)
		Outer	0	(0)	0	(0)	0	(0)	6	(6)
	2.3	Inner	0	(0)	0	(0)	0	(0)	0	(0)
		Outer	0	(0)	0	(0)	0	(0)	0	(0)
Cooper Sulfate	0.3	Inner	103	(78)	101	(36)	78	(25)	95	(61)
		Outer	55	(86)	32	(17)	29	(17)	40	(20)
	1.3	Inner	4	(6)	7	(7)	7	(7)	20	(21)
		Outer	0	(1)	3	(7)	5	(8)	21	(27)
	2.3	Inner	0	(0)	0	(0)	0	(0)	25	(36)
		Outer	0	(0)	0	(0)	0	(0)	23	(33)
Copper naphthenate	0.3	Inner	34	(19)	94	(45)	110	(29)	89	(33)
		Outer	43	(54)	94	(64)	59	(46)	73	(24)
	1.3	Inner	0	(0)	6	(7)	7	(7)	18	(9)
		Outer	0	(0)	5	(11)	4	(8)	9	(7)
	2.3	Inner	2	(5)	0	(0)	0	(0)	1	(2)
		Outer	6	(19)	0	(0)	0	(0)	0	(0)

[a] Values represent means of 9 analyses per position. Figures in parenthesis represent one standard deviation.

Isolation of decay fungi from the inner zones of the poles one year after treatment were limited except from poles treated with basamid amended with copper compounds. Fungi continue to be isolated from the above ground zones of poles treated with basamid amended with copper sulfate, but are now absent from the copper naphthenate amended poles (Table I-2). We suspect the fungi present after one 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. These results suggest that treatment patterns and the zone of protection are more limited with these controlled release formulations than they are with liquid formulations that are applied at much higher dosages.

Figure I-3. Residual MITC in the inner and outer 25 mm segments of increment cores removed from a) 0.3 m or b)1.3 m above the groundline of Douglas-fir pole sections treated with basamid alone or amended with copper naphthenate or copper sulfate.

a) 0.3m



b) 1.3 m

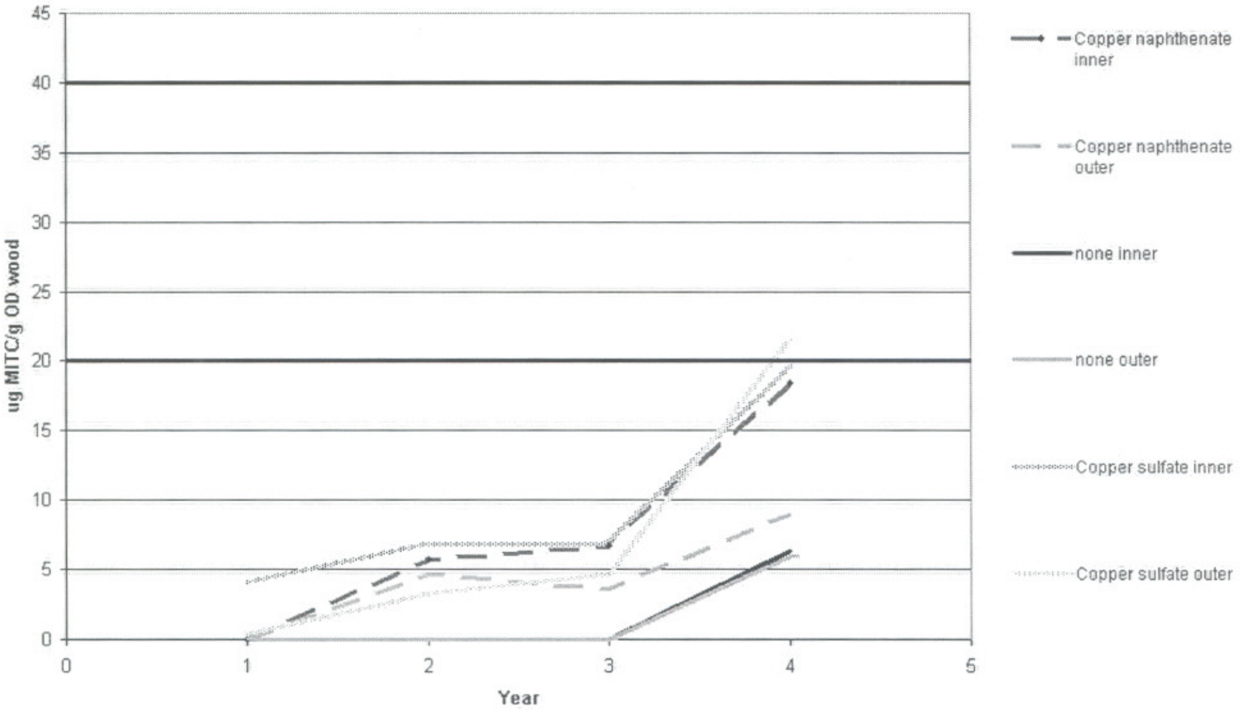


Table I-2 Isolation frequency of decay and non-decay fungi from Douglas-fir pole sections after treatment with 200 g of Basamid alone or amended with copper naphthenate of copper sulfate.

Copper Treatment	Distance above GL meters	Percent of cores with fungi			
		One Year	Two Years	Three Years	Four Years
none	0.3	0^{11}	0^{0}	0^{0}	0^{11}
	1.3	0^{11}	0^{33}	0^{33}	0^{33}
	2.3	0^{11}	0^{33}	0^{0}	0^{56}
copper sulfate	0.3	0^{11}	0^{0}	0^{0}	0^{11}
	1.3	22^{33}	44^{56}	11^{11}	22^{33}
	2.3	0^{44}	0^{33}	0^{33}	11^{33}
copper naphthenate	0.3	33^{33}	0^{0}	0^{0}	0^{0}
	1.3	0^{22}	0^{0}	0^{0}	0^{0}
	23	0^{44}	0^{67}	0^{22}	0^{67}

5. Performance of basamid in rod or powdered formulations:

Basamid was originally supplied in a powdered formulation. This formulation was originally intended for application to fields where it could be tilled into the soil. Once in contact with the soil, the basamid would rapidly react to release MITC, killing potential pathogens prior to planting. The drawbacks to the use of powdered formulations include the risk of spillage during application, as well as the potential for the presence of chemical dusts that can be inhaled. In our early trials, we have produced basamid pellets by wetting the powder and compressing the mixture into pellets, but these were not commercially available. The desire for improved handling characteristics , however, encouraged the development of a rod form. These rods simplified application, but we wondered whether the decreased wood/chemical contact associated with the rods, might reduce basamid decomposition, thereby slowing fungal control.

Pentachlorophenol treated Douglas-fir pole sections (250-300 mm in diameter by 3 m long) were set to a depth of 0.6 m at the Corvallis test site. Three steeply angled holes were drilled into each pole beginning at groundline and moving upward 150 mm and around 120 degrees. The holes received either 160 g of powdered basamid, 107 g of basamid rod plus 100 g of copper naphthenate, 160 g of basamid rod alone, 160 g of basamid rod amended with 100 g of copper naphthenate, 160 g of basamid rod amended with 100 g of water, or 490 g of metam sodium. Each treatment was replicated on five poles.

The poles were sampled one and two years after treatment by removing increment cores from equidistant points around each pole 0.3, 0.8, and 1.3 m above the groundline. The inner and outer 25 mm of each core was extracted in ethyl acetate and the extract was analyzed for MITC by gas chromatography as previously described.

MITC levels 0.3 m above groundline were all well over the 20 ug threshold one year after treatment regardless of chemical treatment (Table I-3; Figure I-4 to 9). The addition of copper compounds have little effect on MITC levels one year after treatment in the inner zones, but MITC levels appeared to be slightly elevated in the outer zones of poles receiving supplemental copper. MITC levels declined markedly in the outer zones 2 years after treatment, regardless of treatment. The addition of copper produced more variable results in the outer zone, but did appear to enhance MITC levels in the inner zones.

MITC levels 0.8 m above groundline were generally below the 20 ug threshold one year after treatment except for the outer zone in the metam sodium treatment. Chemicals levels in the inner zone all rose above the threshold two years after treatment, but there appears to be no real difference between metham sodium and any of the basamid treatments. Chemicals levels 1.3 m above groundline were all uniformly low one year after treatment, then rose dramatically in the inner zones in the second year. The presence of copper had a marked effect on MITC levels in these locations, finding that appears to contradict the results closer to the groundline.

There appeared to be little or no difference in MITC levels between poles receiving basamid in rod or powdered form. This suggests that moisture in the wood was adequate for release of chemicals despite the potential for reduced wood/basamid contact in the rods. The absence of a copper naphthenate effect with the rods may reflect a tendency for more of the liquid chemical to be sorbed by the wood rather than the rod. Conversely, the powdered formulation is more likely to sorb more chemical making it more available to participate in decomposition reactions. Further sampling will be required to determine if there is a real copper stimulatory effect.

Table I-3 Residual MITC in Douglas-fir pole sections at selected distances above the groundline one and two years after treatment with metham sodium, basamid powder, or basamid rods with or without supplemental copper.

Treatment	Dosage	Supplement	Year Sampled	Residual MITC (ug/g wood)[a]											
				0.3 m				0.8 m				1.3 m			
				inner		outer		inner		outer		inner		outer	
Basamid powder	160 g	none	Year 1	50	(35)	24	(24)	6	(17)	4	(8)	0	(0)	0	(1)
			Year 2	52	(70)	16	(55)	42	(54)	1	(3)	25	(32)	27	(41)
Ultrafume	107 g	100g Cu naphthenate	Year 1	45	(57)	46	(44)	2	(4)	6	(8)	0	(0)	0	(0)
			Year 2	51	(70)	1	(2)	36	(51)	1	(3)	73	(101)	14	(28)
Ultrafume	160 g	none	Year 1	54	(95)	30	(30)	2	(4)	4	(7)	0	(2)	1	(3)
			Year 2	29	(37)	3	(6)	35	(53)	1	(3)	33	(46)	6	(12)
Ultrafume	160 g	100g Cu naphthenate	Year 1	49	(63)	85	(88)	9	(16)	9	(16)	1	(2)	1	(2)
			Year 2	80	(104)	17	(45)	49	(64)	4	(9)	62	(75)	5	(11)
Ultrafume	160 g	100 g water	Year 1	22	(22)	29	(35)	4	(6)	6	(10)	0	(0)	1	(2)
			Year 2	33	(47)	1	(2)	32	(34)	1	(5)	41	(41)	6	(11)
Metham sodium	490 ml	none	Year 1	64	(44)	75	(74)	17	(18)	22	(27)	1	(3)	2	(4)
			Year 2	37	(49)	7	(11)	30	(27)	4	(7)	50	(78)	5	(10)

[a] Values represent means of 15 analyses per treatment. Figures in parentheses represent one standard deviation.

Figure I-4 Residual MITC in Douglas-fir poles 1 or 2 years after treatment with 160 g of powdered basamid.

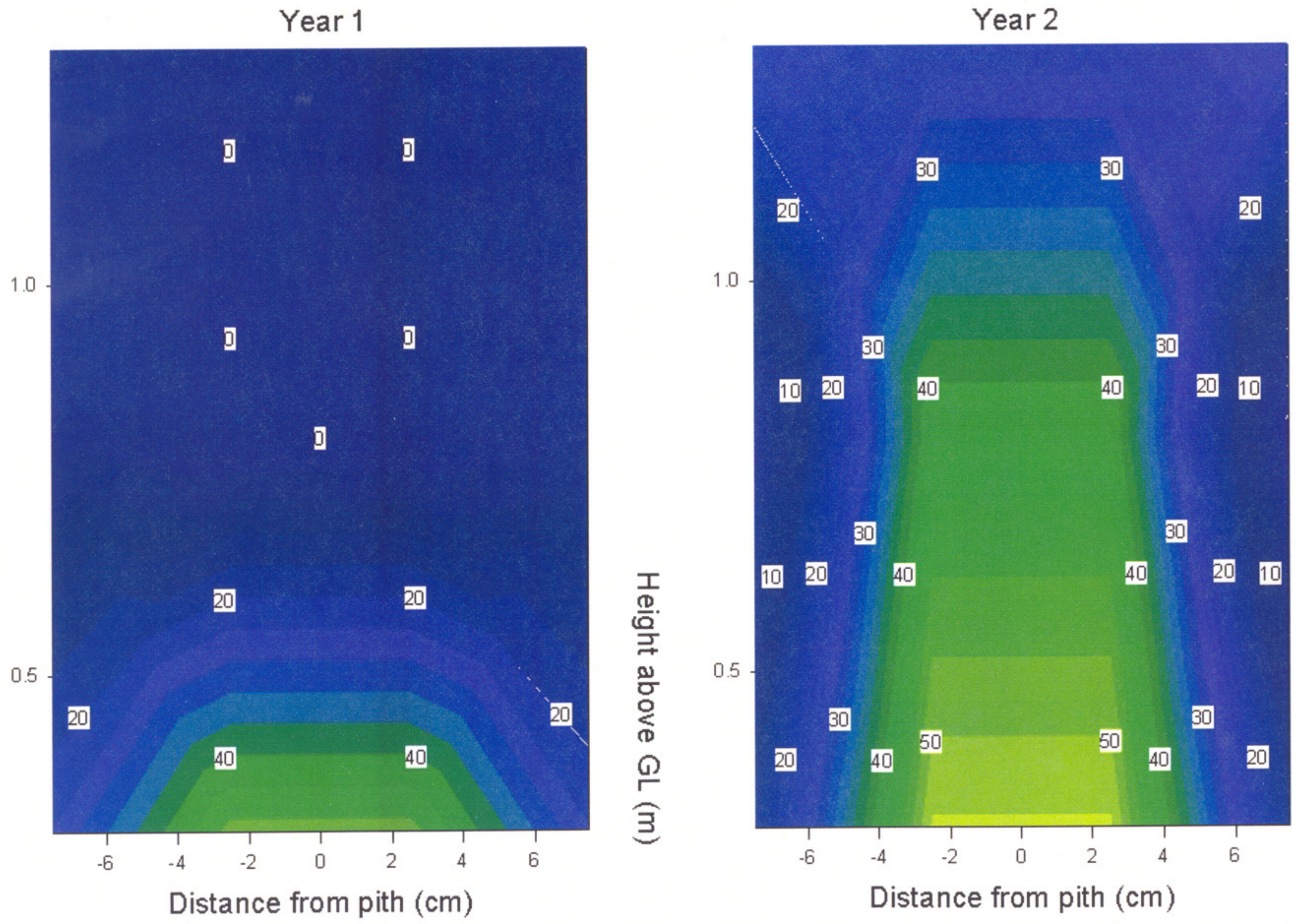


Figure I-5 Residual MITC in Douglas-fir poles 1 or 2 years after treatment with 160 g of Ultrafume rods.

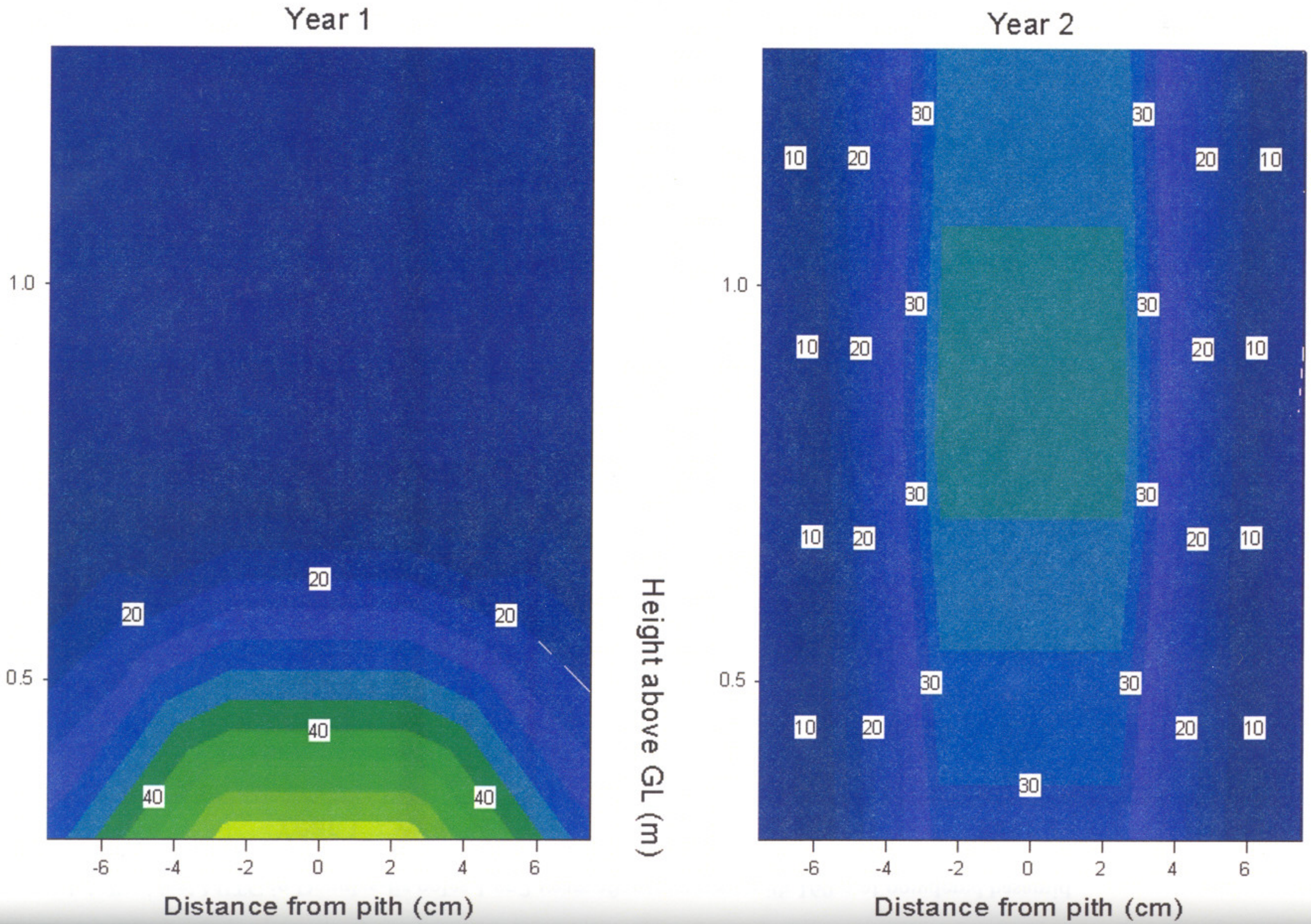


Figure I-6 Residual MITC in Douglas-fir poles 1 or 2 years after treatment with 160 g of Ultrafume rods plus 100 g of water.

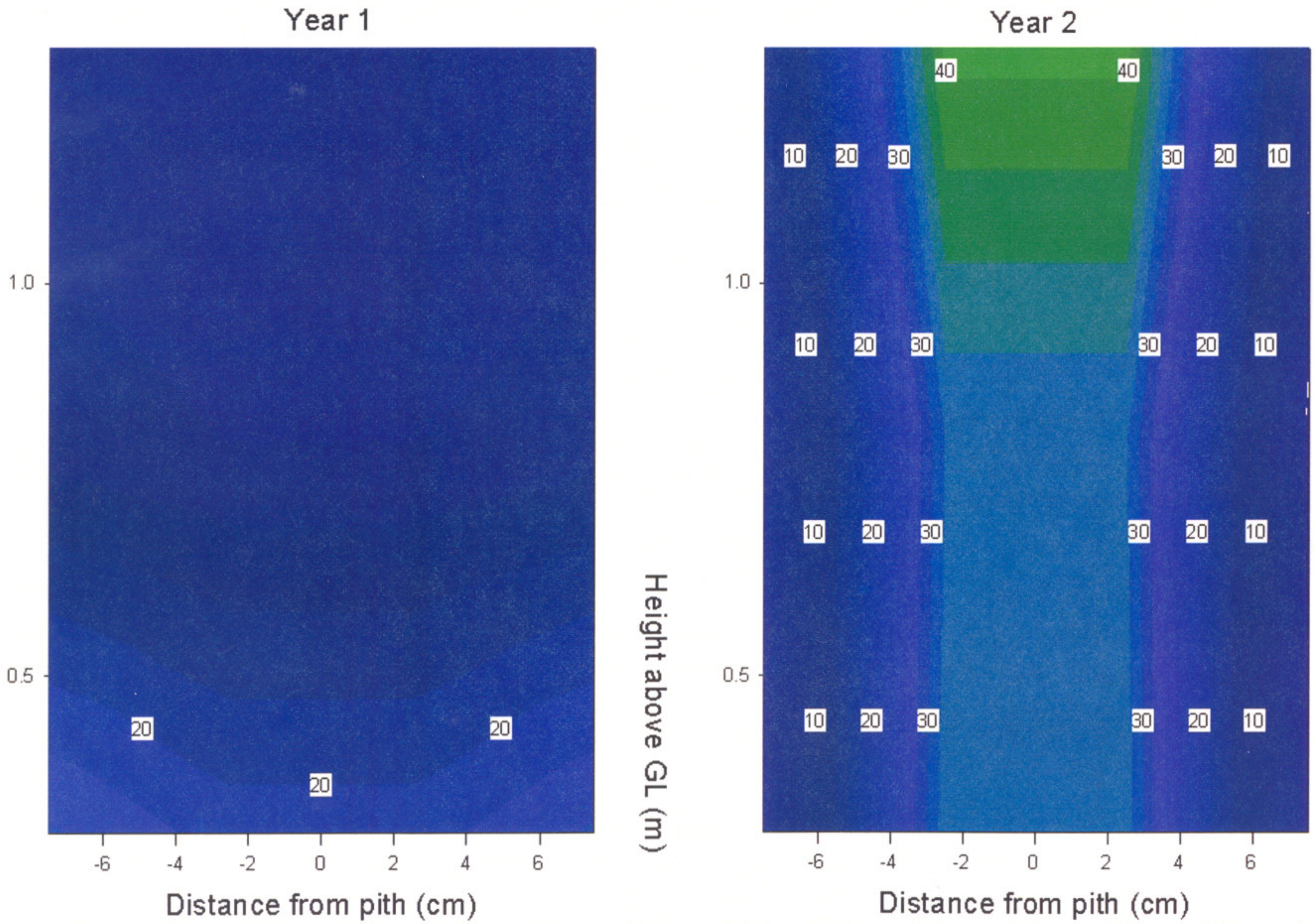


Figure I-7 Residual MITC in Douglas-fir poles 1 or 2 years after treatment with 160 g of Ultrafume rods and 100 g of copper naphthenate.

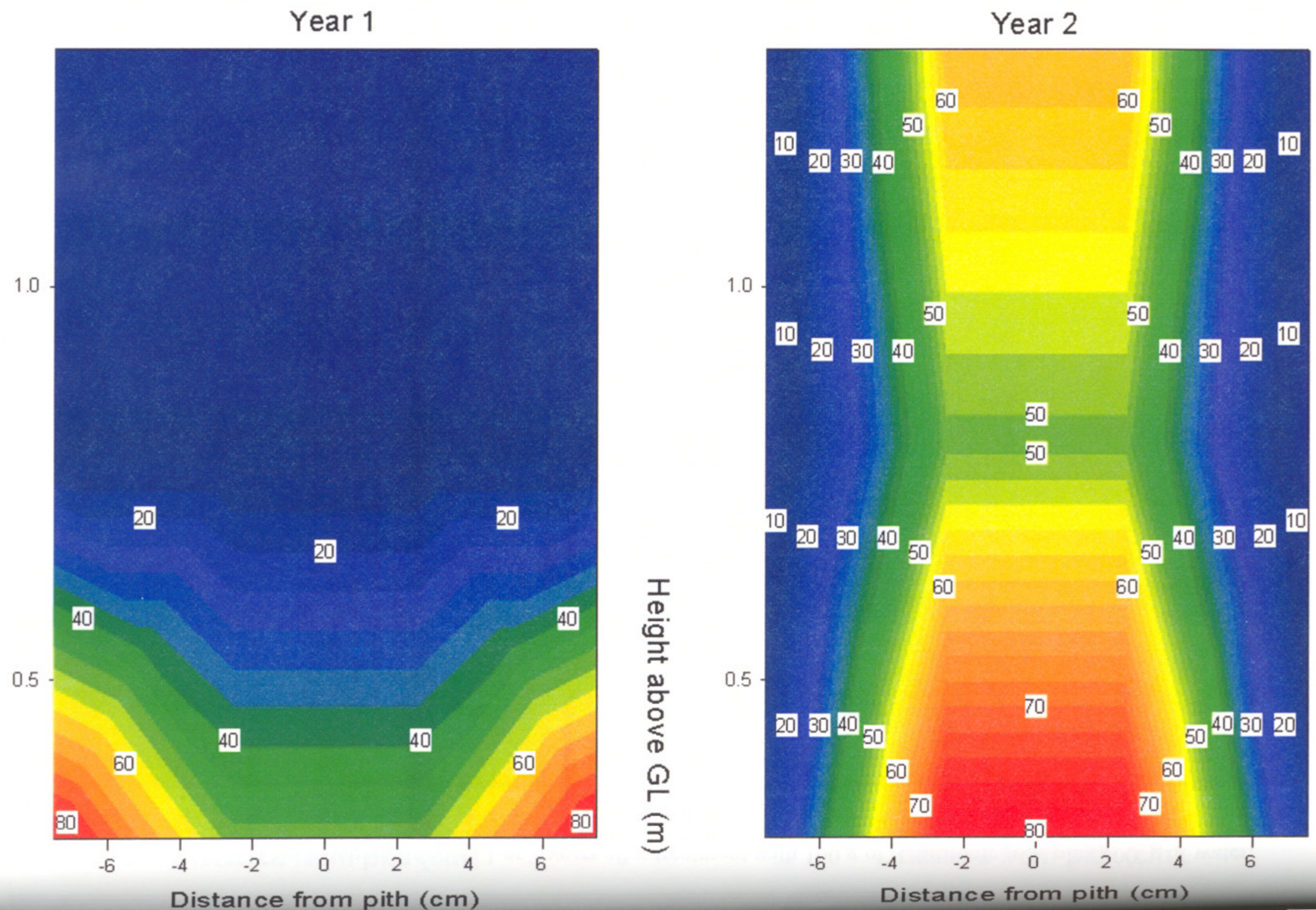


Figure I-8 Residual MITC in Douglas-fir poles 1 or 2 years after treatment with 107 g Ultrafume rods plus 100 g of copper naphthenate.

