Oregon State University
Utility Pole Research Cooperative

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Department of Wood Science & Engineering

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http://www.cof.orst.edu/coops/utilpole/

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- CSI, Inc.
- Dr. Wolman, GMBH
- Genics Inc.
- Hickson, Inc.
- New York State Electric and Gas
- Osmose Utilities, Inc.
- Pacific Gas and Electric
- Pacific Corp.
- Portland General Electric Company
- The Southern Company
- Western Wood Preservers Institute

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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 costly 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 (Table I-1), 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 has been continued performance evaluations to determine when retreatment is necessary and to identify any characteristics that might affect performance.

Table I-1. Characteristics of internal remedial treatments for wood poles

Table I-1. Characteristics of internal remedial treatments for wood poles				
Trade Name	Active Ingredient	Conc. (%)	Toxicity (LD50 mg/kg)	Manufacturer
Timber Fume	trichloronitromethane	96	205	Osmose Inc.
Wood Fume ISK Fume	sodium n-methylisothiocyanate	32.1	1700-1800	Osmose Inc ISK Biosciences
MITC-FUME	methylisothiocyanate	96	305	Osmose Inc
Ultra-Fume	basamid	98		Pole Care Inc.
Impel Rods	boron	100	>2000	Pole Care Inc.
Pole Saver Rods	boron/fluoride	58/24	>2000	Preschem Ltd.
FluRods	fluoride	98		Osmose Inc
Cobra-Rods	boron/copper	?		Genics Inc.

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

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 % F). 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 intervals, the ampules were removed and weighed to assess chemical loss over time.

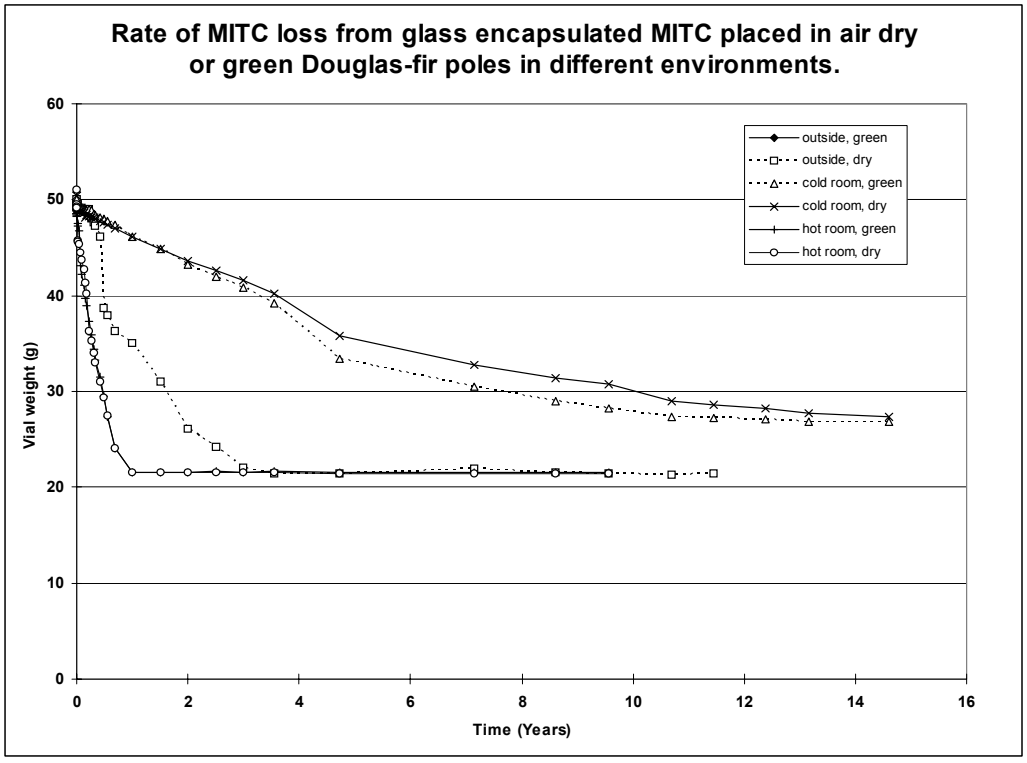
As noted previously, ampules stored at 32 C lost most of their chemical within 1 year (Figure I-1). Ampules stored outdoors lost chemical more slowly and there appears to be a slight, but noticeably more rapid release rate for pole sections that were initially seasoned. The reasons for these differences remain unclear. Ampules stored at ambient conditions required 4 to 8 years to lose all of the initial chemical, although the vast majority of chemical was lost within the first 4 years after treatment.

Ampules stored at 5 C lost chemical very slowly at rates that will require 25 to 30 years for all of the chemical to leave the ampule (Table I-2). MITC is an interesting chemical in that it sublimes directly from a solid to a gas at room temperature. Clearly, cooler temperatures retard this process. Conversely, decay fungi are only marginally active at 5 C, making it unlikely that any significant decay would occur under these conditions. Thus, the slow release of MITC may be attractive from a practical aspect for poles exposed in cooler climates. The only concern about this prolonged release would be that the ampules continue to retain active ingredient for many years. This might become a concern were the pole to be involved in a vehicle accident, since the ampule could be ejected from the hole, or the chemical could be released if the pole were cut through with a chainsaw. However, prior tests by the manufacturer have shown that even cutting through an ampule in the wood results in little or no airborne exposure to the chemical to workers. Thus, there are minimal risks posed by long term residual chemical in the pole.

Table I-2. Residual MITC in glass ampules installed in Douglas-fir pole sections exposed at 5°C, 32°C or ambient outdoor conditions.

	Outside		Cold room		Hot room	
	ampule weight (g)					
Years	wet	dry	wet	dry	wet	dry
0	50.0	50.0	50.1	50.4	50.8	51.1
0.3	49.1	48.0	48.9	48.2	36.0	35.3
0.5	44.7	38.0	47.8	47.4	27.3	27.5
1.0	42.5	35.1	46.2	46.1	E	E
1.5	39.9	31.0	44.8	44.9	E	E
2.0	35.7	26.1	43.3	43.6	E	E
3.0	30.1	22.0	40.8	41.6	E	E
4.7	23.9	E	33.3	35.7	E	E
7.2	23.9	E	30.6	32.8	E	E
8.6	23.0	E	29.0	31.4	E	E
9.6	22.8	E	28.2	30.8	E	E
10.7	22.4	E	27.4	28.9	E	E
11.5	E	E	27.2	28.6	E	E
12.4	E	E	27.1	28.2	E	E
13.2	E	E	26.9	27.7	E	E
14.6	E	E	26.9	27.3	E	E
E denotes that the ampule was empty						

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 14 years.



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

The MITC-Fume treated poles in Washington state were not inspected this year.

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

While chloropicrin, metam sodium, and MITC-Fume have all provided excellent protection, each has handling characteristics that are of concern to some users. In the late 1980's we began work with basamid, a solid, crystalline chemical that decomposes in the presence of water to produce MITC and a host of other compounds. Preliminary trials suggested that the rate of decomposition was too slow to be of use for controlling wood decay, but continuing trials suggested that this chemical might have promise, particularly because of its ease of handling. In a series of laboratory and small-scale field trials, we showed that basamid could produce effective levels of MITC in wood over time and also continued to produce MITC for far longer periods than was found with metam sodium. We also found that the presence of some copper in the system markedly improved MITC production. Following these successful small scale trials, we established the following test on transmission-sized poles.

Three steeply angled holes were drilled beginning at groundline and moving upward at 150 mm increments and around 120 degrees in Douglas-fir transmission poles. Drill shavings from each drill hole were retained. These shavings were briefly flamed and then placed on the surface of malt extract agar in plastic petri dishes. These chips were observed for evidence of fungal growth, which was then examined under a microscope for characteristics typical of basidiomycetes, a class of fungi containing many important wood decayers.

The poles were treated with either 200 or 400 g of basamid with or without 1 % copper sulfate. The dosages were premixed and evenly distributed among the three treatment holes. An additional set of poles was treated with 500 ml of metam sodium, also distributed among three holes at the same locations as those drilled in the basamid treatments. The treatment holes were plugged with tight-fitting wood dowels. Chemical movement and efficacy were assessed annually for the first 5 years after treatment, then 7 and 10 years after chemical application by removing increment cores from three equidistant points around each pole 0.3, 1.3, 2.3, and 3.3 m above groundline. The outer, heavily treated zone was discarded, then the outer and inner 25 mm of each core was removed and placed into 5 ml of ethyl acetate. The cores were stored at room temperature for 48 hours to extract any MITC in the wood, then the increment core was removed, oven-dried, and weighed. The weight was later used to calculate chemical content on a wood weight basis.

The ethyl acetate extracts were injected into a Shimadzu gas chromatograph equipped with a flame photometric detector with filters specific for sulfur (a component of MITC). MITC levels in the extracts were quantified by comparison with prepared standards and results were expressed on an ug MITC/oven dried g of wood basis. The remainder of each core was cultured on malt extract agar for decay fungi as described earlier in this section.

As with our other tests, the threshold for MITC is considered to be 20 ug or more of MITC/g of wood. This level was selected on the basis of comparisons between fungal isolations and residual chemical levels in various field tests. Using this level as our guide, protective MITC levels were present within one year in poles receiving metam sodium or either basamid dosage amended with copper sulfate (Figure I-2 to 8, Table I-3). MITC levels tended to be highest within one meter of the groundline, reflecting the concentration of the original application holes near that zone. MITC levels in metam sodium treated poles remained above the threshold in this zone for the first 3 years after treatment, then declined sharply after the fourth year. These results are consistent with the finding that wood from metam treated poles remains inhibitory to decay fungi in bioassays for 3 to 5 years

after treatment. It also shows the relatively lower fungicidal effects of metam sodium in comparison with other fumigants over time.

Treatment of poles with 200 or 400 g of basamid alone produced more variable MITC levels one year after treatment. Protective levels were present at the groundline within the second year for the 200 g dosage, but levels further above the groundline were more variable. Doubling the dosage improved MITC levels after the first year and also produced increased MITC levels 1 m above the groundline. In addition, both dosages resulted in protective levels at groundline and 1 m above this zone 10 years after treatment. This long term release rate is a secondary benefit of the use of this fumigant for treatment. While initial chemical levels were lower than those found with metam sodium, the longer release period from this treatment should produce more uniform protection against renewed fungal attack.

The addition of copper to basamid at the time of treatment produced marked increases in levels of MITC found one year after treatment. The copper enhancement of basamid decomposition to MITC remained evident for 5 years after treatment, then the effect declined and MITC levels were similar in amended and non-amended treatments. In both cases, the residual MITC levels were well above those required for protection against renewed fungal attack.

Figure I-2. Residual MITC levels in Douglas-fir poles 1 to 10 years after treatment with 200 g of basamid.

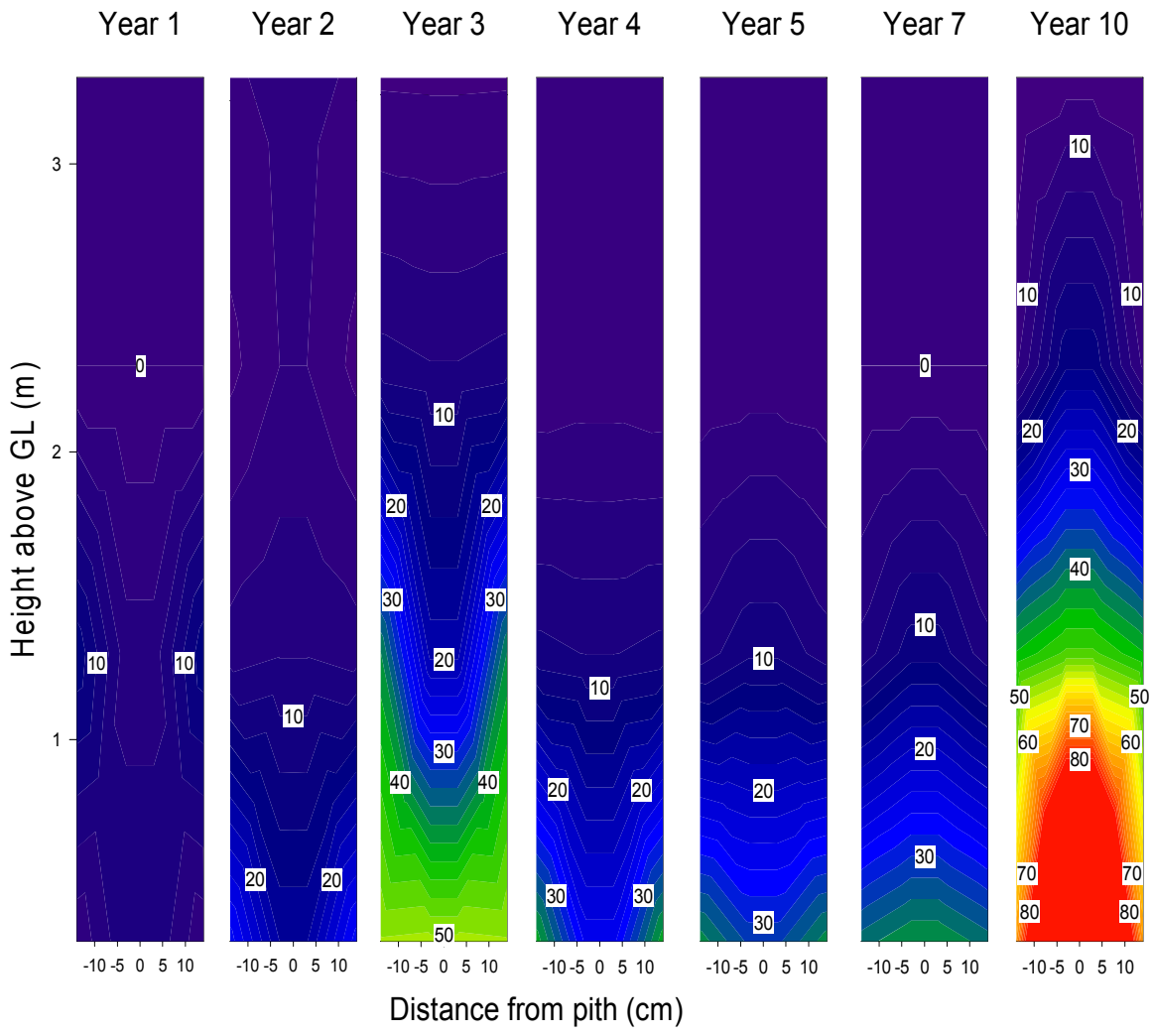


Figure I-3. Residual MITC levels in Douglas-fir poles 1 to 10 years after treatment with 200 g of basamid amended with 1 % copper sulfate.

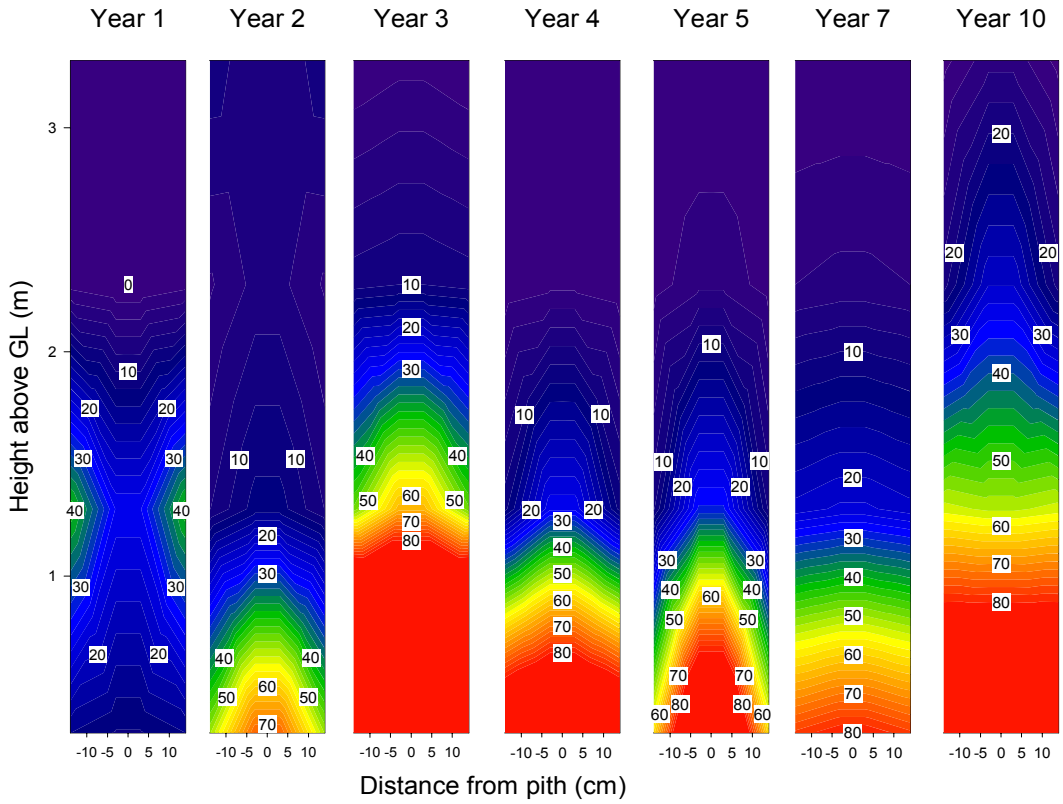


Figure I-4. Residual MITC levels in Douglas-fir poles 1 to 10 years after treatment with 400 g of basamid.

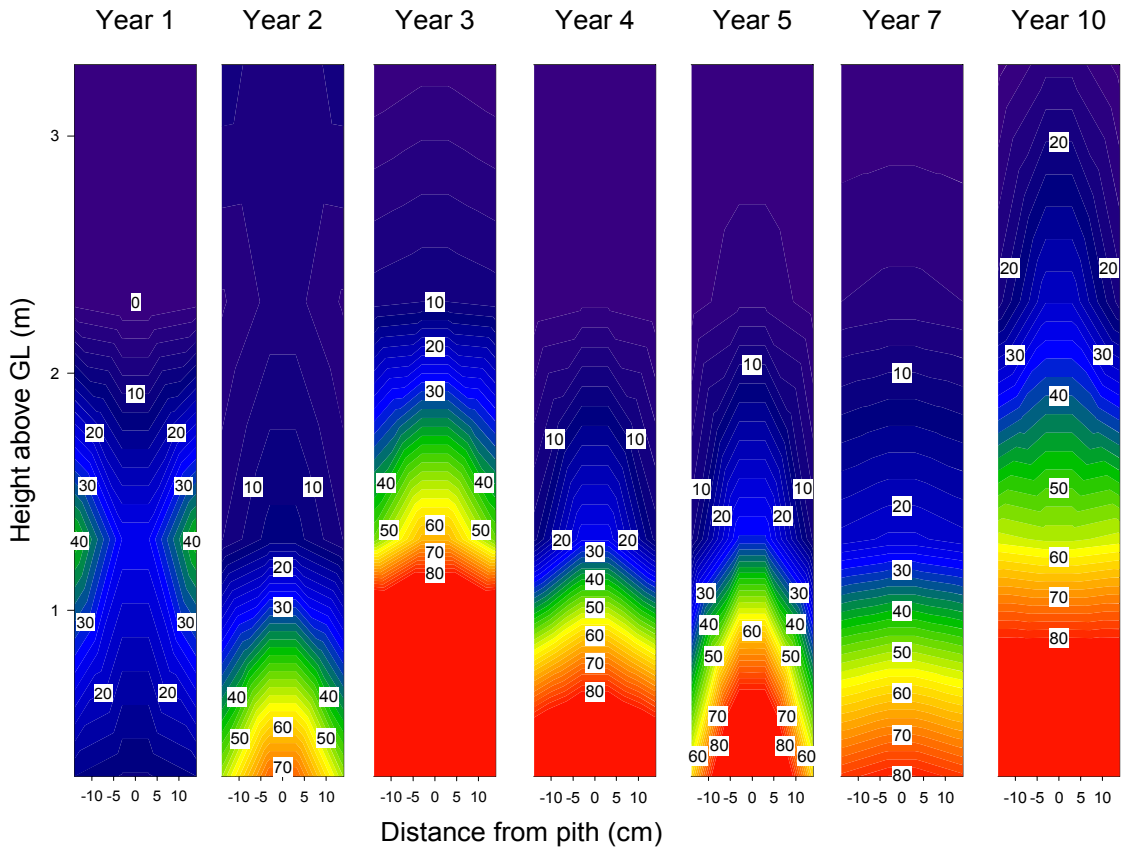


Figure I-5. Residual MITC levels in Douglas-fir poles 1 to 10 years after treatment with 400 g of basamid amended with 1% copper sulfate.