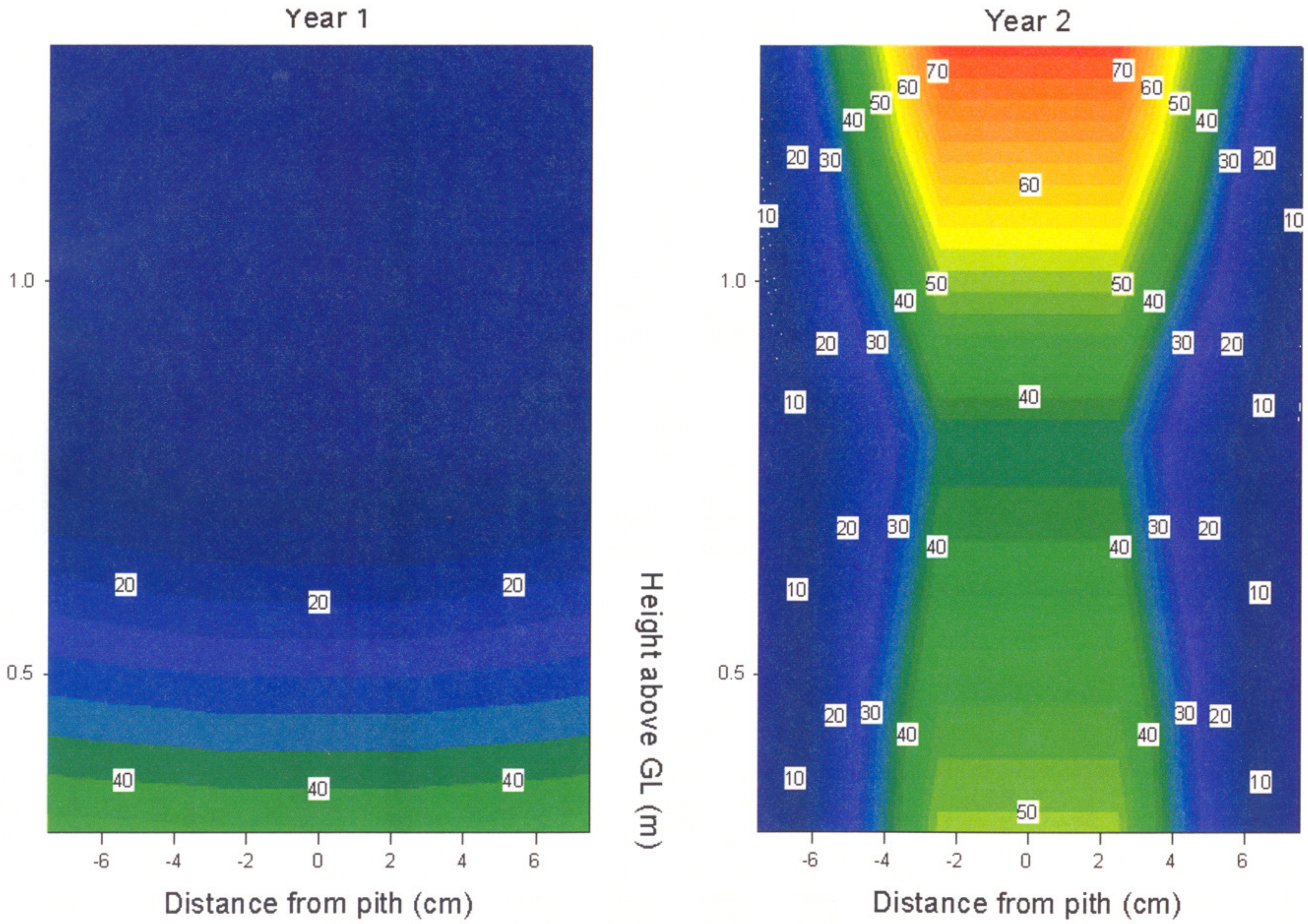
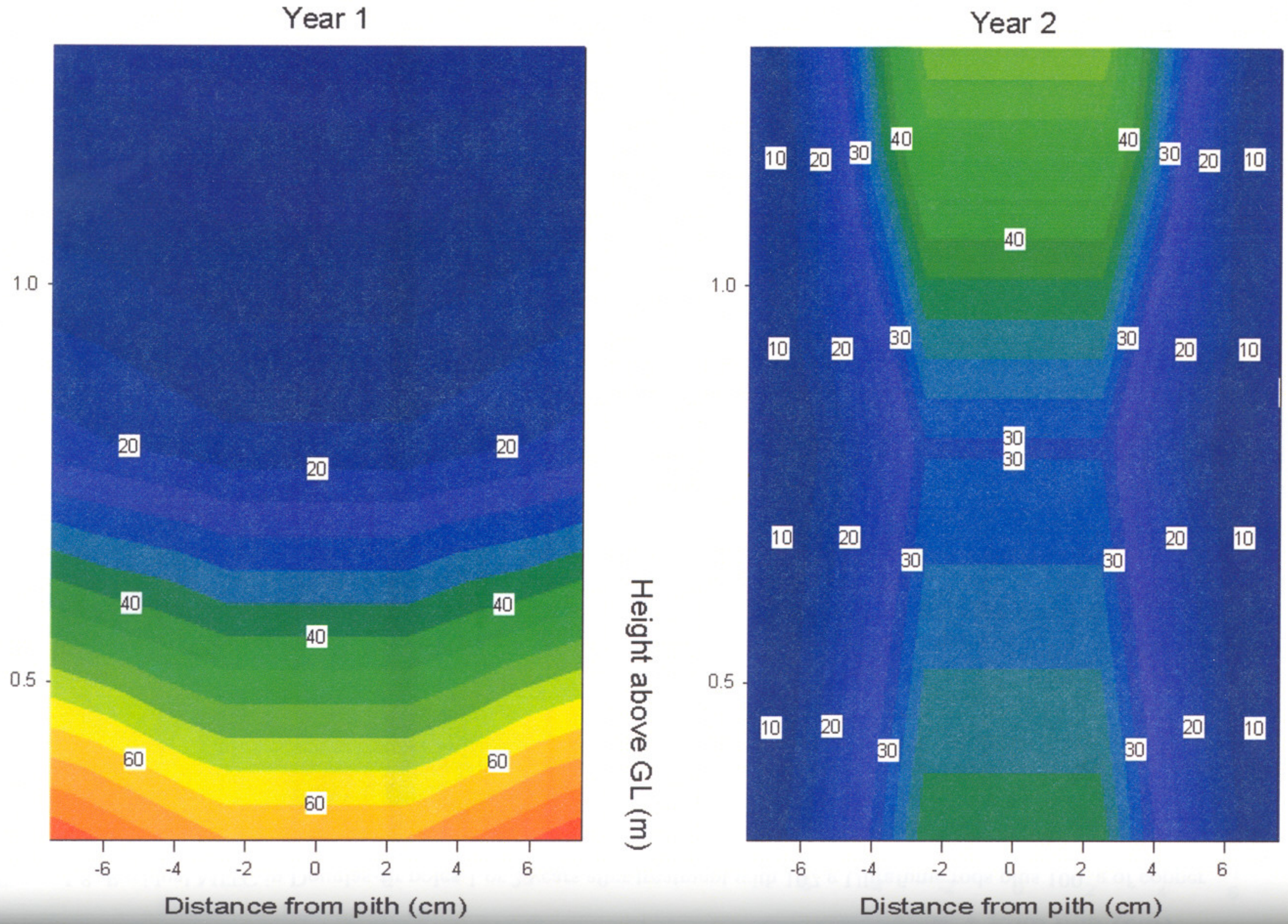


Figure I-9 Residual MITC in Douglas-fir poles 1 or 2 years after treatment with 490 ml of metham sodium.



6. Residual MITC in Douglas-fir posts treated with MITC-FUME:

The Fort Vancouver National Historic site is a reconstructed Hudson's Bay Trading Post. The Fort was reconstructed in the 1960's using Douglas-fir and Lodgepole poles that had been treated with pentachlorophenol in light oil. Shortly after the Fort was completed, it became apparent that deterioration was progressing far more rapidly than had been planned. Investigations showed that posts had been treated with the bark on and many had been frozen at the time of treatment. As a result, the poles were poorly treated and were experiencing substantial internal decay. At that time, the posts were treated with chloropicrin, then in 1992, the posts were retreated with MITC-FUME. This past Spring we had an opportunity to evaluate residual MITC levels on the main support posts in this Fort (called Kingposts) 10 years after treatment.

Increment cores (approximately 150 mm long) were removed from 104 kingposts and gateposts around the Fort. The outer and inner 25 mm of each increment core were placed into individual test tubes containing 5 ml of ethyl acetate, a solvent with a high specificity for methylisothiocyanate (MITC). Each post was sampled at 2 locations approximately 120 degrees apart at groundline and at one location 0.3 m above the groundline. The increment core holes were then plugged with tight fitting wooden dowels to limit the potential for fungal attack in the sampling holes.

The cores were extracted in ethyl acetate for 48 hours at room temperature, then each core was removed, oven dried (104 C) and weighed. The ethyl acetate extracts were then analyzed for MITC content by gas chromatography. Briefly, 3 ul of the extract was injected into a Shimadzu gas chromatograph equipped with a flame photometric detector with filters specific for sulfur. The level of MITC in the extract was determined by similar analysis of prepared standards. The amount of MITC was then calculated on a ug of MITC/ oven dry gram of wood basis. Previous field and laboratory tests have shown that a minimum level of 20 ug of MITC/oven dry gram of wood is required for wood protection.

A total of 104 kingposts and gateposts were sampled and 624 samples were analyzed for MITC content. The results were summarized to show the average MITC content of lodgepole pine and Douglas-fir kingposts or Douglas-fir gateposts in the inner and outer zones. In addition, histograms were created to show the range of MITC retentions in the various locations. The goal was to identify not only the average chemical content, but also the relative numbers of posts with acceptable levels of residual chemical.

MITC levels were generally lower in the outer zones of the posts, regardless of species or type (Table I-4). This probably reflects the tendency for MITC to volatilize near the wood surface. In general, chemical levels deeper in the posts are more important since this is the zone where internal decay is most likely to occur. MITC levels in the inner zones at groundline averaged 25.0 and 15.6 ug/g of wood for Douglas-fir and lodgepole pine kingposts, respectively. MITC levels above the groundline tended to be slightly higher, averaging 29.2 and 49.2 ug/g respectively for Douglas-fir and lodgepole pine. MITC levels in Gateposts were also low in the outer zones, and averaged 26.9 and 18.9 ug/g of wood in the inner zones 0 and 0.3 m above groundline, respectively. Nearly all of these average values are at or above the threshold for fungal attack found in previous tests of Douglas-fir, suggesting that the posts do not need retreatment.

Examination of the distribution of MITC content among the various posts, however, provides a different measure of residual chemical content. Over 80 % of the outer groundline Gatepost samples contained less than 1 ug/g of MITC and all of the samples at 0.3 m contained less than this level of chemical (Figure I-10). MITC levels in the inner zones were slightly better, but nearly 50 % of the inner cores at groundline and over 30 % of those from the 0.3 m location contained less than 1 ug/g of MITC. Clearly, a high percentage of samples contained very low levels of chemical in the gateposts.

A similar examination of the outer zones of the lodgepole pine kingposts showed that virtually all samples contained less than 1 ug/g of wood, while nearly 70 % of inner zone samples at groundline in the posts contained 20 ug or less of MITC (Figure I-11). While the levels were slightly better 0.3 m above groundline, the real risk of internal decay is highest at groundline and declines with distance away from direct soil contact.

A similar examination of the Douglas-fir kingposts showed that outer zone levels were slight better than those found with the lodgepole pine, but a majority of samples contained 1 ug/g or less of chemical (Figure I-12). Examination of MITC distribution in inner zone samples showed that over 40 % of cores from groundline contained less than1 ug/g of MITC and over 60 % contained 20 ug or less. Results were similar 0.3 m above groundline.

Implications: Fumigant performance is a function of the ability of the chemical to eliminate fungi already established and then remain in the wood at levels capable of preventing renewed fungal attack. The protective period provided by most fumigants in the Pacific Northwest is 7 to 10 years. The exception to this rule is chloropicrin, which provides a much longer residual protective period. Determining the exact period of fumigant performance is complicated by the fact that once the chemical levels have depleted, the decay fungi must find pathways for reinvading wood. Thus, the rate of reinvasion and renewed fungal attack is a function of soil conditions and the fungi present. There is also some evidence that fumigant treatment alters the types of fungi present in the wood, sometimes encouraging the growth of fungi that do not cause wood decay. Some of these fungi are capable of inhibiting decay fungi and limit the ability of decay fungi to reinvade the posts.

All of this means that it is sometimes difficult to accurately predict fumigant service life, however, it has been our experience that wood with less than 20 ug of MITC is at a much higher risk of fungal attack. Our results indicate that a majority of the samples examined contain less than this minimum threshold retention and should be retreated. The presence of some residual MITC in most samples, albeit at low levels, does provide some latitude for retreatment. As a result retreatment within the next 2 years would probably provide a reasonable degree of protection to the posts.

Table I-4 Residual MITC in Douglas-fir or lodgepole pine kingposts at the Fort Vancouver National Historic Site.

Post Type	Distance Above Groundline (m)	Residual MITC (ug/oven dry g of wood)[a]							
		Douglas-fir				Lodgepole pine			
		Outer Zone		Inner Zone		Outer Zone		Inner Zone	
		Mean	Max	Mean	Max	Mean	Max	Mean	Max
King	0	3.5 (7.0)	32.2	25.0 (36.7)	150	0.7 (3.7)	34	15.6 (38.7)	358
	0.3	9.4 (15.6)	82.4	29.2 (52.1)	210	1.4 (6.3)	45	49.2 (144.2)	1100
Gate	0	3.6 (9.1)	29.3	26.9 (43.7)	144	-	-	-	-
	0.3	0	0	18.9 (24.3)	64.4	-	-	-	-

[a] Values in parentheses represent one standard deviation.

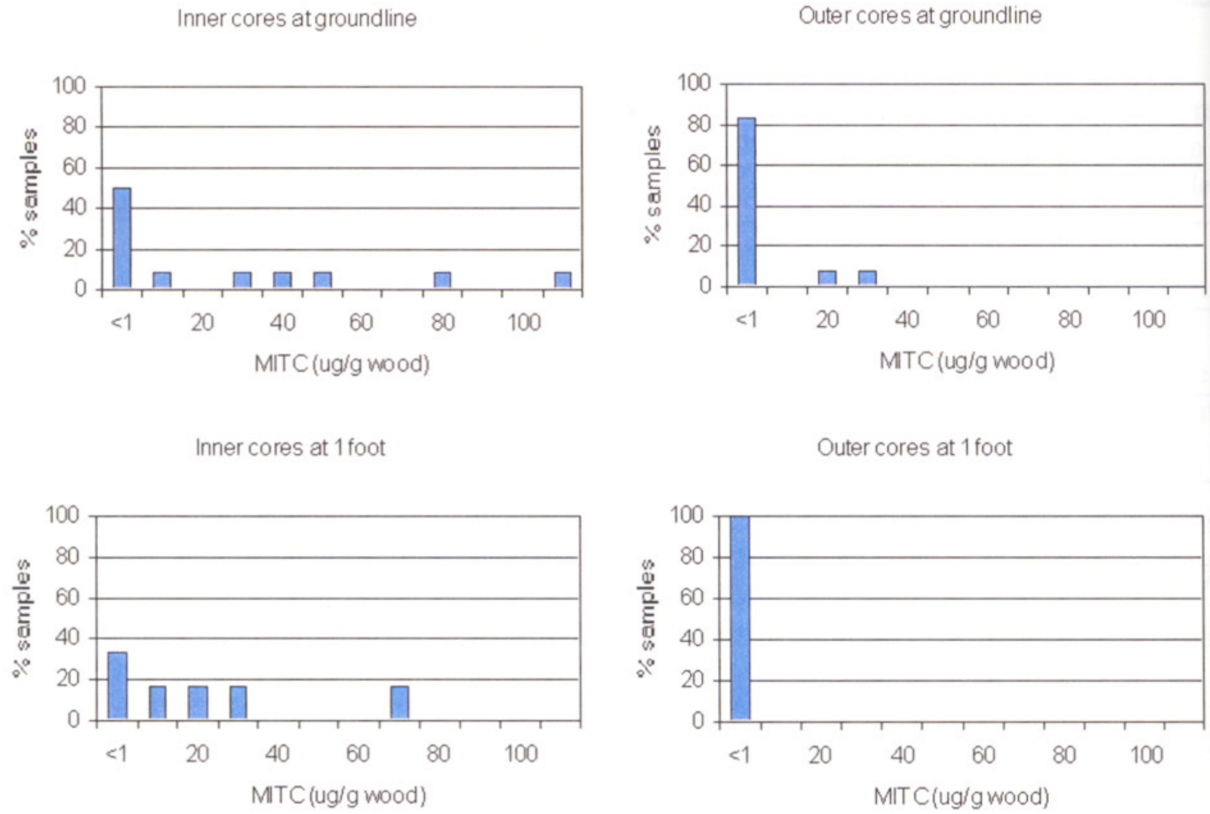
7. Performance of metam sodium in Douglas-fir timbers:

While the majority of our research has focused on remedial treatment of poles, treatment of timbers is also an important component of the remedial treatment markets and these applications help to support the costs for label registration. Given the relatively small markets for wood fumigants, we have taken an approach to develop data for supporting applications wherever the cost for developing this data is small and there are potential benefits in terms of long term continued availability of the chemicals.

Fumigant performance on large timbers might be expected to differ slightly from that found on round stock because of the thinner treated shell and presence of numerous cut fibers on the timber surfaces that can act as conduits for fumigant diffusion from the wood. Under these circumstances, fumigants might be expected to provide shorter protective periods than would be found on round stock, but there is little data available on this subject.

Metham sodium was applied to Douglas-fir timbers in a bridge located near Salem, Oregon. The chemical was applied through 19 mm diameter holes drilled at 1.2 m intervals along the length of each timber. The holes were plugged with tight fitting wood dowels. Residual chemical levels were assessed 1, 3, 6, 7, 10, and 12 years after treatment by removing increment cores from near the top and bottom edges of each timber 0.6 m from the original treatment holes on each of 8 stringers. The outer, treated shell was discarded, then the inner and outer 25 mm of each increment core was placed into 5 ml of ethyl acetate and extracted for 48 hours at room temperature. The resulting extract was analyzed for MITC content by gas chromatography. The remainder of each core was placed on malt extract agar and observed for the growth of decay fungi, which served as a measure of failure of the remedial treatment.

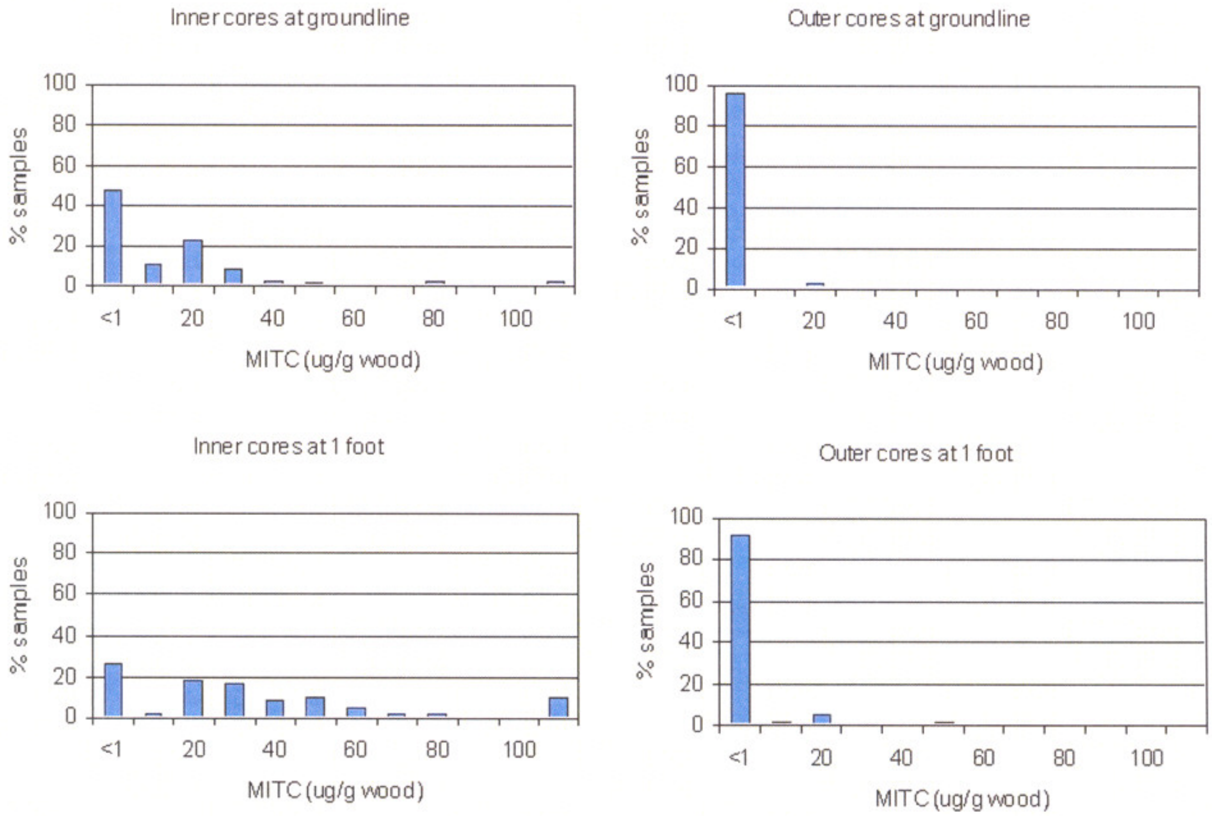
Figure I-10 Residual MITC in the inner and outer 25 mm of increment cores removed from Douglas-fir gateposts10 years after treatment with MITC-FUME.



MITC levels in the timbers continue to remain detectable, although the levels have largely declined below the protective threshold for MITC against fungi (Table I-5). Fungal isolations continue to indicate that few decay fungi have reinvaded the timbers, but non-decay fungi have invaded the timbers in substantial numbers (Table I-6). The absence of decay fungi reflects the residual chemical levels as well as the lack of soil contact. Soil contains high levels of spores and hyphal fragments of a variety of fungal species, including decay fungi. The absence of soil contact sharply slows the rate of fungal attack, further enhancing the effectiveness of the remedial treatment.

The results indicate the retreatment of the timbers would be advisable to provide continued protection.

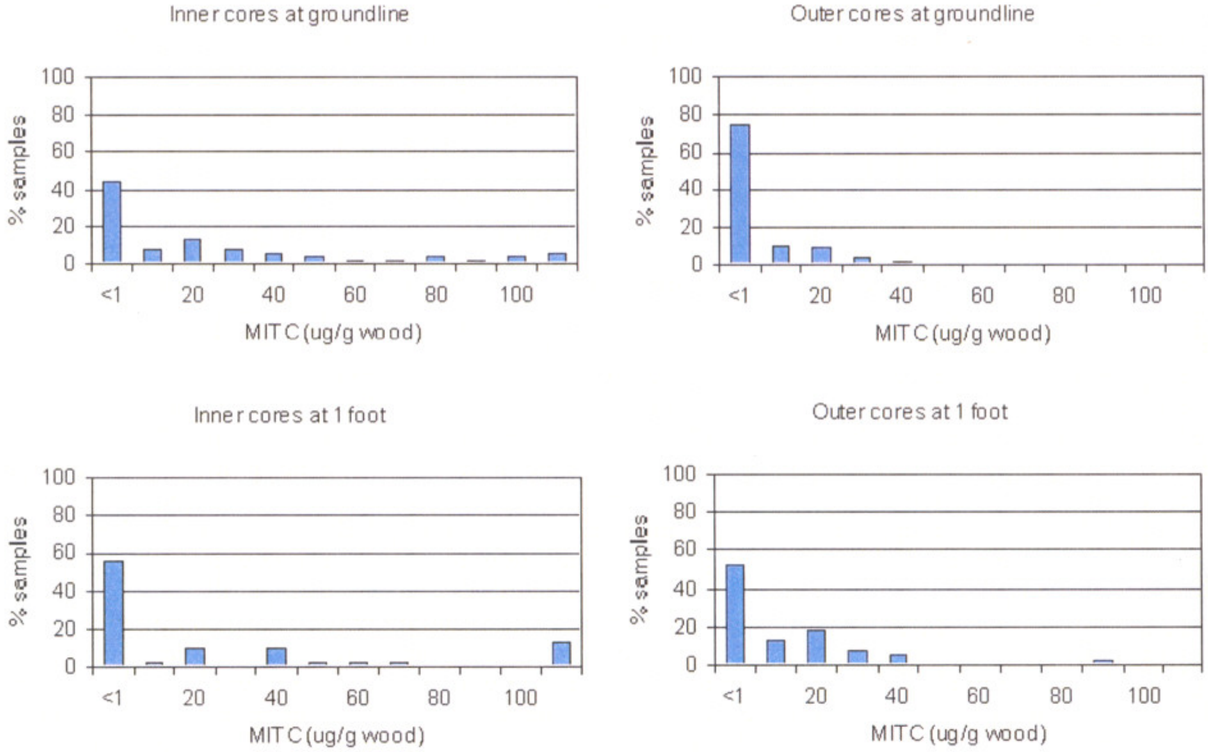
Figure I-11 Residual MITC in the inner and outer 25 mm of increment cores removed from lodgepole pine kingposts 10 years after treatment with MITC-FUME.



8. <u>Release rates of chloropicrin from controlled release ampules exposed in utility poles:</u>

While pressure treatment of wood with preservatives produces a product that will perform extremely well under a variety of environmental conditions, species and treatment characteristics will generally result in a limited percentage of poles that experience biodeterioration at some point in their useful lives (AWPA, 1999; Graham, 1983). These "problem" poles can be detected through a regular inspection program and the problem arrested by application of remedial treatments. Decay in service generally takes two forms, surface decay that is caused by soft rot fungi and internal deterioration that is caused by either decay fungi or insects (primarily carpenter ants or termites). Surface decay has long been controlled by application of topical preservative pastes that kill fungi in the wood near the surface and create a supplemental barrier against renewed attack.

Figure I-12 Residual MITC in the inner and outer 25 mm of increment cores removed from Douglas-fir kingposts 10 years after treatment with MITC-FUME.



Internal decay control has generally posed a greater problem. In most cases, internal decay occurs in the heartwood that originally could not be impregnated using pressures between 100 and 200 psi. The inherent resistance to fluid penetration renders nearly all conventional liquid treatments ineffective for internal decay control. Liquid preservatives can be applied to the voids through inspection or treatment holes, but are unable to move for substantial distances through the heartwood to effectively arrest fungal attack away from the void. For many years, internal decay control treatments were limited to oil and water-based systems that lacked the ability to move rapidly for substantial distances from the point of application (Hand et al., 1970).

Table I-5 MITC levels in increment core segments removed from Douglas-fir timber 1 to 12 years after treatment with metham sodium.

MITC Content (ug/g o.d. wood)																
Structure #	Top/bottom	in/out	Year 1		Year 2		Year 3		Year 6		Year 7		Year 10		Year 12	
5	Bottom	inner	**60**	(85.8)	**35**	(39.4)	**31**	(56.1)	**40**	(27.3)	**28**	(34.9)	**30**	(18.8)	**29**	(16.8)
		outer	**24**	(27.1)	**112**	(120.5)	**84**	(145.7)	**108**	(89.1)	**127**	(60.9)	**38**	(25.9)	**26**	(15.7)
	Top	inner	4	(6.1)	**52**	(106.2)	10	(13.4)	**40**	(64.3)	1	(3.1)	4	(4.2)	6	(15.3)
		outer	0	0.0	**28**	(39.7)	3	(5.3)	**50**	(105.3)	4	(5.2)	0	0.0	5	(10.5)
10	Bottom	inner	**76**	(83.2)	**115**	(110.6)	**43**	(62.7)	**60**	(35.4)	**42**	(20.3)	15	(11.0)	13	(7.5)
		outer	**40**	(27.8)	**59**	(47.0)	**116**	(200.9)	**58**	(42.8)	15	(9.2)	14	(8.3)	19	(9.8)
	Top	inner	**40**	(45.2)	**136**	(110.9)	**71**	(59.4)	**47**	(28.8)	**21**	(15.3)	14	(12.1)	4	(6.5)
		outer	**53**	(49.1)	**60**	(51.6)	77	(92.8)	**43**	(17.5)	**42**	(31.4)	6	(6.8)	10	(12.8)
15	Bottom	inner	16	(27.6)	**100**	(95.1)	18	(26.6)	**38**	(33.9)	**32**	(19.9)	19	(29.1)	2	(5.4)
		outer	**24**	(26.8)	**113**	(111.3)	**43**	(56.3)	**55**	(36.0)	**30**	(27.4)	11	(21.6)	12	(8.8)
	Top	inner	**27**	(30.2)	**66**	(78.2)	**46**	(28.1)	**64**	(40.8)	**54**	(25.3)	**31**	(23.2)	15	(9.8)
		outer	**37**	(67.0)	**59**	(61.7)	**145**	(121.1)	**66**	(46.5)	**43**	(22.3)	**28**	(15.6)	**27**	(9.8)
20	Bottom	inner	**74**	(84.8)	**43**	(52.8)	**68**	(73.4)	**57**	(25.6)	**75**	(49.5)	**28**	(15.0)	17	(7.7)
		outer	**24**	(33.5)	20	(23.9)	**163**	(164.1)	**52**	(22.1)	**72**	58.3)	**33**	(26.1)	**21**	(11.0)
	Top	inner	**26**	(35.9)	**117**	(126.4)	**58**	(31.8)	**32**	(24.7)	**21**	(12.6)	**56**	(77.1)	4	(5.8)
		outer	**65**	(63.9)	**131**	(185.4)	**45**	(46.8)	**66**	(38.6)	**35**	(10.6)	8	(6.4)	10	(6.4)
25	Bottom	inner	**33**	(33.3)	**83**	(146.2)	**86**	(75.1)	**59**	(35.6)	**54**	(21.60	**41**	(20.1)	13	(8.5)
		outer	**66**	(71.8)	**95**	(85.3)	**32**	(21.4)	**52**	(35.2)	**52**	(29.7)	18	(17.5)	**29**	(8.7)
	Top	inner	**26**	(32.5)	**63**	(48.30	**41**	(25.2)	16	(9.5)	20	(19.6)	16	(5.0)	13	(1.6)
		outer	13	(20.1)	**44**	(51.9)	**52**	(37.2)	**29**	(11.3)	**27**	(11.3)	13	(4.4)	12	(2.7)

MITC Content (ug/g o.d. wood)																
Structure #	Top/bottom	in/out	Year 1		Year 2		Year 3		Year 6		Year 7		Year 10		Year 12	
30	Bottom	inner	**84**	(66.4)	**41**	(61.8)	**83**	(87.6)	**28**	(12.0)	**35**	(21.0)	19	(8.5)		
		outer	**76**	(100.8)	**64**	(99.5)	**49**	(34.4)	**40**	(23.6)	**24**	(2.4)	11	(5.2)		
	Top	inner	**73**	(52.9)	**127**	(99.1)	**78**	(42.1)	**40**	(25.5)	**50**	(25.6)	**28**	(13.1)		
		outer	**100**	(74.2)	**96**	(57.6)	**70**	(50.1)	**37**	(26.3)	**36**	(29.1)	**30**	(16.5)		
35	Bottom	inner	14	(19.8)	75	(100.3)	19	(17.9)	**36**	(24.9)	**28**	(7.4)	10	(6.5)		
		outer	9	(17.5)	**42**	(40.7)	9	(10.2)	**37**	(25.3)	15	(12.0)	6	(3.3)		
	Top	inner	**44**	(50.1)	**74**	(88.1)	**109**	(113.0)	**31**	(17.0)	**64**	(30.5)	**31**	(29.5)		
		outer	**61**	(88.6)	**121**	(235.8)	**57**	(56.9)	**59**	(54.5)	**78**	(45.6)	5	(7.8)		
40	Bottom	inner			**92**	(145.1)					18	(12.1)	18	(12.2)		
		outer			**57**	(53.5)					8	(9.8)	9	(5.6)		
	Top	inner			**50**	(70.5)					17	(16.8)	**33**	(15.1)		
		outer			**140**	(112.9)					**50**	(50.3)	**35**	(22.5)		

Values represent means of 6 replicates. Values in parenthesis represent one S.D.
Figures in boldface type are above the fungitoxic threshold of 20ug/g wood.