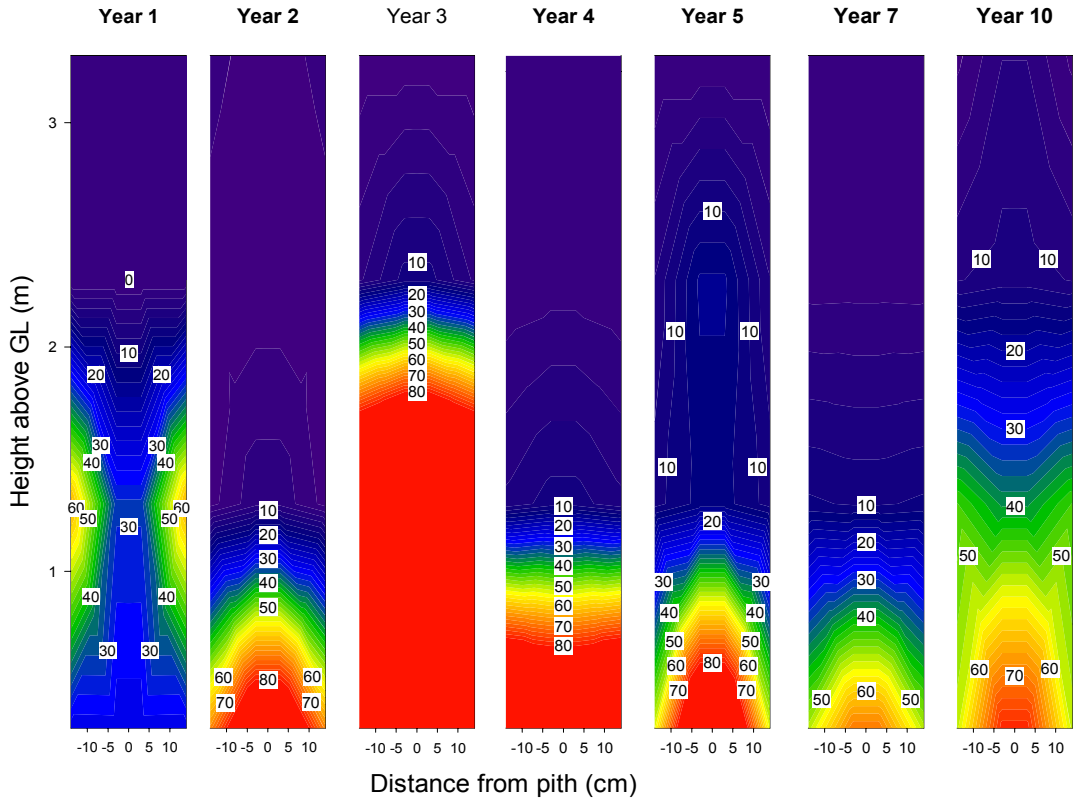


Figure I-6. Residual MITC levels in Douglas-fir poles 1 to 10 years after treatment with 50 ml of metam sodium.

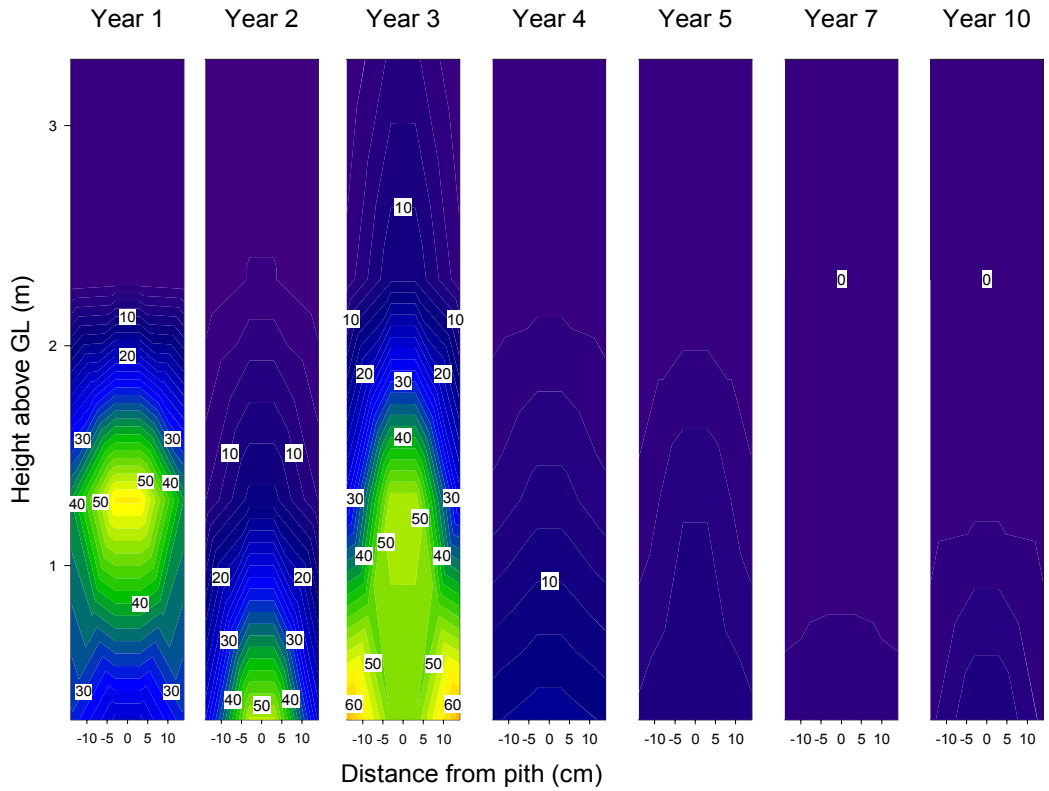


Figure I-7. Residual MITC at selected distances above groundline in Douglas-fir poles 1 to 10 years after treatment with a) 200 g of basamid, b) 200 g of basamid plus 1 % copper sulfate, c) 400 g of basamid, d) 400 g of basamid plus 1 % copper sulfate.

Figure I-7a

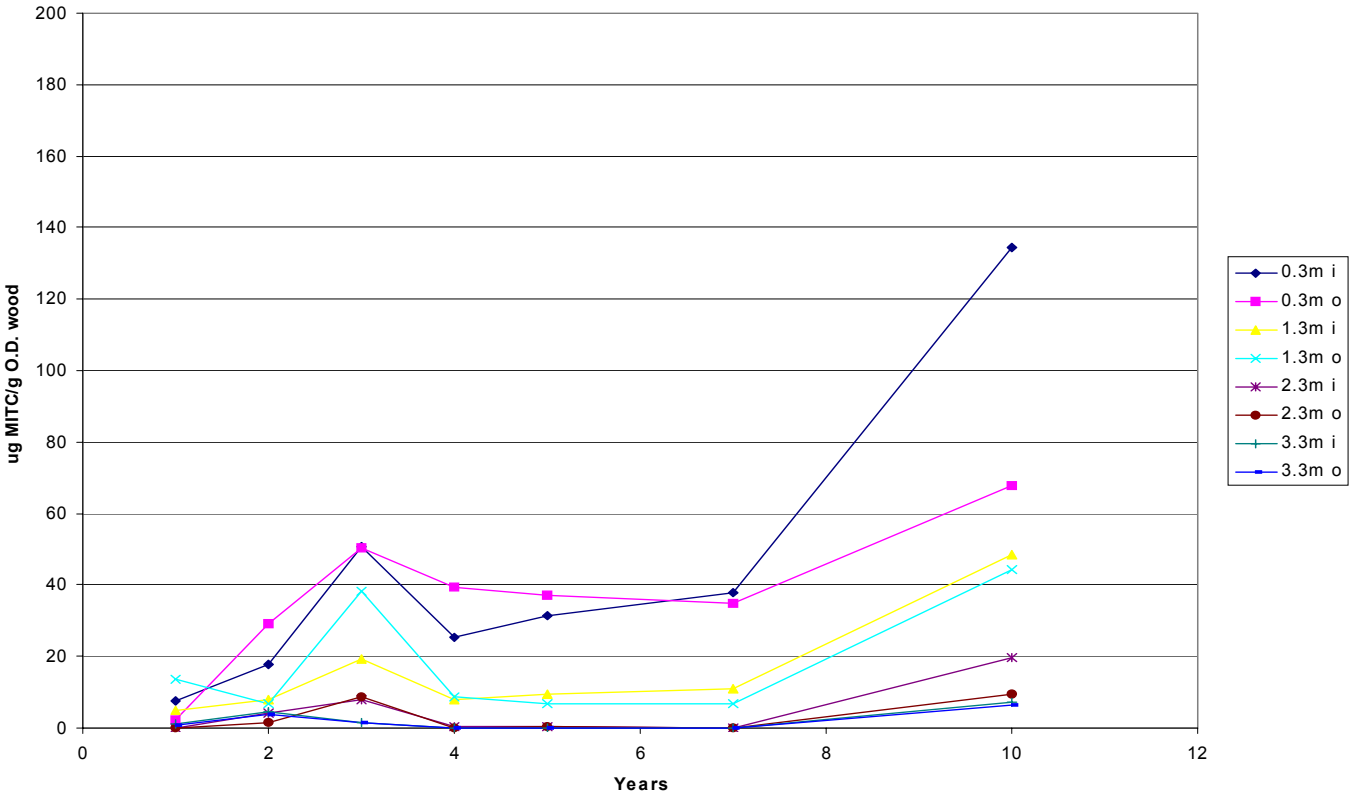


Figure I-7b

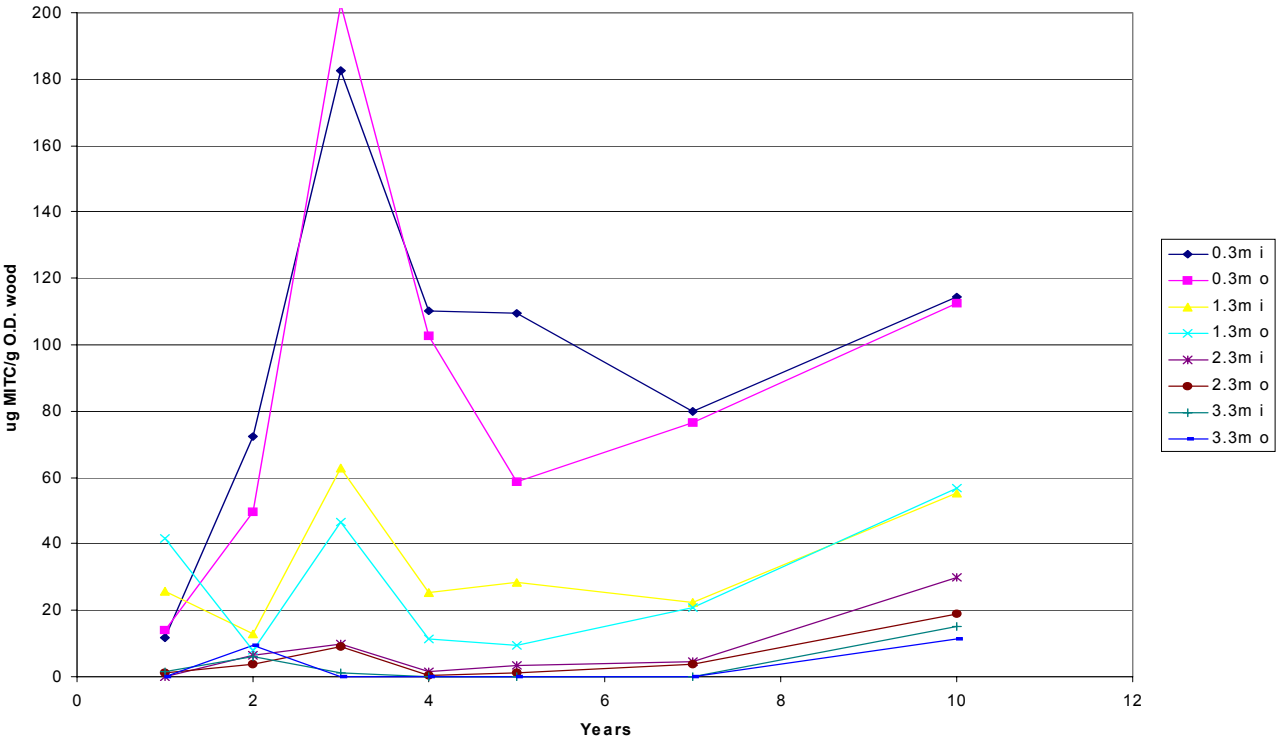


Figure I-7c

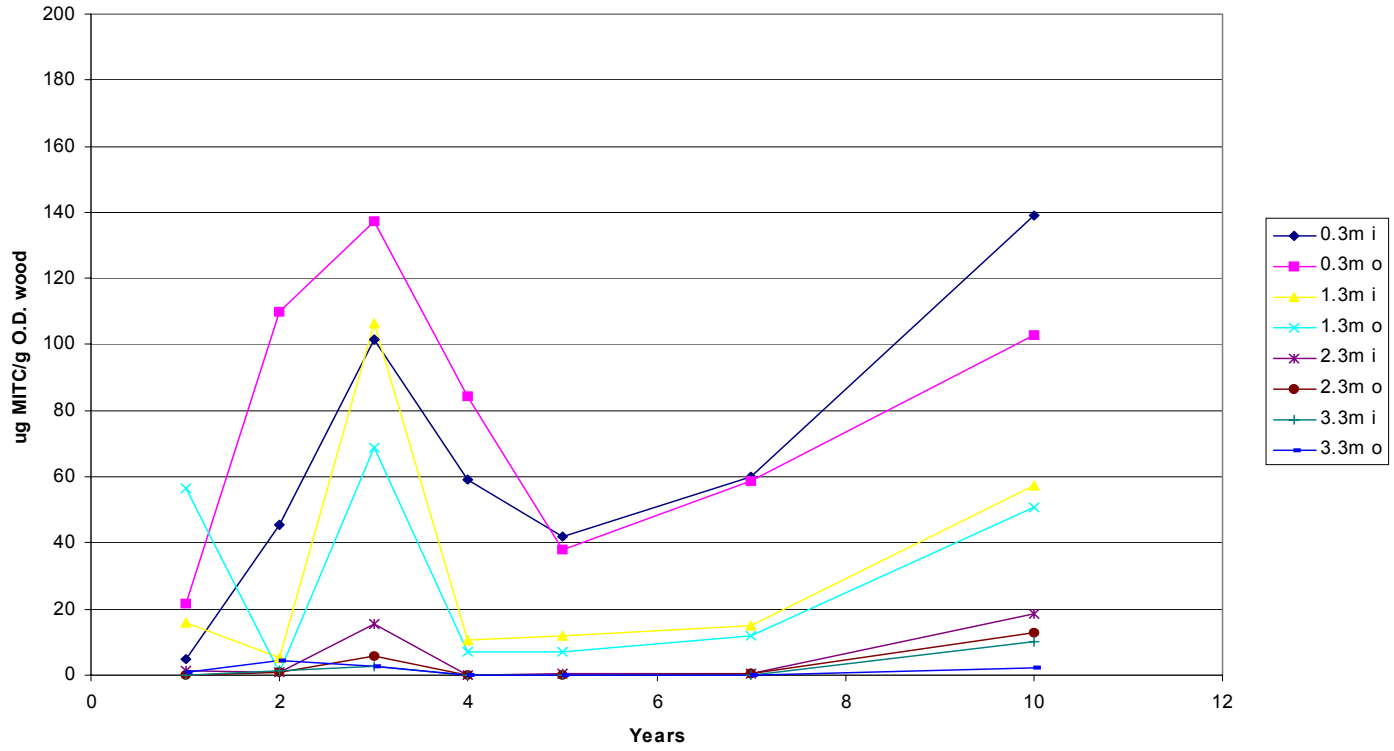


Figure I-7d

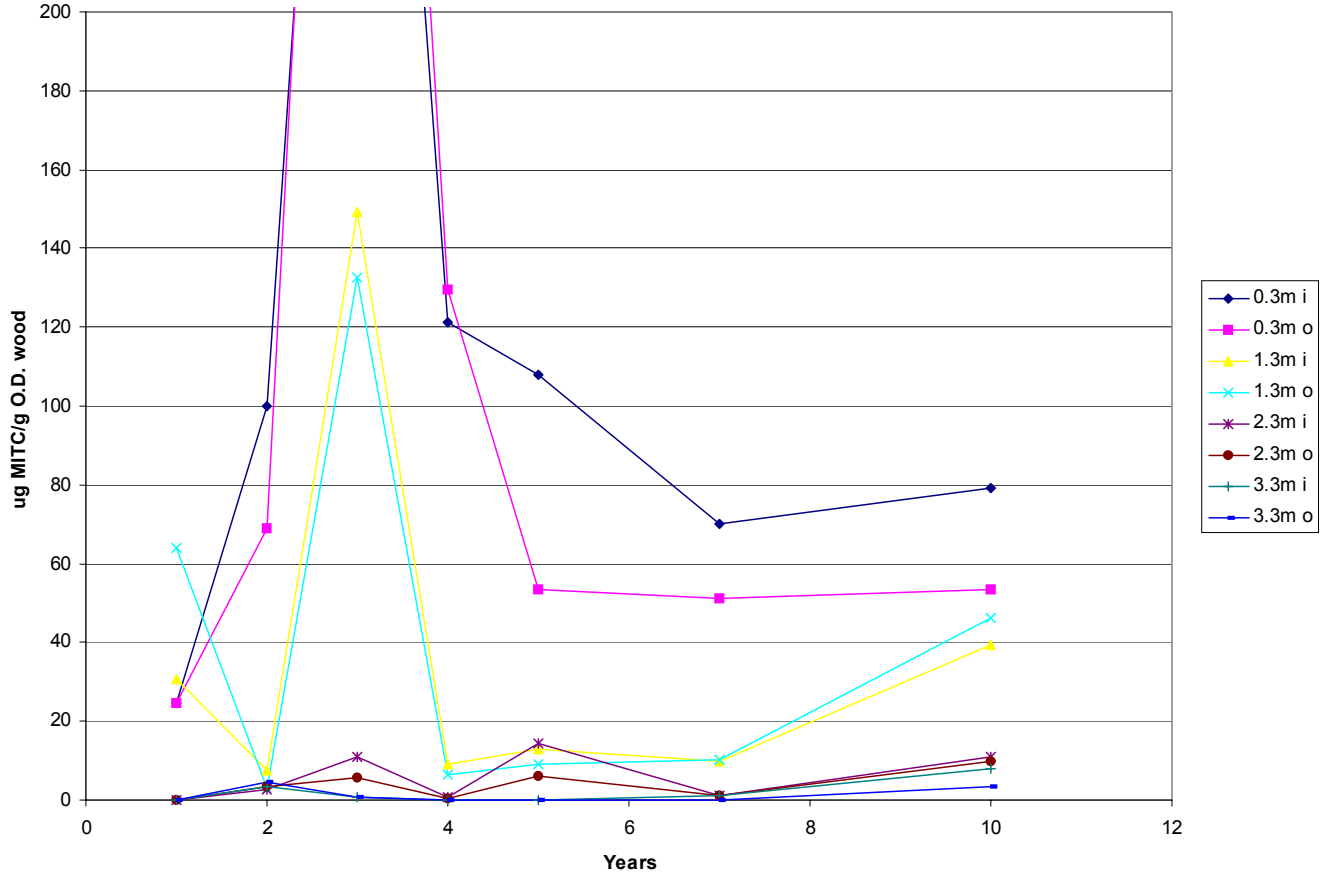
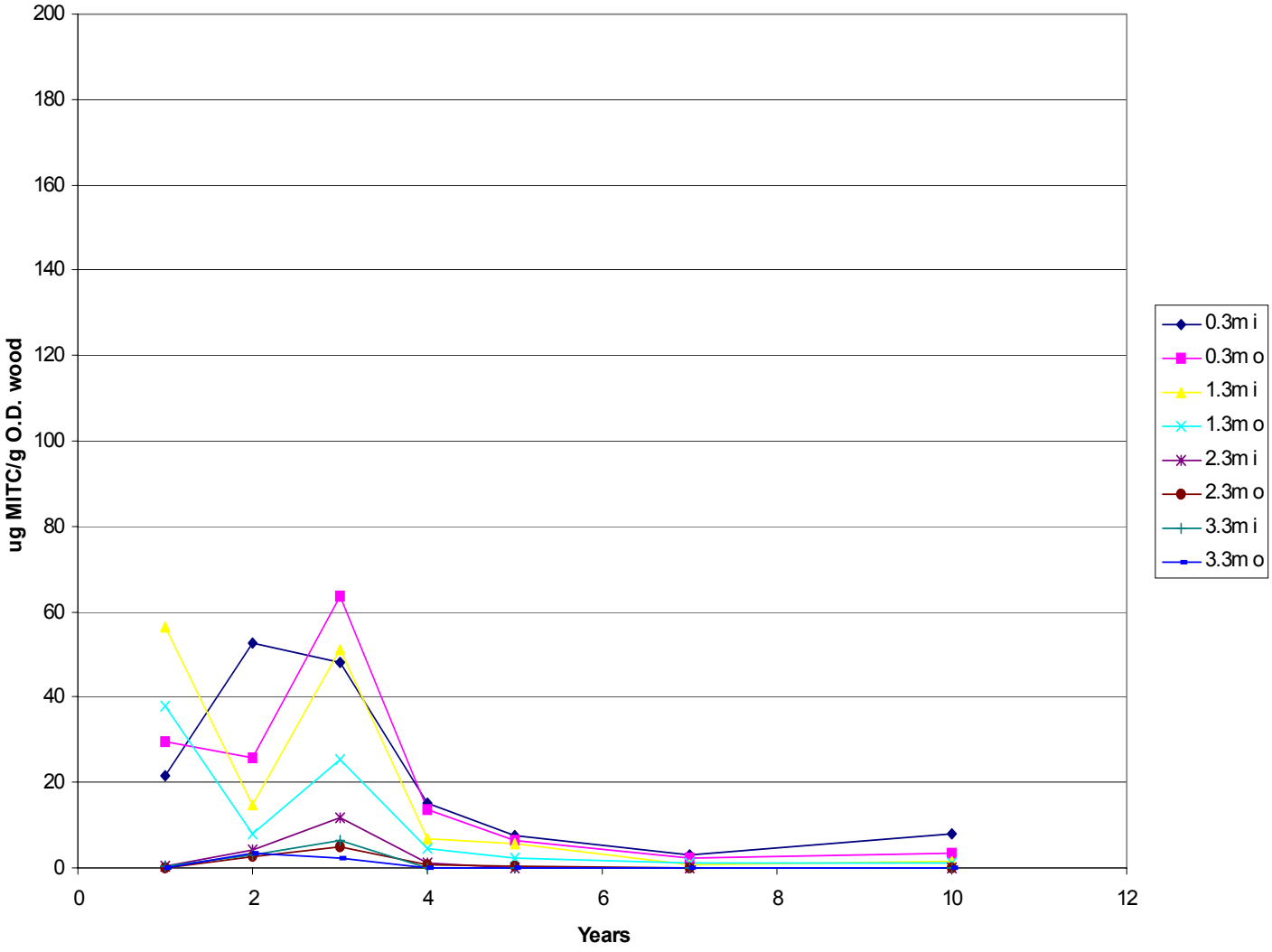


Figure I-8. Residual MITC at selected distances above the groundline of Douglas-fir poles 1 to 10 years after treatment with 500 ml of metam sodium.