Table I-6 Isolation frequency of decay and non-decay fungi from Douglas-fir bridge timbers prior to and 1 to 12 years after treatment with metham sodium.

	Percent of Cores with Fungi[a]							
Structure	0 Year	1 Year	2 Years	3 Years	6 Years	7 Years	10 Years	12 Years
5	$--^{--}$	0^{42}	0^{90}	0^{22}	0^{0}	0^{0}	0^{0}	0^{92}
10	0^{17}	0^{42}	0^{50}	0^{50}	0^{0}	0^{0}	0^{0}	8^{92}
15	0^{17}	0^{0}	0^{100}	8^{67}	0^{0}	0^{0}	0^{0}	0^{92}
20	$--^{--}$	0^{0}	0^{100}	0^{80}	0^{0}	0^{0}	0^{0}	0^{100}
25	0^{29}	0^{0}	0^{100}	8^{50}	0^{0}	0^{17}	0^{0}	0^{50}
30	29^{40}	0^{0}	0^{100}	0^{0}	0^{0}	0^{0}	0^{0}	$--^{--}$
35	13^{87}	0^{0}	0^{17}	8^{90}	0^{27}	0^{0}	0^{0}	$--^{--}$
40	0^{17}	$--^{--}$	8^{42}	$--^{--}$	$--^{--}$	0^{0}	0^{0}	$--^{--}$
Average	8^{35}	0^{10}	1^{70}	4^{60}	0^{7}	0^{4}	0^{3}	2^{87}

[a] Values represent mean percent of 12 cores containing decay fungi. Superscripts represent percent of non-decay fungi present in same cores.

The prospects for internal decay control received a substantial boost in the early 1960's with the development of fumigants (Ricard et al., 1967; Hand et al., 1970; Graham, 1973, Graham and Corden, 1980). These volatile chemicals were widely used in agriculture for sterilizing soil prior to planting. Field trials in poles indicated that some fumigants including chloropicrin and metham sodium, were capable of moving rapidly through Douglas-fir heartwood to eliminate established decay fungi. More importantly, these chemicals remained in the wood for 3 to 20 years after application where they limited recolonization by decay fungi (Graham, 1973; Helsing et al., 1984; Morrell and Scheffer, 1985; Schneider et al., 1995). Although they appear to provide a shorter protective period in more permeable species such as southern pine (Zabel et al., 1982), these treatments are also applied these species, albeit at more frequent intervals. The effectiveness of fumigants was widely recognized and by 1983, nearly 90 % of utilities surveyed used fumigants as a part of their inspection and maintenance programs (Goodell and Graham, 1983).

While fumigants are widely used, many applicators remained concerned about the risk of spills (Morrell and Corden, 1986). In addition, chloropicrin, the most effective of the registered chemicals, requires the use of full face respirators during application. This was clearly a negative public-image issue with many utilities, who responded by either using only metham sodium or restricting chloropicrin use to overland transmission poles away from inhabited areas.

The development of methylisothiocyanate (MITC) in the early 1980's provided the first alternative to metham sodium and chloropicrin (Zahora and Corden, 1985). This formulation is a solid at room temperature, but must be encapsulated to limit the risk of skin burns. It is also the active ingredient of metham sodium (Turner and Corden, 1963; Lebow and Morrell, 1993; Morrell, 1994). The MITC formulation was first encapsulated in glass tubes, then finally aluminum. Field tests showed that the MITC released from the capsules over periods ranging from several months to years, depending on the temperature and provided performance that was slightly better than metham sodium, but did not approach that of chloropicrin (Morrell et al., 1992).

Chloropicrin is an especially attractive remedial treatment. It is effective against a range of fungi at low dosages, and tends to be strongly sorbed to wood (Goodell, 1989; Peralta and Morrell, 1992). These properties have continued to encourage studies to identify safer application methods that overcome chloropicrin's strong lachrymatory properties. Goodell (1989) developed a gelled chloropicrin formulation which reduced the risk of spills but had little effect on volatility. Fahlstrom (1982) developed an encapsulating tube for containing chloropicrin prior to delivery in to the wood. While this system limited the risk of spills, the tubes had to be filled on the job site and could not be stored for long periods. As a result, it has only been used for treating timbers in bridges or other structures where large amounts of wood are being treated in one area.

The desire to produce a safer chloropicrin formulation led the Electric Power Research Institute (EPRI) to sponsor a research program through the Southwest Research Institute (SwRI) (San Antonio, TX) to develop a controlled release formulation that was safe to store, handle and apply and that provided an estimated protective period of 20 years (Bernstein et al., 1998; Schlameus et al., 1996; Love et al., 1996; Morrell et al., 1994). A series of polymer encapsulated formulations of chloropicrin were developed and evaluated in pole sections exposed near Corvallis, Oregon. The results from these tests indicated that one polymer appeared to provide the desired release rate and this material was subsequently registered with the U.S. Environmental Protection Agency. As with any material destined for utility use, field performance data in actual utility systems provides the best basis for assessing the value of the treatment. A series of field trials were established to assess the formulation under a variety of climatic conditions. This report describes the continuing field tests of this controlled release formulation.

At the conclusion of the initial EPRI support, a single polymer was selected for further field testing. The ampule selected was installed in a series of utilities across the U.S. The goal was to identify sites with varying climatic conditions as well as pole species. In most instances, the cooperating utilities were also selected on the basis of their willingness to participate through EPRI's Tailored Collaboration Program.

A total of 10 sites were selected (Table I-7) which ranged from Gulf Coast to the dry Rocky Mountain region. Each utility was asked to identify up to 45 poles that included the most prevalent wood pole species in their service area. The ampules were applied to each pole through three steeply angled holes drilled at groundline then upward at 150 mm intervals and around the pole 120 degrees. The holes were plugged with tight fitting, but removable plastic plugs.

Chloropicrin movement from the ampules was measured 1, 2 and 3 years after treatment by first removing the ampules from each pole for weighing. The ampules were returned and the holes were replugged. Ampule weights were monitored at all test sites for the first three years of the test, then at three of these sites over the next 3 years.

Chloropicrin content in the poles was also assessed for the first 3 years after treatment by removing increment cores from 3 sites around the poles, 0.3, 0.6, and 1.2 m above the groundline. An additional core was taken 150 mm below the groundline on one side of the pole directly below the highest treatment hole. The results from these assays have already been presented (Bernstein et al., 1998) and showed that the chemical moved at fungitoxic levels into the wood, despite the slower release rate. We have continued to monitor ampule weights at several sites when other activities bring us near the lines.

Chloropicrin release rates

Chloropicrin release rates varied from as little as 0.60 to 2.35 g per month, depending on location (Table I-8). Release rates were fastest at the Galveston, Texas site, reflecting the warm, humid conditions that are prevalent at this site for much of the year. Chemical release was slow in poles at the Oregon, Indiana, and Missouri sites as well as in one species of poles at the New York site. The Oregon site is a drier location with widely fluctuating temperatures. Climatically, it is very similar to the Colorado site and we were surprised by the differences in release rates between these two sites. Release rates were generally similar between the New York, New Jersey and Pennsylvania sites (with the exception of the cedar and pine poles in New York). These similarities reflect the close proximity of the test sites which are within 100 miles of each other.

Chloropicrin release rates appeared to vary between species at a given site, but the differences were not consistent. The lack of consistency implies that other factors such as initial treatment, pole age or microclimate may be affecting release rates. As a result release rate data should be used cautiously for predicting retreatment cycles

Continued monitoring of ampules in poles at the Oregon, Colorado and Texas sites shows that the chemical continued to diffuse at a steady rate (Figure I-13). Ampules at the Galveston site were nearly empty after 4 years, while those in Oregon and Colorado still contain considerable quantities of chemical.

Table I-7 Locations and characteristics of poles used to evaluated a controlled release chloropicrin formulation at 10 sites across the U.S.

Location	Pole Species	Age of pole (Years)	Pole type
Lapine, Oregon	26 western redcedar 19 Douglas-fir	47	Transmission
Liberty, New York	15 Douglas-fir 15 Western redcedar 15 Southern pine	20	Transmission Distribution
Sterling, Colorado	45 Douglas-fir	20	Transmission
Galveston, Texas	19 Douglas-fir 23 Southern pine	15 to 36	Transmission Transmission
Charlotte, NC	45 Southern pine	17 to 50	Distribution
Chattanooga, Tennessee	45 Southern pine	9 to 46	Transmission
Edison, New Jersey	30 Southern pine	N/A	Distribution
Philadelphia, Pennsylvania	45 Southern pine	14 to 39	Distribution
St. Louis, Missouri	45 Southern pine	17 to 52	Distribution
Merrillville, Indiana	35 western redcedar 10 Southern pine	14 to 38	Transmission Transmission

The release rate data clearly show that chloropicrin will move rapidly from ampules in more tropical climates and implies that the retreatment cycle will be correspondingly shorter. This trend differs little from that found with liquid fumigants and reflects both the higher biological hazard and more rapid diffusion of chemical under warmer temperatures.

Future Trends

The results indicate that chloropicrin readily moved from the ampules and into the surrounding wood over a three year period. Except at the Texas site, all of the ampules still contained chloropicrin 3 to 6 years later and should release chemical for an 4 to 5 additional years. Once the chemical release is completed, it will be essential to sample these poles as the chloropicrin continues to diffuse from wood and eventually declines below a toxic threshold. Based upon current data, our results suggest that a 5 to 10 year release rate coupled with 3 to 5 years for the chemical to diffuse from the wood should produce a minimum protective period of 8 to 15 years. Previous studies have also shown that reinvasion by decay fungi is relatively slow; taking 3 to 5 years in some instances. The exception to these assumptions is the Texas site, where the release occurred much more rapidly. Determining appropriate retreatment rates for this site will require additional sampling to more accurately characterize loss and reinvasion rates.

Table I-8 Release rates of chloropicrin from ampules placed in Douglas-fir, western redcedar or southern pine poles at 10 field test sites located across the United States.

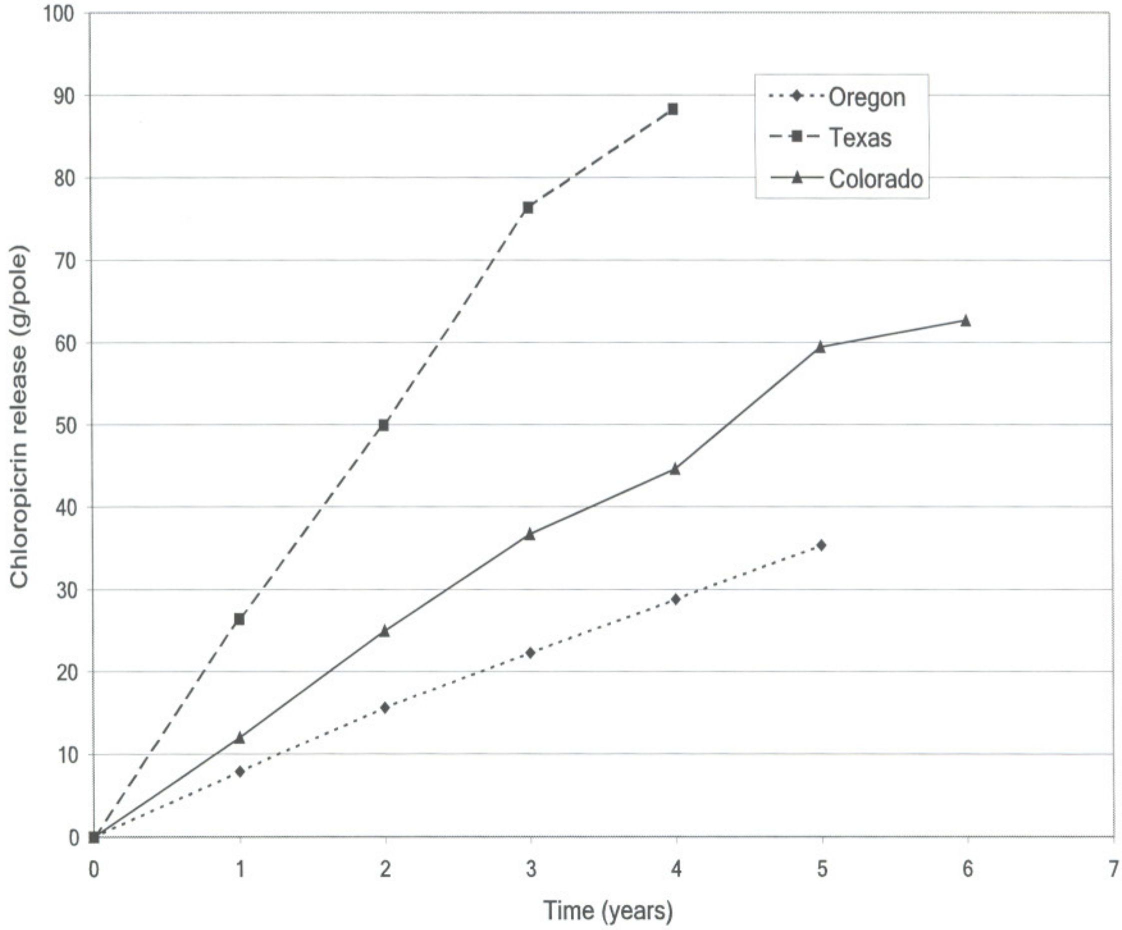
Site	Species	# Poles	Average Fumigant Release/pole/month (g)					
			0-12	12-24	24-36	36-48	48-60	60-72
Oregon	WRC DF	26 19	0.66 0.65	0.66 0.66	0.56 0.51			
New York	WRC DF SYP	15 15 15	0.60 0.83 0.59	0.65 0.97 0.66	0.81 1.12 0.81	- - -	- - -	- - -
Colorado	DF	45	1	1.09	1.06	0.91	1.07	1.14
Texas	DF SYP	19 23	1.82 2.51	1.96 2.08	1.67 2.12	0.56 0.67	- -	- -
N. Carolina	SYP	45	1.16	1.27	-	-	-	-
Tennessee	SYP	45	1.11	1.21	1.16	-	-	-
New Jersey	SYP	30	0.96	1.02	0.9	-	-	-
Pennsylvan ia	SYP	45	0.9	0.92	0.9	-	-	-
Missouri	SYP	45	0.64	0.73	0.72	-	-	-
Indiana	WRC SYP	35 10	0.60 0.63	0.61 0.64	0.72	- -	- -	- -

One aspect of the ampules that has raised considerable concern among potential users is the long time period in which the liquid chemical remains in the ampules. While slow release was the original goal of this project, the longer the liquid remains in the pole the greater the risk that the pole may be struck by a vehicle or otherwise fail. While the ampules have been shown to be capable of resisting impacts and crushing, no design could make the ampules completely tamper proof. One alternative may be to select alternative polymers that allow for more rapid release of chemical following application. Thus, utilities could take advantage of the exceptional application safety of the system while avoiding the long term risk.

B. Performance of Water Diffusible Preservatives as Internal Treatments

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

Figure I-13 Chloropicrin release rates from ampules installed in poles in Texas, Oregon and Colorado.



Boron has a long history of use as an initial treatment of freshly sawn lumber to prevent infestations by various powder posts 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 the groundline and this moisture can provide the vehicle for boron to move from the point of application to wherever decay is occurring. 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, the boron is released as the rods come in contact with free 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 has a slightly higher toxicity profile than boron and it can be corrosive to metals. Sodium fluoride is also formed into rods for application, although the rods contain less chemical per unit area than the boron rods.

Both of these chemicals have been available for remedial treatments for several decades, widespread use of these systems 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 data on performance on U.S. species used for utility poles.

1. <u>Performance of fused boron rods in Douglas-fir pole sections</u>:

   The field tests evaluating fused borate rods in Douglas-fir pole sections were evaluated two years ago 10 years after treatment and the 12 year data will be presented next year. Boron levels in the various treatments were at or slightly above the threshold at or below the treatment holes, but there was little evidence of upward movement after 10 years. Levels after 10 years had declined to the point where retreatment would be advisable. These poles will be inspected in 2002.

2. <u>Performance of fluoride rods in Douglas-fir poles</u>:

   The test to evaluate sodium fluoride rods in Douglas-fir poles was last sampled in 2000 (5 years after treatment) and is not scheduled to be sampled until the summer of 2002. The results to date indicate that fluoride levels generally remained below the accepted threshold for fungal protection (based upon previous soil block tests) but near our laboratory determined threshold levels .

3. <u>Effect of voids on movement of remedial treatments in above ground locations of Douglas-fir poles:</u>

   Voids in poles pose an especially vexing problem to utilities. While large voids can generally be detected using conventional sound and bore techniques, arresting existing fungal attack and preventing renewed colonization can be difficult. This is particularly true when cavities are located some distance above the groundline. In most cases the void is connected to the surface through a check. As a result, application of traditional internal liquid void treatments could result in contamination of the area surrounding the pole as well as to the applicator.

   One alternative to the traditional liquid internal treatments is to apply either water or gas diffusible internal remedial treatments above and/or below the void and allow these materials to diffuse across the void. This reduces the risk of environmental contamination or worker exposure.

   In previous trials, we created simulated voids in Douglas-fir pole sections and then treated below the voids with either MITC or chloropicrin. The results showed that both chemicals were capable of diffusing across the void at levels that would produce effective fungal control. While these data were promising, they were also criticized because they were not produced using natural voids. Efforts to locate test poles with suitable voids have proven difficult, owing to the inability to accurately assess the size of the void without extensive sampling that could alter subsequent chemical movement. This past year, we obtained poles from the Portland General Electric system that had been removed from service. We used these poles to determine if sufficient moisture is present in the above ground portions of Douglas-fir poles to allow for boron, fluoride, or copper diffusion or dazomet decomposition to methylisothiocyanate.

Twenty one Douglas-fir, 2 western redcedar, and 1 ponderosa pine pole in the Portland General Electric system were inspected. Six were found to have substantial above ground decay pockets. Each pole was cut to a length of approximately 8 m and removed from the ground for transport to a site near Salem, Oregon.

While on the ground, each pole was thoroughly inspected to characterize the location and size of the void. The poles were divided into four groups of six poles each. Each group contained at least one pole with a void.

The poles in each group were treated with three rods applied to three 20 mm diameter holes drilled above and below the void.

Each pole received 3 rods applied to 3 horizontal holes drilled around the pole at the top and bottom of the void, or if no void was detected, the 3 holes were drilled 1 m apart. The rods evaluated were fused borate rods (Impel Rods), copper/boron rods (Cobra Rods), fluoride rods (Flurod), and basamid (Ultrafume).

The treated poles were set in a spacing that permitted easy access around each pole. Two poles from each treatment group were removed 12 months after treatment. The treated section was cut from the pole and split with wedges. Each exposed surface was sprayed with the appropriate indicator. Poles treated with the copper/boron rods had one exposed face sprayed with chrome azurol S, a copper indicator and the other with the boron indicator. The sprayed surfaces were photographed. Then the percentage of area between the 2 sets of treatment holes stained by the indicator was measured by counting squares in a 2.5 cm grid.

Poles treated with basamid rods were sampled by removing increment cores from three equidistant locations around each pole 300 mm above and below the treatment sites. The outer, treated shell was discarded, then the inner and outer 25 mm of the remaining core were placed into 5 ml of ethyl acetate, and extracted for 48 hours. The resulting extract was analyzed for MITC by gas chromatography since there is no indicator for MITC. The extracted cores were oven-dried and weighed. MITC content in the poles was expressed on a ug MITC oven-dried g of wood basis.

The first 6 months of the exposure were during the drier summer months when very little movement of chemical would be likely to occur. The remainder of the first year of exposure was an average rainfall period at the test site. Boron and fluoride both diffused between the two points of application in the poles within one year after treatment (Figure I-14 to16), although the degree of movement was variable. For example, fluoride movement from the Flurods differed by ten fold between the two poles sampled, while boron levels in the Cobra rod treated poles differed by a factor of 7 (Table I- 9). Interestingly, copper movement appears to be slightly better than boron movement in this poles, a finding that contradicts prior work. The results indicate that diffusion of the boron or fluoride into the wood remains variable in above ground locations. Examination of the rods removed from the treatment holes showed that all had experienced some degree of degradation, but a majority of the originally applied material remained in the treatment hole (Figure I-17). The condition of the rods suggests that additional diffusion is likely as moisture conditions once again become favorable.

MITC concentrations in poles receiving basamid rods also varied widely (Table I-10). One pole contained chemical levels that would meet or exceed the threshold for fungal protection, while the other has levels that were only 20 to 50 % of the threshold. Basamid tends to decompose more slowly than other fumigants and this rate of decomposition is tied to the levels of moisture present in the wood. The long drying periods typically found above the groundline clearly affected MITC levels in these poles much in the same was as it affected the diffusion of the boron and fluoride.

These results must be viewed cautiously since they represent a limited sample taken early in the treatment cycle. Additional poles will be sampled in the coming year to further delineate the rate of chemical movement in the above ground portion of the poles.

Figure I-14 Degree of fluoride movement in Douglas-fir pole sections treated with fluoride rods in three holes drilled around the pole at two locations one meter apart as determined using an indicator which turns yellow in the presence of fluoride.

Figure I-15 Degree of boron movement in Douglas-fir pole sections treated with fused borate rods in three holes drilled around the pole at two locations one meter apart as determined using an indicator which turns red in the presence of boron.

Figure I-16. Degree of boron and copper movement in Douglas-fir pole sections treated with fused borate/copper rods in three holes drilled around the pole at two locations one meter apart as determined using indicators that turn red in the presence of boron or green in the presence of copper.

Figure I-17 Condition of fluoride, fused borate, and copper/borate rods removed from poles one year after application.

Table I-9 Degree of fluoride, boron or copper movement from remedial treatment rods applied to Douglas-fir pole sections and exposed for one year near Salem, Oregon.

Original Treatment	Rod Treatment	Degree of Treatment (% of area)			
		Area (cm^2)	Fluoride	Boron	Copper
DF-Penta	Impel	2530	-	31	-
DF-Creosote	Impel	1860	-	64	-
WRC- Penta	Cobra	1390	-	4	18
DF-Penta	Cobra	1860	-	30	25
DF-Penta	Flurod	1860	47	-	-
WRC Creosote	Flurod	1860	4	-	-

Table I-10 Residual MITC content in Douglas-fir poles one year after application of basamid above and below the sampling zone.

Original Treatment	Residual MITC Content (ug/g of wood)			
	0.3 m		0.7 m	
	inner	outer	inner	outer
Creosote	9.4 (8.5)	0	8.4 (7.3)	4.5 (7.7)
Penta	52.9 (9.2)	20.8 (20.3)	54.5 (19.2)	13.3 (12.1)

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Objective II

IDENTIFY CHEMICALS FOR PROTECTING EXPOSED WOOD SURFACES IN POLES

Preservative treatment prior to installation provides an excellent barrier against fungal, insect, and marine borer attack, but this barrier only remains effective as long as it is intact. Deep checks that form after treatment, drilling holes after treatment for attachments such as guy wires, cutting poles to height after setting and heavy handling of poles that results in fractures or shelling between the treated and untreated zone can all expose untreated wood to possible biological attack. The Standards of the American Wood Preservers' Association currently recommend that all field damaged to treated wood be supplementally protected with solutions of copper naphthenate. While this treatment will never be as good as the initial pressure treatment, it provides a slight barrier that can be effective above the ground. Despite their merits, these recommendations are often ignored by field crews who dislike the oily nature of the treatment and know that it is highly unlikely that anyone will later check to confirm that treatment has been properly applied.

In 1980, The Coop initiated a series of trials to assess the efficacy of various field treatments for protecting field drilled bolt hole, for protecting untreated western redcedar sapwood and for protecting untreated Douglas-fir timbers above the groundline. Many of these trials have been completed and have led to further tests to assess the levels of decay present in above ground zones of poles in this region and to develop more accelerated test methods for assessing chemical efficacy. Despite the length of time that this Objective has been underway, above ground decay and its prevention continues to be a problem facing many utilities as they find increasing restrictions on chemical usage. The problem of above ground decay facilitated by field drilling promises to grow in importance as utilities find a diverse array of entities operating under the energized phases of their poles with cable, telecommunications and other services that require field drilling for attachments. Developing effective, easily applied treatments for the damage done as these systems are attached can lead to substantial long term cost savings and is the primary focus of this objective.

A. Evaluate Treatments for Protecting Field Drilled Bolt Holes

The test to evaluate field drilled bolt holes was inspected last year after 20 years of exposure. This test is largely completed, although some follow-up inspection to assess residual chemical levels around bolts in specific poles is planned.

B. Develop Methods for Ensuring Compliance With Requirements for Protecting Field-Damage to Treated Wood.

While most utility specifications call for supplemental treatment whenever a hole or cut penetrates beyond the depth of the original preservative treatment, it is virtually impossible to verify that a treatment has been applied without physically removing the bolt and inspecting the exposed surface. Most line personnel realize that this is highly unlikely to happen, providing little or no motivation for following the specification.

Given the low probability of specification compliance, it might be more fruitful to identify systems that ensure protection of field damage with little or no effort by line personnel. One possibility for this approach is to produce bolts and fasteners that already contain the treatment on the threaded surface. Once the "treated" bolt is installed, natural moisture in the wood will help release the chemicals so that they can be present to inhibit the germination of spores or hyphal fragments of any invading decay fungi.

The potential for these treatments was evaluated using both field and laboratory tests. In the laboratory tests, bolts were coated with either copper naphthenate paste (Cop-R-Nap) or copper naphthenate plus boron (CuRap-20) and installed in Douglas-fir pole sections which were stored for one or two weeks at 32 C. The poles were then split through the bolt hole and the degree of chemical movement was assessed using specific chemical indicators. Penetration was measured as average distance up or down from the bolt.

Penetration of copper from bolts coated with only copper naphthenate was 2 mm one week after treatment and not detectable after 2 weeks of exposure (Table II-1). These results suggest that the copper was largely unable to move from the rod into the wood. While limited movement might not pose a problem if the preservative created a sufficient barrier around the surface of the bolt hole, small checks or cracks could easily compromise this barrier. The inability of the copper to move into these cracks would largely negate the benefits of treatment. The inability to move with moisture into freshly opened checks also appeared to be one of the primary causes of failure for topically applied bolt hole treatments such as the pentachlorophenol in diesel oil treatment used in the original bolt hole test in Objective IIA of this report.

Bolts treated with the the copper/boron paste also had minimal copper penetration 1 week after treatment, but the depth of penetration increased markedly with a second week of exposure. Boron distribution proved more variable. Initially, boron movement appeared to be substantial, but samples exposed for 2 weeks tended to have much shallower boron penetration. These results suggest that measurement errors influenced the initial results. The boron indicator is very sensitive and even small amount of boron inadvertently smeared across the wood surface could lead to a positive result.

The preliminary tests suggested that the presence of a water diffusible component in the paste would be useful for providing deeper protection to the field damaged wood. For this reason, we established the subsequent field trial.

Table II-1 Degree of longitudinal penetration of copper or boron from rods coated with preservative paste and installed in Douglas-fir poles for one or two weeks.

Treatment	Exposure Period (weeks)	Chemical Penetration (mm)			
		Copper		Boron	
		Upward	Downward	Upward	Downward
Cop-R-Nap	1	2	2	-	-
	2	0	0	-	-
CuRap 20	1	2	2	36	42
	2	7	10	6	5

Galvanized rods (300 mm long by 12.7 mm in diameter) were coated along the center 200 mm with a layer of either 5 g of Cop-R-Plastic (copper/fluoride) or 3 g of CuRap 20 (copper/boron)(oven dry basis). The rods were oven dried (54 C), then painted with 2 coats of Plastidip (Figure II-1). One rod from each treatment was applied to each of 26 pentachlorophenol treated Douglas-fir pole sections that were exposed at the Peavy Arboretum test site. Selected poles were split lengthwise around the bolt hole one year after treatment and the average and maximum degree of diffusion of the each paste components was measured after the wood had been sprayed with the appropriate chemical indicator.

The average degree of copper penetration away from the rods tended to be small, ranging from less than 1 mm to 3 mm, while the maximum penetration of copper approached 30 mm in some samples (Table II-2). The copper naphthenate in the CuRap 20 formulation has some water solubility that should help it to move away from the rod, although it clearly did not have an enormous effect on movement.

Average boron and fluoride diffusion were also somewhat limited 1 year after treatment, although substantial diffusion was noted at some locations along the rods (Table II-2, Figures II-2,3). The relatively slow rate of diffusion might reflect, in part, the presence of the spray-on plastic coating. This coating was applied to protect the chemical prior to application since the dry chemical was prone to flaking during handling. We presumed that the plastic coating would be disrupted as the rod was driven into the hole and would also decompose in the presence of the oil. It is unclear if this, in fact, occurred, but the application of only one coat or the use of other less robust coatings might be prudent.

Figure II-1 Examples of galvanized rods coated with copper/boron and copper/fluoride pastes.

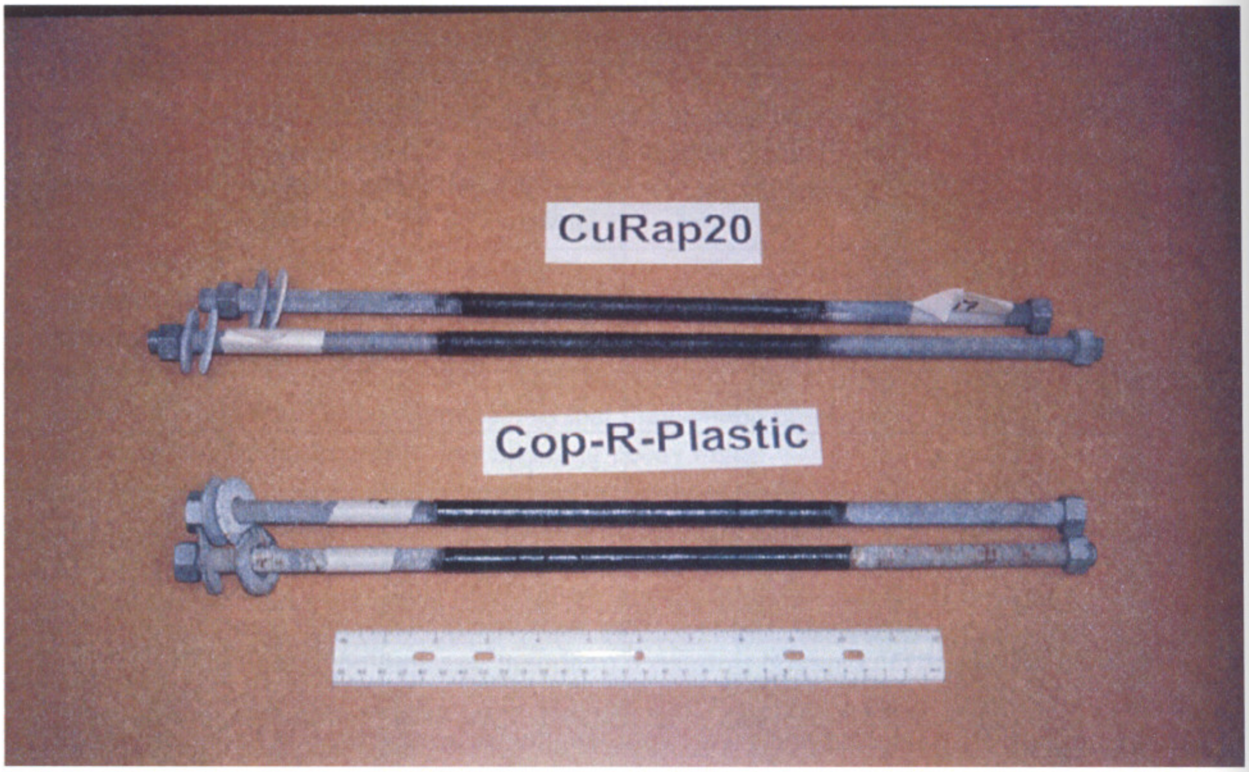


Figure II-2 Degree of copper and fluoride movement away from the sites in Douglas-fir poles where Cop-R-Plastic coated galvanized rods were installed one year earlier.

Figure II-3 Degree of copper and boron movement away from the sites in Douglas-fir poles where CuRap 20 coated galvanized rods were installed one year earlier.

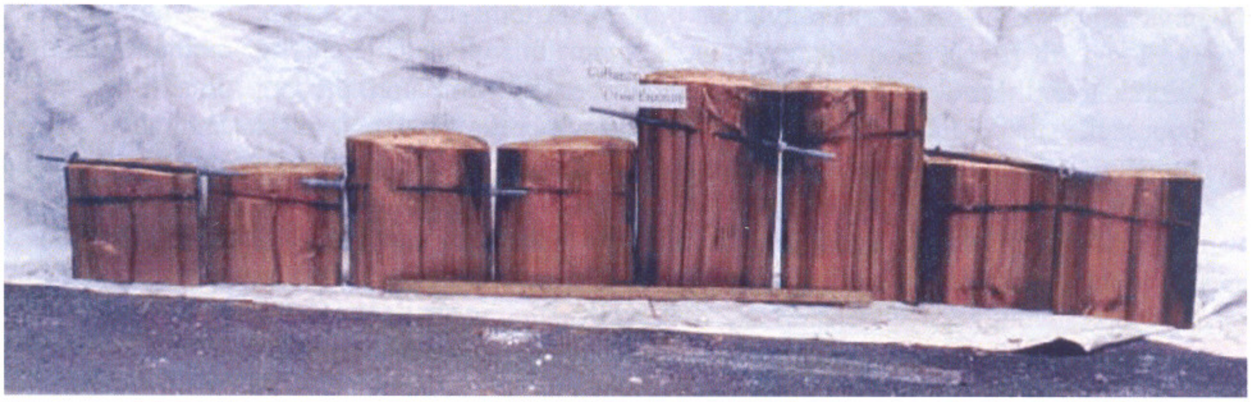


Table II-2. Degree of copper, boron , or fluoride diffusion from galvanized rods one year after installation in creosote treated Douglas-fir pole sections.

	Degree of Chemical Movement (mm)[a]	
Treatment	**Copper Average**	**Boron or Fluoride Average**
Cop-R-Plastic	<1	<1
CuRap 20	3 (1)	3 (1)

[a]. Value represent means, while figures in parentheses represent 1 standard deviation

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 would produce even greater investment savings for utilities. The goals of Objective III are to develop new treatment methods, explore the potential for new species, assess various inspection tools and explore methods for producing more durable wood poles.

A. Seasonal Moisture Content of Douglas-fir and Western Redcedar Poles

Moisture plays a number of important roles in the performance of wood poles. Wood is hygroscopic and will tend to sorb moisture from the surrounding air until it reaches an equilibrium moisture content (emc). In most environments where there is no potential for liquid water contacting the wood, the emc will range from 12 to 17 % (Peck, 1955). Wood will also sorb liquid water and it is this water which can have dramatic effects on both material properties and susceptibility to biodegradation.

Wood strength tends to decrease as the wood sorbs moisture until the moisture content approaches the fiber saturation point (the point where the wood cell wall has bound all the moisture it can, but no liquid water is present in the cell) (USDA, 1999). Wood properties do not change appreciably above this point. The moisture content of a pole can have important implications for line design, depending on the moisture assumptions. For example, utilities in the dry Great Basin Region of the Western U.S. could assume that a large percentage of their poles would be well below the fiber saturation point at or above the groundline and could assume that they have a stronger pole. This might allow them to use smaller poles for equivalent designs. This assumption is predicated on the hope that the pole never became wet, a risky assumption given our inability to control climate. Utilities could, however, use an understanding of moisture distribution in a pole along with finite element analysis of stress distribution to determine where wet or dry values are appropriate. Poles in utility systems in regions with higher precipitation will tend to have MC's above the fiber saturation point at or below ground for longer periods each year rendering this consideration moot. The American National Standards Institute Standards eliminate any possible interpretation of moisture regimes by requiring that utility designers use green design values (above the fiber saturation point), but it has not prevented this concept from being periodically raised by utilities.

A more important concern about in-service moisture contents is the role of moisture in decay. Nearly all wood degrading organisms require that the moisture content of the wood be at or above the fiber saturation point before substantial attack can occur (Zabel and Morrell, 1992). Water plays a number of important roles in the decay process: acting as a swelling agent that allows fungal enzymes to move through the wood, acting as a diffusion medium for both the enzymes and the breakdown products, and serving as a reactant in hydrolysis of the cellulose. Eliminating moisture is one of the most effective methods for preventing biodeterioration.

It is generally assumed that moisture contents in poles are above the fiber saturation point at or below the groundline, but that moisture levels decline sharply above this level. This premise does not appear to hold for poles exposed in wetter climates where poles experience considerable above ground decay (Schneider et al, 1998), but there are few studies of in-service moisture content. Forest Products Laboratory data showed that a majority of poles in the Midwest and the Western U.S. had moisture contents below 15 percent 0.15 and 1.2 m above the groundline, but the tests did not investigate moisture levels below the groundline nor did they specify the time of year when the measurements were made (Wood et al., 1960)

Graham (unpublished) examined moisture contents to a depth of 150 mm in 4 in-service poles over a 4 month period during the wet season in Oregon and found that average moisture contents above the groundline did not exceed 20 % and varied by no more than 3 %, even at the deepest sampling location. He also examined the moisture contents of an additional 13 poles that had been in service for 9 years and found average moisture contents increased from 9 to 18 % from 4 to 75 mm from the wood surface 0.6 m above the groundline. Although not directly related to poles, moisture measurements of Douglas-fir marine piling above the splash zone suggest that internal moisture contents are relatively low, ranging from 10 to 18 % inward from the wood surface in piling (Helsing et al., 1979). The low moisture levels found in these studies seem to contradict the presence of decay above the ground. One possible explanation for these anomalies is seasonal moisture cycling. Poles might be suitably wet for only a short period of time each year thereby limiting the times when fungal attack could be initiated. Once the moisture ingress ceases, the poles slowly dry out, leaving scattered moisture pockets that can support fungal growth, but no uniformly wet wood that would be most easily detected by random sampling. In order to better understand seasonal moisture distribution, we performed the following survey.

Ninety Douglas-fir and western redcedar transmission poles located in the mid-Willamette Valley of Western Oregon were selected for study (Table III-1). All poles had been in service for at least five years, which presumably allowed the poles to equilibrate to their in service moisture contents (Gilfedder and Keating, 1973). The moisture content of each pole was measured 12.5, 25, 50, and 75 mm from the wood surface at four cardinal directions around the pole at groundline, 0.3 m, and 1.2 m above groundline using a Delmhorst Model RC-1B moisture meter equipped with a 18-ED two-prong electrode. Manufacturer's correction factors were used to adjust moisture content readings for the two-prong electrode and ambient temperature. The meter was calibrated for use on Douglas-fir. Values published by Salamon (1972) were used to correct for western redcedar poles. The moisture contents were measured in June 2000, September 2000, December 200 and March 2001. Rainfall in the Willamette Valley typically averages 1125 mm per year, with most of that precipitation falling between October and May. Rainfall totals during the test period were abnormally low for the Valley and may have affected our results (Figure III-1).

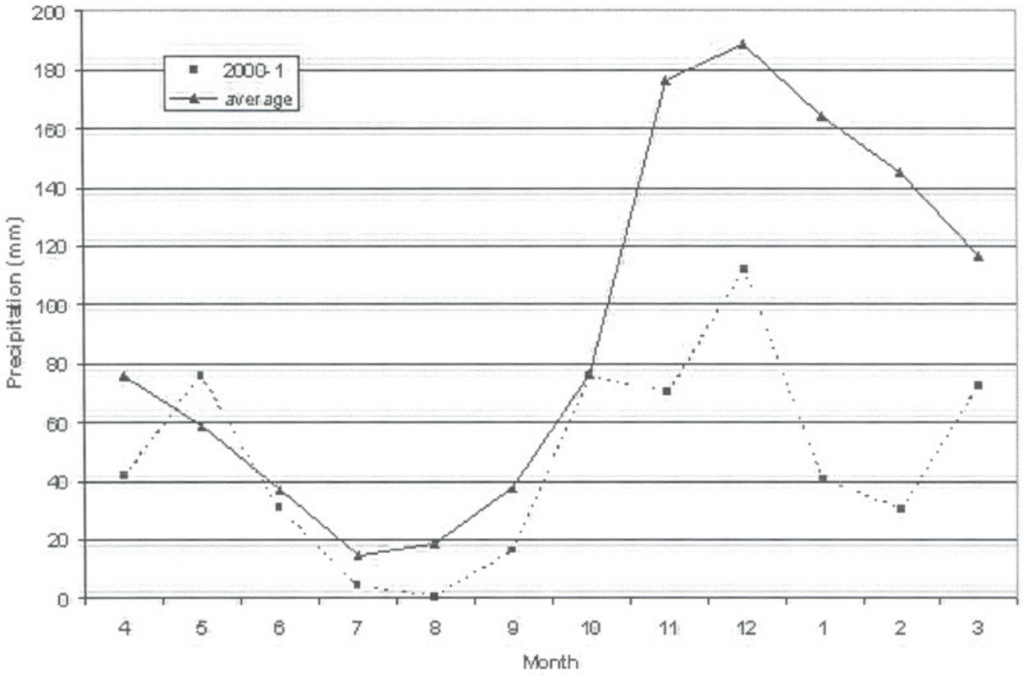
Average moisture contents of kerfed Douglas-fir poles ranged from 14 to 29 % in pentachlorophenol (penta) and 19 to 40 % at the groundline in creosote treated poles (Figure III-2). The moisture levels for both treatments tended to increase steadily from December to April, then declined (Figure III-3, 4) The reasons for the differences between the two treatments may reflect pole age; the creosoted poles were over 35 years old, while the penta treated poles had only been installed 5 years earlier. The older poles may have been more heavily weathered, creating more checks for moisture entry. Oil treatments should provide a barrier against water sorption, but checks in the poles that penetrate beyond this treated shell should largely negate the benefits of this barrier at the groundline. This effect is likely to be more of a problem under higher moisture regimes, such as those found in a normal rainfall year.

Table III-1 Characteristics of Douglas-fir and western redcedar poles used to study in-service moisture content.

Wood Species	Initial Treatment	Supplemental Treatment	Year Treated	Replicates
Douglas-fir	pentachlorophenol	kerfed	1995	10
Douglas-fir	creosote	kerfed	1966	12
Douglas-fir	pentachlorophenol	through-bored	1994-1996	6
Douglas-fir	creosote	through-bored	1981-1989	10
Douglas-fir	copper naphthenate	through-bored	1990-1992	7
Douglas-fir	creosote	deep-incised/kerfed	1966	1
Douglas-fir	pentachlorophenol	through bored/deep incised	1967-1979	5
western redcedar	pentachlorophenol (full length)	full length incised	1962-1966	5
western redcedar	creosote (butt)	butt incised	1938-1939	35

Moisture contents of creosote and copper naphthenate treated through-bored Douglas-fir poles were consistently lower than those found with kerfed or penta treated through bored poles (Figure III-5). The presence of oil throughout the cross section in through-bored poles should present a more formidable barrier to moisture ingress in these poles. Average moisture contents at groundline in through-bored creosote and copper naphthenate treated poles were all below 25 % indicating that conditions were not suitable for fungal attack in these poles (Figures III-6,7). Average moisture contents in many penta treated poles just exceeded 30 % seventy five mm from the surface, suggesting that oil used in this treatment might have been less water repellent, but that it still largely limited water ingress (Figure III-8). Average moisture contents above the groundline all declined to well below 30 %, suggesting that conditions were largely unsuitable for fungal growth above the groundline. The absence of substantial moisture pockets above the groundline, even at the end of the rainy season, implies that decay should be absent from these zones. However, many utilities in this region experience considerable above ground decay, particularly in larger, transmission poles (Morrell and Schneider, 1995). This decay is often initiated in small moisture pockets immediately adjacent to deep checks, Moisture meters would have a low probability of intersecting and detecting such small pockets.

Figure III-1 Monthly rainfall totals for the mid-Willamette Valley from March 2000 to March 2001 and the historical averages for each month.



Mean moisture contents of full-length treated western redcedar poles ranged from 28 to nearly 40 % at groundline and tended to increase in the wet season (Figure III-9). Moisture contents above the groundline decreased slightly 0.3 m above groundline and were all below 30 % 1.3 m above the groundline (Figure III-10). The exact moisture content required for fungal attack of western redcedar above ground is not known, but given the toxic nature of the heartwood of this species, it is likely that the risk of fungal colonization at lower moisture contents is probably far lower than would be found for less durable wood species. As a result, the risk of decay in the full-length cedar poles probably remains low despite the slightly elevated moisture levels.

Moisture contents of the butt-treated cedar poles were extremely high both at groundline and 0.3 m above this zone (Figure III-11). While moisture levels fell off sharply 1.2 m above the groundline, it is clear that moisture conditions nearer the groundline in these poles were well above those required for fungal attack. The poles sampled were older than the full-length treated poles and some had obvious internal and external decay, making it difficult to directly compare the two populations.

Western redcedar has a naturally durable heartwood that has proven to be extremely durable in pole applications, but our data suggests that butt treatments allow for markedly higher seasonal moisture levels. Elevated moisture levels are not, in themselves detrimental to the pole, but over time they could lead to higher rates of extractive loss that eventually permit invasion by decay fungi. Excessive moisture sorption and the resulting leaching of heartwood extractives could prove a serious concern in wetter regions, given the lack of external remedial treatment options for protecting the above ground portions of butt-treated western redcedar in service (Scheffer et al., 1988). Further evaluation of additional butt treated poles would help to better delineate this risk.

Figure III-2 Mean seasonal internal moisture contents at selected distances from the surface in kerfed Douglas-fir poles treated with a) pentachlorophenol, b) creosote, or c) deeply incised and creosoted.

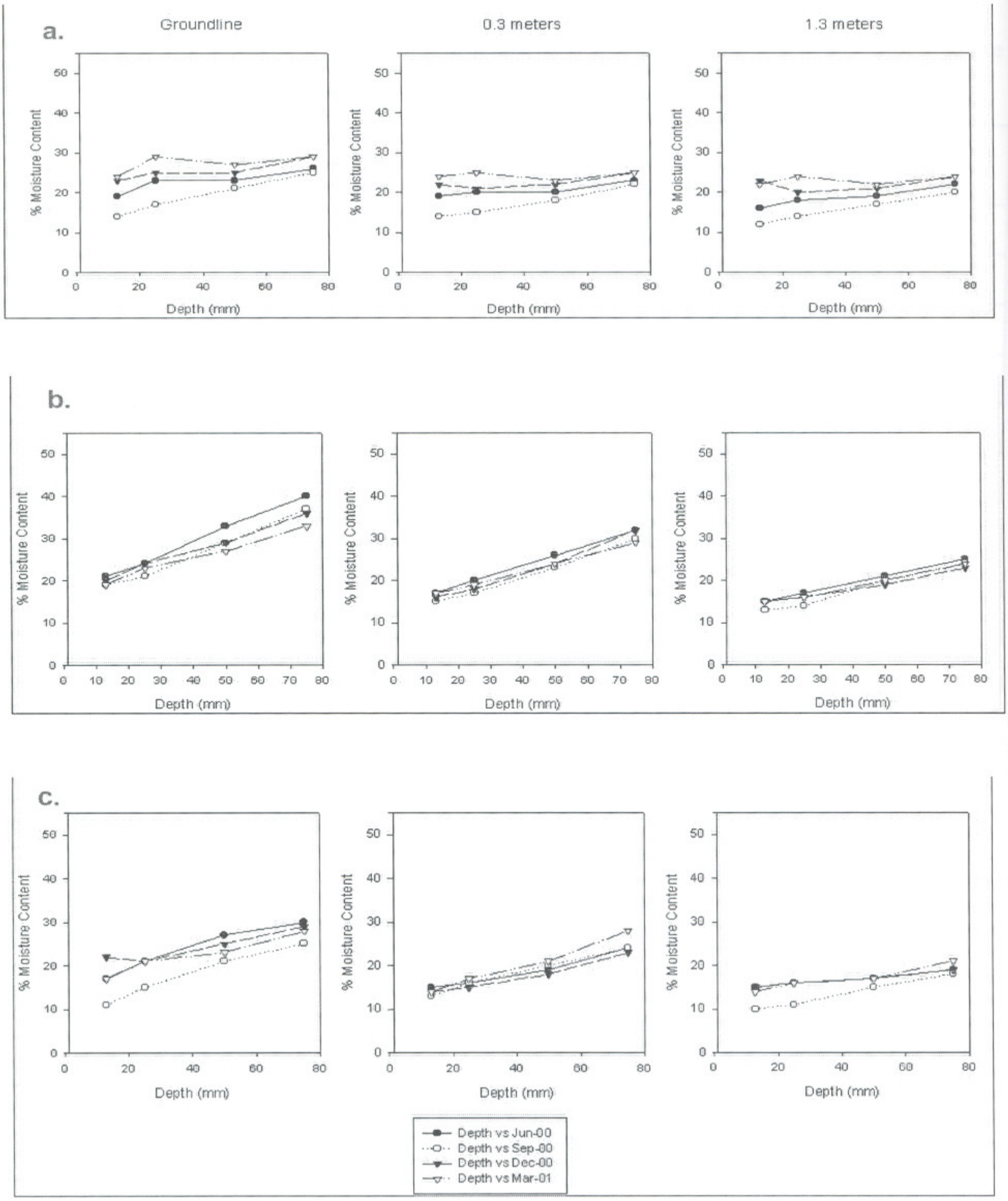


Figure III-3 Mean seasonal variation in wood moisture content in Douglas-fir poles that were kerfed prior to treatment with creosote and exposed in the mid-Willamette Valley of Western Oregon.

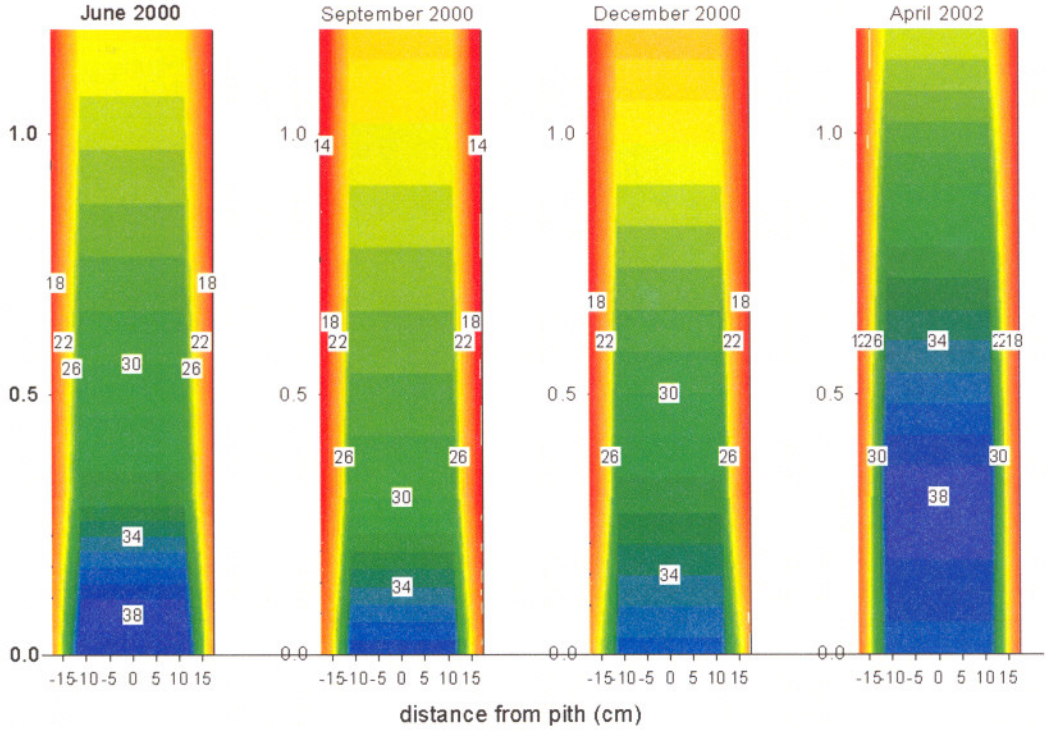


Figure III-4 Mean seasonal variation in wood moisture content in Douglas-fir poles that were kerfed prior to treatment with pentachlorophenol and exposed in the mid-Willamette Valley of Western Oregon.

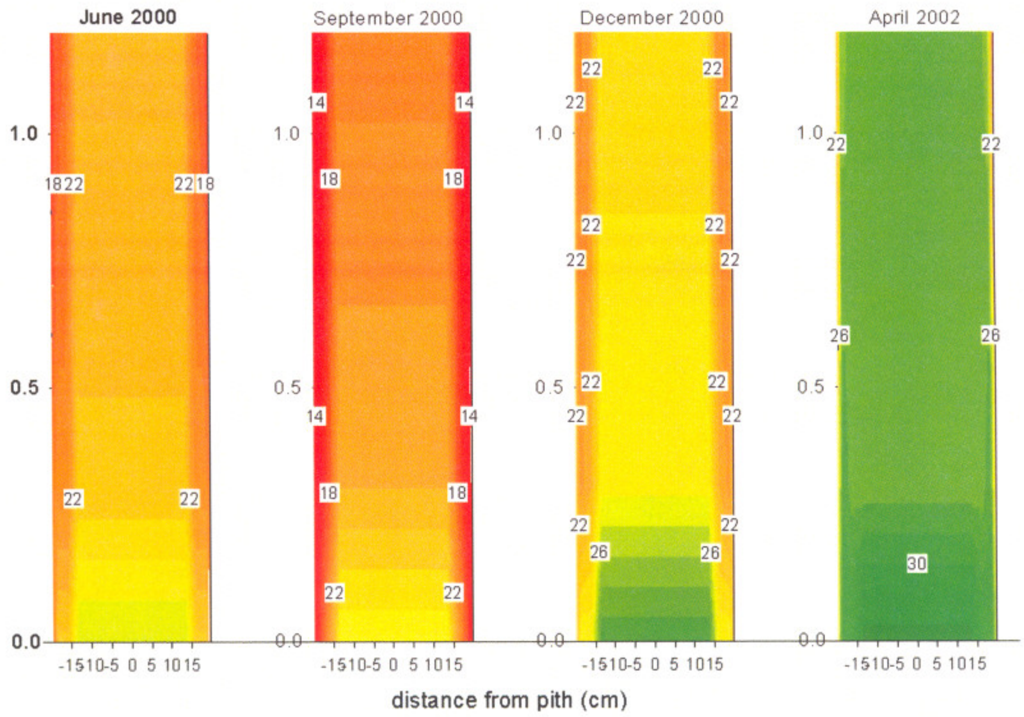


Figure III-5 Seasonal internal moisture contents in through bored Douglas-fir poles treated with a) pentachlorophenol, b) creosote, or c) copper naphthenate.