Culturing increment cores from the poles revealed that decay fungi were periodically isolated from various locations over the course of the test, but there was no consistent increase in fungal frequency over the 10 year test. For example, decay fungi were isolated near the groundline in poles 5 years after treatment with 200 g of basamid plus copper sulfate; however, no decay fungi were isolated from this location 7 or 10 years after treatment. The inconsistent isolations indicate that the treatment remains largely protective (Table I-4).

The 10 year results indicate that basamid provides a slower initial protection, but that MITC remains in the poles at effective levels for far longer periods than would be found with metam sodium. The addition of copper to the basamid markedly improves MITC release rates, producing a treatment that is initially comparable to metam sodium, but provides a far longer period of protection against renewed fungal attack.

Table I-3. Residual MITC levels at selected locations in Douglas-fir poles 1 to 10 years after treatment with metam sodium or basamid.

Chemical treatment	Dosage	year	MITC content (ug/g of wood)							
			0.3 m		1.3 m		2.3 m		3.3 m	
			inner	outer	inner	outer	inner	outer	inner	outer
Basamid	200 g	1	8 (21)	2 (7)	5 (9)	13 (23)	0 (0)	0 (0)	1 (4)	1 (2)
		2	18 (20)	29 (37)	8 (11)	7 (16)	4 (6)	1 (4)	4 (8)	4 (7)
		3	51 (44)	50 (63)	19 (21)	38 (36)	8 (5)	9 (7)	2 (4)	2 (3)
		4	25 (15)	39 (31)	8 (4)	9 (11)	0 (1)	0 (0)	0 (0)	0 (0)
		5	31 (31)	37 (26)	10 (5)	7 (6)	0 (1)	0 (1)	0 (0)	0 (0)
		7	38 (20)	35 (30)	11 (7)	7 (8)	0 (0)	0 (0)	0 (0)	0 (0)
		10	134 (178)	68 (75)	48 (17)	44 (25)	20 (11)	10 (9)	7 (9)	6 (7)
Basamid plus copper	200 g	1	12 (27)	14 (31)	26 (38)	42 (65)	0 (0)	1 (5)	2 (5)	0 0
		2	72 (100)	50 (74)	13 (18)	8 (13)	7 (19)	4 (9)	6 (13)	10 (21)
		3	182 (215)	203 (272)	63 (70)	47 (52)	10 (13)	9 (17)	1 (4)	0 (0)
		4	110 (86)	103 (86)	25 (20)	11 (16)	1 (2)	0 (2)	0 (0)	0 (0)
		5	110 (92)	59 (101)	28 (21)	10 (10)	3 (4)	1 (2)	0 (0)	0 (0)
		7	80 (73)	77 (87)	22 (14)	21 (18)	5 (4)	4 (5)	0 (0)	0 (0)
		10	114 (111)	112 (90)	55 (35)	57 (56)	30 (20)	19 (14)	15 (12)	11 (9)
Basamid	400 g	1	5 (9)	22 (49)	16 (31)	56 (86)	1 (4)	0 (0)	0 (0)	1 (3)
		2	45 (47)	110 (108)	5 (5)	1 (3)	1 (2)	1 (3)	1 (2)	4 (10)
		3	102 (97)	137 (207)	107 (106)	69 (105)	15 (15)	6 (8)	3 (6)	3 (6)
		4	59 (35)	84 (54)	11 (8)	7 (6)	0 (0)	0 (0)	0 (0)	0 (0)
		5	42 (23)	38 (31)	12 (8)	7 (6)	1 (2)	0 (0)	0 (0)	0 (0)
		7	60 (31)	59 (27)	15 (7)	12 (6)	1 (2)	0 (2)	0 (0)	0 (0)
		10	139 (128)	103 (80)	58 (20)	51 (36)	19 (7)	13 (8)	10 (7)	2 (4)
Basamid plus copper	400 g	1	25 (41)	25 (76)	31 (46)	64 (139)	0 (0)	0 (0)	0 (0)	0 (0)
		2	100 (93)	69 (126)	7 (8)	3 (5)	2 (5)	3 (5)	3 (5)	4 (6)
		3	435 (613)	501 (787)	149 (162)	132 (185)	11 (11)	6 (8)	1 (2)	1 (2)
		4	121 (82)	130 (116)	9 (10)	7 (10)	1 (2)	0 (1)	0 (0)	0 (0)
		5	108 (89)	54 (70)	13 (14)	9 (10)	14 (48)	6 (21)	0 (0)	0 (0)
		7	70 (89)	51 (30)	10 (8)	10 (7)	1 (2)	1 (2)	1 (4)	0 (0)
		10	79 (43)	53 (29)	40 (22)	46 (46)	11 (10)	10 (7)	8 (8)	3 (7)
Metham sodium	500 mL	1	21 (43)	30 (61)	57 (82)	38 (46)	1 (3)	0 0	1 (3)	0 (0)
		2	53 (47)	26 (28)	15 (17)	8 (16)	4 (7)	3 (5)	3 (6)	3 (5)
		3	48 (34)	64 (106)	51 (122)	25 (31)	12 (9)	5 (5)	7 (15)	2 (6)
		4	15 (16)	14 (11)	7 (8)	4 (7)	1 (3)	1 (2)	0 (0)	0 (0)
		5	8 (8)	7 (6)	6 (6)	2 (4)	0 (1)	0 (1)	0 (0)	0 (0)
		7	3 (5)	2 (4)	1 (2)	1 (2)	0 (0)	0 (0)	0 (0)	0 (0)
		10	8 (15)	3 (7)	1 (4)	1 (3)	0 (0)	0 (0)	0 (0)	0 (0)

Table I-4. Isolation frequency of basidiomycetes from Douglas-fir poles 1 to 10 years after application of metam sodium or basamid alone or amended with 1 % copper sulfate.

Height above groundline	year	Vapam	Basamid 400 g	Basamid 400g copper	Basamid 200g	Basamid 200g copper
0.3 m	0	0 47	0 14	0 27	7 20	0 0
	2	0 10	0 7	0 7	0 27	0 0
	3	0 5	0 0	0 20	0 0	0 0
	4	0 13	0 0	0 0	0 0	0 7
	5	0 27	0 27	0 27	0 33	13 13
	7	0 40	0 0	0 0	0 7	0 20
	10	3 28	0 0	0 7	0 0	0 0
1.3 m	2	0 13	0 23	0 13	0 33	13 0
	3	0 3	0 0	0 7	0 0	0 20
	4	0 10	0 0	0 0	0 7	0 0
	5	0 30	0 13	0 27	0 40	7 40
	7	0 20	0 0	0 0	0 0	0 20
	10	0 28	0 0	0 0	0 0	0 0
2.3 m	2	0 10	0 7	0 13	0 27	0 27
	3	0 7	0 25	0 7	0 14	0 0
	4	0 10	0 20	0 7	7 33	0 7
	5	3 40	0 27	0 33	0 33	0 27
	7	13 27	0 7	0 7	0 27	0 7
	10	0 21	0 7	0 7	0 13	0 0
3.3 m	2	0 10	0 14	0 7	0 40	0 0
	3	0 3	0 25	0 13	0 0	0 13
	4	0 13	7 7	0 0	7 27	0 7
	5	0 50	7 33	0 33	0 33	0 27
	7	7 7	0 27	7 0	0 40	0 0
	10	0 0	0 13	0 13	0 7	0 0

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

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 copper 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 annually after treatment by removing increment cores from three equidistant points around each pole at sites 0.3, 1.3, and 2.3 m above the groundline. The outer and inner 25 mm of each core were placed into 5 ml of ethyl acetate, extracted for 24 hours 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 tended to be greater in the inner zones, reflecting the tendency of the treatment holes to encourage chemical movement to the pole center. MITC levels in poles receiving no supplemental treatment barely reached the threshold level 0.3 m above ground 1 year after treatment (Figure I-9). MITC levels increased slightly over the next 4 years in these poles, but appear to have stabilized at levels well above the threshold by 4 years after treatment. MITC levels in these poles declined to just at or below the threshold this past year. Chemical levels above this zone were extremely low, suggesting that the treatment effect was confined to a relatively narrow zone around the application point (Table I-5).

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-9). MITC was also detectable 1.3 and 2.3 m above groundline 4 years after treatment at levels above the threshold. These results clearly support the application of copper sulfate at the time of basamid treatment to increase the initial release rate.

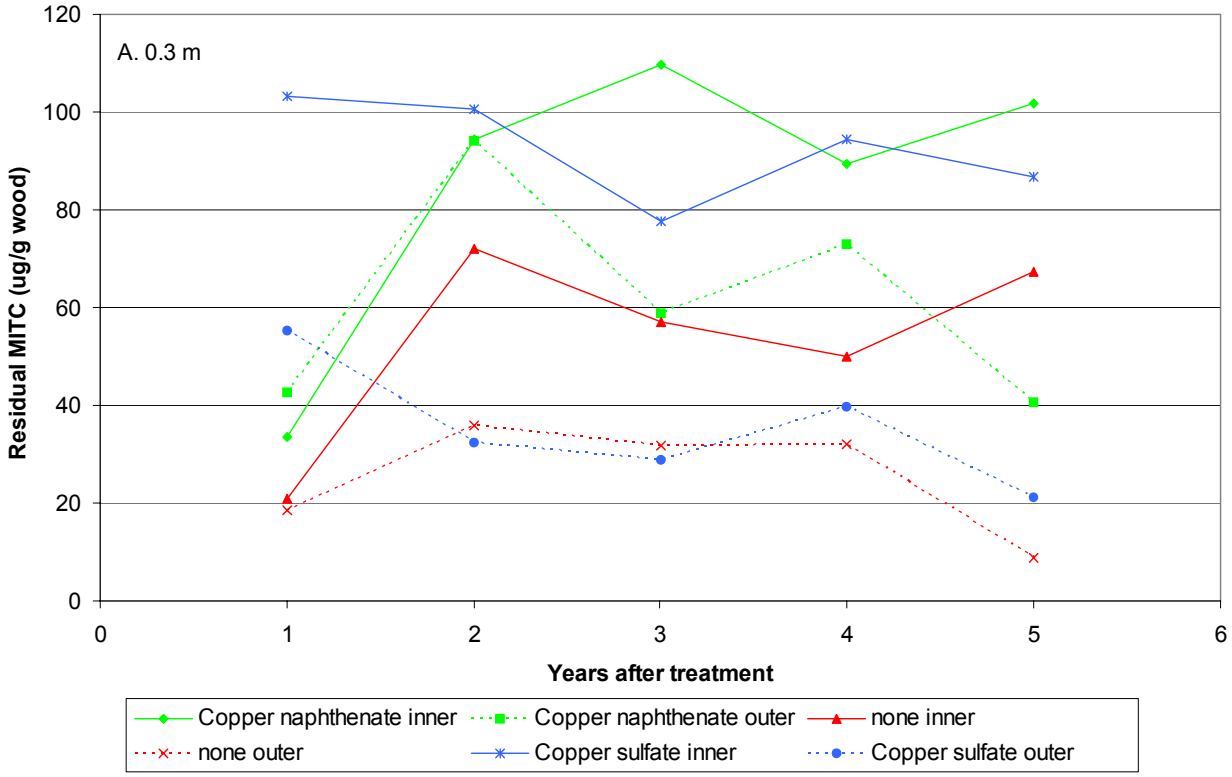
MITC levels in pole sections receiving copper naphthenate appeared to experience less of an initial boost in release rate than poles receiving copper sulfate following treatment; however, chemical levels rose sharply 2 years after treatment and have remained elevated and similar to those for the copper sulfate treatment. MITC was also detectable 1.3 and 2.3 m above groundline, but was only just approaching the threshold 1.3 above groundline in the inner assay zone. These results indicate that copper naphthenate enhanced basamid decomposition to MITC, but the levels were slightly lower than those found for copper sulfate. Despite the lower levels, copper naphthenate does appear to be useful for encouraging MITC production to more rapidly eliminate any decay fungi established in the wood.

Table I-5. Residual MITC in Douglas-fir pole sections 1 to 5 years after treatment with 200 g of Basamid supplemented with copper naphthenate or copper sulfate.

Copper treatment	Height (m)	Core section	Residual MITC (ug/g o.d. wood)									
			year 1		year 2		year 3		year 4		year 5	
none	0.3	inner	21	(14)	72	(47)	57	(27)	50	(41)	67	(31)
		outer	18	(37)	36	(33)	32	(42)	32	(32)	9	(8)
	1.3	inner	0	(0)	0	(0)	0	(0)	6	(5)	12	(4)
		outer	0	(0)	0	(0)	0	(0)	6	(6)	10	(29)
	2.3	inner	0	(1)	0	(0)	0	(0)	0	(0)	0	(0)
		outer	3	(8)	0	(0)	0	(0)	0	(0)	0	(0)
Copper sulfate	0.3	inner	103	(78)	101	(36)	78	(25)	95	(61)	87	(12)
		outer	55	(86)	32	(17)	29	(17)	40	(20)	21	(6)
	1.3	inner	4	(6)	7	(7)	7	(7)	20	(21)	18	(15)
		outer	0	(1)	3	(7)	5	(8)	21	(27)	3	(6)
	2.3	inner	0	(0)	0	(0)	0	(0)	25	(36)	7	(10)
		outer	0	(0)	0	(0)	0	(0)	23	(33)	0	(0)
Copper naphthenate	0.3	inner	34	(19)	94	(45)	110	(29)	89	(33)	102	(18)
		outer	43	(54)	94	(64)	59	(46)	73	(24)	41	(39)
	1.3	inner	0	(0)	6	(7)	7	(7)	18	(9)	23	(8)
		outer	0	(0)	5	(11)	4	(8)	9	(7)	1	(2)
	2.3	inner	2	(5)	0	(0)	0	(0)	1	(2)	2	(3)
		outer	6	(19)	0	(0)	0	(0)	0	(0)	0	(0)

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 the poles, but the isolations are sporadic and suggest that isolated fungal colonies are present in the above ground zones of the poles (Table I-6). 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 in these zones. 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. As a result, some adaptation of treatment patterns may be necessary where decay control is desired above the groundline; however, one advantage of these treatments over liquids is the ability to more safely apply the chemical above the groundline.

Figure I-9. 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.



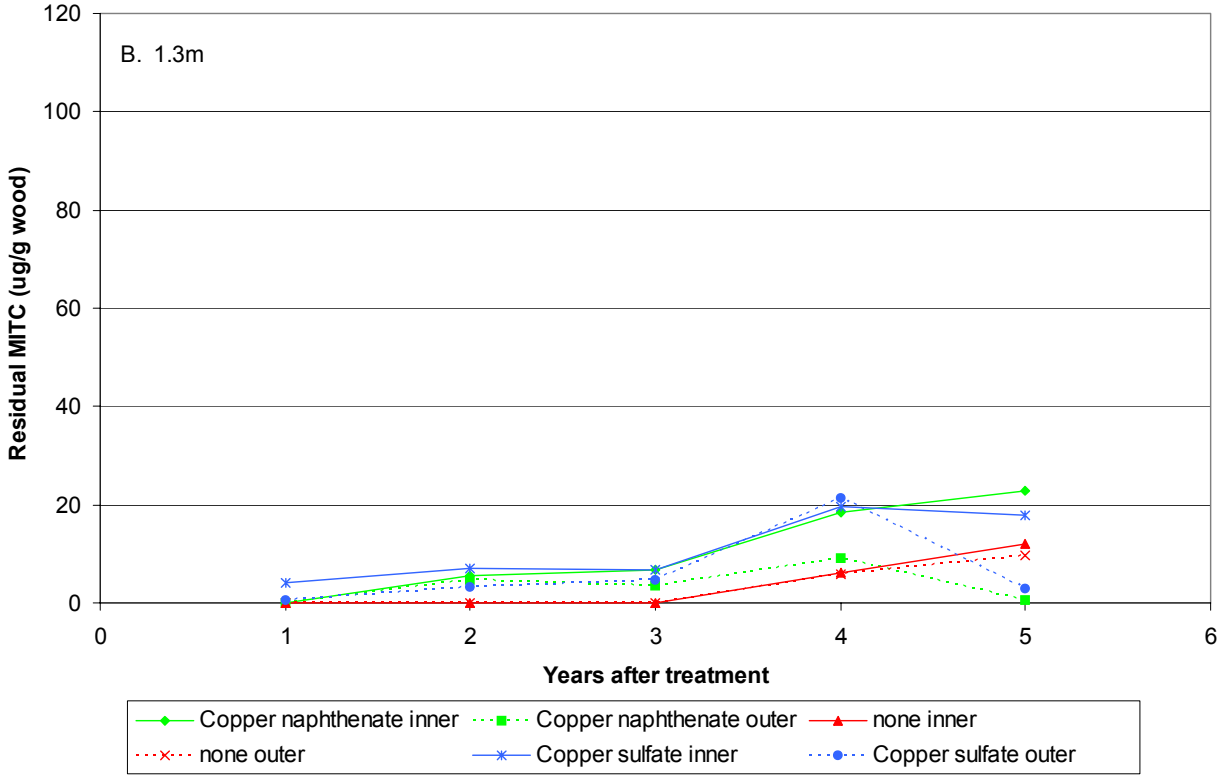


Table I-6. Isolation frequency of decay and non-decay fungi from Douglas-fir pole sections 1 to 5 years after treatment with 200 g of Basamid alone or amended with copper naphthenate or copper sulfate.

Copper treatment	height above GL (m)	Percent of cores with fungi				
		one year	two year	three year	four year	five year
none	0.3	0 [11]	0 [0]	0 [0]	0 [11]	0 [0]
	1.3	0 [11]	0 [33]	0 [33]	0 [33]	0 [0]
	2.3	0 [11]	0 [33]	0 [0]	0 [56]	0 [100]
copper sulfate	0.3	0 [11]	0 [0]	0 [0]	0 [11]	0 [0]
	1.3	22 [33]	44 [56]	11 [11]	22 [33]	0 [67]
	2.3	0 [44]	0 [33]	0 [33]	11 [33]	0 [89]
copper naphthenate	0.3	33 [33]	0 [0]	0 [0]	0 [0]	0 [0]
	1.3	0 [22]	0 [0]	0 [0]	0 [0]	11 [11]
	2.3	0 [44]	0 [67]	0 [22]	0 [67]	0 [78]

Values represent the average of nine cores containing decay fungi.
Superscripts represent average of non-decay fungi in the same cores.

5. Performance of basamid in rod or powdered formulations:

Basamid was originally supplied in a powdered formulation which was 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 for treatment of internal decay in wood poles 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 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 to three 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. The remainder of each core was then cultured for decay fungi 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-7; Figure I-10-12). The addition of copper compounds had little effect on MITC levels in the inner zones one year after treatment, 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 in the inner zones 3 years after treatment were similar to those found after 2 years for most treatments, although the levels in metam sodium treated poles continued to decline. MITC levels in the outer zones increased markedly in most treatments 0.3 m above groundline after 3 years. The reasons for the decline after 2 years are unknown, but it appears that MITC continues to move into the wood near the surface for all treatments

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 and there appeared to be no real difference between metam sodium and any of the basamid treatments. These trends have continued after three years. 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, a finding that appears to contradict the results closer to the groundline. MITC levels 3 years after treatment were still largely above the threshold 1.3 m above ground, except for the inner and outer zones in the metam sodium treatment and the outer zone in the 160 g of Ultrafume plus water treatment. These results also appear to contradict those found with the original basamid test described under Objective I–3 which had low MITC levels 2 to 3 m above the groundline; however, the test poles in the earlier test were much larger. As a result, the MITC from the 200 g dosage would have diffused into a larger area, resulting in correspondingly lower chemical levels per unit area.

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.

No decay fungi were isolated from any of the treated poles, suggesting that all of the treatments were effective (Table I-8). Non-decay fungi were isolated from a number of treatments, but there appeared to be no specific pattern to the isolations. We will continue to monitor fungal levels in these poles over the remainder of the test to determine when chemical levels fall below the minimums for fungal growth.

Table I-7. Residual MITC in Douglas-fir pole sections at selected distances above the groundline one to three years after treatment with metam sodium, basamid powder, or basamid rods with or without supplemental copper.