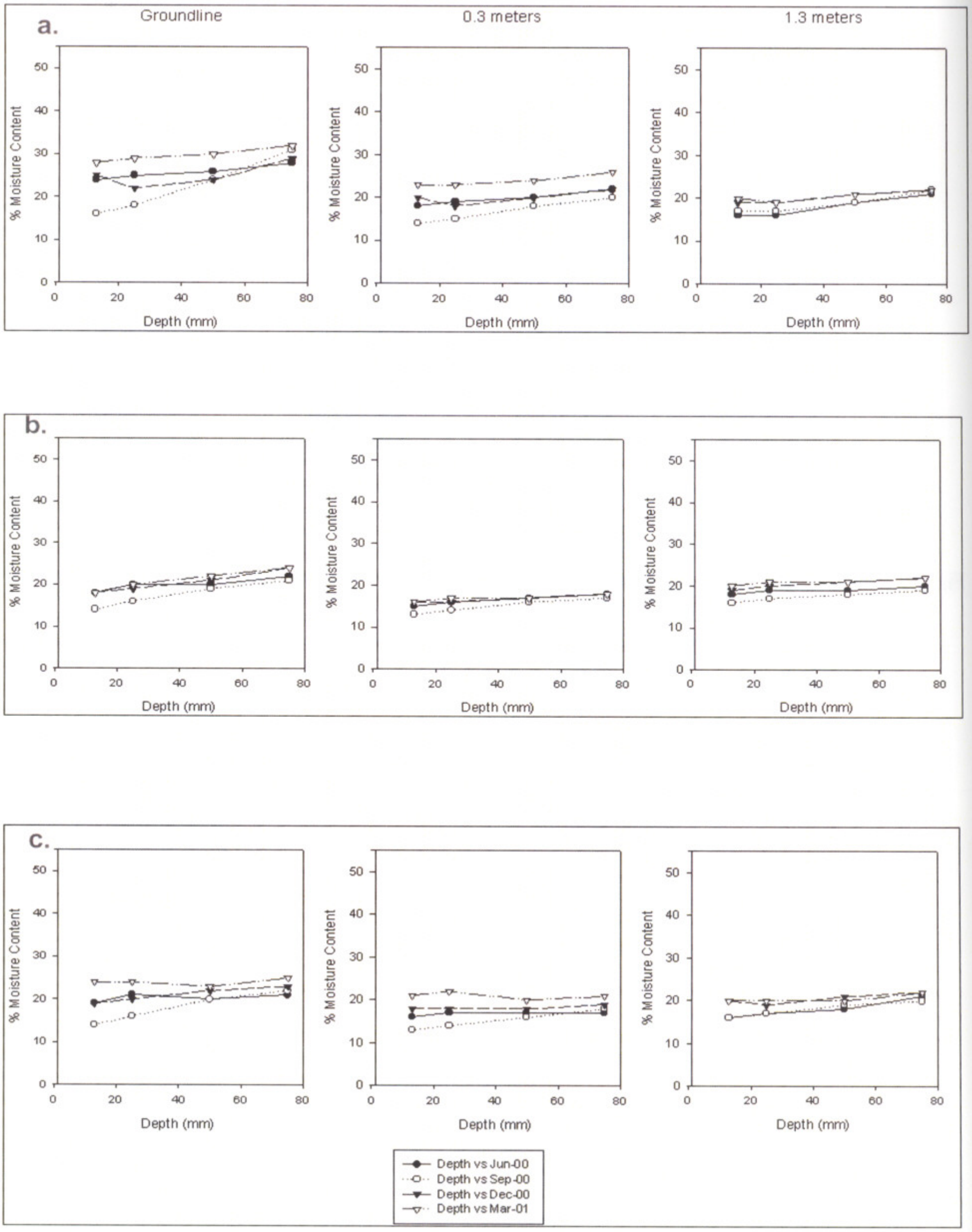


Figure III-6 Mean seasonal variation in wood moisture content in Douglas-fir poles that were through-bored prior to treatment with creosote and exposed in the mid-Willamette Valley of Western Oregon.

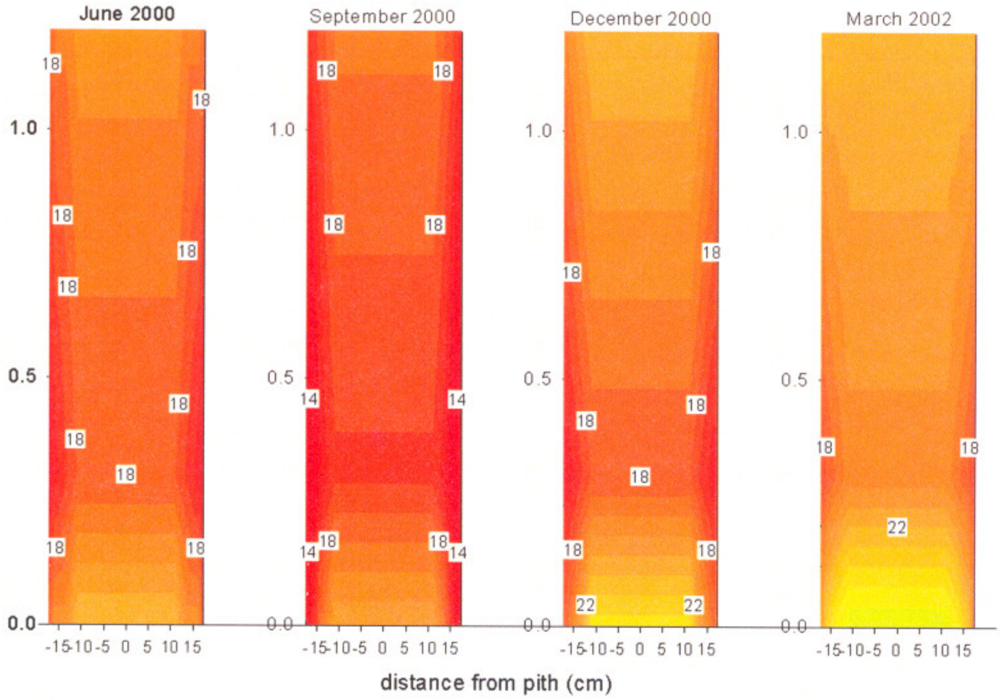


Figure III-7 Mean seasonal variation in wood moisture content in Douglas-fir poles that were through-bored prior to treatment with copper naphthenate and exposed in the mid-Willamette Valley of Western Oregon.

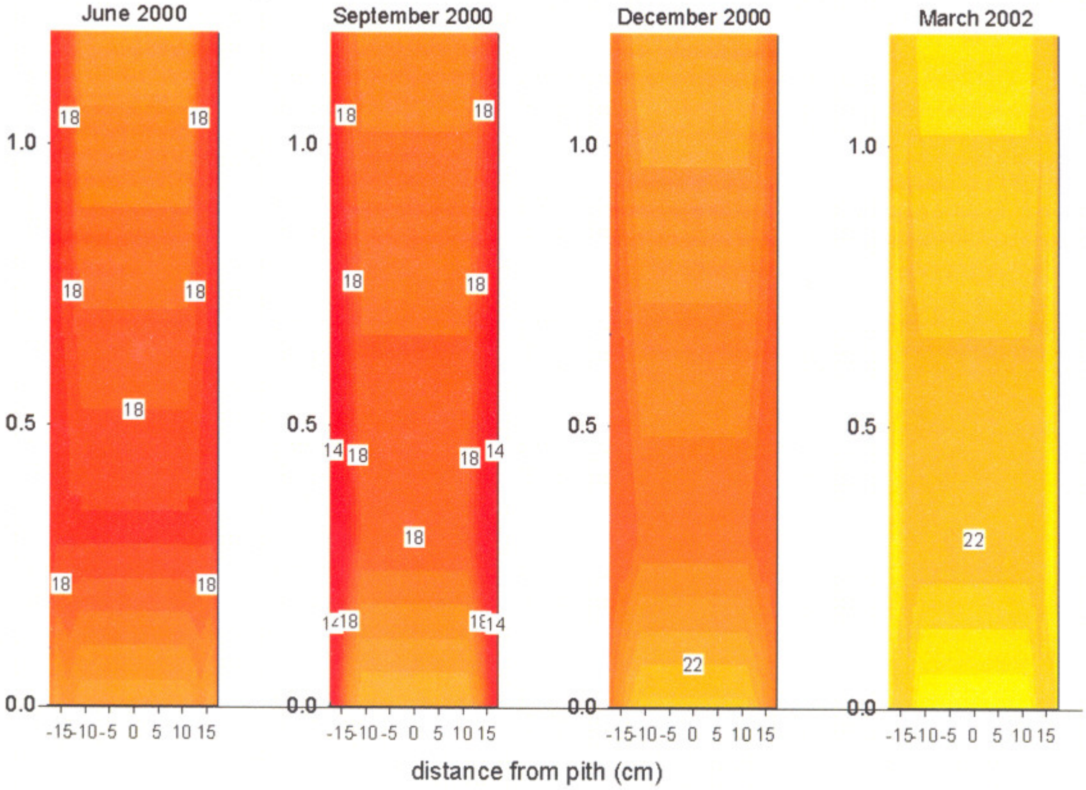


Figure III-8 Mean seasonal variation in wood moisture content in Douglas-fir poles that were through-bored prior to treatment with pentachlorophenol and exposed in the mid-Willamette Valley of Western Oregon.

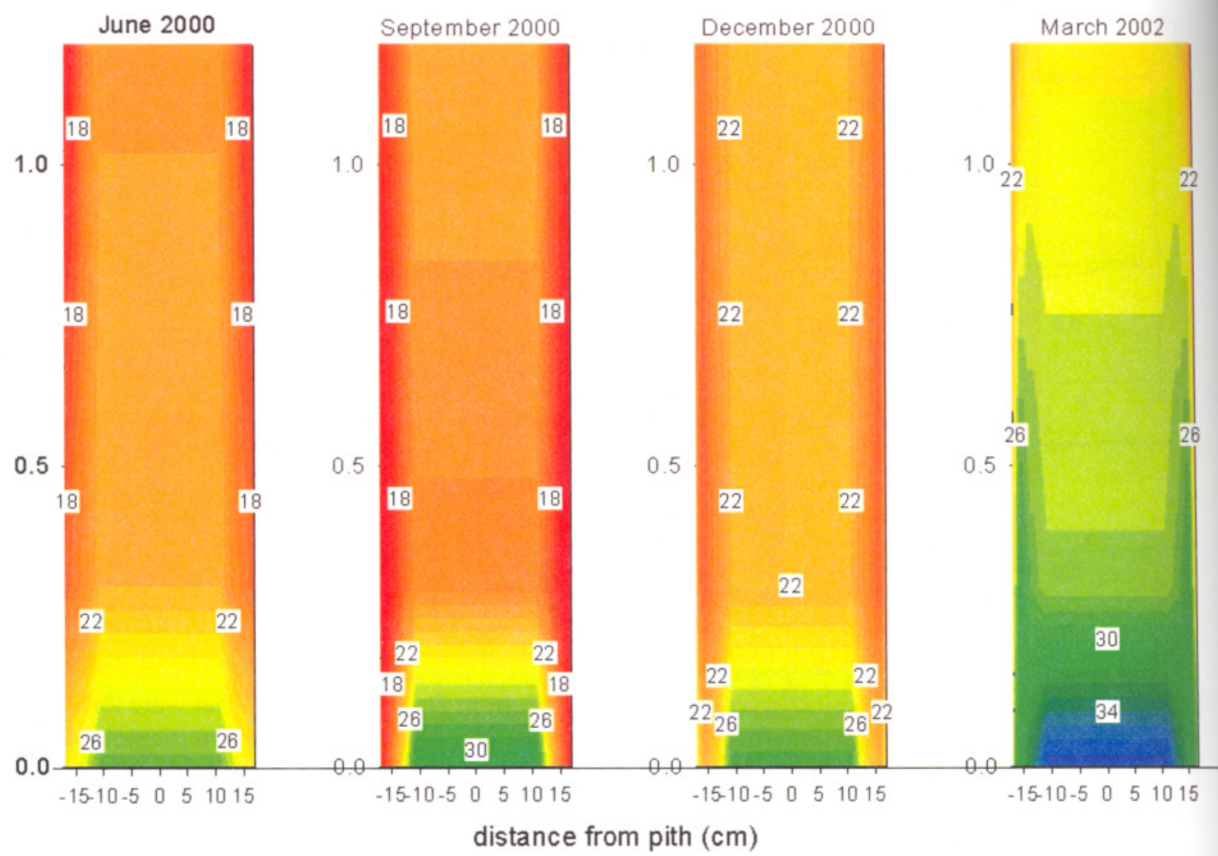


Figure III-9 Seasonal internal moisture contents in western redcedar poles that were a) full length treated with pentachlorophenol or b) butt treated with creosote.

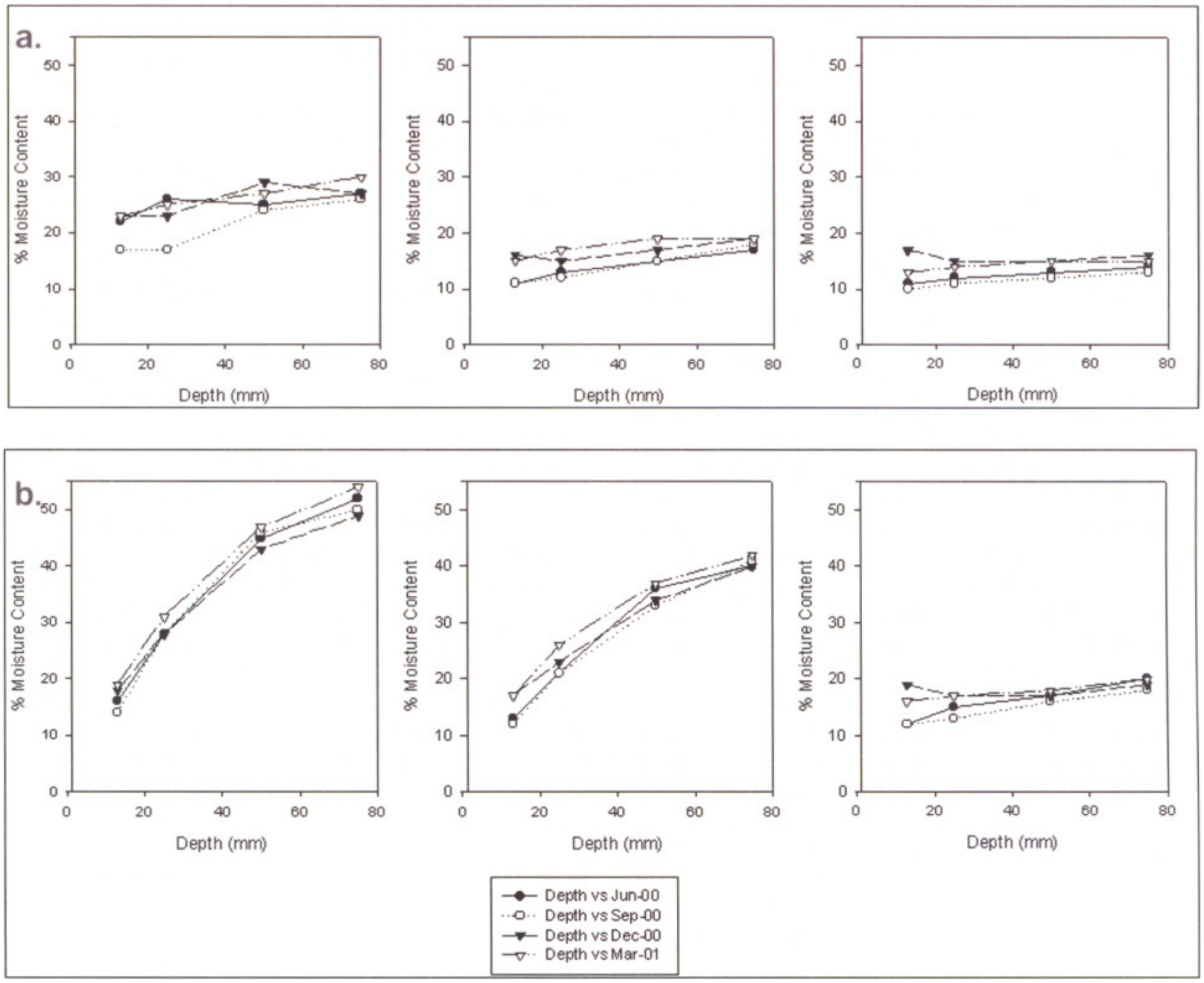


Figure III-10 Seasonal variation in wood moisture content in western redcedar poles that were full length treated with pentachlorophenol and exposed in the mid-Willamette Valley of western Oregon.

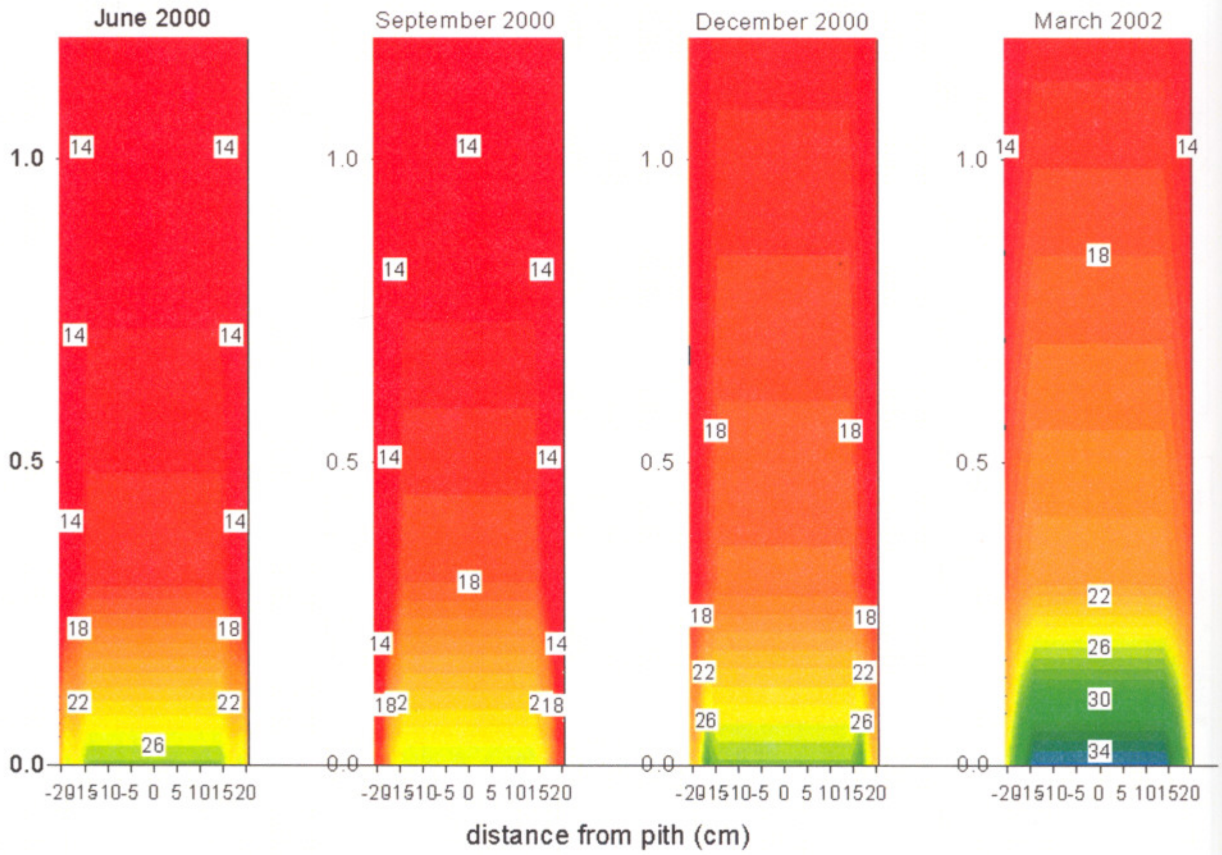
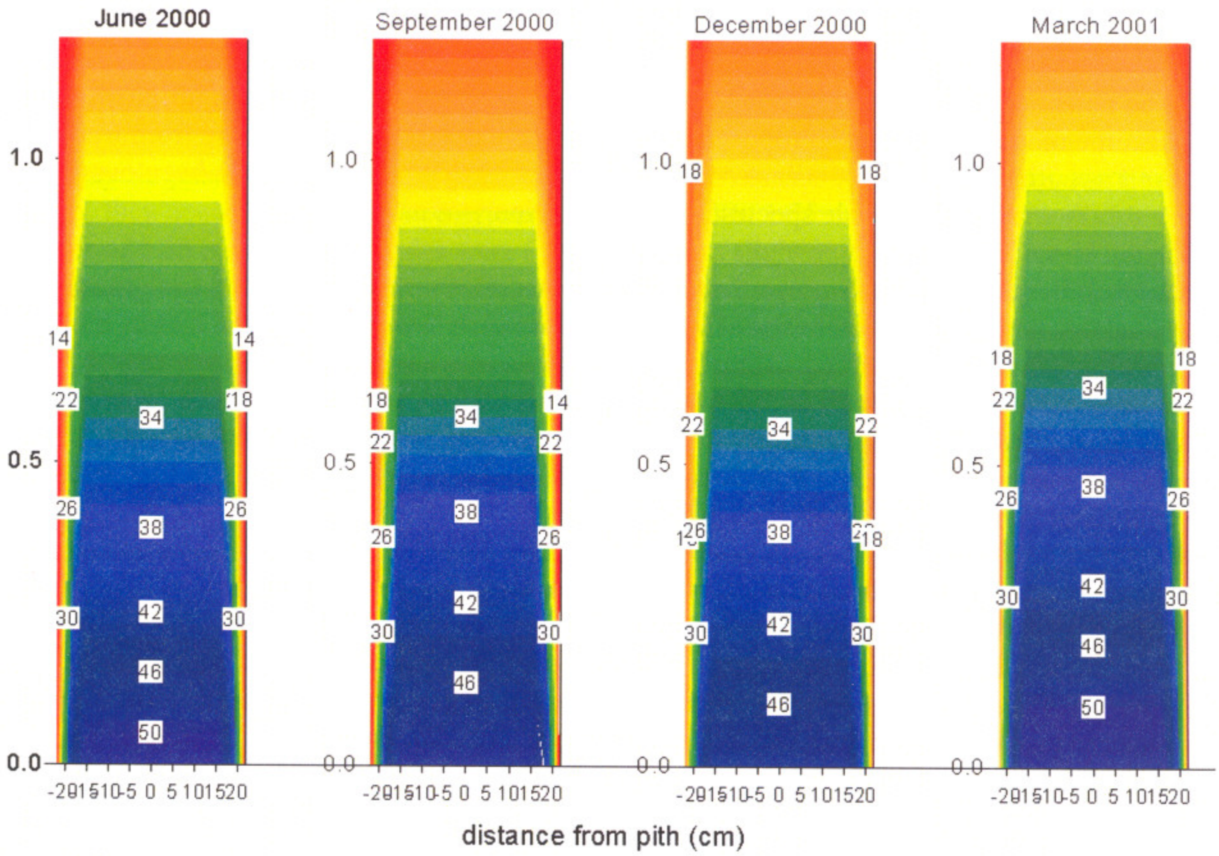


Figure III-11 Seasonal variation in wood moisture content in western redcedar poles that were butt treated with creosote and exposed in the mid-Willamette Valley of western Oregon.



Average moisture contents in most Douglas-fir poles were below the point where fungal growth can occur except nearer the groundline, where they were slightly above the fiber saturation point. Through bored poles tended to have lower moisture contents than kerfed poles, suggesting that the extra oil at the center of these poles served as a barrier against moisture sorption. Moisture levels were extremely high in butt-treated western redcedar, although the effects of these elevated moisture levels on pole service life are unclear.

B. Effect of Through Boring on Treatment and Material Properties of Lodgepole Pine

The specifications for utility poles are among the most stringent requirements for any forest product. The U.S. requirements for utility poles in American National Standard Institute Standard ANSI 05.1 sharply limit a variety of common wood features including the surface area occupied by knots, the growth rate of the wood, the width of checks, and stem form (ANSI, 1992). Despite these limitations, the ANSI Standard lists 16 species or species groups in its size tables. In general, however, the majority of wood poles are western redcedar, Douglas-fir and southern pine. These use-preferences reflect a combination of utility comfort and proximity to treatment facilities. These three species have provided excellent performance in terms of service life and reliability and a number of studies have shown that the high value obtained for poles in forest sales will continue to encourage availability. Underlying that supply, however, is the fact that utility poles from the major species tend to be among the most expensive logs removed from the woods. This higher cost per log can make wood less competitive in an environment that has an ever increasing array of competitors. One approach to addressing the issue of cost is to locate alternative species that could substitute for the major species in some markets.

The potential for substitute species has become of increasing importance as utilities seek to become more competitive. Proposals have been developed to use scots pine from Europe as well as native red pine in the eastern U.S. One species that appears to have been overlooked in this re-evaluation of pole species is lodgepole pine.

Lodgepole pine is found through the western United States and ranks as the forth most extensive timber type west of the Mississippi with nearly 748 million cubic meters of growing stock (Koch, 1996). The supply in Canada is even greater, totaling nearly 1.3 billion cubic meters. Much of this stock is in over-stocked, suppressed stands characterized by slow growth and high mortality. The risk of catastrophic fire in these stands has encouraged a major federal effort to identify markets for materials that would then encourage fuel reductions through forest manipulation.

While much of the material that might be removed in forest restoration projects is unsuitable for poles, there is clearly the potential for pole sales from many areas. Lodgepole pine has a number of characteristics that make it suitable for utility poles, particularly for distribution classes. The species has straight boles, minimum taper, and small knot diameters. While its material properties are similar to those for western redcedar, it is far less expensive.

Lodgepole pine has been used for decades in parts of the Great Basin Region of the western U.S. but has seen little use outside this region. Lodgepole pine poles show up in Rural Electrification Administration surveys and appear to have provided a reasonable service life in the drier regions of the country. One aspect that has probably limited interest in the eastern part of the U.S. is the treatment characteristics of this species. Lodgepole pine has a relatively thin sapwood layer surrounding a moderately durable heartwood core. As result, this species tends to be more difficult to treat and requires slightly longer treatment cycles than would be used for species such as the southern pines.

The limited sapwood creates the potential for the development of internal decay as fungal spores and moisture enter untreated wood exposed as the poles season in service. This situation is similar to that found with Douglas-fir poles; which are characterized by a thin shell of treated sapwood surrounding an untreated core. One method for reducing the risk of decay in critical zones of the pole is to through-bore prior to treatment. Through-boring results in nearly complete penetration in the drilled zone and largely eliminates the risk of internal decay at the groundline. Through-boring is used by most major utilities in the western U.S., and is increasingly used by others outside the region to enhance treatment in critical decay areas.

While through-boring has been used for over 40 years on Douglas-fir poles, there is little information on the use of this process on other species, including lodgepole pine. Presumably, through-boring should improve heartwood penetration without adversely affecting wood strength, but this effect may vary by species.

In this report, we describe preliminary tests to evaluate the effects of through-boring on preservative penetration and bending strength of lodgepole pine pole sections treated with creosote.

Lodgepole pine (*Pinus contorta*) pole sections (120 mm in diameter by 3 m long) were kiln dried, then coated with an elastomeric sealent from 0.3 to 1.35 m above the groundline. A series of 6.35 mm diameter holes were then drilled at a slight angle into one face of the poles beginning approximately 12.5 mm from one edge, then moving across 50 mm and downward 25 mm so that holes were spaced at least 75 mm apart longitudinally. The elastomeric sealant was used to limit surface penetration and concentrate penetration around the through-bored holes. An additional set of 20 pole sections was drilled using a 50 mm lateral spacing but a 150 mm longitudinal spacing. One additional set of posts was not drilled and served as the control. Each treatment was replicated on 22 pole sections.

The poles were subjected to pressure treatment where the wood was flooded in creosote and heated for 3 hours at 90 C. The oil was removed, and the wood was subjected to a 30 minute pressure period at 50 psi. The treatment solution was added, then the pressure was raised to 150 psi and held for 6 hours. Pressure was released and the solution was withdrawn. The poles were then subjected to a series of vacuums and steam periods to clean the surface and encourage solution recovery.

Following treatment, the pole sections were tested to failure in a four-point flexural test as described by Boughton and Crews (1996) and used by Crews et al. (1998). Load and deflection were continuously recorded. These data were used to calculate modulus of rupture at the location of maximum moment and modulus of elasticity for each pole. Pole sections were tested with the load applied either parallel or perpendicular to the direction of the through-boring. Following testing, the degree of preservative penetration around each through-bored hole was assessed by cutting a series of cross and longitudinal sections around each hole. The degree of preservative penetration around each hole was measured either vertically or radially (depending on the cut), and the percentage of surface area penetrated by preservative was estimated by placing a grid over the wood surface and counting the number of squares containing preservative treated wood. Longitudinal penetration was measured on poles not subjected to bending tests. These pole were ripped, lengthwise, then penetration was measured on the exposed face.

Material Properties: Nearly all of the pole sections failed in bending tension, although bending compression and shear were also observed failure modes in eight specimens. Two specimens failed at knot whorls. Material properties for the through-bored sections tended to be slightly lower than for those for the non-through-bored control poles.

Through boring had only slight effects on MOE. MOE of poles receiving the more dense through boring pattern was 87.9 % of the control while those receiving the more widely spaced pattern were 89.2 % of the control. In addition, poles receiving the more dense through-boring patterns and tested so that the force was applied perpendicular to the holes tended to have slightly lower MOE values. The potential losses in MOE may be of less importance if there is a corresponding increase in durability that limits the potential for strength losses in service.

The effects of through-boring on material properties were more apparent in the MOR data, where poles receiving the higher density of through-boring had MOR's that were 79.7 % of the control and those receiving the lower density were 88.9 % of the control. The effects were most apparent when the load was applied perpendicular to the holes (Table III-2). For example, MOR was 70 % of the control in pole sections with the higher density through-boring pattern when load was applied perpendicular to the holes and 89.4 % of the control when the load was applied parallel to the holes. This effect was somewhat reduced in the wider spacing, with MOR values 82 and 95.9 % of the controls when tested perpendicular and parallel to the holes, respectively. There are several important features that must be noted in assessing this data. First, the number of holes per unit area and the percentage of volume of wood removed are both much higher than from full size poles. This was necessary because smaller diameter drill bits would tend to drift more as the pole was drilled, making it more difficult to assess material properties. As a result, our through-boring patterns will tend to accentuate any strength effects in comparison with similar patterns on larger poles particularly with regard to the presence of through-boring holes within 50 mm of the poles surface. Despite these factors, our results indicate that there is some potential for a directional effect with through-boring. Crews et al. (1998) observed failures associated with inspection holes in 34 percent of the tests during an assessment of power poles removed from service in Australia. Most poles are framed so that the through-boring pattern is applied to the same face as the tag or brand along with any framing for cross arms and other attachments. Line crews will tend to place the tags in the line direction, thereby ensuring that nearly all of the through-bored poles are oriented with their holes parallel to the line direction. The presence of a directional through boring effect would suggest that it may be more suitable to orient through-boring on alternate faces in a charge to ensure that all of the poles are not oriented in line with through-boring in the same direction.

Preservative treatment: Preservative penetration was extremely variable in the sections (Table III-3). Longitudinal movement of creosote above and below the through-bored holes averaged 106 mm but the standard deviation was 57 mm, indicating a wide degree of variability in penetration. Penetration ranged from as little as 18 mm to 246 mm above and below the through-bored hole. The wide range in penetration suggests that it would be difficult to spread the through-boring pattern further to reduce any potential impacts on material properties or reduce framing costs.

Table III-2 Bending strength of lodgepole pine pole sections with or without through-boring.[a]

Through bore Pattern	Test Direction[b]	n	Maximum Force (kN)	Bending Strength (MPa)	E (MOR) Apparent (MPa)
none	-	22	37.1 (4.6)	94.1 (11.4)	32,118 (12,909)
Narrow	Parallel	11	34.0 (2.9)	85.1 (8.3)	29,771 (2,606)
	Perpendicular	10	26.9 (5.9)	65.9 (15.0)	26,681 (4,316)
Wide	Parallel	9	33.6 (9.1)	90.2 (15.3)	28,628 (4,335)
	Perpendicular	12	30.5 (3.4)	77.2 (8.4)	28,696 (2,079)

[a] Values represent means, while figures in parenthesis represent one standard deviation.
[b] Test direction denotes orientation to the through-boring direction

The degree of preservative penetration on a given cross section also varied widely. There appeared to be little meaningful difference in cross-sectional area treated between through-bored and non-through bored poles. Through-bored poles had 48 to 56 % of the cross section treated in the narrow spaced treatment and 43 to 48 % treated in the wider spacing. Non-through-bored poles had 51 to 54 % preservative penetration. The absence of improvement in preservative penetration was surprising, given the degree of observed end penetration; however, there was little evidence of substantial penetration radially from the through-bored holes. Radial penetration around the through-bored holes often extended no more than 3 to 4 mm from the hole. This limited degree of radial penetration suggested that through-boring patterns in lodgepole pine would need to be more closely spaced to produce complete preservative treatment. Complete preservative treatment, however, may not be necessary if a sufficient percentage of the cross section is treated and the remaining untreated zone is not exposed to the soil (Morrell and Schneider, 1994). The treatment results found with lodgepole pine differed markedly from those with Douglas-fir pole sections, where treatment often extended beyond 150 mm above and below a through-bored hole and 18 mm radially. Decreased radial penetration requires more closely spaced holes that should increase the number of holes in any given plane of the pole thereby increasing any potential strength effects.

Through-boring did not appear to markedly improve preservative treatment of lodgepole pine and induced negative strength effects, particularly when the loads were applied perpendicular to the holes. The results suggest that through-boring may not be appropriate for improving treatment of this species.

Table III-3 Preservative penetration of lodgepole pine pole sections with or without through-boring

Through-boring treatment	Reps	Cross Section Penetrated (%)[a]	
		Surface Open	Surface Sealed
None	23	54.7 (20.2)	51.4 (17.3)
Narrow	21	48.7 (14.1)	56.2 (14.2)
Wide	22	43.7 (17.7)	48.6 (17.2)

[a] Values represent means of 21 or 22 samples. Figures in parentheses represent one standard deviation

C. Performance of Ammoniacal Copper Arsenate Treated Douglas-Fir Poles

Ammoniacal copper arsenate (ACA) is a waterborne inorganic arsenical preservative that was developed at the University of California in the 1940's (Gordon, 1947; Fritz, 1947; Ott, 1947). This system has a number of advantages over acidic based waterborne preservatives such as chromated copper arsenate (CCA). First, the formulation lacks hexavalent chromium. The ammonia in this system is primarily used to solubilize the copper, but it also plays an important role in treatment, acting to swell the wood and dissolving extractives on pit membranes. These activities enhance wood permeability, making the wood more receptive to preservative treatment. As a result, ACA developed a market for treatment of refractory wood species, notably Douglas-fir on the West Coast of the U.S. where the treatment characteristics of CCA make it extremely difficult to obtain acceptable preservative penetration (Hartford, 1996).

ACA has generally performed well in a variety of field tests, but there is relatively little long term field performance data with this chemical. ACA was supplanted by an improved formulation, ammoniacal copper zinc arsenate, that replaced some of the arsenic with zinc (Morgan, 1989). While this reformulation was primarily driven by cost and a desire to reduce solution corrosivity, it also has an unintended benefit of enhancing fixation in wood (Lebow and Morrell, 1994). While ACA is no longer used, a considerable volume of material treated with this chemical remains in service. Included in this material are a large number of Douglas-fir poles installed in the Willamette Valley in Western Oregon between 1946 and 1950. Although records for treatment of these poles are unavailable, Gordon (1947) reported that poles treated several years earlier in the region received approximately 4.8 kg/m^3 of ACA on gauge salt retention basis. Morgan (1992) reported that ACA treated Douglas-fir poles in the Pacific Northwest performed at least as well as pentachlorophenol or creosote treated poles of the same species, but provided no specific condition data regarding residual preservative content or surface condition. Increasing numbers of older poles, including ACA, in utility systems have raised concerns about how these structures should be managed, but there are few detailed assessments of pole condition that would allow utilities to make more informed maintenance decisions. In a preliminary evaluation, we assayed four older ACA treated poles and found excellent preservative penetration and extremely low retentions, but little or no evidence of decay (Table III-4). This limited sample encouraged us to look more closely at older ACA treated Douglas-fir poles in Western Oregon.

Table III-4 Preservative penetration, retention and degree of fungal colonization in ACA-treated Douglas-fir poles.

Pole Class/Length	Retention (kg/m³)	Penetration (mm)	Age (Yrs)	Frequency of Decay $^{non-decay}$ (%)		
4-25	1.44	32.4	54	0^{100}	0^{63}	0^{63}
4-40	0.64	31.1	55	0^{100}	0^{70}	0^{60}
4-40	1.76	35.5	55	0^{90}	0^{90}	0^{100}
3-40	1.6	25.1	55	0^{90}	0^{80}	0^{67}

Thirty two ACA treated Douglas-fir poles were selected for inspection. The poles had been installed between 1946 and 1950 and had been subjected to 3 internal inspection cycles that consisted of drilling 3 or 4 holes beginning at groundline and moving upward approximately 300 mm and one third around the circumference. The holes were examined for evidence of decay, then used to apply one of two liquid fumigants, metham sodium or chloropicrin. In the most recent inspection, the poles received fumigants but also were also treated with a supplemental external preservative bandage.

Each pole was inspected by digging out three sides of the pole to a depth of 450 mm, then taking an increment core from each side 150 mm below the groundline. Additional increment cores were removed from 3 equidistant locations around each pole 0.3 and 1.2 m above groundline. The presence of external decay was noted, then the outer zones (0-6 mm) of each increment core were digested in a 50:50 mixture of acetic acid and 30 % hydrogen peroxide at 60 C for one hour to break up the fibers (Berlyn and Miksche, 1976). The fibers were then examined for evidence of soft rot attack and the percentage of fibers in each section that contained Type 1 soft rot attack (cavities) was estimated. Finally, the remainder of each core (6-25 mm) was assayed for residual ACA by x-ray fluorescence spectroscopy (XRF). An additional sample was then digested and analyzed by atomic absorption spectroscopy to confirm the XRF analyses. Finally, the remainder of each increment core was plated on 2 % malt extract agar and observed for the presence of basidiomycetes, a class of fungi containing many important wood decayers.

The poles were originally treated to a target retention of 4.8 kg/m³ (salt basis), although treatment practices at the time were largely dependent on gauge assays and post treatment quality control, particularly with regard to chemical assays, was rare (Scheffer, 1988). As a result, it is difficult to determine the actual initial retention. The poles were generally in excellent shape, a reflection of the regular maintenance and fumigant applications which each received. While fumigants can arrest internal fungal attack, fumigants appear to have little effect on attack of the pole surface by soil inhabiting soft rot fungi (Corden et al., 1988). The poles did not receive any supplemental external preservative until 1998, so the surface condition of the poles should reflect the protection afforded by the original preservative treatment.

Pole Condition: While a number of poles exhibited some evidence of surface softening, the damage did not extend for more than a few mm from the surface. Two poles, however, had much more extensive exterior decay suggesting more substantial surface depletion of preservative.

Evaluation of the outer 6 mm of cores removed from the three sampling heights revealed that soft rot cavities were present in 21 percent of the wood cells in cores taken below groundline (Table III-5). These results suggest that soft rot attack was beginning to exert a substantive surface effect on some poles. This attack, however, remained sporadic, as evidenced by the high standard deviation around the mean. Soft rot attack is a particular problem in poles because it exerts its effects near the surface, effectively reducing the cross sectional area.

The presence of soft rot attack in these structures suggests that excavation inspection and application of supplemental treatments may be advisable in older (>40 years old) ACA treated poles.

No basidiomycetes were isolated from increment cores removed from the 32 poles. This was not surprising, given the prior fumigant cycles to which the poles have been subjected. Recolonization of fumigant treated wood by decay fungi is generally slow and is believed to be affected by both residual chemicals and microfungi that colonize the wood (Helsing et al., 1984; Giron and Morrell, 1989). A variety of microfungi were isolated from the cores, but the roles of these fungi in pole performance remains largely undefined.

Table III-5 Incidence of soft rot attack in macerated cells removed from below groundline (GL) or 0.3 or 1.2 m above that zone.

Frequency of soft rot cavities (%)[a]		
0.15 m Below GL	**0.3 m above GL**	**1.2 m above GL**
22 (33)	11 (23)	6 (18)

a. Values represent mean of 98 values for the groundline, 33 for the 0.3 m sample and 35 for the 1.2 meter sample. Figures in parentheses represent one standard deviation.

Residual Preservative: Preservative penetration in the cores in the initial four pole sample was generally good, ranging from 25 to 35 mm and appeared to completely treat the sapwood. As mentioned earlier, one of the advantages of ACA is its ability to penetrate refractory wood species. Analyses of the AWPA assay zone for the first four Douglas-fir poles (6-25 mm from the surface) (AWPA, 2000) sampled in the original survey revealed that preservative retentions ranged from 0.64 to 1.76 kg/m^3. These samples were composites of 10 cores taken from 0.3 m below groundline to the highest attachment point on each pole. The more extensive survey of cores from 32 poles revealed that the average retention below groundline was 1.142 kg/m^3 while the retention 1.2 m above the groundline was 0.827 kg/m^3

(Table III-6). In general, arsenic was virtually absent, a finding that confirms earlier reports on long term depletion from ACA treated wood (Jin et al., 1992). The retention values fall far below the original target retention, a finding that highlights the limited amount of copper needed to provide protection under some environmental conditions, but also reinforces the suggestion for more vigilant inspection of these aging structures.

The excellent performance of these ACA-treated structures despite declining chemical loadings can be explained, in part, by the actual thresholds for copper and arsenic. Ammoniacal copper preservatives with a co-biocide, appear to have thresholds between 1.60 and 2.40 kg/m^3. Higher retentions are initially specified for poles because of the need for long, reliable performance with little chance for sudden early failure. The performance of the copper compound is presumably supplemented by the co-biocide. For example, arsenic reduces the risks posed by copper tolerant fungi, provides insect protection, and potentially acts synergistically with the copper. It is clear that the great majority of arsenic has migrated from the poles, but it is possible that small amounts remain and could still supplement performance.

Older ACA-treated Douglas-fir poles remained in excellent condition and were largely free of internal fungal attack. Declining preservative levels and the presence of soft rot cavities near the surface in these poles, however, suggest that more rigorous below ground inspections of these aging structures may be warranted. The overall results clearly demonstrate the excellent performance attributes of ACA.

Table III-6 Copper and arsenic retentions in increment cores removed from selected distances above or below the groundline of ACA treated poles. [a]

Distance From Groundline (m)	Copper Retention (kg/m^3)		Arsenic Retention (kg/m^3)		Total (kg/m^3)
	Range	Mean	Range	Mean	Mean
-0.15	0.108-3.741	1.041 (0.662)	0.040-1.017	0.101 (0.173)	1.142 (0.798)
0.3	0.175-1.331	0.644 (0.279)	0.054-0.963	0.238 (0.208)	0.901 (0.383)
1.2	0.081-1.322	0.640 (0.316)	0.045-0.506	0.187 (0.131)	0.827 (0.400)

[a] Values represent means of 32 samples on an oxide basis. Figures in parenthesis represent one standard deviation

D. Ability an Acoustic Inspection Device to Detect Small Voids in Douglas-fir Pole Sections

Properly specified, treated, and maintained poles provide exceptional service supporting overhead electrical and telecommunication lines. Over time, however, checks can develop in some poles to points beyond the depth of the original preservative treatment. These checks permit entry of moisture, fungal spores, and insects, particularly termites, into the untreated core. Over time, fungi and insects can degrade the interior, compromising strength and reducing service.

There are a diverse array of internal remedial treatments available that can rapidly arrest internal insect or fungal attack (Morrell and Corden, 1986). Detecting the early stages of attack, however, poses a major challenge (Nelson, 1996). The most common methods for detecting internal damage in poles are sounding with a hammer and boring with a drill (Goodell et al., 1983). A well trained inspector can usually detect advanced voids using a hammer to sound the pole, but this technique has a relatively low probability of detecting damage at earlier stages (Inwards and Graham, 1980; Zabel et al., 1980). Boring can detect visible decay pockets before they enlarge to voids, but detection is very much driven by the boring pattern, making it very likely that small decay pockets will be missed.

The inability to reliably detect early decay and estimate residual wood strength has long frustrated both pole inspectors and utility engineers. A number of inspection devices have been developed to detect decay including the Shigometer, various controlled torque drills, spring driven pin penetration devices (Pilodyn) and an array of sonic devices (Morris and Friis-Hansen, 1984; Nelson, 1996; Shigo et al., 1977; Wilson, 1990, Zabel et al., 1980).

While all of these approaches have some merit as inspection devices, sonic approaches appear to have attracted the most attention in North America.

In theory, sonic waves moving through wood poles are affected in two ways. Defects such as voids slow the rate at which sound is transmitted through wood and this increased time of flight of a sound wave can be used to detect voids. Sound waves are also altered or attenuated by various wood characteristics and these changes can be used to detect internal defects (Pellerin et al., 1985; Wilcox, 1988). In general, however, sonic inspection devices have yet to live up to their promise, in part, because wood is such a heterogeneous material. As a result, internal voids may be confused with other natural wood defects such as large knots or ring shakes. While the inability to reliably separate decay from natural defects makes it difficult to use sonic devices as stand alone inspection tools, these devices do appear to be sensitive to more substantial internal damage.

One sonic inspection device that claims to be able to accurately detect and quantify internal voids in the PURL-1 (Pole Ultrasonic Rot Locator, Intraline Inc., Burlingame, CA) a device originally developed in the United Kingdom. This device fixes a transmitter in the pole then a series of readings are taken with a receiver around the pole at the same height as well as above or below that location. The receiver produces a series of positive (sound) and negative (some type of defect) readings that can be used to construct a map delineating voids. Increasing the number of readings potentially increases the accuracy of detection. There are a number of reports concerning the ability of the PURL-1 to detect internal decay (Nelson, 1996), but one area where information is lacking with this device is its sensitivity to incipient termite infestations. Detecting termite galleries may pose a different challenge because the tunnels, while discrete, can be widely scattered at the early stages of attack. In addition, workers sometimes pack older tunnels with dirt and frass. There appears to be little information on the sensitivity of the PURL-1 for termite galleries. In this report, we describe tests to assess the ability of this device to detect simulated termite galleries in pole sections.

Untreated Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) pole sections (200-250 mm in diameter by 600 mm long) were employed. The transmitter was attached on one side of the pole, 300 mm from one end, then nine readings were taken at equidistant points around the pole 150 mm above or below or directly in line with the transmitter. The holes were then drilled longitudinally to a depth of 370 mm and 9, 11, 12.5, or 14 mm in diameter to produce cross sectional area losses ranging from 0.1 to 7 %. Holes were drilled either in the center of the pole or off to one side to determine how void position affected the sensitivity of the device (Figure III-12). The pole sections were reassessed at the same locations after each drill series and the percentage of negative readings, as well as their location were recorded. In principle, increasing void volume should increase the probability of negative readings. The percentage of negative readings was plotted against the cross sections area removed to determine the threshold for void detection at each sampling height.

No negative readings were obtained when the PURL-1 was used 150 mm below the transmitter. The absence of negative readings below the transmitter reflects the fact that the holes only extended downward 370 mm and the PURL-1 receiver was 80 mm below this level. This sharply reduced the likelihood that the most direct pathway for the sound way would be near a void.

The percentage of negative readings tended to increase with increasing percentage of pole area removed when the holes were off to one side of the pole, although it was sometimes difficult to detect holes when less than 0.5% of the cross section was removed (Figure III-13). The number of negative readings was reasonably correlated with percentage pole area removed ($r^2 = 0.59$), but there was wide scatter suggesting a high probability of error. The ability of the device to detect voids was sharply reduced when holes were centered in the pole, with the correlation between negative readings and percent pole area removed declining to 0.125%. From the perspective of total cross section removed, the PURL-1 proved fairly sensitive when the holes were not centered, detecting all but one set of damage when as little as 1% of the cross section was removed. The inability of the device to detect voids when the holes were centered is perplexing. The PURL-1 was capable of detecting 6 of 11 conditions where voids exceeded 1% of the cross section, although it did improve at higher percentages of wood removal. It is important to consider that removing 1 to 3% of the cross section has little effect on pole properties and that this device was fairly reliable for detecting damage above this level.

Sampling above the transmitter increased the correlation between negative readings and void volume when the holes were skewed to one side, but has little effect when voids were centered (Figure III-14). The ability to detect voids declined slightly for poles with holes to one side, while it remained the same when hole were centered. The improved correlation between negative readings and void volume probably reflect the placement of the sensors. Placement above the transmitter in the zone where the voids were present, increases the likelihood that the flow path will be through a void.

One other aspect of these tests that might have improved sensitivity of the device was the regular nature of the galleries. Termites are far less cooperative in their tunneling and their irregular galleries may be more difficult to detect. Further trials using termite infested wood would be helpful in this regard.

The PURL-1 was easily capable of detecting higher levels of internal defect, a feature making this device useful for detecting intermediate infestation levels. Most utilities use rejection criteria requiring that somewhere between 40 to 50 % of the original cross section be removed before a pole is rejected. This device was clearly capable of this detection level and appeared to be sensitive to far lower levels. No negative readings were recorded for pole sections without voids, suggesting that any negative readings are cause for further investigation using more invasive techniques.

One drawback to this method was the amount of time required to take numerous readings at several heights for maximum reliability, but this effort was offset by the non-destructive nature of the technique.

The PURL-1 appeared to be sensitive to relatively low levels of loss in cross section area and might be useful for detecting termite attack at the earliest stages before substantial damage occurs.

Figure III-12 Void conditions evaluated on Douglas-fir pole sections using the PURL-1.

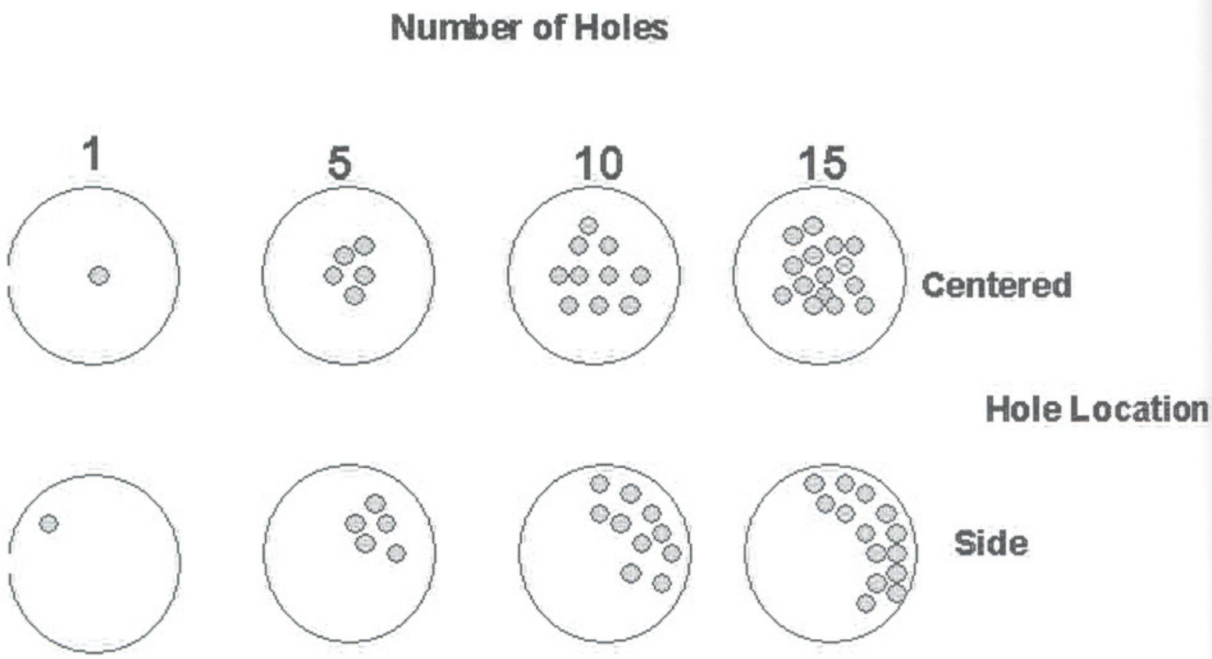
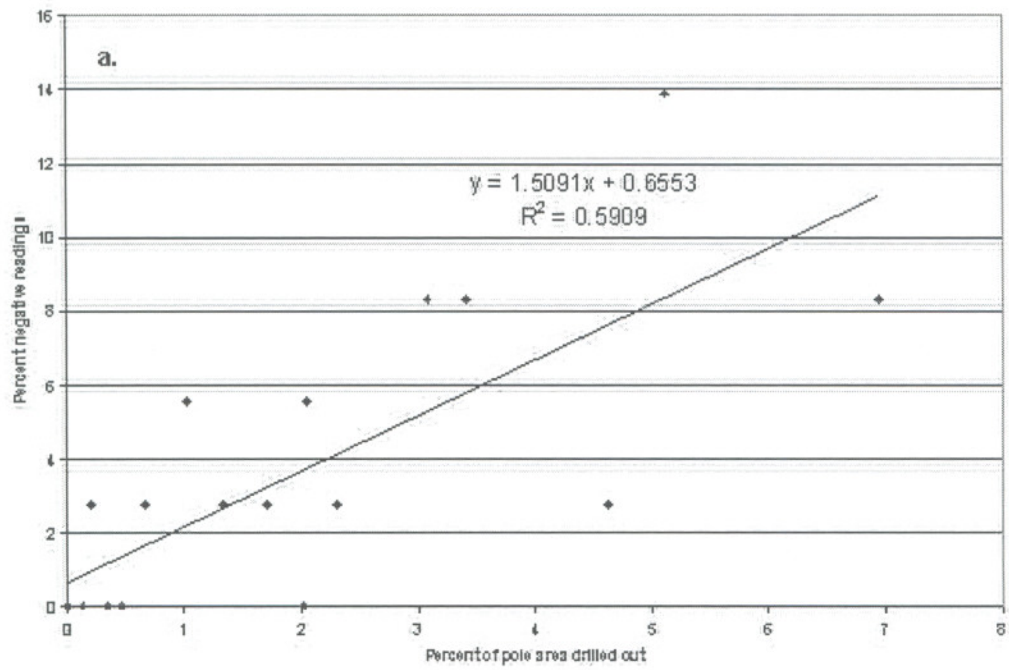


Figure III-13 Frequency of negative readings from the PURL-1 inspection device on Douglas-fir sections with increasing amounts of wood cross sectional area removed a) to one side of the pole, or b) from the center of the pole when the receiver is in line with the transmitter.



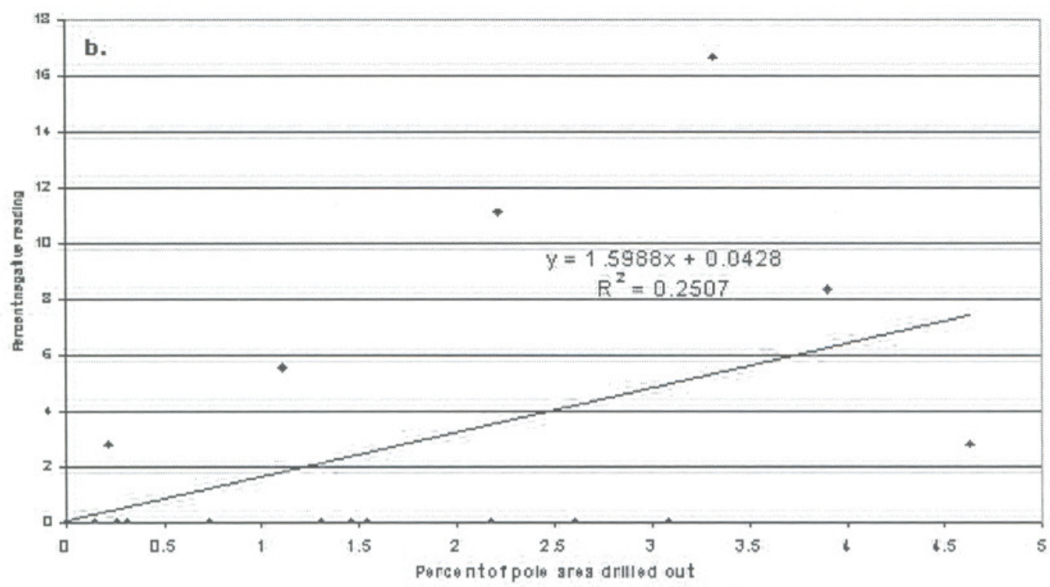
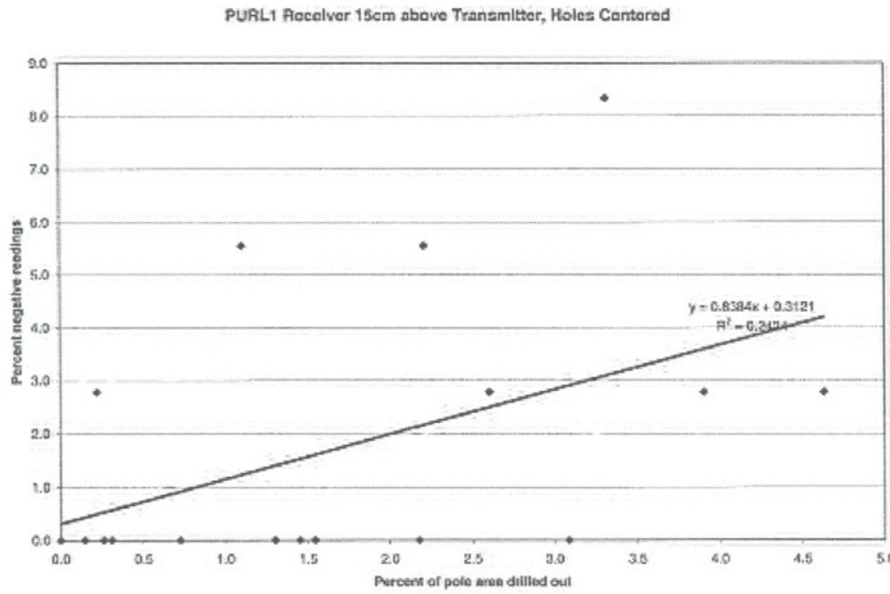
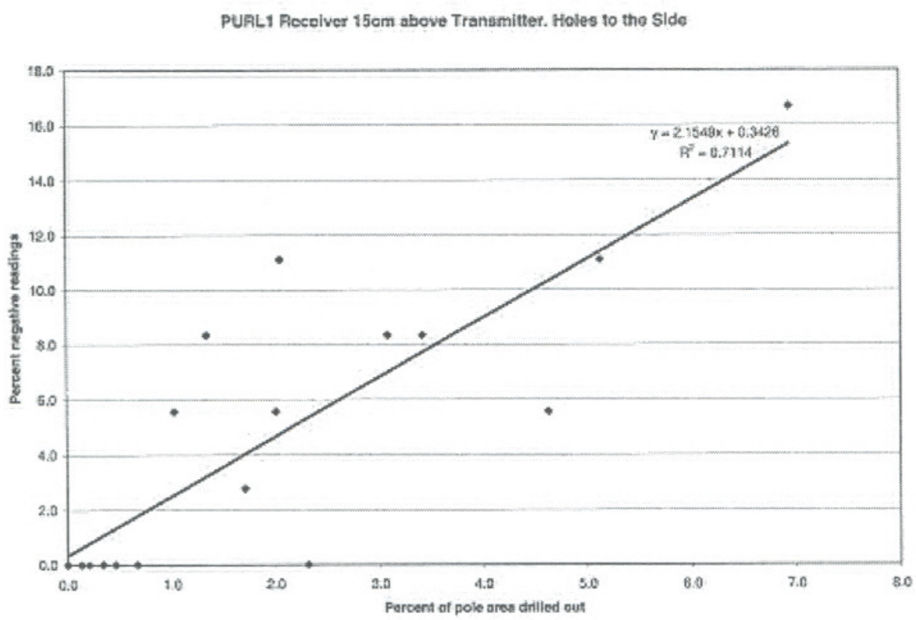


Figure III-14 Frequency of negative readings from the PURL-1 inspection device on Douglas-fir sections with increasing amounts of wood cross sectional area removed a) to one side of the pole, or b) from the center of the pole when the receiver is 150 mm above the transmitter.