Treatment	Dosage	Supplement	year sampled	0.3 m		0.8 m		1.3 m	
				inner	outer	inner	outer	inner	outer
Powdered Basamid	160 g	none	year 1	50 (35)	24 (23)	6 (17)	4 (8)	0 (0)	0 (1)
			year 2	52 (70)	16 (55)	42 (54)	1 (3)	25 (31)	27 (41)
			year 3	38 (41)	28 (44)	28 (28)	39 (65)	54 (98)	34 (51)
Basamid rod	107 g	100 g copper naphthenate	year 1	44 (57)	46 (44)	2 (4)	6 (8)	0 (0)	0 (0)
			year 2	51 (70)	0 (2)	36 (51)	1 (3)	73 (101)	14 (28)
			year 3	67 (81)	66 (102)	52 (98)	31 (46)	49 (67)	37 (71)
Basamid rod	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 (11)
			year 3	26 (36)	31 (43)	38 (51)	15 (20)	29 (34)	21 (49)
Basamid rod	160 g	100 g copper naphthenate	year 1	49 (63)	85 (88)	9 (16)	9 (16)	1 (2)	0 (2)
			year 2	80 (104)	17 (45)	49 (64)	4 (9)	62 (75)	5 (11)
			year 3	76 (101)	39 (53)	47 (55)	73 (115)	47 (52)	28 (48)
Basamid rod	160 g	100 g water	year 1	22 (21)	29 (35)	4 (6)	6 (10)	0 (0)	1 (2)
			year 2	33 (47)	1 (2)	32 (34)	1 (5)	41 (41)	6 (11)
			year 3	25 (23)	24 (28)	22 (31)	14 (26)	37 (45)	14 (27)
Metham sodium	490 ml	none	year 1	64 (43)	75 (73)	17 (18)	22 (27)	1 (2)	2 (4)
			year 2	37 (49)	7 (11)	30 (27)	4 (7)	50 (78)	5 (10)
			year 3	22 (19)	22 (22)	17 (18)	21 (20)	18 (15)	17 (19)

Table I-8. Percentage of increment cores containing decay and non-decay fungi 1 to 3 years after application of metam sodium or basamid to Douglas-fir pole sections.

Treatment	Isolation frequency (% cores infested)								
	Height above groundline								
	0.3 m			0.8 m			1.3 m		
	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
160g Basamid powder	0 [7]	0 [7]	0 [0]	0 [7]	7 [27]	0 [7]	0 [20]	0 [47]	0 [0]
107g Basamid rods + CuNap	0 [0]	0 [33]	0 [0]	0 [0]	0 [27]	0 [0]	0 [0]	0 [7]	0 [0]
160g Basamid rods	0 [13]	0 [13]	0 [0]	0 [0]	0 [47]	0 [0]	0 [0]	0 [53]	0 [0]
160g Basamid rods + CuNap	0 [0]	0 [7]	0 [0]	0 [0]	0 [27]	0 [0]	0 [7]	0 [20]	0 [0]
160g Basamid rods + water	0 [7]	0 [20]	0 [13]	0 [7]	0 [13]	0 [7]	0 [0]	0 [53]	0 [13]
Metham sodium	0 [20]	0 [33]	0 [7]	0 [13]	0 [20]	0 [7]	0 [13]	0 [13]	0 [7]

Figure I-10. Residual MITC in Douglas-fir poles 1 to 3 years after treatment with a) 500 ml of metam sodium or b) 160 g of powdered basamid

Figure I-10a

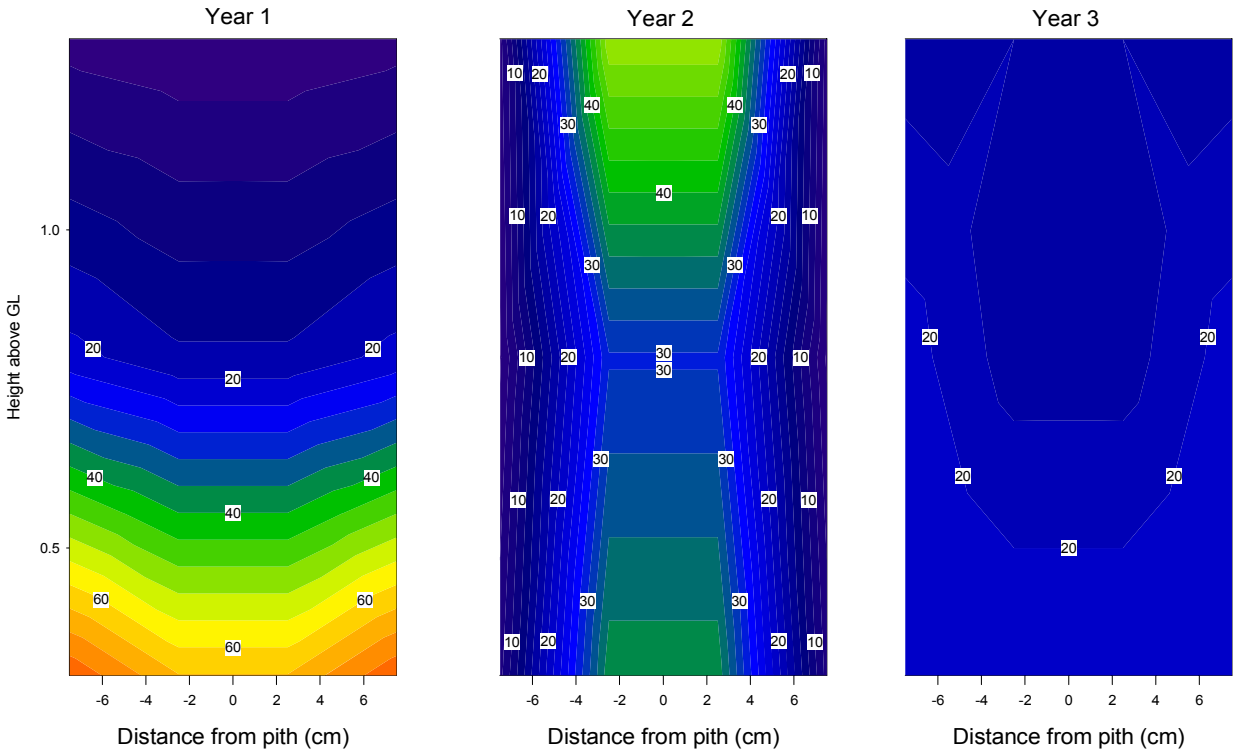


Figure I-10b

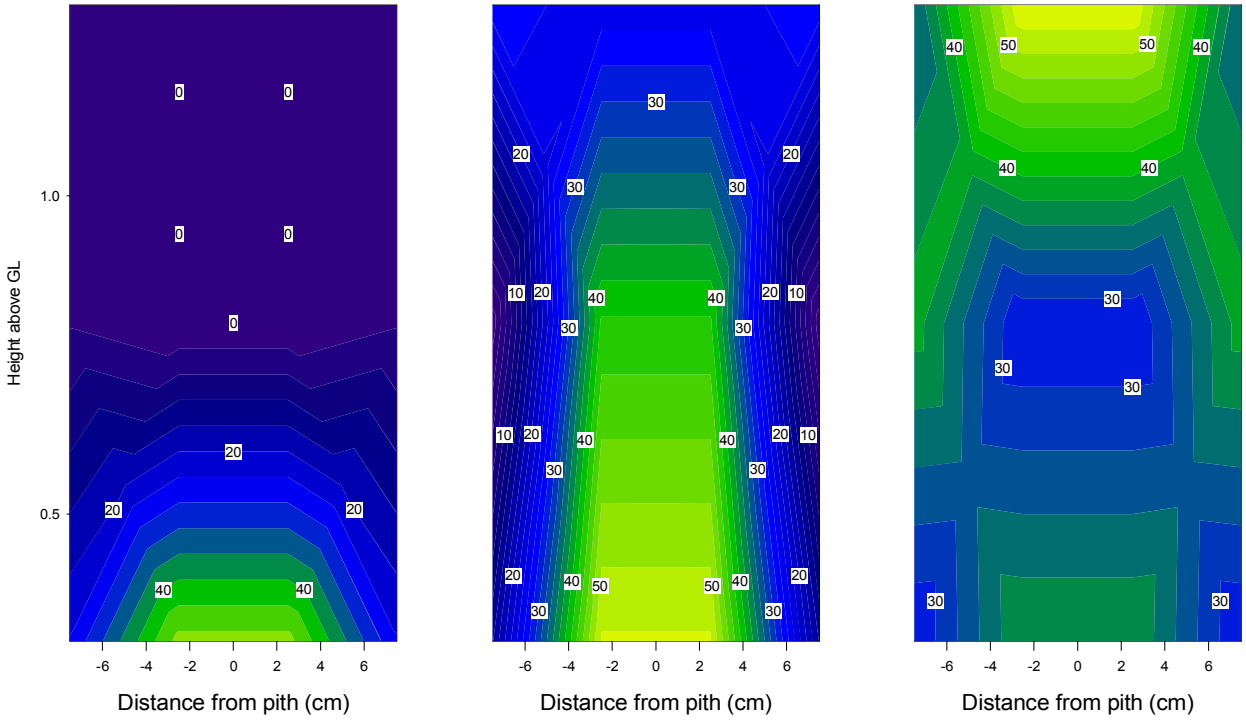


Figure I-11. Residual MITC in Douglas-fir poles 1 to 3 years after treatment with 160 g of Ultrafume rods a) without water or b) with water.

Figure I-11a

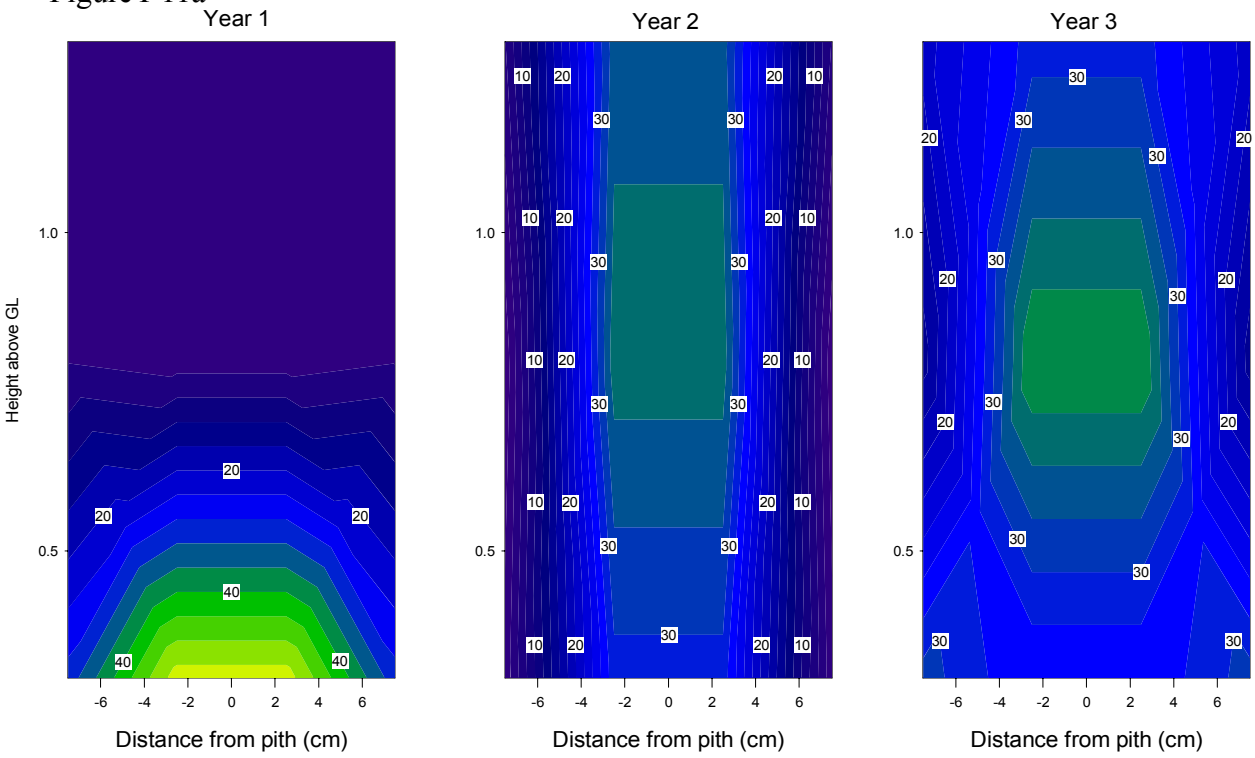


Figure I-11b

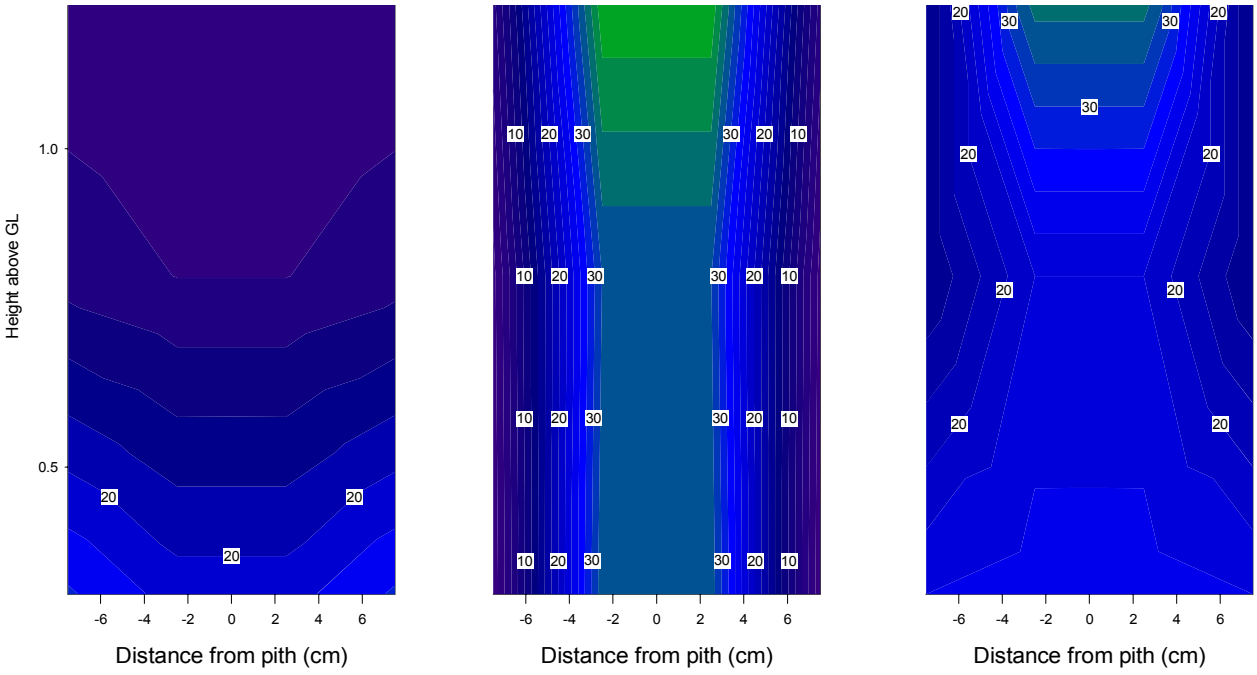


Figure I-12 Residual MITC in Douglas-fir poles 1 to 3 years after treatment with 6 or 9 Ultrafume rods and 100 g of copper naphthenate.

Figure I-12a

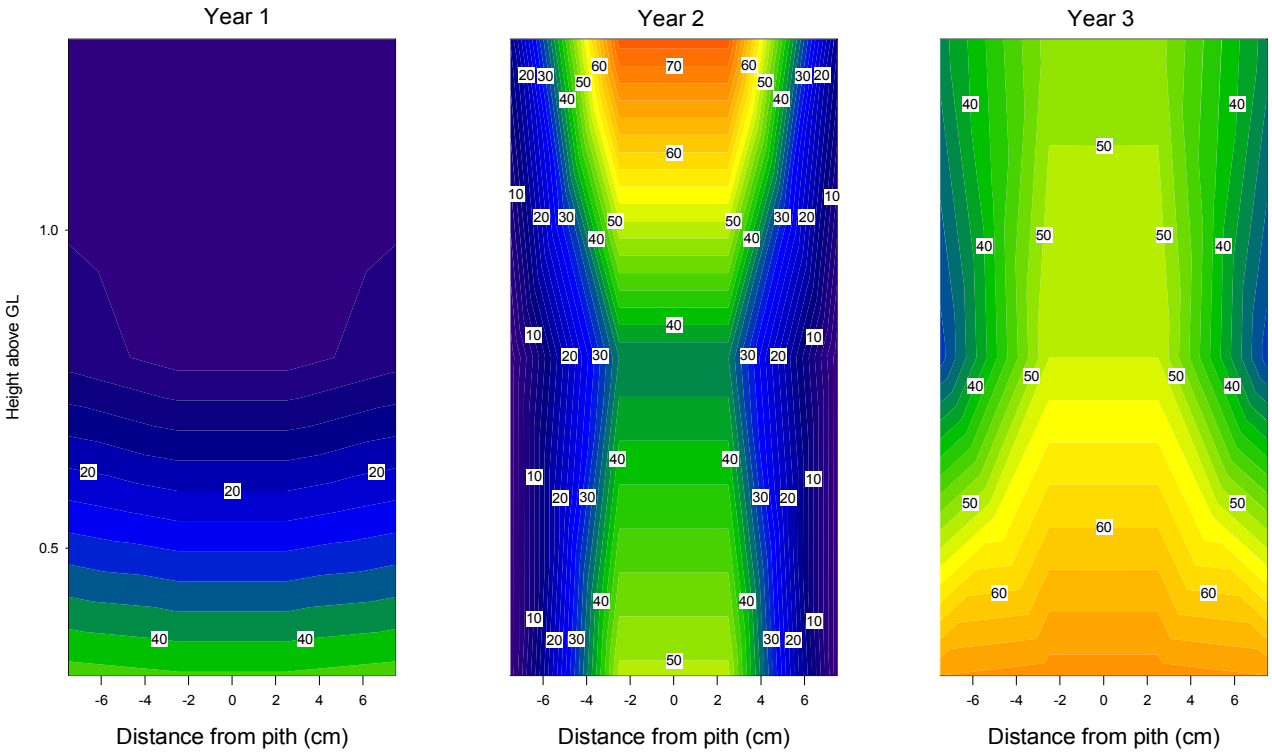
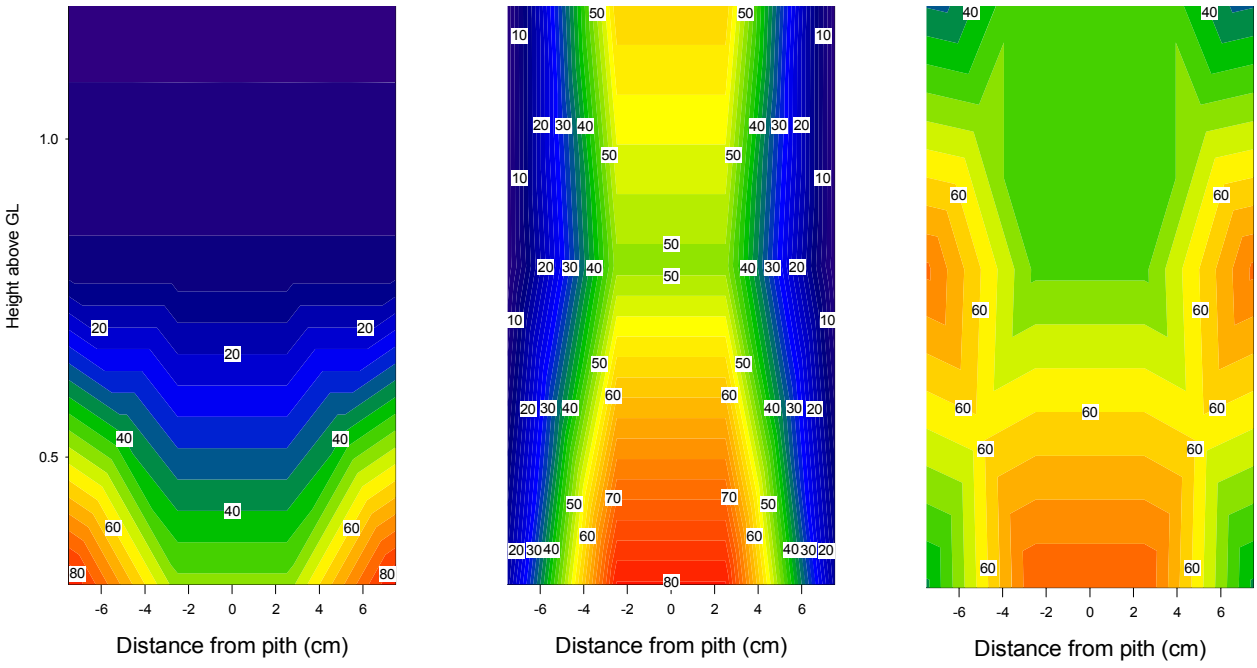


Figure I-12b



6. Performance of metam sodium in Douglas-fir timbers

The test of metam sodium in Douglas-fir timbers in a highway bridge in Oregon was not sampled this past year. They will be sampled in 2004.

7. Release rates of chloropicrin from controlled release ampules exposed in utility poles:

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.

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).

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-9) 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 levels in the wood were monitored for the first three years after treatment by removing increment cores for extraction and analysis. The chemical analysis have not been continued for the utility sites, but sampling has continued at the Corvallis field test site. These poles were originally sampled 2 , 3, 4, and 5 years after treatment but had not been sampled for 4 years.

Increment cores were removed from each pole at 3 equidistant locations 300 mm below the groundline as well as at groundline, 300, 900 and 1500 mm above that zone. The outer and inner 25 mm of each core were broken off and placed, individually, into test tubes containing 5 ml of hexane. The inspection holes were then plugged with tight fitting wooden dowels. The tubes were stored for 48 hours, then the increment core segments were removed, oven dried and weighed. The extracts were analyzed by gas chromatography using a Shimadzu Gas Chromatograph equipped with a Nickel 63 electron capture detector. Chloropicrin levels were quantified by comparison with standard solutions and concentrations were expressed on a of chloropicrin per μg of wood weight basis. The poles treated with the slow release polymer encapsulated material as well as those treated with an equal amount of liquid chloropicrin were sampled.

Chloropicrin release rates

Chloropicrin release rates varied from as little as 0.60 to 2.35 g per month, depending on location (Table I-10). 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. Ampules at the Galveston site were nearly empty after 4 years, while those in Oregon and Colorado still contain considerable quantities of chemical.

Chloropicrin Analysis at the Corvallis Site

For the purposes of assessing efficacy, we have used a target chloropicrin level of 20 ug/g of wood as a minimal effective value. This level is probably a bit higher than necessary, but it provides a buffer against variations in chloropicrin distribution.

Chloropicrin levels in Douglas fir and southern pine poles continue to remain well above the threshold level in the inner zone 300 mm below the groundline 9 years after treatment. Chemical levels had steadily increased for the first 5 years in this zone, but have declined slightly over the past 4 years (Table I-11). Chloropicrin levels in the same zone in western redcedar poles were well below the threshold. Previous tests of chloropicrin treated western redcedar pole sections suggested that this treatment remained at extremely high levels 7 years after application; however, the poles in the earlier tests were protected from the weather. As a result, they may have lost chemical more slowly than those exposed to more variable conditions.

Chloropicrin levels in the outer zones below ground were lower, but still above the threshold for Douglas-fir and the encapsulated treatment on southern pine, but below the threshold for the non-encapsulated treatment of southern pine as well as both western redcedar treatments. Low levels nearer the surface would be expected if

the chemical were slowly depleting into the surrounding soil. Although they may exert some slight protective effect near the wood surface, fumigants are primarily internal treatments. Thus, lower levels nearer the surface would be of less concern.

Chloropicrin levels at groundline in all three species were above the threshold for the first 5 years after treatment, but had fallen below that level after 9 years. Similar trends were noted 300 mm above groundline. Levels 900 and 1500 mm above groundline were generally low over the entire test period for Douglas-fir and southern pine poles. Interestingly, chloropicrin levels were initially much higher 300 to 1500 mm above the ground in western redcedar poles. Over the past 4 years, however, these levels have declined to concentrations similar to those found with the other species. The reasons for the higher initial migration above ground in western redcedar are unclear, although they may reflect lower initial moisture levels in this species. The naturally durable heartwood of western redcedar also exhibits some moisture repellency. The resulting lower moisture contents may have allowed more effective longitudinal chloropicrin diffusion. Further tests would be required to better define the effects of species on diffusion of this chemical.

Another facet of our results was the overall low residual levels of chloropicrin in all treatments 9 years after chemical application. Chloropicrin has generally been viewed as more likely to remain in the poles for longer time periods after treatment and our results would suggest that this was not the case. However, the poles in this study received only 90 to 100 ml of chloropicrin, while field treated poles normally received nearly 5 times this dosages. As a result, the lower levels of chemical in the poles may reflect the low initial dosage. One positive aspect of the results was the minimal difference in chemical levels between the encapsulated and liquid treatments. These results indicate that the slow release did not adversely affect chemical retention in the poles. In addition, the results indicated that chloropicrin was more tightly retained in southern pine poles than previously noted. Prior studies of southern pine poles in New York indicated a residual life as short as 3 years (Zabel et al., 1980). Our results clearly show that chloropicrin is retained at effective levels below the groundline for at least 9 years and, given the residual levels present at that point, probably far longer. These results support the use of chloropicrin as an effective internal remedial treatment for this species.

Culturing of the residual wood from the increment cores revealed that no viable decay fungi were isolated from the below ground portion of any wood species (Table I-12). Decay fungi were isolated with increasing frequency at groundline and 300 and 900 mm above the groundline, in Douglas fir poles. No decay fungi were isolated from the above ground portions of western redcedar or southern pine poles. It is extremely difficult to isolate fungi from western redcedar, so the absence fungi in these poles may be misleading. Similarly, isolating decay fungi from southern pine can be difficult owing to the rapid growth of competing mold fungi. As a result, we suspect the southern pine and western redcedar results may be misleading. The Douglas-fir results, however, clearly reflect the ability of the higher levels of chemical present near the groundline to inhibit fungal attack. The incidence of decay fungi above the groundline parallels the lower chloropicrin levels in these zones.

Table I-9 Locations and characteristics of poles used to evaluate a controlled release chloropicrin formulation at 10 sites across the U.S.

Location	Pole number and Species	Age of poles (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	15 to 36	Transmission
	23 Southern pine		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-10. 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	60-84
Oregon	WRC	26	0.66	0.66	0.56	0.60	0.74	-	0.66
	DF	19	0.65	0.66	0.51	0.57	0.79	-	0.64
New York	WRC	15	0.60	0.65	0.81	0.70	-	--	0.62
	DF	15	0.83	0.97	1.12	1.09	-	-	0.77
	SYP	15	0.59	0.66	0.81	0.79	-	-	0.74
Colorado	DF	45	1.00	1.09	1.06	0.91	1.07	1.14	0.95
Texas	DF	19	1.82	1.96	1.67	0.56	-	-	
	SYP	23	2.51	2.08	2.12	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	0.90	-	-	-	
Pennsylvania	SYP	45	0.90	0.92	0.90	-	-	-	
Missouri	SYP	45	0.64	0.73	0.72	-	-	-	
Indiana	WRC	35	0.60	0.61	0.72	-	-	-	
	SYP	10	0.63	0.64		-	-	-	

Table I-11. Residual chloropicrin in Douglas-fir, southern pine and western redcedar poles treated with liquid or encapsulated chloropicrin and sampled over a 9 year period.

			Residual chloropicrin (ug/g wood)									
			Height above groundline (m)									
Species	Treatment	year	-0.3		0		0.3		0.9		1.5	
			inner	outer	inner	outer	inner	outer	inner	outer	inner	outer
Douglas-fir	Ampule	2	**231**	**80**	**140**	**106**	**59**	**51**	1	1	10	3
		3	**312**	**125**	**164**	**183**	**30**	**70**	10	5	1	0
		4	**833**	**797**	**521**	**336**	**91**	**58**	11	8	1	1
		5	**1506**	**784**	**279**	**236**	**88**	**86**	9	5	1	1
		9	**391**	**40**	9	14	4	5	1	2	1	1
	Liquid CP	2	**322**	**135**	**129**	**112**	**96**	**55**	**34**	16	5	1
		3	**272**	**197**	**93**	**113**	**70**	**103**	**64**	**28**	5	2
		4	**773**	**471**	**308**	**108**	**53**	**46**	**43**	9	4	3
		5	**1384**	**1263**	**411**	**220**	**30**	**40**	9	14	6	4
		9	**250**	**62**	16	14	2	5	1	2	2	2
Southern pine	Ampule	2	**70**	1	**32**	18	0	8	0	0	0	0
		3	**192**	5	**55**	**77**	17	16	0	0	0	0
		4	**54**	**21**	**465**	**67**	6	4	0	0	0	0
		5	**513**	**53**	**36**	5	3	6	0	0	0	0
		9	**387**	**33**	2	8	2	3	2	2	2	2
	Liquid CP	2	**206**	**40**	**120**	**39**	**25**	2	3	0	0	0
		3	**197**	**58**	**54**	**39**	16	1	0	0	0	0
		4	**347**	14	**59**	3	3	1	0	0	0	0
		5	**239**	3	**54**	0	0	0	0	0	0	0
		9	**257**	0	1	0	0	0	0	0	0	0
Western redcedar	Ampule	2	**171**	18	**118**	**86**	**31**	**20**	9	3	3	4
		3	**250**	**125**	**158**	**134**	**81**	**47**	16	10	5	4
		4	**549**	**214**	**280**	**84**	**63**	**28**	16	10	4	4
		5	**1099**	**365**	**124**	**63**	**117**	**35**	**77**	**58**	11	8
		9	3	15	2	6	1	1	1	2	0	1
	Liquid CP	2	**243**	**182**	**166**	**95**	**112**	**94**	**57**	**36**	**24**	9
		3	**279**	**191**	**40**	**57**	**41**	**39**	**44**	**41**	15	17
		4	**134**	**83**	**66**	**37**	**34**	**41**	**27**	**33**	10	12
		5	**212**	**71**	**94**	**124**	**62**	**51**	**31**	12	8	6
		9	2	2	1	1	1	1	1	1	0	1
Numbers in bold are above threshold												

Table I-12. Percentage of decay fungi cultured from increment cores removed from Douglas-fir poles 9 years after application of chloropicrin in liquid or encapsulated form.

		Isolation frequency (% cores infested)[a]				
		Height above groundline				
Species	Treatment	-0.3	0	0.3	0.9	1.5
Douglas-fir	Ampule	0 ^{6}	3 ^{9}	6 ^{9}	6 ^{10}	4 ^{11}
	Liquid CP	0 ^{1}	4 ^{13}	4 ^{13}	4 ^{9}	3 ^{7}
Southern pine	Ampule	0 ^{1}	0 ^{6}	0 ^{4}	0 ^{6}	0 ^{6}
	Liquid CP	0 ^{6}	0 ^{16}	0 ^{10}	0 ^{11}	0 ^{7}
Western redcedar	Ampule	0 ^{3}	0 ^{1}	0 ^{4}	0 ^{6}	0 ^{9}
	Liquid CP	0 ^{6}	0 ^{4}	0 ^{9}	0 ^{7}	0 ^{9}

a. Superscripts are non-decay fungi, regular numbers are decay fungi

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.

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, but 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. Performance of fused boron rods in Douglas-fir pole sections:

Fused boron rods are produced by heating boron to approximately 800 C, which expels moisture. The molten boron is then poured into molds and allowed to cool. The resulting rods provide a highly concentrated boron treatment that can be applied to the same holes typically used for internal fumigant treatment. Boron rods have been used for many years in Europe to arrest decay in window frames, railway ties, and utility poles, but there is little performance data on U.S. species. In order to develop such data, the following test was established.

Untreated Douglas-fir pole sections (200-250 mm in diameter by 1.05 m long) were dipped in 2 % chromated copper arsenate type C and allowed to dry. A 9 mm diameter hole was drilled through each pole 400 mm from the top and a galvanized metal bolt with a slot cut perpendicular to the threads was inserted into each hole. A second 9 mm diameter by 200 mm long hole was drilled into the pole 150 mm above the original hole to serve as a treatment hole. Each hole received either 40 or 80 g of fused boron rod (1 or 2 rods)., then the holes were plugged with tight fitting wooden dowels. One half of the poles were sent to Hilo, Hawaii, while the remainder were exposed out of soil contact near Corvallis, Oregon. The Hilo poles experienced extensive checking that we believe largely negated the value of the test. The Corvallis poles did not experience severe checking and have continued in test for 12 years.

Boron movement has been assessed 1, 6, 7, 10, and 12 years after treatment by removing two sets of increment cores from two sites 90 degrees around and 75 mm below the bolt hole. One set of cores was cultured for the presence of decay fungi as described earlier. The second set of cores from these sites were segmented into zones corresponding to the inner and outer 50 mm. A second set of cores were removed 75 mm above the treatment hole and were segmented in the same manner. The segments were ground to pass a 20 mesh screen, then the resulting dust was extracted. The resulting extract was originally analyzed by ion-coupled plasma spectroscopy, but later was analyzed using the azomethine H method.

Background boron levels in untreated poles were relatively low (<0.2 kg/m^3) (Figure I-13). We generally use two thresholds for assessing boron efficacy, 0.5 and 1.25 kg/m^3. The higher level is the threshold as determined using the AWPA soil block method, while the second was determined for non-soil contact in previous studies in our laboratory. For the purposes of our discussion, we will use the lower level because it more closely reflects the risk of decay in the interior of the poles exposed above ground.

Boron levels in poles receiving 40 g of rod were initially extremely high in some locations one year after treatment, then declined precipitously over the next five years (Figure I-13b, Table I-13). Boron levels slowly declined in these poles, but levels were still largely over the minimum threshold 10 years after treatment. In the

most recent tests, boron levels in the sites 75 mm above the treatment hole and in the inner zone 75 mm below this zone were still above the threshold, but the remainder had declined below the threshold.

Boron levels in poles receiving the 80 g dosage had lower boron levels than were found in the 40 g treatment one year after treatment (Figure I-13c). This tendency towards the absence of a dosage effect in boron and fluoride treatments has been noted in a number of our tests. We suspect the lower chemical levels reflect moisture interactions around the treatment hole, whereby, the higher rod dosage tends to sorb moisture near the treatment hole that might otherwise improve diffusion. Boron levels tended to increase steadily in these treatments for 7 years after treatment, then began to decline. Boron levels after 12 years are at or slightly below the threshold value at most locations. In one case, a rather large retention was due to one outlier with an extreme boron retention. Boron levels in the outer zone 75 mm below the treatment hole fell off sharply when this value was removed.

The results indicate that boron levels have declined to concentrations at or below the threshold and suggest that fungi should be capable of invading these poles. As with other internal treatments, this invasion will not occur immediately, but will occur slowly over time as spores land in suitable locations in checks on the poles.

Eventually however, we would expect the poles to be colonized by fungi that will cause internal decay. Isolations from the poles 7 to 12 years after treatment appear to mirror this assertion (Table I-14). Decay fungi were isolated sporadically from all the poles (treated and untreated) 7 years after treatment. Isolations of decay fungi from untreated poles rose after 10 years of exposure, then declined slightly at the 12 year point. Fungal isolations from poles receiving the 40 g treatment were low (10 %) after 10 years, then rose to 50 % at year 12. Isolations from poles the 80 g treatment remained low even at the 12 year point. These results suggest that the chemical levels in the poles receiving the lower dosage have declined to the point where fungal attack is possible, while those in the poles treated to the higher dosage remain somewhat protective.

These result suggest that a 10 year retreatment cycle is probably advisable for boron rod treatments, although the condition of these poles will continue to be monitored to determine the appropriate time point for retreatment of the poles receiving the higher boron dosage.

Figure I-13. Residual boron levels at selected distances above or below the treatment hole in Douglas-fir poles sections receiving a) 0 g, b) 40 g or c) 80 g of fused boron rod.

Figure I-13a

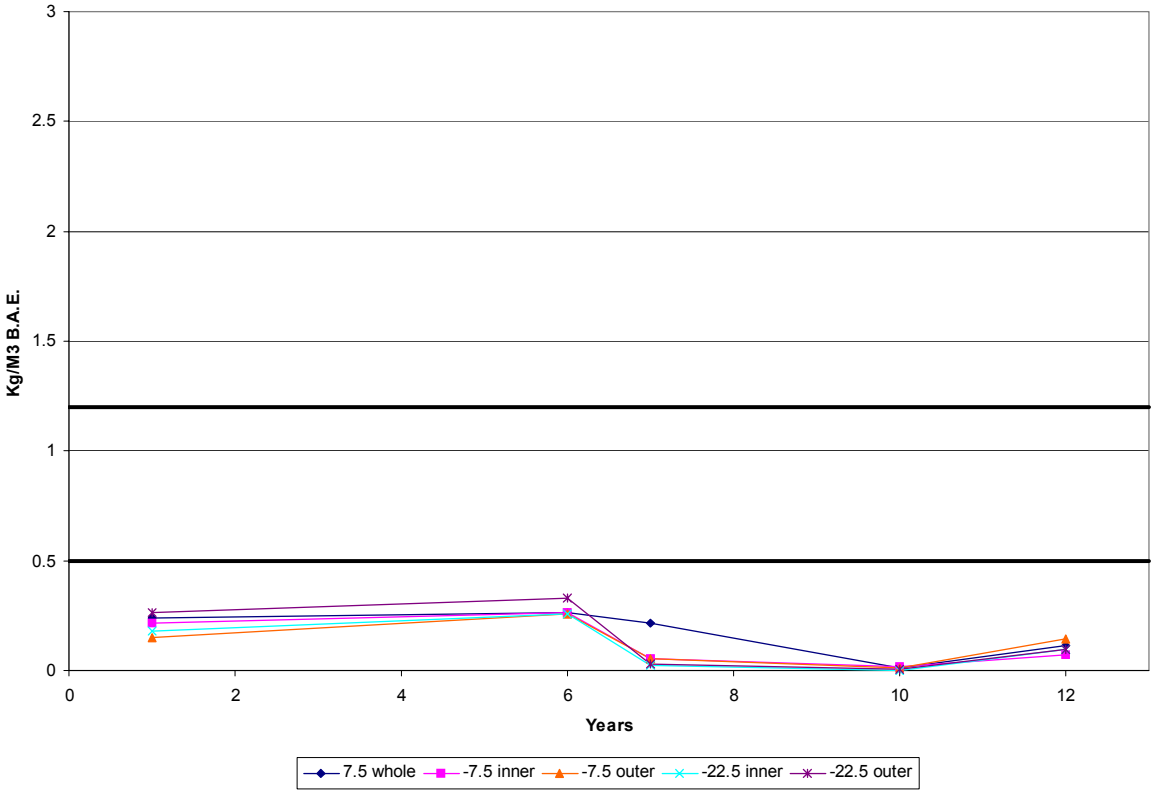


Figure I-13b

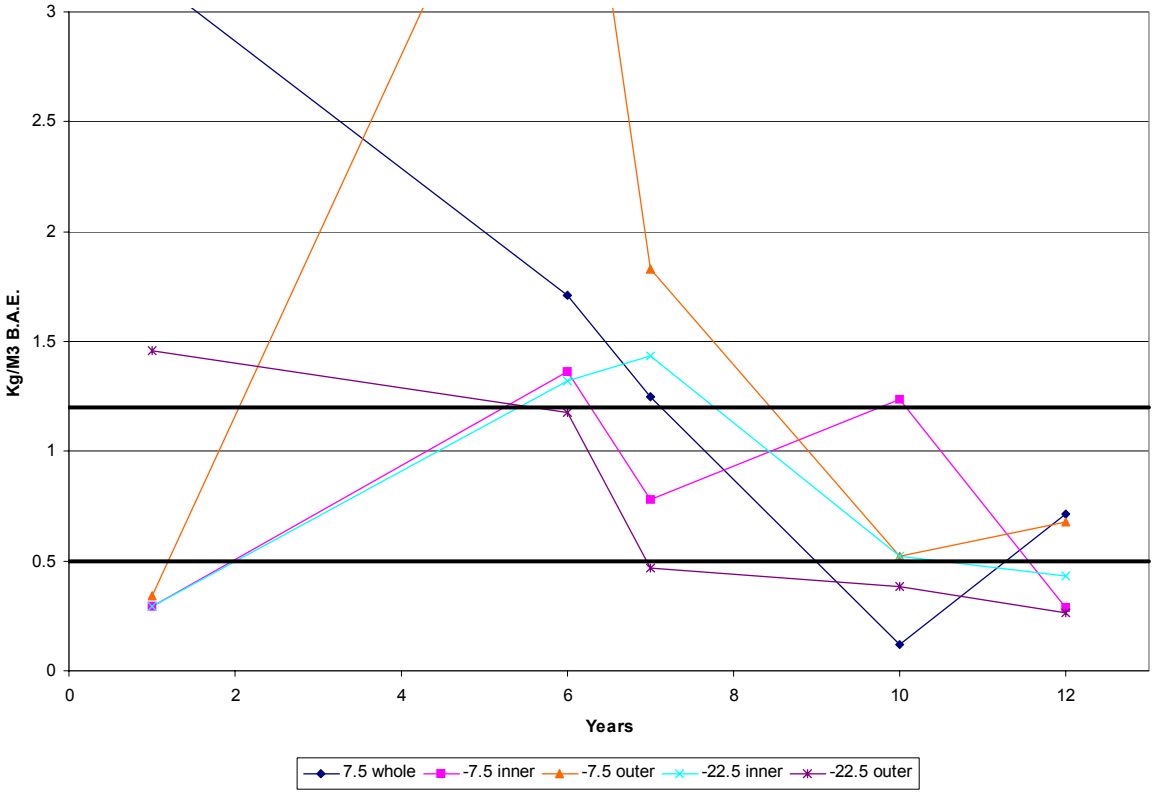


Figure I-13c

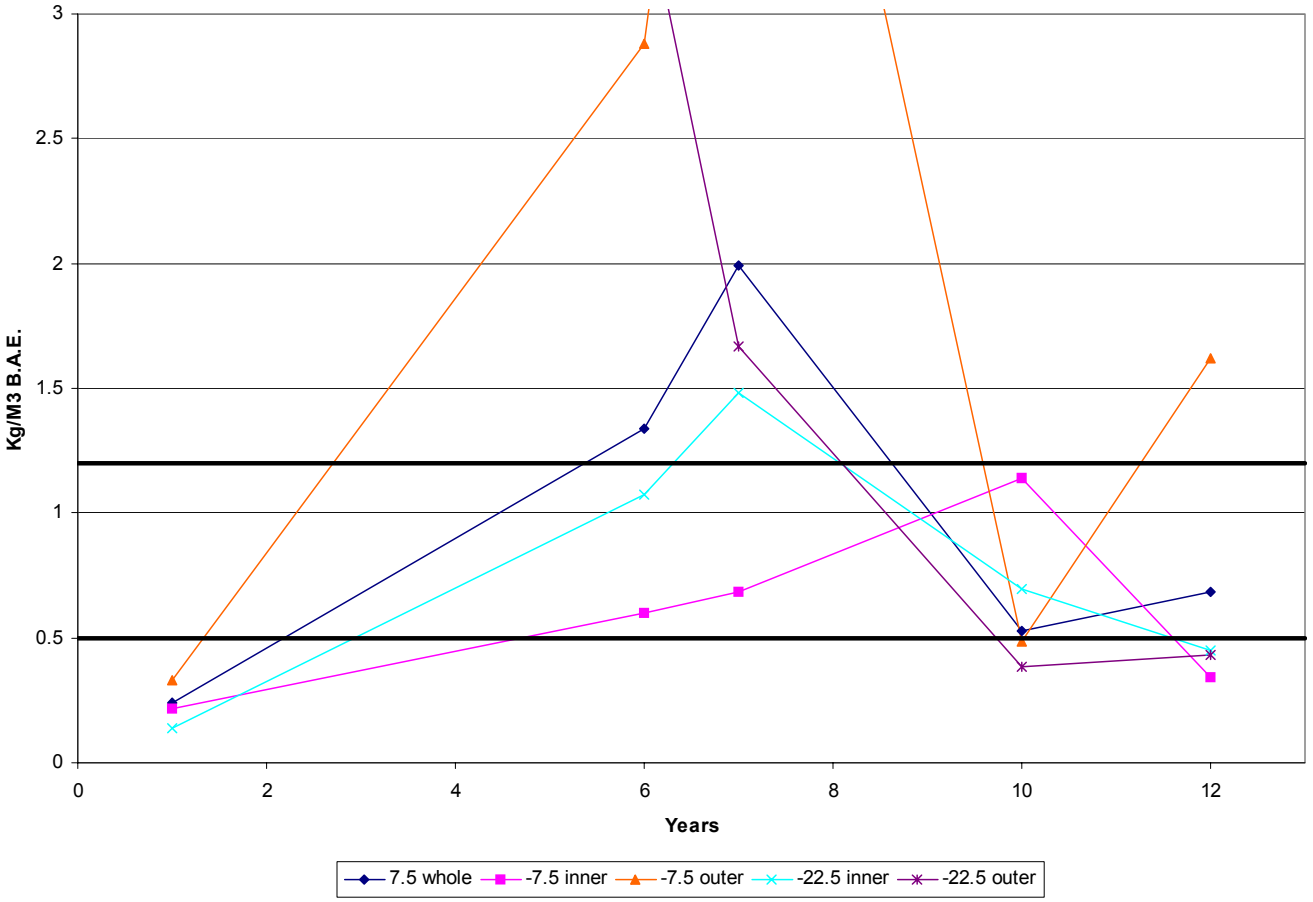


Table I-13. Residual boron at selected locations above and below the point of application of 40 or 80 g of fused boron rod in Douglas-fir pole sections 1 to 12 years after treatment.