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Objective IV

PERFORMANCE OF EXTERNAL GROUNDLINE PRESERVATIVE SYSTEMS

While preservative treatment provides excellent long term protection against fungal attack in a variety of environments, there are a number of service applications where the treatment eventually loses its effectiveness. Soft rot fungi can then decay the wood surface, gradually reducing the effective circumference of the pole until replacement is necessary. In these instances, pole service life can be markedly extended by periodic application of external preservative pastes that eliminate fungi in the wood near the surface and provide a protective barrier against reinvasion by fungi in the surrounding soil.

For many years, the pastes used for this purpose incorporated a diverse mixture of chemicals including pentachlorophenol, potassium dichromate, creosote, fluoride and an array of insecticides. The re-examination of pesticide registrations by the U.S. Environmental Protection Agency in the 1980's resulted in several of these components being listed as restricted use pesticides. This action, in turn, encouraged utilities and chemical suppliers to examine alternative preservatives for this application. While these chemicals had prior applications as wood preservatives, there was little data on their efficacy as preservative pastes and this lack of data led to the establishment of this Objective. The primary goals of this objective are to assess the laboratory and field performance of external preservative systems for protecting

A. Performance of External Preservative Systems on Douglas-fir, Western redcedar, and Ponderosa Pine Poles in California

Sixty nine Douglas-fir, ponderosa pine and western redcedar poles located near Merced, California were selected for testing. The poles were first sampled by removing increment cores from locations near groundline. The outer 25 mm of the three cores from each pole were ground to pass a 20 mesh screen and assayed for residual preservative by x-ray fluorescence. The retentions were then used to allocate poles to treatment groups so that the groups had similar preservative retention distributions.

The poles were then excavated to a depth of 500 mm, the surfaces were scraped clean of any adhering soil or weakened wood, and the various groundline preservative systems were applied. The treatments included Patox II (Osmose Wood Preserving Inc., Buffalo, NY, sodium fluoride), CuNap Wrap (Pole Care Inc., Charlotte, NC, copper naphthenate), and CuRap 20 (ISK Biotech, Memphis, TN, copper naphthenate, sodium tetraborate decahydrate). Each treatment was replicated on 10 poles.

Chemical movement was assessed 1, 2, 3, 5, 7 and 10 years after treatment by removing increment cores or plugs (depending on the year) from locations 150 mm below the groundline at 3 equidistant points around each pole. The cores or plugs were divided into zones corresponding to 0-4, 4-10, 10-16, and 16-25 mm from the surface. Wood from a given zone was combined for a given treatment. Copper naphthenate was analyzed by x-ray fluorescence. Initially, the assay was performed on an ASOMA 8620 XRF Analyzer using the CCA mode. For the 10 year sample, the wood was analyzed using a Specto Titan using curves specifically developed for both the water and oilborne formulations in the respective pastes. Boron levels were determined by extracting the wood in hot water, then analyzing the extract for boron using the Azomethine H method. Fluoride was analyzed by ashing the wood, then, through a series of procedures, isolating the fluoride. Fluoride concentration was determined using a specific ion electrode according the procedures described in AWPA Standard A2 Method 16.

None of the poles experienced substantial surface decay at the start of the test. This was an intentional decision on our part to reduce the potential for variations that might arise from having differing degrees of damage among the various treatments.

Copper levels in poles treated with CuNap Wrap tended to be above the approximate threshold for protection (0.6 kg/m^3) one year after treatment for all three wood species (Figure IV-1). Copper levels continued to rise near the surface in pine poles 2 years after treatment, but declined slightly in Douglas-fir. Copper levels 4-10 mm into the wood were near the threshold in Douglas-fir and pine, but below this level in western redcedar. Copper levels fell off sharply 10 to 16 mm in form the surface for both Douglas-fir and western redcedar, but remained stable for pine . The differences in chemical levels most probably reflect the depth of sapwood on each species. Pines tend to have deeper sapwood, followed by Douglas-fir and finally Western redcedar. Since sapwood is generally several orders of magnitude more permeable that heartwood, it follows that chemical movement should closely follow this trend. Chemical levels near the surface of all three species have fallen below the threshold for fungal attack; however, the copper is not the only chemical available for protection since these poles also contain considerable amounts of residual pentachlorophenol. As a result, we suspect that the external pastes continues to provide supplemental protection to the poles.

Fluoride levels in poles receiving the Patox II bandage tended to be elevated near the surface in all three species (Figure IV-2). There is some difficulty in determining how much fluoride is required for ground protection. As a result, we have listed a threshold range for this chemical. Surface concentrations of fluoride remain well above the threshold for both Douglas-fir and pine, but have fallen below the lower threshold range in western redcedar. This decline in western redcedar has only occurred during the last three years. Chemical levels deeper in the wood tended to exceed the lowest threshold at most depths over all but the final sampling time. One of the primary advantages of fluoride is its ability to move with moisture into the wood to arrest the growth of fungi away from the wood surface. While fluoride was clearly capable of movement, the data suggest that fluoride levels have not yet equilibrated in the wood. As with the copper naphthenate, the relative threshold for fluoride in combination with pentachlorophenol is difficult to precisely quantify. As a result, it may be possible for retreatments to be delayed even though levels of the remedial treatment have fallen below the reported threshold.

Copper levels in poles receiving the CuRap 20 paste tended to be well above the threshold in the outer 4 mm of the poles for all three species for the first 7 years after treatment (Figure IV-3). As expected, chemical levels declined further inward, but copper was still detectable 16 to 25 mm in from the surface in all three species at some point in the test. The mobility of copper in this treatment most likely reflects the higher water solubility of the amine copper naphthenate used in this system. Copper levels appeared to decline sharply in western redcedar and Douglas-fir poles at the 10 year sampling point, but were still well above the threshold in pine poles. These results suggest that retreatment of the former two species would be advisable, while treatment of the pine can be delayed. Boron levels in CuRap 20 treated poles tended to be extremely high in all three wood species one or two years after treatment, then declined with increasing time (Figure IV-4). Boron is more mobile and will tend to move with moisture either further into the pole or outward into the surrounding soil. In either case, boron was virtually undetectable 10 years after treatment at any sampling depth. These results, in combination with those for the copper naphthenate, suggest that retreatment of the Douglas-fir and western redcedar poles treated with this system is advisable.

Figure IV-1 Residual copper levels at selected distances from the surface of Douglas-fir, western redcedar or western pine poles 1 to 10 years after application of a copper naphthenate impregnated external groundline bandage.

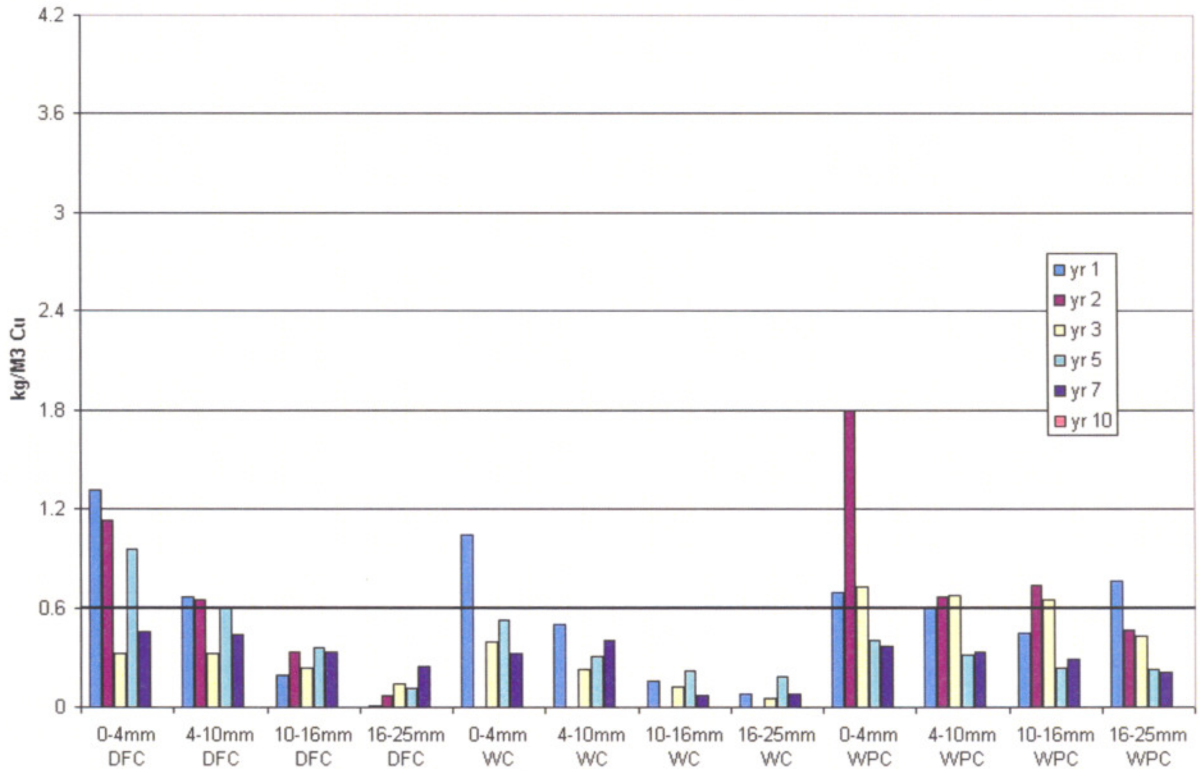


Figure IV-2 Residual fluoride levels at selected distances from the surface of Douglas-fir, western redcedar or western pine poles 1 to 10 years after application of a sodium fluoride external groundline paste.

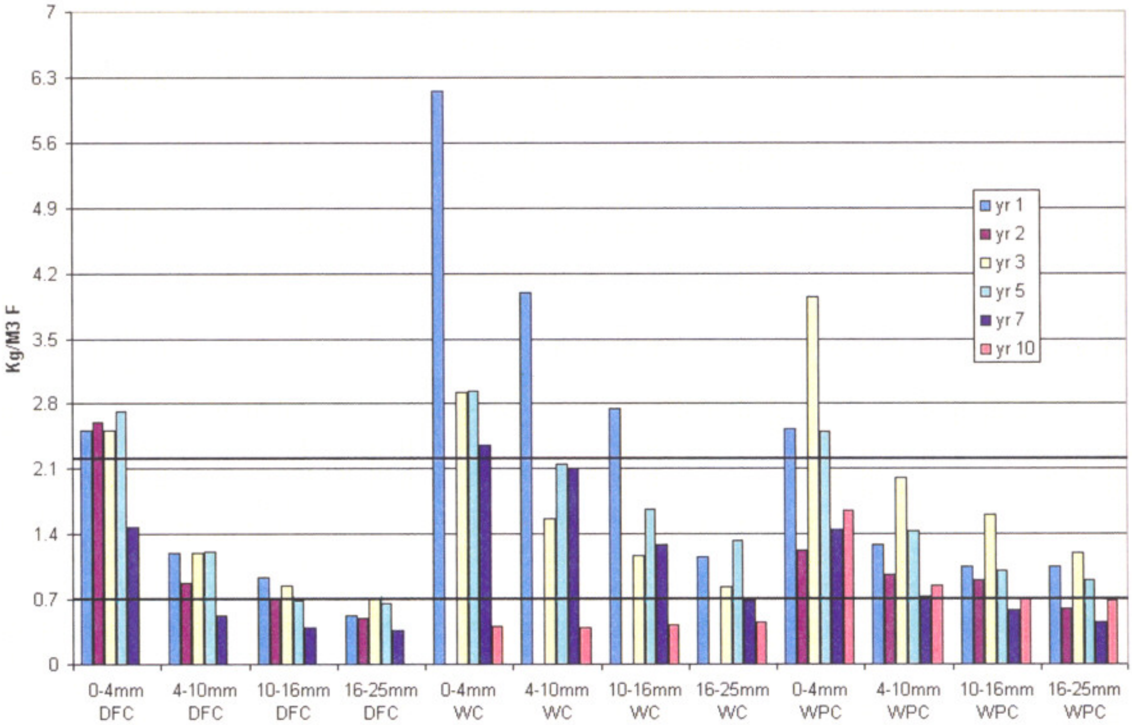


Figure IV-3 Residual copper levels at selected distances from the surface of Douglas-fir, western redcedar or western pine poles 1 to 10 years after application of a copper naphthenate/boron external groundline paste.

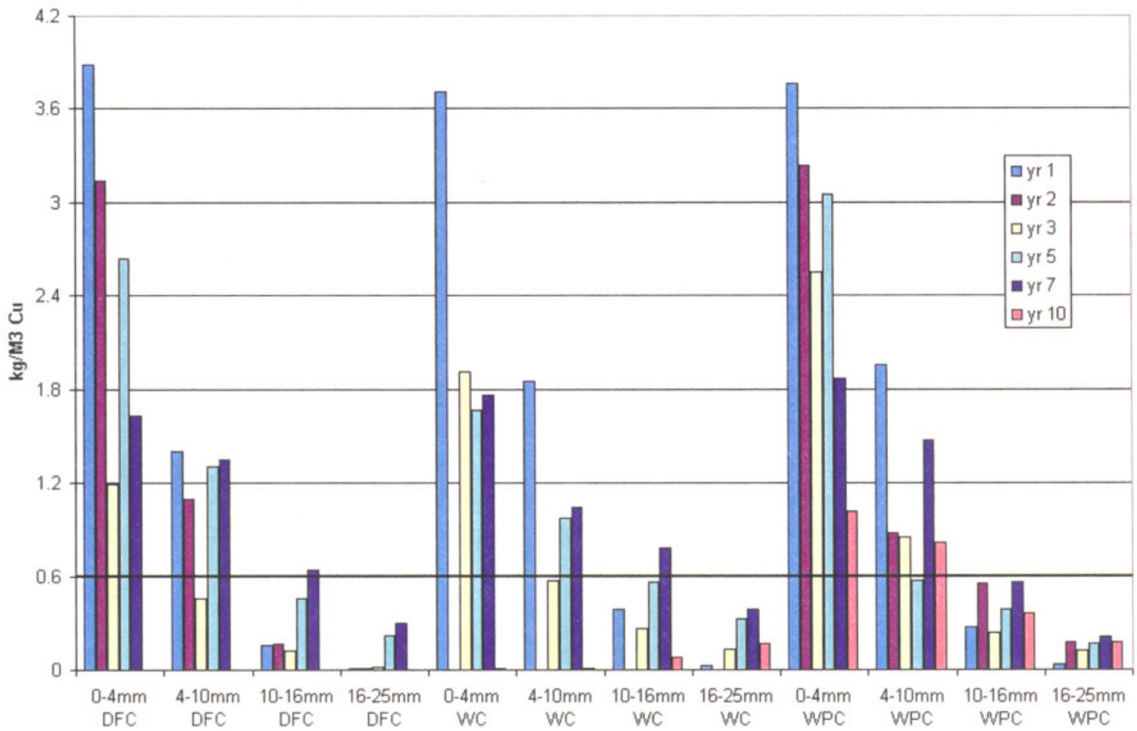
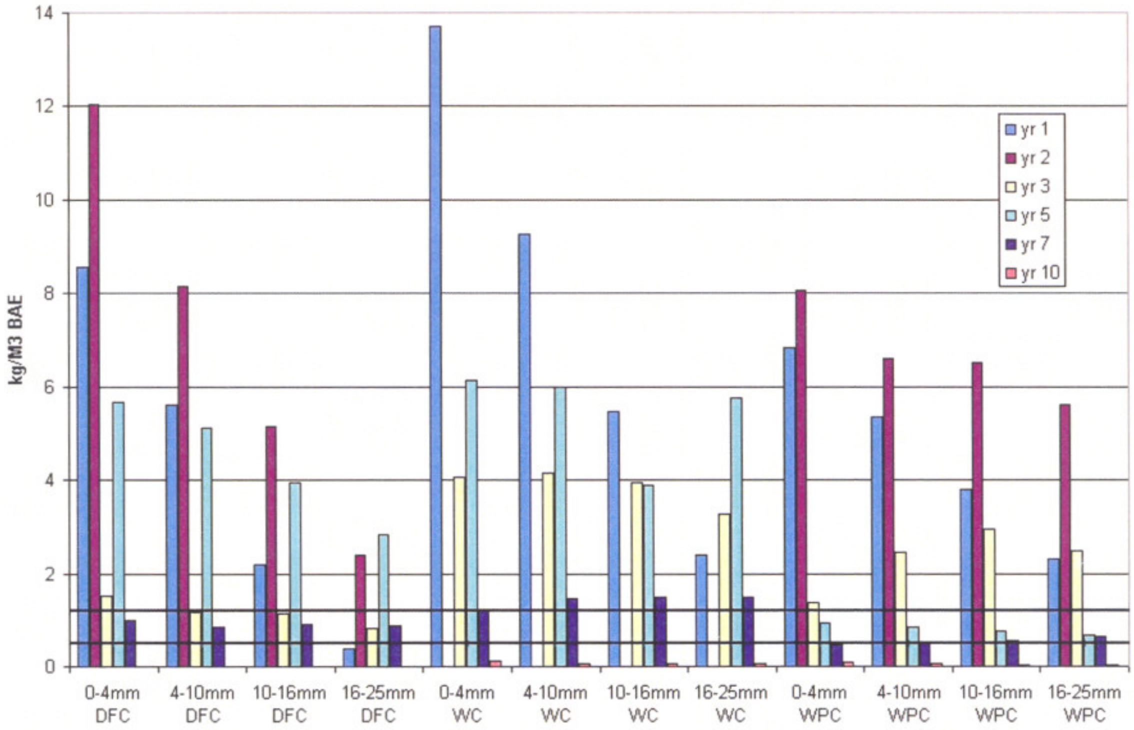


Figure IV-4 Residual boron levels at selected distances from the surface of Douglas-fir, western redcedar or western pine poles 1 to 10 years after application of a copper naphthenate/boron external groundline paste.



B. Performance of Selected Supplemental Groundline Preservatives in Douglas-fir- Poles Exposed Near Corvallis Oregon

The field utility sites have proven useful for exposing formulations under commercial conditions; however, these tests are more difficult to establish and sample and they carry with them the risk that a contractor will inadvertently treat a field test. As a result, we try to mix utility tests with those established at our own field test site.

Twenty one seasoned, untreated Douglas-fir poles (250-300 mm in diameter by 2.0 m long) were selected for the test. The poles were treated from the butt upward 0.8 m with one of three external preservative systems:

Dr. Wolman: A system with sodium fluoride, boron, and copper carbonate on foam pad
CuRap 20: a copper naphthenate/boron paste covered with polyethylene
Propiconazole paste: a propiconazole gel covered with polyethylene.

The Dr. Wolman system was applied to 15 poles while the CuRap 20 was applied to 5 poles and the propiconazole was applied to 6 poles. The poles were set to a depth of 0.6 m at the Corvallis test site (Figure IV-5). The poles were sampled 2 and 3 years after treatment by removing plugs from three equidistant points around each pole 150 mm below groundline. The plugs were divided into zones corresponding to 0-4, 4-10, 10-16, and 16-25 mm from the surface. Wood from a given zone was combined for each pole and ground to pass a 20 mesh screen. The resulting dust was first analyzed for copper (where appropriate). Dr., Wolman samples were split and half was extracted in hot water and the resulting extract was analyzed for boron using the Azomethine H method (AWPA Standard A2-Method 16). The remainder was analyzed for fluoride by extraction in 0.1 m $HClO_4$ and analysis of the extract by specific ion electrode. Propiconazole was analyzed by extraction in methanol and analysis for the active ingredient by High Performance Liquid Chromatography according to AWAP Standard A23-94.

Figure IV-5 Douglas-fir poles at the Corvallis test site treated with selected external preservative systems.

Copper levels in poles treated with the Cu/F/B system tended to vary over the two year sampling. Copper levels in the outer 4 mm were nearly double the threshold two years after treatment, but were only 2/3 of the threshold one year later (Table IV-1). Copper levels further inward declined precipitously, suggesting that the copper in this system was relatively immobile. Boron levels in the Cu/F/B system tended to be uniform but relatively low at both sampling times at all four sampling depths. Boron should be capable of substantial migration which should result in a relatively uniform distribution over time. Fluoride levels in the poles receiving this system tended to be far higher than those for boron, although the retentions fell off somewhat between years 2 and 3. The exact retentions required for performance of this multi-biocide system are difficult to determine. While copper and boron are present at levels that would not, by themselves confer protection, the presence of these compounds plus the near threshold fluoride levels might provide adequate protection, particularly in combination with residual levels of the initial preservative treatment.

Copper naphthenate levels in poles receiving the copper/boron system tended to be much higher than those found with the Cu/B /F system at both sampling times for the outer three sampling depths (Table IV-1). Copper levels associated with the Cu/B system were far in excess of those required for protection against fungal attack. Boron levels in these sample poles were initially very high ranging from 1.6 to 3.4 kg/m^3 (BAE), but declined by nearly 50 % at the 3 year sampling point. Boron is sensitive to moisture and our site is characterized by very high winter moisture levels. While boron levels were still protective, the declining concentrations suggest that the benefits of boron in this system will be more temporary than those provided by the copper.

Propiconazole levels near the surface were extremely high and far in excess of the levels required for fungal protection (Table IV-1). Chemical levels dropped sharply in the 4 to 9 mm assay zone, indicating that the propiconazole formulation had relatively little abilitiy to move inward.

C. Movement of External Preservative Components Through Douglas-fir Sapwood Blocks

The self-contained wraps largely eliminate questions about applicaiton levels under field conditions, but they also make it difficult to compare the various systems. Last year, we installed a laboratory test to assess the relative degree of chemical movement from two external preservative systems; one a self contained wrap and the other a paste. The wraps contained copper carbonate, sodium fluoride and sodium octaborate tetrahydrate, while the paste contained amine copper naphthenate and sodium tetraborate decahydrate.

Douglas-fir sapwood blocks (nominally 50 by 100 by 150 mmm long) were machined on one surface to produce a 20 mm deep well in an area 25 mm in diameter. The blocks were oven-dried and weighed before being pressure soaked with water. The blocks were conditioned to 60% moisture content, then the well area was covered with duct tape and the entire block was dipped in molten paraffin to retard further moisture changes. The blocks were then stored at 5 C for one month prior to use.

The blocks were treated by removing the duct tape and applying either a 25 mm square of the copper/fluoride/boron bandage or a layer of the copper/boron paste that was 1.5, 3.0, 6.0 or 9.0 mm thick to the well. The paste or bandage was held in place using the duct tape and the blocks were incubated for 1, 3, 6, or 12 months at room temperature. At each time, 5 blocks from each treatment group were removed and the bandage was removed or excess paste was scraped away from the well. A 25 mm square block was cut from the zone around the well region using a bandsaw, taking care to remove any paste that might be adhering the wood surface. The section was then segmented into zones corresponding to 0-5, 5-10, 10-15, 15-20, and 20-25 mm from the wood surface. The wood from a given zone was ground to pass a 20 mesh screen. Samples were first analyzed for copper by x-ray fluorescence. Samples from the same bandage system were then throughly mixed and divided into 2 parts. The first was hot water extracted and the extract was analyzed for boron by the Azomethine H method. The other sample was extracted in dilute $HClO_4$ and the resulting extract was analyzed for fluoride using a specific ion electrode. Wood from the copper/boron samples were analyzed for copper and then analyzed for boron as described above.

Table IV-1 Copper, boron, fluoride and propiconazole levels at selected distances from the surfaces of Douglas-fir poles two or three years after application of external remedial treatments.

Treatment	Assay Zone (mm)	Residual Chemical Loading (kg/m³)[a]							
		Copper		Boron (BAE)		Fluoride		Propiconazole	
		Yr. 2	Yr. 3	Yr. 2	Yr. 3	Yr. 2	Yr. 3	Yr. 2	Yr. 3
Cu/B	0-4	**3.689** (1.04)	**4.057** (1.88)	**3.434** (2.52)	**1.725** (0.88)				
	4-9	**1.195** (0.86)	0.328 (0.24)	**3.167** (1.72)	**0.999** (0.57)				
	9-16	0.247 (0.34)	0.088 (0.1)	**2.968** (2.04)	**0.916** (0.46)				
	16-25	0 0	0.016 0	**1.559** (1.37)	**0.764** (0.48)				
Cu/B/F	0-4	**1.138** (0.39)	0.428 (0.2)	0.114 (0.1)	0.272 (0.29)	0.522 (0.19)	0.314 (0.15)		
	4-9	0.152 (0.24)	0.144 (0.1)	0.158 (0.18)	0.188 (0.11)	0.352 (0.11)	0.185 (0.11)		
	9-16	0 0	0.63 (0.1)	0.152 (0.14)	0.173 (0.1)	0.361 (0.18)	0.163 (0.11)		
	16-25	0 0	0.019 0	0.166 (0.1)	0.166 (0.1)	0.317 (0.14)	0.135 (0.1)		
Propiconazole	0-4							**1.063** (1.18)	**8.023** (18.83)
	4-9							0.045 0	0.099 (0.168)
	9-16							0.028 0	0.014 (0.01)
	16-25							0.023 0	0.028 (0.06)

[a] Numbers in parentheses represent one standard deviation.
Figures in **boldface** are above threshold.

In an ideal system, one would expect retentions of chemicals with some water solubility to be highest near the surface, but over time, the concentrations should gradually equilibrate. This would be especially true for the test blocks, since there was no opportunity for loss of chemical to the outside environment. Boron levels in blocks treated with the copper/boron system followed this trend, with copper levels gradually increasing deeper in the wood over time in most treatments (Figure IV-6). Boron levels also increased with increasing paste thickness and these increases translated to increased levels deeper in the wood. These trends suggest that the 1.5 mm thick application level provided too little boron for deeper migration, while the 9 mm treatment probably provided too much boron as evidenced by there being relatively little difference in boron levels 15 to 20 mm from the surface in the 6 and 9 mm thick paste treatments. Boron levels in the Cu/F/B bandage were initially far below those found with the thinnest paste treatment, but these levels tended to rise and remain stable over the test, while the boron levels declined in the thin paste treatment. Boron levels in the Cu/F/B system were all above the threshold in the outer zone and in the remaining zones 12 months after treatment.

Copper in the pastes and bandages tended to be largely confined to the outer 5 mm of the blocks, although some migration into the next zone was noted at the two highest paste thicknesses (Figure IV-7). Copper levels were all above the threshold for fungal attack over the entire test period. Surface copper levels tended to rise with increasing paste thickness, but varied only a small amount over time at a given application thickness. These results suggest that the amount of copper migration is limited by factors other than surface dosage. As with boron, copper levels in the Cu/F/Bandage were lower than those found with the pastes, but the levels in the outer 5 mm of the blocks were still well above the threshold for protection against fungal attack. Once again, there was little evidence of substantial copper migration inward from the outer 5 mm in blocks receiving the bandage.

Fluoride levels in blocks receiving Cu/F/B bandage were above the lower threshold for fungal attack in the outer 10 mm for the first 6 months, then declined to well below the threshold 12 months after treatment (Figure IV-8). The reasons for this sudden decline in chemical levels are unclear. Fluoride levels followed a similar trend 5 to 10 mm below the surface although the maximum fluoride levels in this zone were just below the threshold.