dosage	height	position	Boron (kg/m^3 BAE)[a] years after treatment				
			1	6	7	10	12
0	-22.5	inner	0.24 (0.13)	0.26 (0.08)	0.22 (0.38)	0.01 (0.03)	0.11 (0.14)
		outer	0.22 (0.09)	0.26 (0.03)	0.05 (0.04)	0.02 (0.03)	0.07 (0.06)
	-7.5	inner	0.15 (0.10)	0.26 (0.10)	0.05 (0.04)	0.01 (0.02)	0.14 (0.24)
		outer	0.18 (0.08)	0.26 (0.06)	0.02 (0.02)	0.00 (0.00)	0.09 (0.09)
	7.5	whole	0.26 (0.15)	0.33 (0.16)	0.03 (0.03)	0.01 (0.01)	0.10 (0.13)
40	-22.5	inner	**3.16** (5.86)	**1.71** (1.29)	**1.25** (0.94)	0.12 (0.12)	**0.72** (0.33)
		outer	0.29 (0.15)	**1.36** (0.81)	**0.78** (0.58)	**1.23** (3.15)	0.29 (0.11)
	-7.5	inner	0.34 (0.51)	**4.44** (5.50)	**1.83** (2.08)	**0.52** (0.98)	**0.68** (0.53)
		outer	0.29 (0.24)	**1.32** (0.75)	**1.43** (1.56)	**0.52** (0.54)	0.43 (0.44)
	7.5	whole	**1.46** (1.69)	**1.18** (1.12)	0.47 (0.42)	0.39 (0.29)	0.26 (0.17)
80	-22.5	inner	0.24 (0.14)	**1.34** (1.28)	**1.99** (1.26)	**0.53** (0.55)	**0.69** (0.46)
		outer	0.22 (0.18)	**0.60** (0.58)	**0.68** (0.44)	**1.14** (1.72)	0.34 (0.19)
	-7.5	inner	0.33 (0.59)	**2.88** (3.27)	**5.70** (4.03)	0.49 (0.33)	**1.62** (2.53)
		outer	0.14 (0.09)	**1.07** (0.77)	**1.48** (1.28)	**0.69** (0.56)	0.45 (0.56)
	7.5	whole	**3.99** (3.62)	**3.49** (6.00)	**1.67** (1.86)	0.38 (0.25)	0.43 (0.42)

a. Bold numbers are above the toxic threshold of 0.5 kg/m^3 BAE

Table I-14. Percentage of increment cores removed 75 mm below the treatment holes in Douglas-fir poles that contained decay and non-decay fungi 7 to 12 years after application of 40 or 80 g of fused borate rod.

Borate Rod (g)	Cores Containing Decay Fungi (%)		
	7Yr	10 Yr	12 Yr
0	20 [100]	80 [100]	60 [100]
40	0 [90]	10 [100]	50 [100]
80	10 [100]	0 [100]	10 [100]

[a] Superscripts denote percentage of non-decay fungi isolated from the same cores.

2. Performance of fused borate rods in internal groundline treatments of Douglas-fir poles:

Twenty pentachlorophenol treated Douglas-fir poles (250-300 mm in diameter by 2 m long) were set to a depth of 0.6 m at the Peavy Arboretum test site. Three 19 mm diameter by 200 mm long holes were drilled perpendicular to the grain beginning at groundline and moving around the pole 120 degree and upward 150 mm. Each hole received either 1 or 2 boron rods (180 or 360 g of rod, respectively). The holes were then plugged with tight fitting wooden dowels. Each treatment was replicated on 10 poles.

The poles were sampled 1, 3, 4, ,5, 7, and 10 years after treatment by removing increment cores from sites located 150 and 75 mm below groundline as well as 225, 450, and 600 mm above the groundline. The outer, treated shell on each core was removed and discarded, then the remainder of each core was divided into inner and outer halves. Core segments for a given height and position (inner/outer) were combined for a given treatment and ground to pass a 20 mesh screen. The resulting sawdust was hot water extract and analyzed using the azomethine H method for boron which was expressed on a kg/m^3 basis. As with the previous test, we used the lower threshold value as our target level.

As expected, background boron levels in untreated control poles were extremely low, ranging from 0.01 to 0.11 kg/m^3 (Table I-15). Boron levels in poles receiving either 180 or 360 g of rod were extremely low 450 and 600 mm above groundline, reflecting the limited ability of boron to diffuse upward (Figure I-14). Boron levels in the remaining locations tended to vary. Boron levels in the inner zones were initially low, then rose to levels well above the threshold 5 years after treatment. Concentrations then declined by the seventh year after treatment, then increased slightly 10 years after treatment. Boron levels remained well above the threshold 150 and 75 mm below groundline in the inner zone 10 years after treatment. Analysis of the outer zones from these same poles revealed that boron levels tended to remain lower over the earlier parts of the test, but did not have the concentration fluctuations noted in the inner assay zones. The reasons for this difference are unclear. Boron levels remain above the lower threshold both 150 and 75 mm below ground 10 years after treatment.

As with the lower boron rod dosage, boron levels in the inner zones of poles receiving the 360 g dosage of boron rod tended to fluctuate more than those in the outer zone for the first 5 years after treatment (Figure I-15). In addition, overall boron levels in the outer zone were similar for the two treatment levels, suggesting that the increased dosage did not markedly improve treatment efficacy. Boron levels in the inner zones of poles receiving the higher dosage were slightly higher 75 mm below groundline, but the remaining boron levels were similar to those found with the lower dosage.

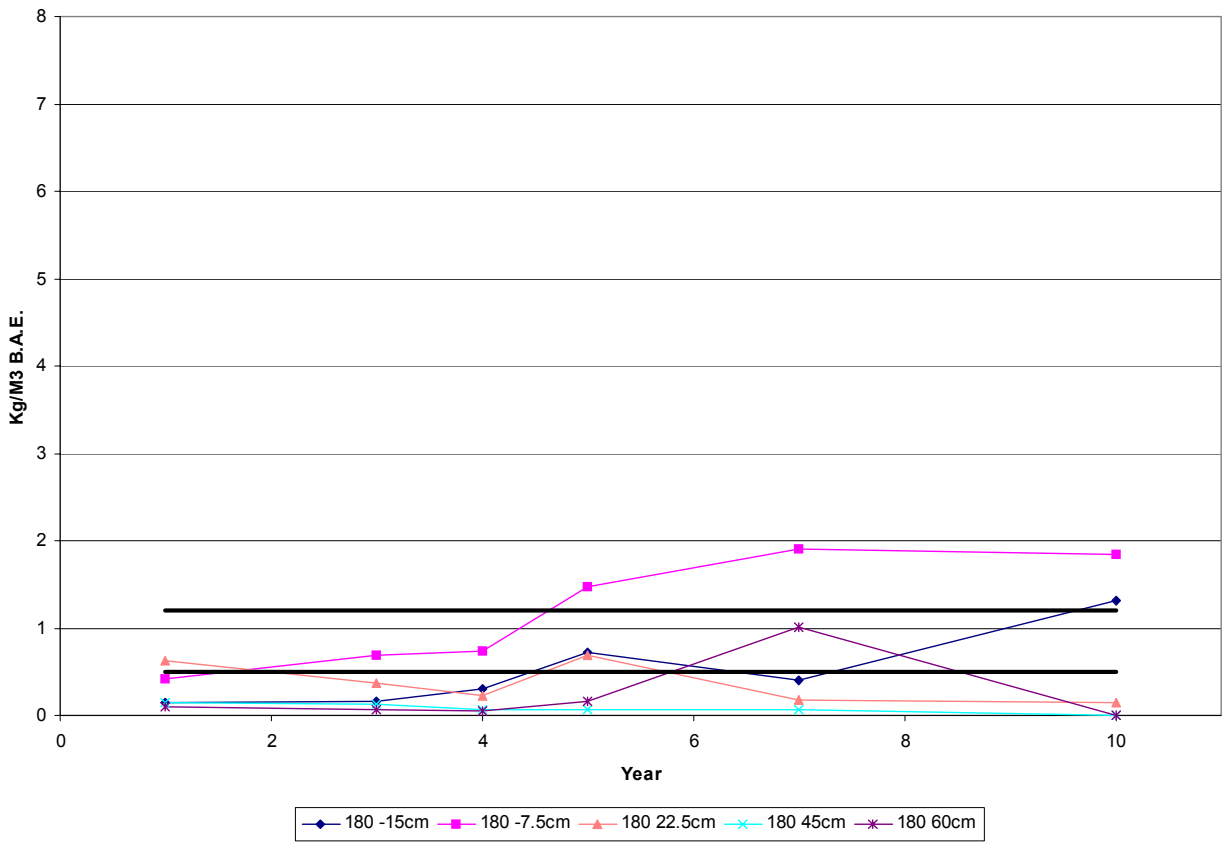
The lack of a substantial treatment effect with higher loadings of boron rod remains a perplexing phenomena, but one that appears to be consistent among out various field trials. This effect can be seen when boron levels are plotted in distribution maps for both dosages (Figures I-16 to 17). While there is a slight effect after 5 years, its appears to be more advantageous to use the lower dosage after ten years. This treatment effect merits further study, particularly given the high cost of the rod treatments.

Table I-15. Residual boron levels in inner and outer zones of increment cores removed from Douglas-fir poles 1 to 10 years after treatment with 180 or 360 g of boron rod.

Dosage	Sampling	Core	Boron (kg/m^3 BAE)					
grams	Height	Section	Year 1	Year 3	Year 4	Year 5	Year 7	Year 10
180	-15	inner	0.38	**1.81**	**2.39**	**1.85**	**1.54**	**2.16**
		outer	0.24	0.25	0.49	**1.14**	**0.70**	**1.32**
	-7.5	inner	**2.82**	**3.75**	**6.02**	**6.40**	**2.05**	**2.83**
		outer	**0.65**	**1.10**	**1.16**	**2.32**	**3.38**	**1.84**
	22.5	inner	**0.89**	**3.16**	**2.09**	**2.82**	**1.47**	**0.81**
		outer	**0.98**	**0.58**	0.35	**1.10**	0.31	0.14
	45	inner	**0.54**	0.22	0.21	0.17	0.15	0.00
		outer	0.22	0.20	0.11	0.09	0.12	0.00
	60	inner	0.18	0.24	0.19	0.41	0.08	0.00
		outer	0.14	0.09	0.06	0.25	**1.80**	0.00
360	-15	inner	0.09	**0.76**	**0.62**	**0.60**	**1.00**	0.09
		outer	0.07	0.23	0.27	**3.00**	**1.42**	**3.94**
	-7.5	inner	**0.96**	**10.88**	**7.27**	**12.01**	**3.28**	0.11
		outer	**0.59**	**0.61**	**1.33**	**3.93**	**0.85**	**0.89**
	22.5	inner	0.48	**3.21**	**1.35**	**7.30**	**0.95**	**2.27**
		outer	0.13	0.14	0.42	**4.34**	**0.77**	0.07
	45	inner	0.04	0.11	0.08	**1.24**	0.21	0.00
		outer	0.02	0.09	0.07	**0.83**	0.17	0.00
	60	inner	0.05	0.39	0.21	0.16	0.10	0.00
		outer	0.02	0.09	0.09	0.16	**1.02**	0.00
control	-15	inner	0.02	0.09	0.02	0.05	0.06	0.00
		outer	0.02	0.09	0.02	0.07	0.06	0.00
	-7.5	inner	0.02	0.06	0.06	0.03	0.05	0.00
		outer	0.02	0.07	0.02	0.02	0.05	0.00
	22.5	inner	0.01	0.08	0.02	0.05	0.05	0.00
		outer	0.01	0.07	0.02	0.03	0.04	0.00
	45	inner	0.03	0.06	0.02	0.03	0.03	0.00
		outer	0.02	0.10	0.02	0.02	0.03	0.00
	60	inner	0.02	0.08	0.02	0.27	0.08	0.00
		outer	0.01	0.09	0.03	0.11	0.04	0.00

Figure I-14. Residual boron in increment cores removed from selected locations above and below the groundline of Douglas-fir poles 1 to 10 years after treatment with 180 g of boron rod as shown in the 2) outer and b) inner zones of the cores.

A



B

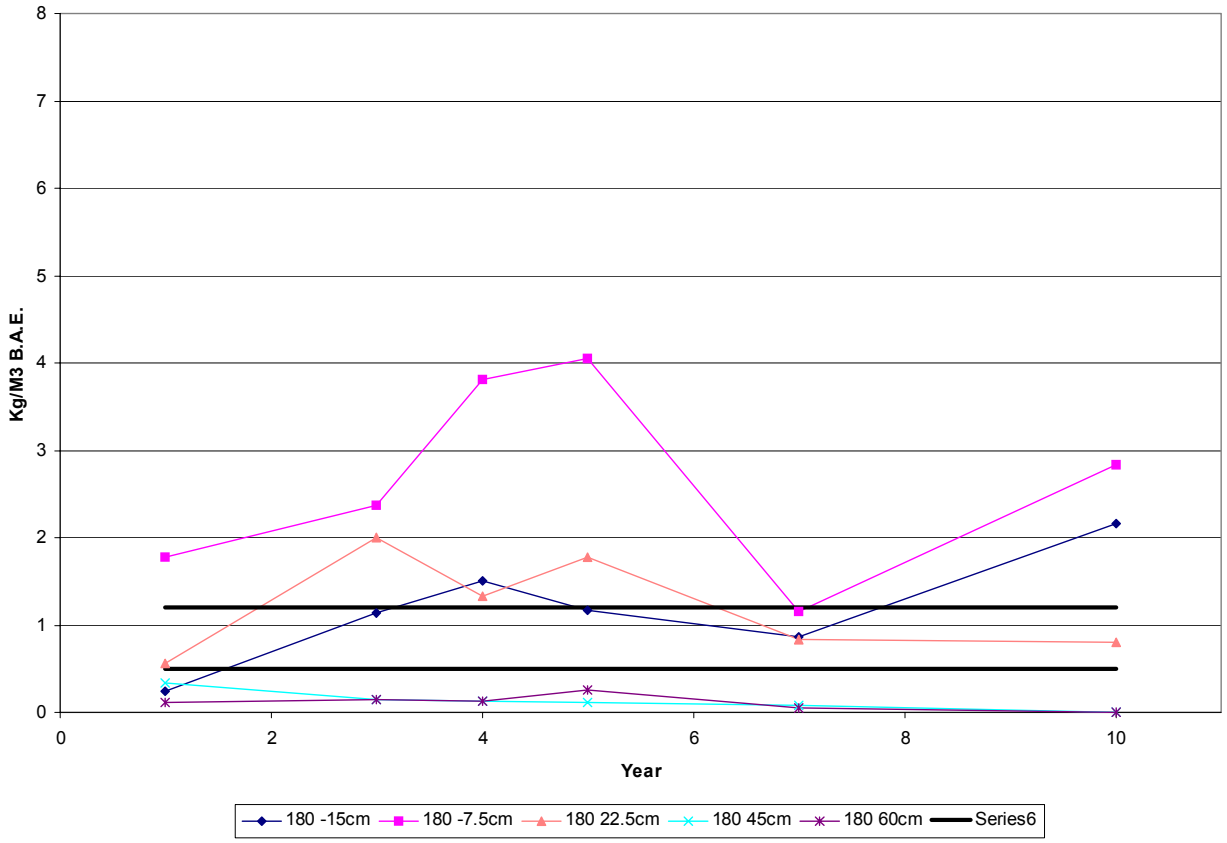
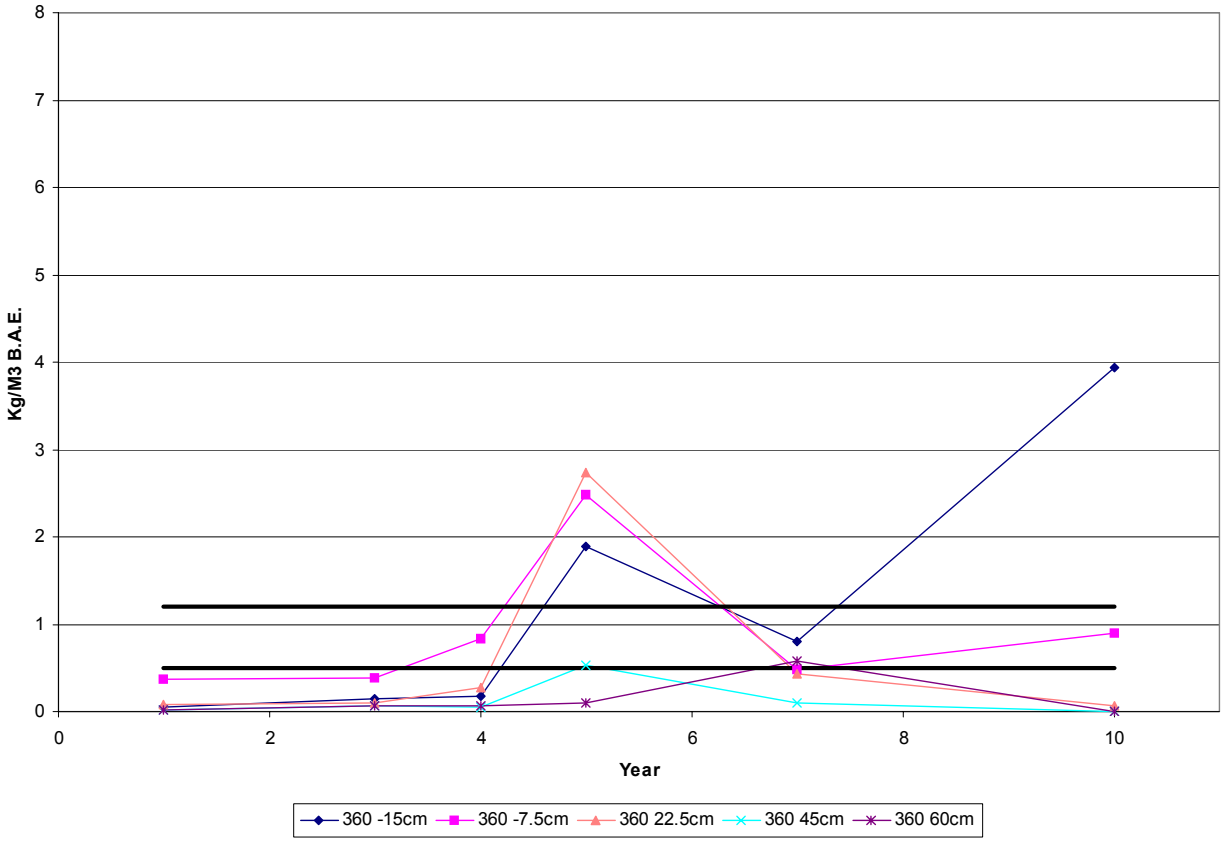


Figure I-15. Residual boron in increment cores removed from selected locations above and below the groundline of Douglas-fir poles 1 to 10 years after treatment with 360 g of boron rod as shown in the 2) outer and b) inner zones of the cores.

A



B

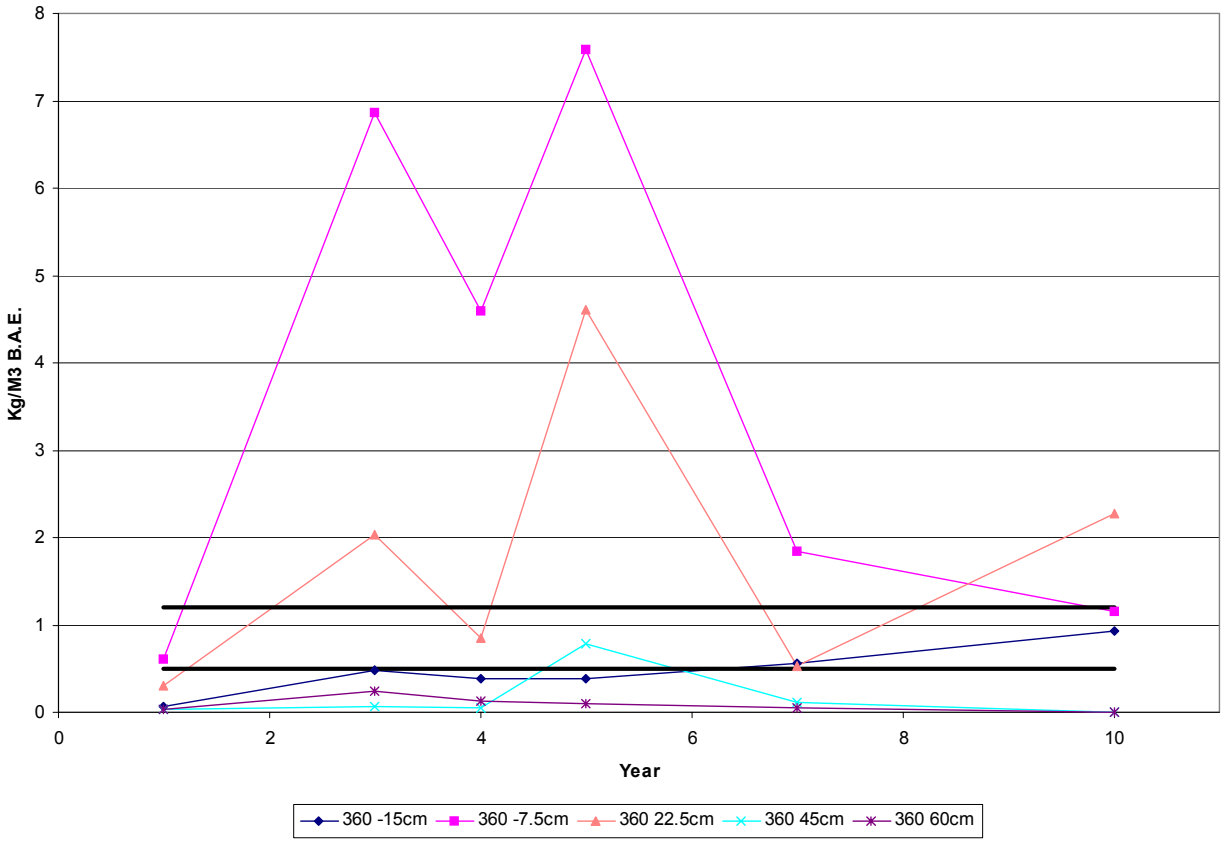


Figure I-16. Boron distribution in Douglas-fir pole sections 1 to 10 years after treatment with 180 g of fused boron rod. Blue indicates low boron levels, while red indicates elevated levels of this chemical.

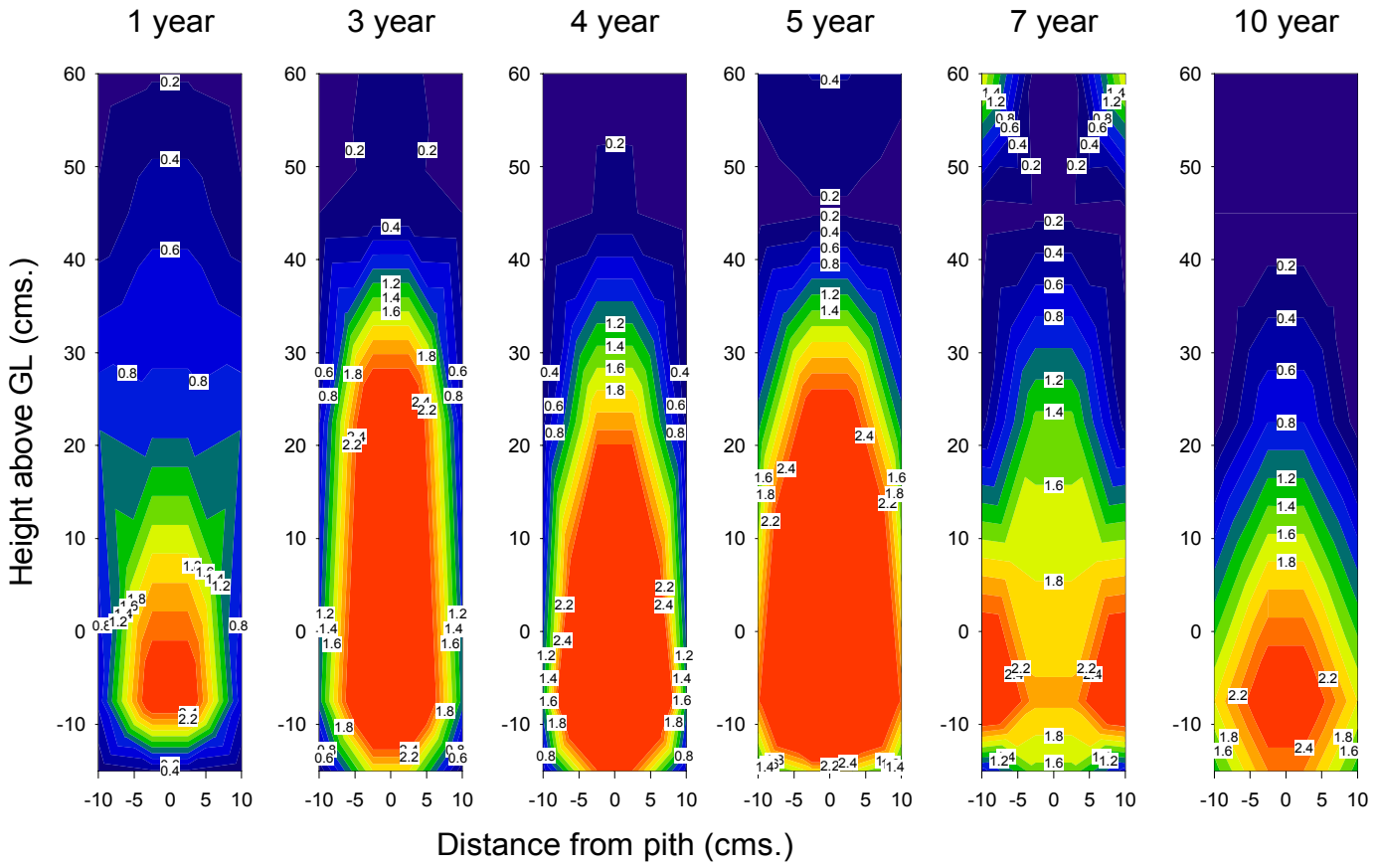
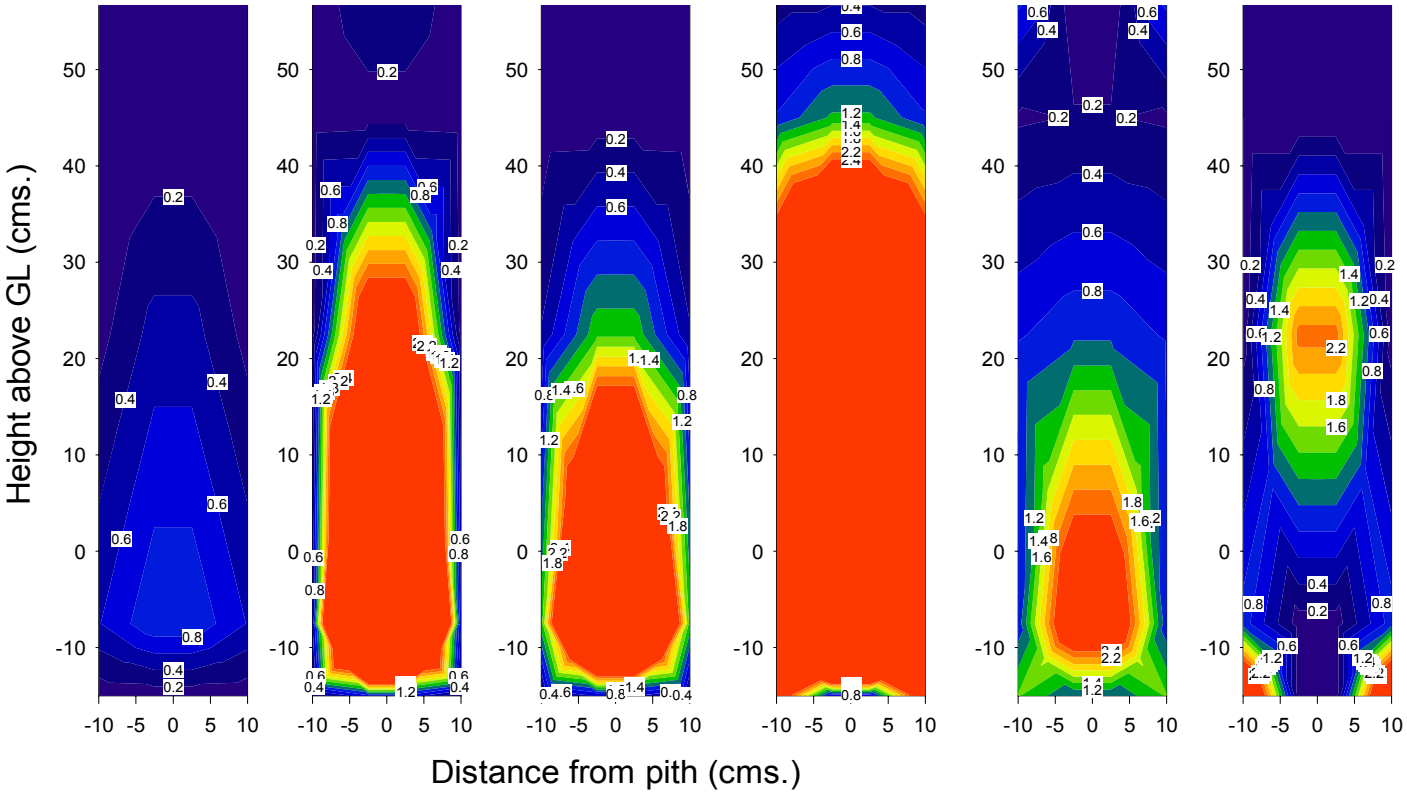


Figure I-17. Boron distribution in Douglas-fir pole sections 1 to 10 years after treatment with 360 g of fused boron rod. Blue indicates low boron levels, while red indicates elevated levels of this chemical.



3. Performance of a copper amended boron rod

Boron rods have been available for internal treatment for nearly 3 decades, but their cost is often a deterrent to use. As an alternative, boron rods are also available with supplemental copper. While this formulation has also been available for several decades, there is little data on the performance of these amended rods. In this test, we compared the ability of boron to move from the copper boron rods with that found in the conventional boron rods.

Douglas-fir pole sections were treated by drilling holes perpendicular to the grain beginning at groundline and moving upward 150 mm and around the pole 90 or 120 ^{o}. The poles were then treated with 4 or 8 Cu/B or 4 B rods. The holes were plugged with plastic plugs.

Boron movement, as well as copper for the Cu/B system, was assessed one year after treatment by removing increment cores from 150 mm below ground as well as groundline, 300, and 900 mm above this zone. The outer, treated shell of each core was discarded and the remaining sections were divided into inner and outer halves. These segments from a given treatment and location were combined for the poles in each treatment, then ground to pass a 20 mesh screen. The resulting material was first analyzed for copper by x-ray fluorescence for the Cu/B treatment, then all samples were hot water extracted and the extract was analyzed for boron by the azomethine H method.

With the exception of the groundline of poles receiving 4 Cu/B rods in a 120 ^{o} spacing, copper levels were extremely low at all locations (Figure I-18). The low levels of copper suggest that this treatment is primarily a boron treatment. Boron levels in the poles one year after treatment varied widely, reflecting the natural variations in moisture in these poles (Table I-16). The highest boron levels were found at the groundline of poles treated with boron rod treatments applied using a 90 ^{o} hole pattern; however, higher boron levels were also found at groundline with one of the Cu/B treatments. As expected, boron levels were at or near the threshold near groundline for all of the treatments (Figure I-19). Boron levels 300 mm above the groundline were more variable and levels 900 mm above groundline were generally minimal. The exception was the 4 Cu/B rod treatment using a 90 ^{o} spacing. The reason for the sudden increase in boron levels is unclear, particularly since the boron levels 300mm above groundline in this same treatment were extremely low.

The use of eight Cu/B rods instead of four produced slight increases in boron levels in most assay zones, but the differences were not always in proportion to the increased dosage. The reduced dosage effect would be consistent with similar findings for the traditional boron rods. Boron levels above the lower threshold were only present at 3 of the 8 assay locations for the 8 rod treatment (Figures I-18 and 19).

The results indicate that boron is moving into the wood from the Cu/B rods. Although there are slight differences in boron levels between the Cu/B and B rods, these differences are inconsistent and may reflect natural variations in diffusion as a result of moisture differences in individual poles.

Culturing of wood from the poles revealed that no decay fungi were isolated from any of the test poles (Table I-17). Non-decay fungi were isolated from some poles; however, the number of fungal isolations remains small. As these pole season and check, we will expect fungal colonization to proceed. The presence of non-decay and decay fungi should help provide data on the relative effectiveness of the various treatment combinations.

Figure I-18. Distribution of copper in Douglas-fir pole sections one year after treatment with 4 or 8 Cu/B rods.

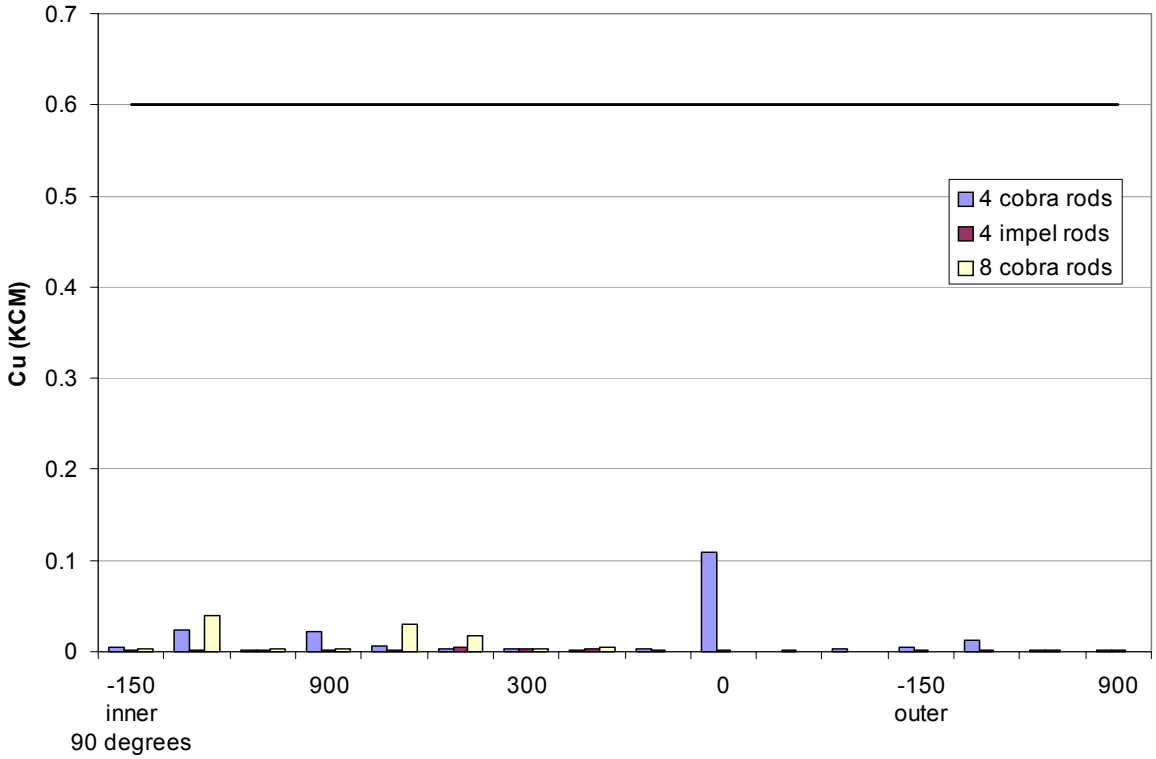


Figure I-19. Distribution of boron (BAE basis)in Douglas-fir pole sections one year after treatment with 4 or 8 Cu/B rods or 4 B rods..

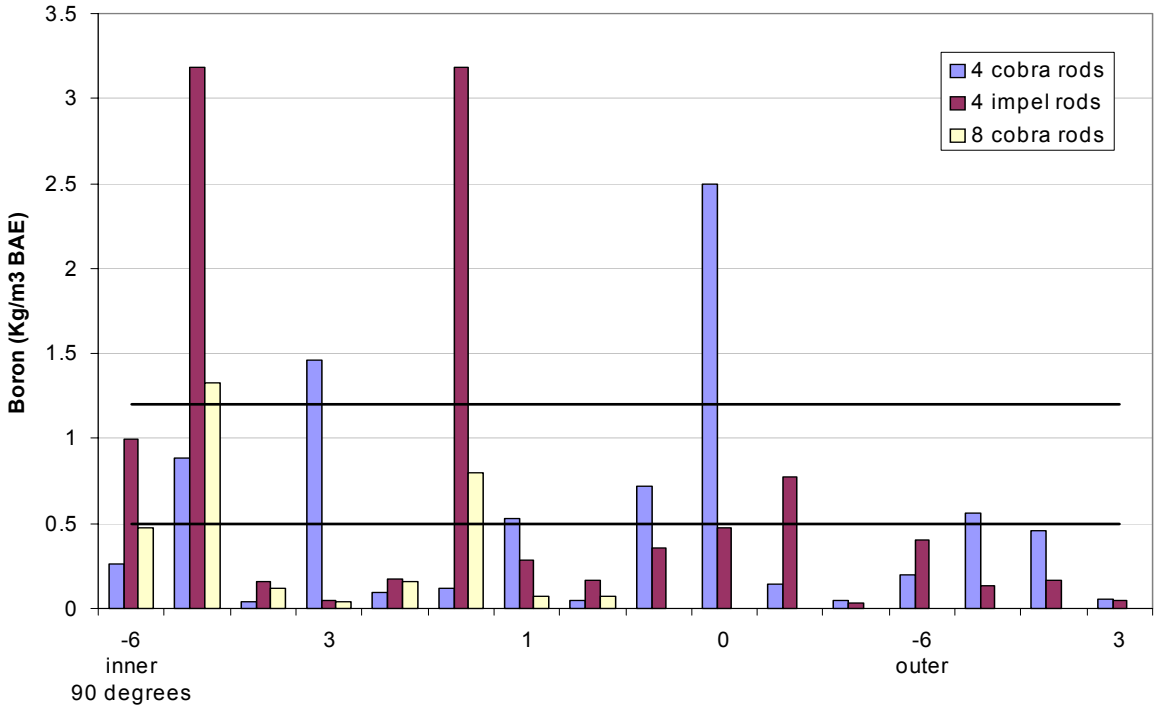


Table I-16. Chemicals levels in Douglas-fir poles one year after application of 4 or 8 Cu/B rods or 4 B rods at spacings of either 90 or 120 °.

Spacing of treatment	core section	height above GL (mm)	4 cobra rods		4 impel rods	8 cobra rods	
			Boron	Copper	Boron	Boron	Copper
			(Kg/m^3 BAE)	(Kg/m^3 Cu)	(Kg/m^3 BAE)	(Kg/m^3 BAE)	(Kg/m^3 Cu)
90 degrees	inner	-150	0.26	0.01	**1.00**	0.48	0.00
		0	**0.88**	0.02	**3.19**	**1.33**	0.04
		300	0.04	0.00	0.16	0.12	0.00
		900	**1.46**	0.02	0.05	0.04	0.00
	outer	-150	0.09	0.01	0.17	0.16	0.03
		0	0.12	0.00	**3.19**	**0.80**	0.02
		300	**0.53**	0.00	0.28	0.07	0.00
		900	0.04	0.00	0.16	0.07	0.00
120 degrees	inner	-150	**0.72**	0.00	0.35		
		0	**2.50**	0.11	0.47		
		300	0.14	0.00	**0.77**		
		900	0.05	0.00	0.03		
	outer	-150	0.19	0.00	0.41		
		0	**0.56**	0.01	0.13		
		300	0.45	0.00	0.17		
		900	0.05	0.00	0.05		

Table I-17. Fungal isolations from Douglas-fir poles one year after application of 4 or 8 Cu/B rods or 4 B rods at spacings of either 90 or 120 °.

(% cores infested)				
Spacing of treatment	height above GL (mm)	4 Cobra rods	4 Impel rods	8 Cobra rods
90 degrees	-150	0^{7}	0^{7}	0^{7}
	0	0^{10}	0^{10}	0^{0}
	300	0^{20}	0^{0}	0^{0}
	900	0^{7}	0^{0}	0^{7}
120 degrees	-6	0^{40}	0^{0}	
	0	0^{0}	0^{0}	
	1	0^{0}	0^{0}	
	3	0^{13}	0^{20}	

Superscripts represent average of non-decay fungi in the same cores.

4. Effect of glycol on movement of boron from fused borate rods

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

Pentachlorophenol treated Douglas-fir pole sections (250 to 300 mm in diameter by 2.1 m long) were set to depth of 0.6 m in the ground at the Peavy Arboretum test site. The pole test site received an average yearly precipitation of 1050mm with 81 % falling between October and March.

Four 20 mm diameter holes were drilled at a 45 ^{o} downward sloping angle in each pole, beginning 75mm above the groundline, then moving 90 ^{o} around and up to 230, 300, and 450 mm above the groundline. An equal amount of boron (227 g Boric acid equivalent) was added to each pole, but was delivered in different combinations of boron, water, or glycol (Table I-18). The borate rods (Impel) were 100 mm long by 12.7 mm in diameter and weighed 24.4 g each. An equal weight of boron rod composed of one whole rod and a portion of another, were placed in each hole followed by the appropriate liquid supplement or were left dry. The holes were then plugged with tight fitting wooden dowels. Each treatment was replicated on five poles.