Figure IV-6 Residual copper levels at selected depths beneath the application points in Douglas-fir sapwood blocks treated with a Cu/F/B bandage or 1.5 to 9.0 mm of a Cu/B paste

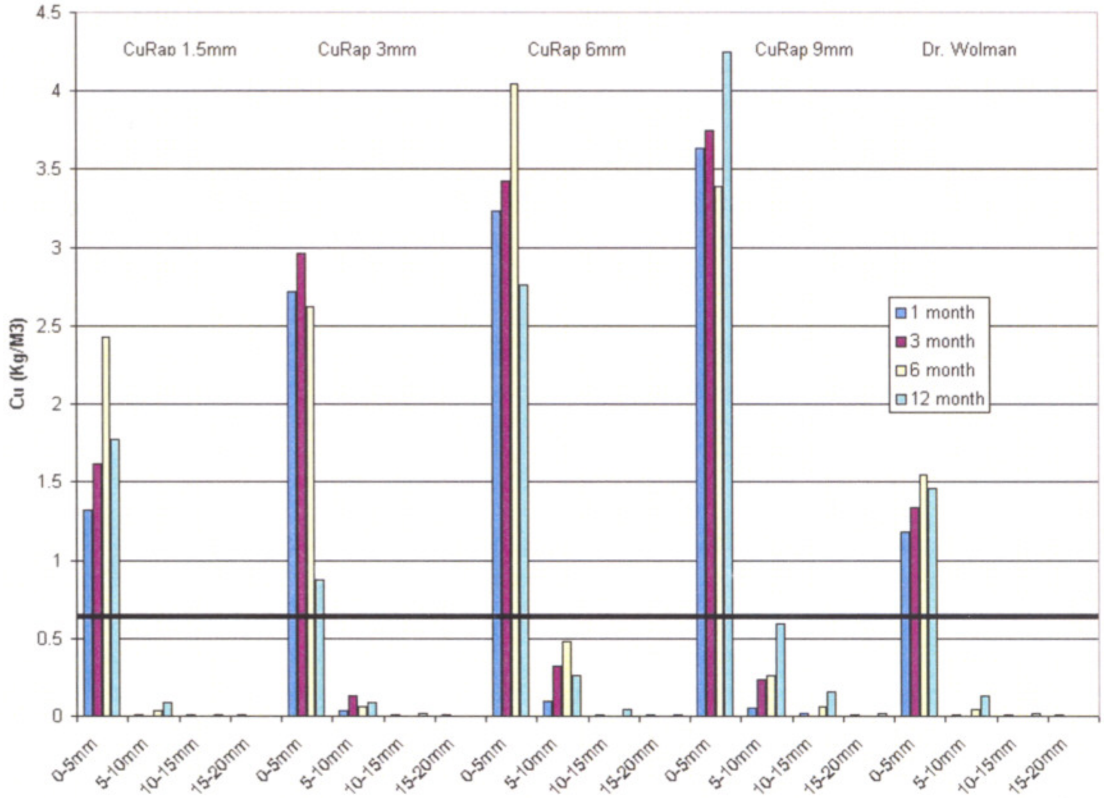


Figure IV-7 Redisual boron levels at selected depths beneath the application points in Douglas-fir sapwood blocks treated with a Cu/F/B bandage or 1.5 to 9.0 mm of a Cu/B paste.

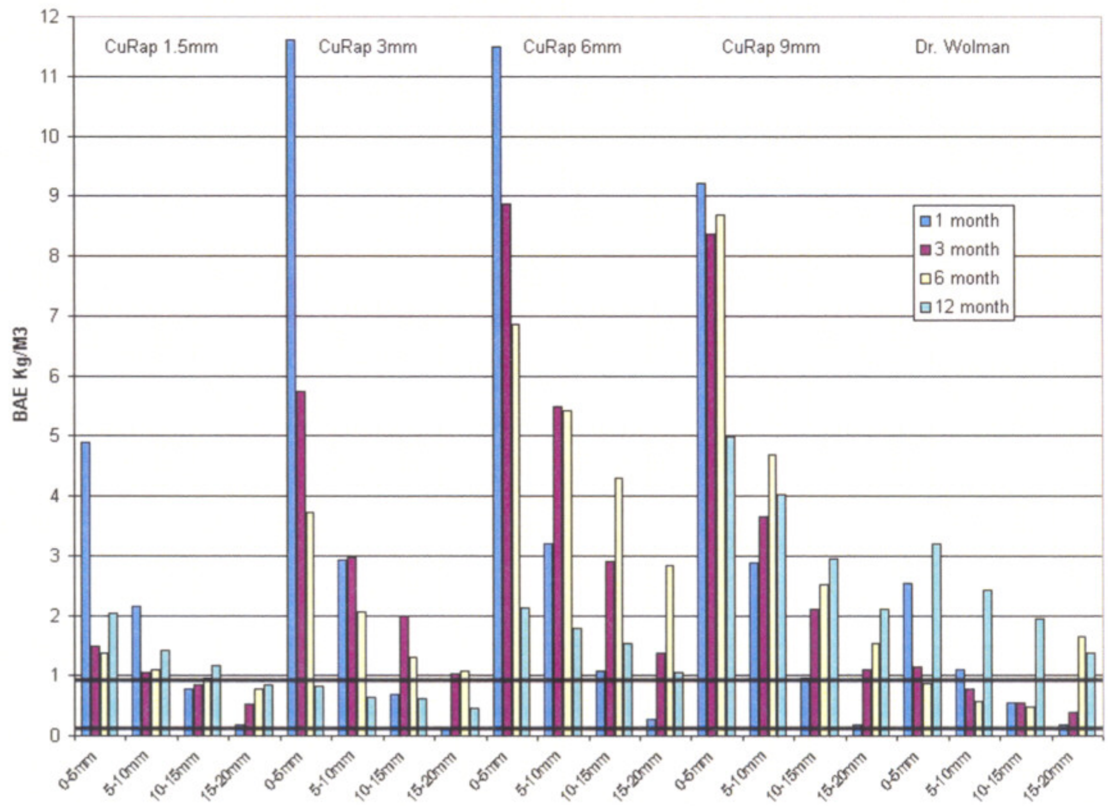
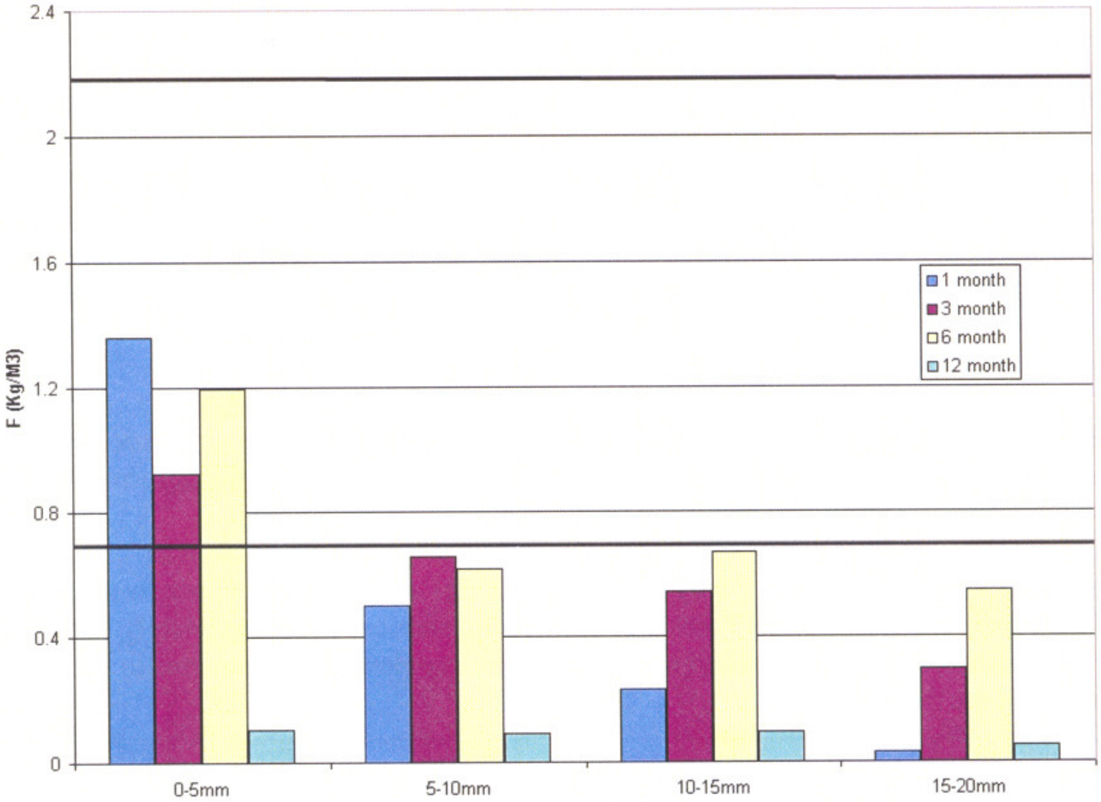


Figure IV-8 Residual fluoride levels at selected depths beneath the application points in Douglas-fir sapwood blocks treated with a Cu/F/B bandage.



Objective V

PERFORMANCE OF COPPER NAPHTHENATE TREATED WESTERN WOOD SPECIES

Copper naphthenate has been available as a wood preservative since the 1940's but the real commercial use of this system has only occurred in the last decade, as utilities sought chemicals that were less restrictively labeled. Copper naphthenate is currently listed as a non-restricted use pesticide, meaning that this chemical does not require special licensing. This has little bearing on the use of preservative treated wood, since there are no restrictions on who can use any of the preservative treated wood products currently on the market (although there are recommended applications for each product); however, many users have sought to soften their environmental image by shifting to alternative preservatives such as copper naphthenate.

Copper naphthenate has provided reasonable protection in a variety of field stake tests, but there is relatively little long term data on western wood species. To help develop this information, we established the following test.

Western redcedar sapwood stakes (12.5 by 25 by 150 m long) were cut from either freshly sawn lumber of the outer surfaces of utility poles that had been in service for approximately 15 years. The latter poles were butt treated, but had not received any supplemental treatments to the above ground portion of the pole.

The stakes were conditioned to 13 % moisture content, then weighed prior to pressure treatment with copper naphthenate dilute 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 10 freshly sawn and 10 weathered stakes. The stakes were then exposed in a fungus cellar maintained at 28 C and approximately 80 % relative humidity. Soil moisture was allowed to cycle between wet and dry conditions to avoid favoring soft rot attack (which tends to dominate in soils that are maintained at high moisture levels). The condition of each stake was visually assessed annually using a scale from 100 (completely sound) to 0 (completely destroyed).

The stakes cut from freshly sawn sapwood have consistently out performed those cut from weathered wood at each retention level (Figures V-1, 2). Weathering is generally a surface effect, the stakes also tended to have numerous small checks that could act as pathways for chemical loss and fungal attack. Ratings for stakes cut from freshly sawn lumber tended to average between 9.5 and 10.0 five years after treatment, while stakes treated with diesel alone rated approximately 8.5. Untreated stakes have largely been destroyed. The diesel performance probably reflects the initial high loadings of solvent in these materials (80 to 90 kg/m^3). In actual practice, post treatment steaming and other activities would reduce the amount of residual solvent slightly. Weathered stakes had consistently lower ratings 120 months after treatment. Diesel treated weathered stakes were nearly completely decayed, while the untreated controls had failed after 5 years of exposure. The difference in condition of the diesel stakes in comparison with similarly treated stakes cut from freshly sawn lumber illustrates the effects of weathering on performance. Weathered wood was originally included in this test because the cooperating utility had planned to remove poles from service for retreatment and reuse in other parts of the system.

While this process remains possible, it is clear that the performance characteristics of the weathered retreated material will differ substantially from that of freshly sawn material. As a result, it is important to consider the potential benefits of recycling the pole in comparison with a reduced performance in comparison with freshly harvest poles. This could have important implications for both maintenance costs and system reliability.

The results indicate that copper naphthenate treatment of freshly sawn western redcedar sapwood provides excellent protection against fungal attack at the currently specified retention. Weathered stakes treated to the same approximate retention were also still performing well after 10 years of soil exposure, although performance differences between weathered and freshly sawn stakes continued to emerge and suggest that retreated poles will have reduced performance characteristics in comparison with freshly harvested materials.

Figure V-1 Condition of freshly sawn western redcedar sapwood stakes treated with selected retentions of copper naphthenate in diesel oil and exposure in a soil bed for 120 months.

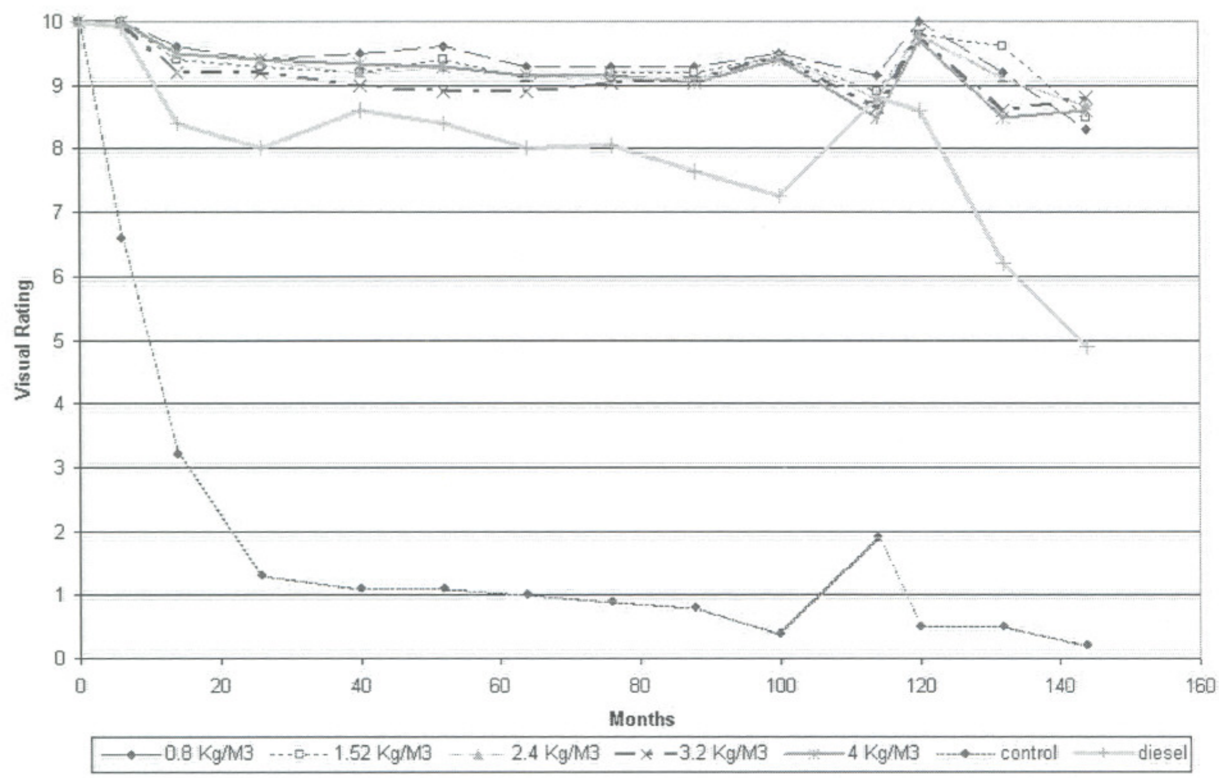
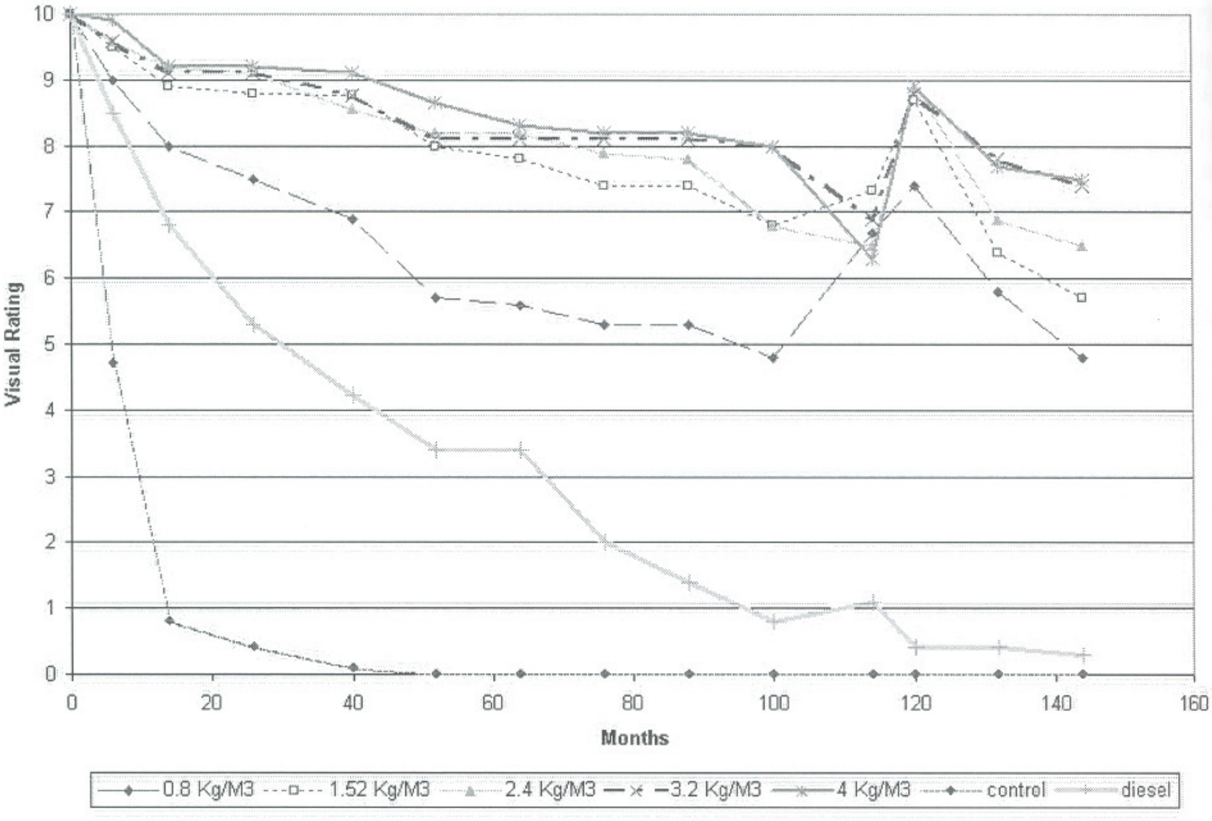


Figure V-2 Condition of weathered western redcedar sapwood stakes treated with selected retentions of copper naphthenate in diesel oil and exposure in a soil bed for 120 months.



Objective VI

ASSESS THE POTENTIAL ENVIRONMENTAL IMPACTS OF WOOD POLES

Preservative treated wood poles clearly provide excellent service under a diverse array of conditions, but the increasing sensitivity of the general public to all things chemical has raised a number of questions concerning the preservatives used for poles. While there are no data indicating that preservative treated wood poles pose a risk to the environments in which they are used, it is important to continue to develop exposure data wherever possible. The goal of this objective is to examine usage patterns for preservative treated wood (specifically poles) and develop exposure data that can be employed by utilities to assess their use patterns and to answer questions that might arise from either regulators or the general public.

A. Assess the Potential for Preservative Migration From Pentachlorophenol Treated Poles in Storage Yards

In an ideal system, utilities would only receive poles as needed for specific activities; however, most utilities must stock poles of various sizes at selected depots around their system so that crews can quickly access poles for emergency repairs that result from storms or accidents. In previous studies, we examined the potential for decay in these stored poles and made recommendations for either regular stock rotation of poles so that no single pole was stored for longer than two to three years or for a system of periodic remedial treatment of stored poles to ensure that these structures did not develop internal decay during storage. These recommendations were primarily based upon long term storage, but there was little concern about the potential for any preservative migration during this storage.

The potential for preservative migration from stored poles has received little attention, but could be a concern where large numbers of poles are stored for long periods. Preservative present on the wood surface could be dislodged or solubilized during rain events and subsequent heating in sun could encourage oil migration to the wood surface. There is, however, little data on the potential for migration of preservative from poles in storage. Treating plants have less concern about this issue because surface water from their sites are already regulated and must be treated prior to discharge (or be shown to contain less than permissible levels). Pole storage facilities, however, are not currently regulated, nor are there recommendations or best management practices that might help utilities minimize the potential for chemical loss.

The purpose of this section was to assess the levels of preservative migrating from pentachlorophenol treated Douglas-fir poles sections subjected to natural rainfall in Western Oregon with the ultimate goal of developing recommendations for pole handling and storage by utilities.

Douglas-fir poles sections (250 to 300 mm in diameter by 1.2 m long) were air-seasoned and pressure-treated with pentachlorophenol in P9 Type A oil to a target retention of 9.6 kg/m^3 in the outer 6 to 25 mm of the poles. Treatment conditions followed the current Best Management Practices as outlined by the Western Wood Preservers' Institute. Following treatment, one end of each pole was end sealed with an elastomeric paint designed to reduce the potential for chemical loss from that surface, while the other end was left unsealed. The idea was to simulate a longer pole section where some end-grain loss was possible, but the amount of exposed end-grain did not dominate the overall surface area exposed. Six poles were then stacked on stainless steel supports in a stainless steel tank designed so that all rainfall striking the poles would be captured. The poles were set 150 mm above the tank bottom to reduce the risk that the wood would be submerged and, therefore, have the potential to lose more chemical (Figure VI-1). The poles were then exposed outside the Richardson Hall laboratories where they were subjected to natural heating and rainfall.

The tank was sampled whenever there was measurable rainfall by draining all of the water collected in the tank bottom as soon as possible after the rainfall event had concluded. In some cases, the rainfall, while measurable, did not result in collectible water samples because the conditions were so dry prior to rain that the falling moisture was either sorbed by the wood or evaporated. In addition, early in the process, it became obvious that debris (primarily leaves) was falling into the tanks between collections. Since these materials had the potential to sorb any chemical solubilized by the rainfall, we placed a large mesh screen around the tank to limit the potential for debris entering the tank, but still allow rainfall to strike the wood.

Tank sampling involved collecting all liquid and weighing this material. A 250 ml aliquot of this material was then retained for penta analysis. The sample collecting apparatus was a 250 mL volumetric flask (named #1) with a 300 mL glass filtration unit on the top. The filtration unit is a glass funnel and a glass base combined together by an aluminum clamp. The 47 mm glass base held a 42 mm OD stainless steel screen, which supported a 42mm OD 10 μm mesh stainless steel filter. The filtration unit was sealed with three Teflon® washers sandwiched between the screen and the filter. The glass base also was connected to the volumetric flask and to the vacuum line. There was a glass jacket outside the stem of the base. The lower part of the jacket was a male standard taper 24/25 ground joint, which fitted to the standard taper 24/25 ground glass top of the volumetric flask beneath the base. The upper part of the jacket was branched to connect to a vacuum line to maintain filtration speed. This glass jacket was custom fused to the stem of the filtration base. The filtration funnel was held on a metal clamp on a support stand.

The volumetric flask #1 and a Teflon® stirring bar inside were weighed before and after collecting leaching water. The board ID, date and the time of the day were recorded. Approximately 230 mL of leaching water was collected. In the process of sampling wood dust and the majority of any oil film were retained on the filter and the wall of the filtration funnel while water and a minor portion of any oil film entered the volumetric flask.

Two extractions were required for the separation of PCP from an oil contaminated aqueous environment. Thus the aqueous sample, or filter solid, was first adjusted to a high pH with sodium hydroxide forming pentachlorophenate anion in the aqueous phase. An extraction with iso-octane then removed the petroleum oil residues from the water phase, leaving the PCP in the aqueous phase. The water phase was then acidified, converting the pentachlorophenate back to pentachlorophenol. A second extraction with iso-octane now removed the PCP from the aqueous phase. This second extraction was analyzed for PCP content using high resolution gas chromatography with low resolution mass spectrometer detection system (HRGC-LRMS).

Reagents:

a. DI water: Deionized water from Richardson Hall DI water line
b. Sodium Hydroxide: VWR, reagent grade
d. Hydrochloride acid: JT baker, Baker analyzed
e. Ethanol: McCormick, absolute-200 proof
f. Iso-octane: Fisher, Optima grade
g. Methanol: Fisher, HPLC grade
h. Pentachlorophenol: Aldrich, 98%
I. [$^{13}C_6$] labeled Pentachlorophenol: Cambridge Isotope Laboratories 99%, internal standard (IS)
j. P9A oil (Imperial): Shell, 124 process

Extraction from base: A 50 µL portion of 200 µg/mL IS was spiked into the two volumetric flasks. Then 2.4 mL 0.1N NaOH was added to each of the two flasks using an Oxford pipette yielding a pH of approximately 11. The flasks were placed on a stirring plate. The stirring speed was increased until a vortex was obtained and continued for 1 minute. The flasks were then allowed to stand for 30 minutes, after which 2.4 mL of iso-octane was added to the #1 flask using a bottle top dispenser. Both flasks were stirred for one minute. Water was added to bring the total volume to the bottom of the neck of the volumetric flask. The solvent layer was removed with a disposable glass pipette and discarded. The procedure was repeated, except the stirring time was reduced to 30 seconds. After the second separation, the weight of the two flasks was recorded. A 3mL of aqueous solution was removed with an Oxford pipette.

Extraction from acid The solutions were acidified to a pH of approximately 3 by adding 3 mL of 0.5M H_2SO_4 to each of the two flasks with an Oxford pipette. The two flasks were stirred for 1 minute and allowed to stand for 30 minutes, then 2.4 mL of iso-octane was added. The two flasks were stirred for one minute. The extract was collected using two new glass pasture pipettes and transferred to two 20 mL HRGC-LRMS vials. The procedure was repeated, except using 2.6 mL of solvent and 30 seconds stirring. The second extract was transferred to the same vial as the first and mixed.

HRGC-LRMS analysis: The HRGC-LRMS analysis was carried out on Shimadzu HRGC-LRMS system class 5000 with injector AOC-17 and capillary column XTI-5 from Restek. This column is composed of fused silica with a 0.25 µm thick film of 95% dimethyl, 5% diphenyl polysilarylene. The column dimensions were 0.25mm ID X 30 m long.

HRGC parameters

Carrier gas: Helium grade 5.0
Flow rate: 1.2mL/min
Split rate: 5
Injector temperature: 250˚C
Detector interface temperature: 280˚C
Temperature program: 2 min. hold, 35˚C to 260˚C at 25˚C/min.,
Injection volume: 1 uL
Solvent wash: methanol

The National Institute of Science and Technology (NIST) Mass Spectral Library #107 software was installed on the system. The PCP standard (50 μg/mL) and [$^{13}C_6$] PCP internal standard (50 μg/mL) were scanned and identified by the Library search function of the HRGC-LRMS instrument. The retention time for PCP was 9.70 min. The selected ion for PCP quantitative analysis was m/z = 266, the reference ions were 264 and 268. The selected ion for the internal standard [$^{13}C_6$] PCP was m/z = 274, the reference ions were 276 and 172. The chromatograph settings are listed in Appendix A.

HRGC-LRMS auto-tuning was perfomed with perfluorotributlyamine. The calibration was carried out with PCP concentrations of 0.1, 0.2, 0.5, 1.0, 2.0, 5.0, 10.0, and 20.0 μg/mL; 2 μg/mL IS was added for each standard solution or sample. Five point calibration was employed, i.e., for each single batch a minimum of 5 consecutive standards were selected depending on the range of concentration of the samples.

Each sample was diluted to bring the PCP concentration into the selected calibration range. Linear regression software was chosen for the calculation of the calibration curve.

The volume of water collected was measured by weight. A density of 1.00g/mL was used for water. The limit of detection (LOD) of this method was estimated to be 0.025 ng/mL cm^2. The LOD is defined according to Part 136, Appendix B, procedure (b) (Federal Register, 1984), as three times the standard deviation of replicate analyses of the analyte.

The test has only been operating since June and we have had only one rainfall event that produced sufficient quantities of water for analysis. Penta levels in the runoff from this event were 0.379 ug/ml . A total of 1.83 mg of penta was obtained from the 8,823.3 g of runoff. The total surface are of the material was 11.31 square meters, which translates to 0.16 mg/m^2 of pentachlorophenol from the first rainfall event. Other tests suggest that any migration from the freshly treated wood occurs shortly after exposure and that these levels of release decline relatively quickly as any surface deposits from the original treatment are removed. Once these deposits are removed, the chemical release levels fall to near background levels. While we would expect a similar response in our test, further collections will be necessary confirm these results.