Table I-18. Combinations of boron treatments applied internally to Douglas-fir pole sections in 1995. All treatments deliver 227 g boric acid equivalent per pole.

Supplement	Supplement (g)	Total Glycol (g)	Total water (g)	Supplement Source	Supplement Formulation
None	0	0	0		
Bora-Care® 1:1 in water	118	28	65	Nisus Corp. Rockford, TN	Disodium octaborate tetrahydrate plus poly and monoethylene glycol
Boracol 20®	122	77	20	CSI Inc. Charlotte, NC	Disodium octaborate tetrahydrate plus polyethylene glycol (20%)
Boracol 40®	164	95	0	CSI Inc. Charlotte, NC	Disodium octaborate tetrahydrate plus polyethylene glycol (40%)
Ethylene glycol	100	100	0	VanWaters and Rogers, Seattle, WA	
Timbor® 10% in water	118	0	106	U.S. Borax Inc.	Disodium octaborate tetrahydrate

The pole sections were sampled 1, 2, 3, 5, and 7 years after treatment by removing increment cores 180 ° apart from 300 mm below the groundline and cores from 3 equidistant locations around the pole 150 and 300 mm above the groundline. The treated portion of the cores was discarded, then the remainder of each core was divided into zones corresponding to 0-50, 51-100, and 101-150 mm from the edge of the treated zone. The zones from the same depth and height from a given treatment were combined and ground to pass a 20 mesh screen. The resulting sawdust was then extracted and analyzed using the azomethine H method.

Boron continues to be detectable in virtually all pole sections 7 years after treatment. As in previous boron tests, chemical levels were low in poles receiving only the borate rods one year earlier (Table I-19). Boron levels were much higher in poles receiving any of the various combinations of Boracare, Boracol, Timbor, or glycol, suggesting that some supplemental liquid enhanced boron movement, whether or not the additive contained boron. Boron levels in all treatments were at effective levels near the groundline, reflecting the presence of moisture in this zone. Interestingly, boron levels in the rod alone treatments were extremely low below ground 7 years after treatment, suggesting the elevated moisture in these zones might have hastened boron losses (Figure I-20). Boron levels in poles receiving Boracol 20 tended to be lower than those receiving the Boracol 40 supplement (Figures I-22-23). These results suggest that the liquid boron can provide long term improvement to residual boron levels and that the higher concentration of boron in the supplement does have a lasting effect on treatment efficacy. The addition of Boracare also produced a lasting improvement in boron levels in comparison with the rod alone treatment (Figure I-21). The long-lasting improvement in boron levels appear to be related to both the boron in the treatment as well as the additional liquid. This is evidenced by the improvement afforded by addition of glycol alone to the boron rods as well as the benefits of adding a water borne Timbor solution (Figures I-24, 25). These effects suggest that addition of some liquid at the time of boron rod application has both short term and longer lasting effects on treatment efficacy. As a result, supplemental applications in conjunction with boron rods should especially be considered where these formulations are being applied to actively decaying wood where considerable additional damage might occur while the boron diffused from the rods into the surrounding wood.

Figure I-20. Residual boron in Douglas-fir timbers 1 to 7 years after application of fused borate rod alone.

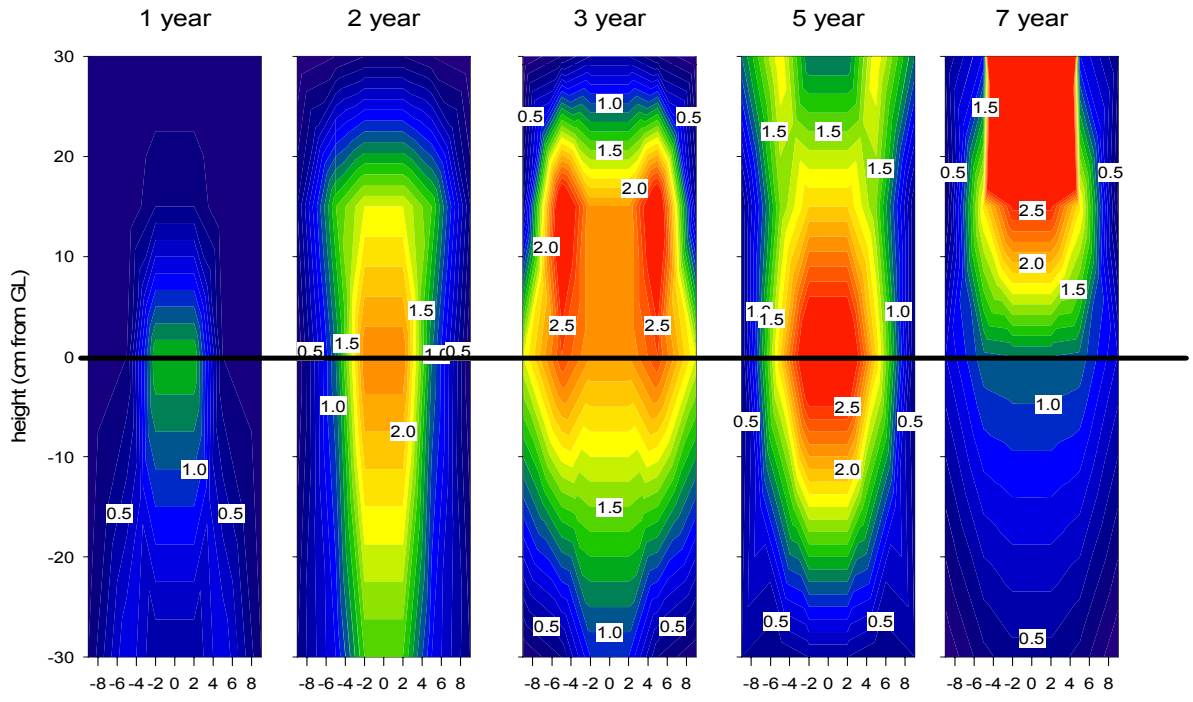


Figure I-21. Residual boron in Douglas-fir timbers 1 to 7 years after application of various combinations of fused borate rod and Boracare.

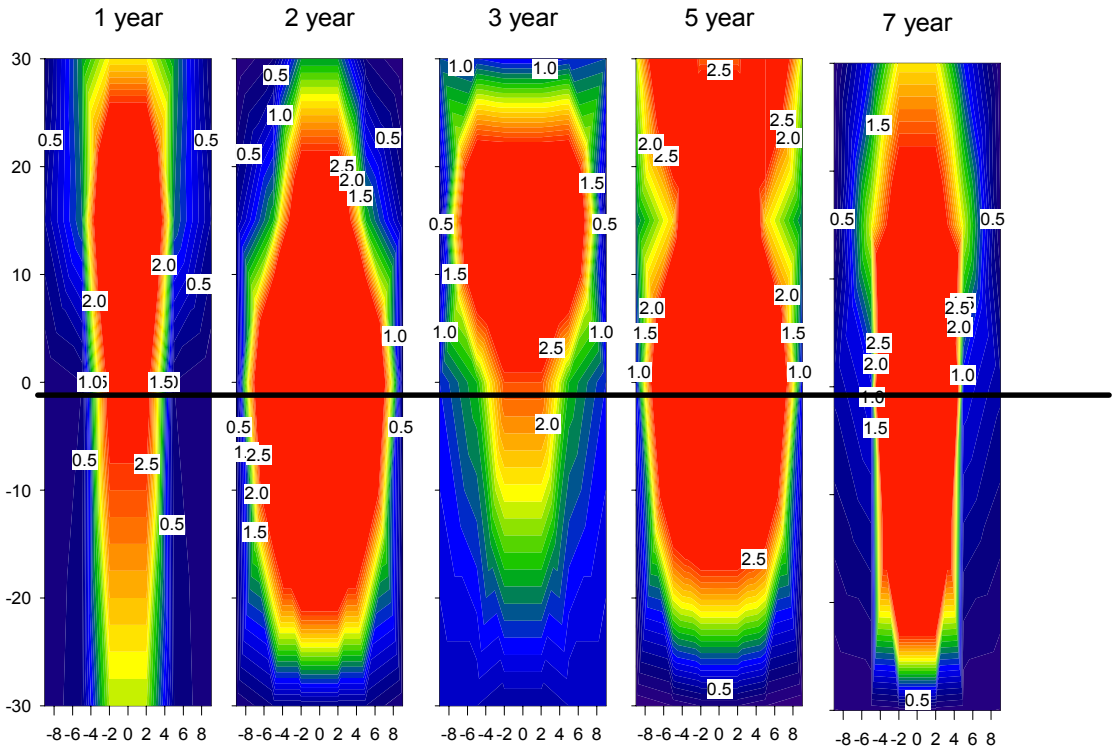


Figure I-22. Residual boron in Douglas-fir timbers 1 to 7 years after application of various combinations of fused borate rod and Boracol 20.

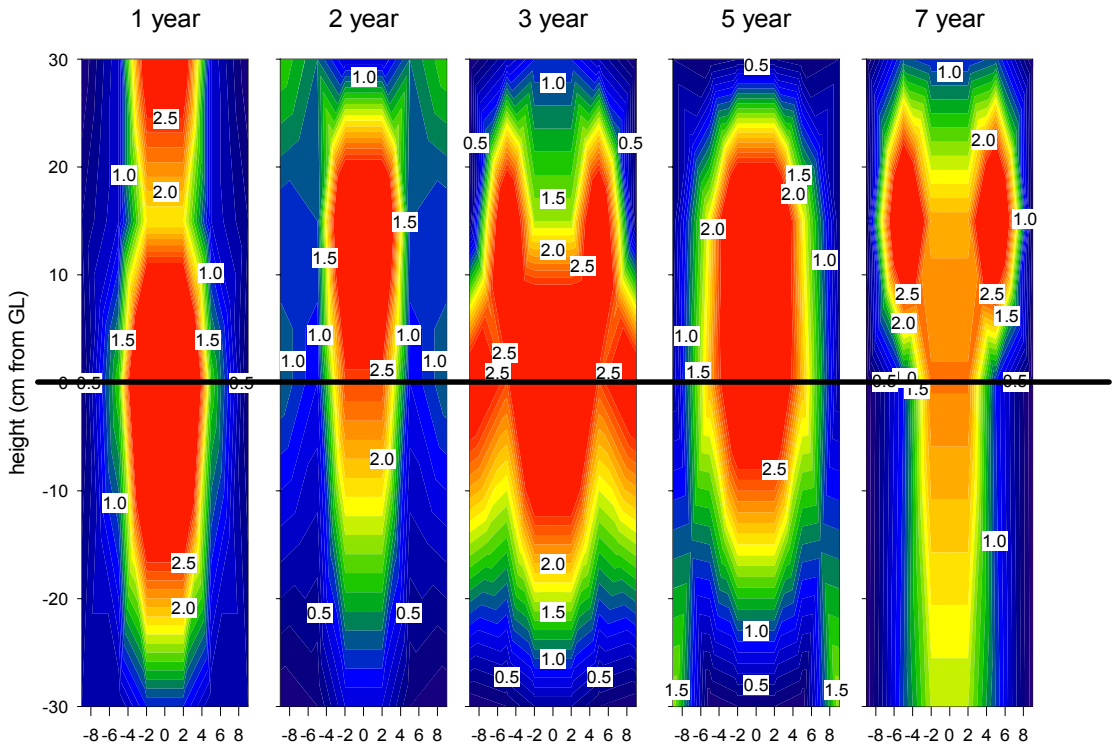


Figure I-23. Residual boron in Douglas-fir timbers 1 to 7 years after application of various combinations of fused borate rod and Boracol 40.

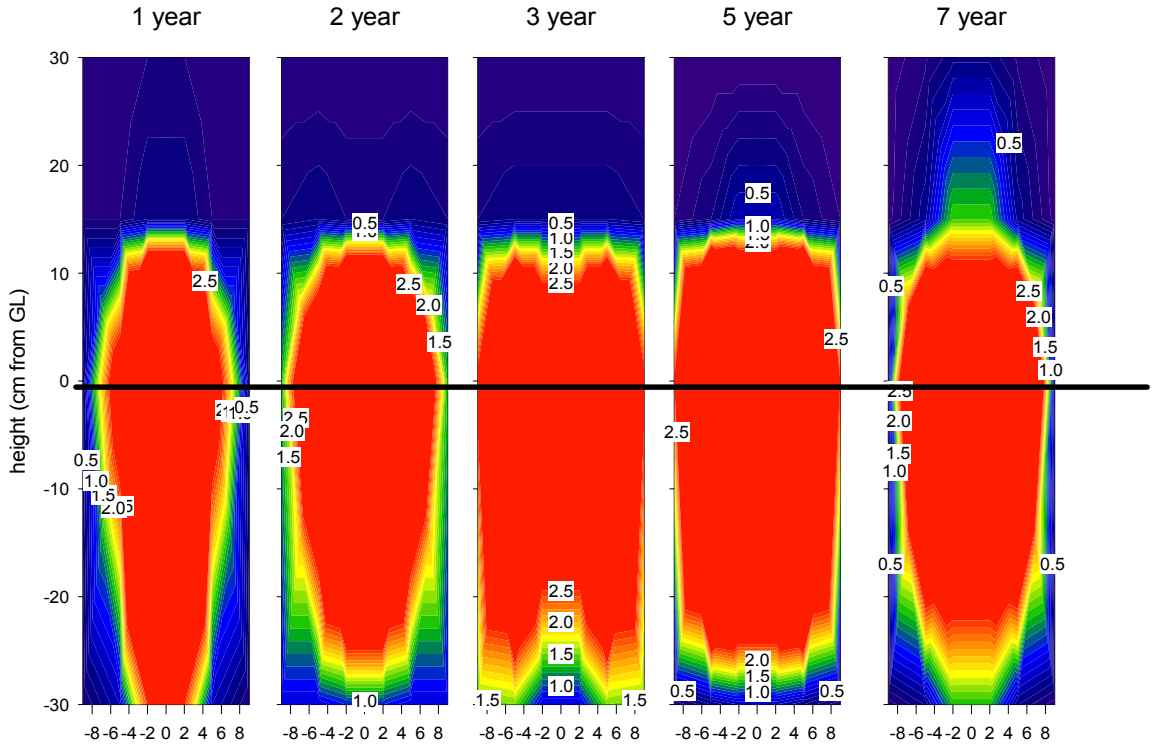


Figure I-24. Residual boron in Douglas-fir timbers 1 to 7 years after application of various combinations of fused borate rod and ethylene glycol.

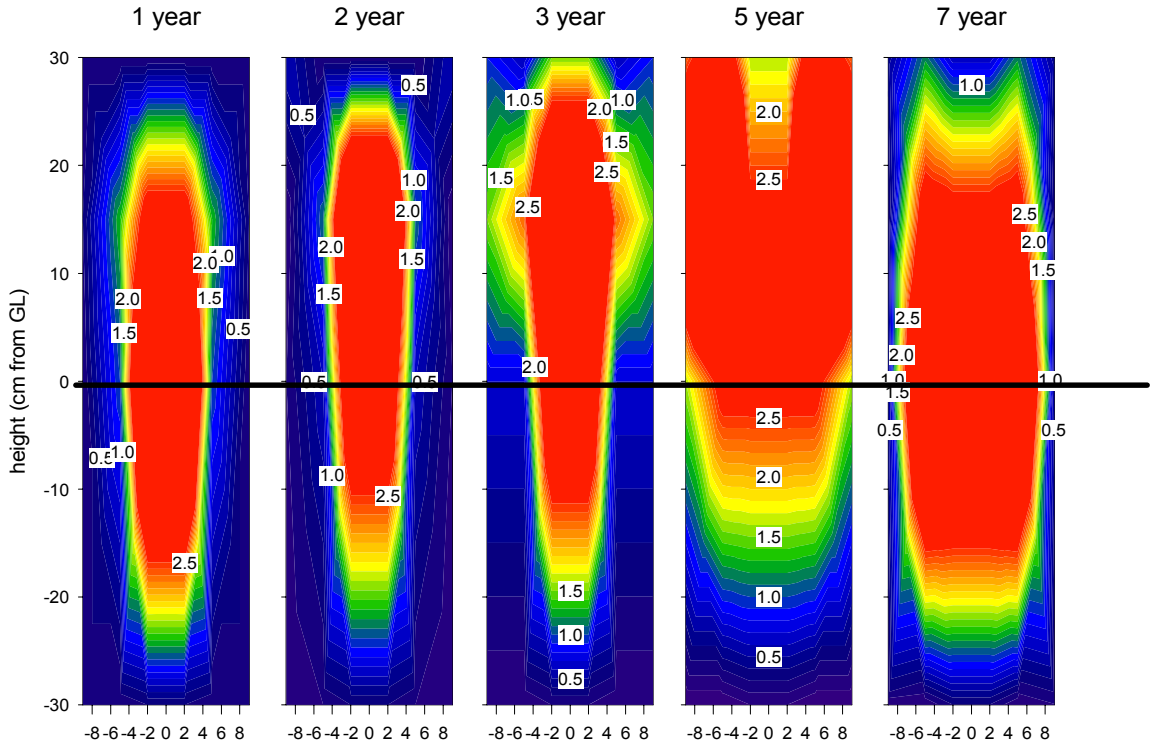


Figure I-25. Residual boron in Douglas-fir timbers 1 to 7 years after application of various combinations of fused borate rod and Timbor.

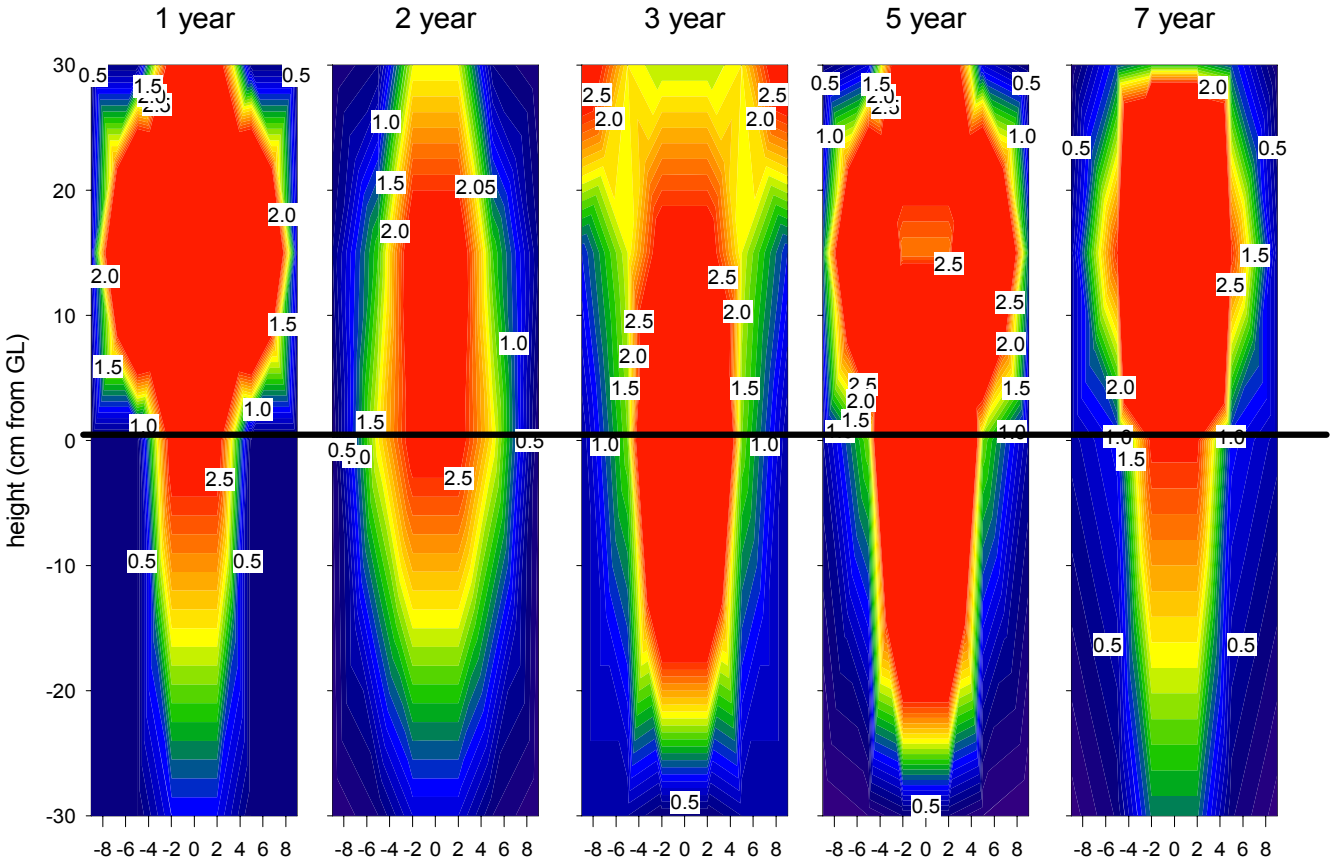


Table I- 19. Residual boron levels in Douglas-fir poles treated with various combinations of glycol, water, and various forms of boron (See Table I-18).

treatment	height (mm)	depth	Boron (Kg/m^3 BAE)				
			year 1	year 2	year 3	year 5	year 7
Rods alone	-300	I	**0.52** (0.45)	**1.40** (1.23)	**0.87** (0.82)	**0.53** (0.92)	0.46 (0.64)
		M	0.81 (1.34)	0.83 (0.91)	0.37 (0.30)	0.37 (0.69)	0.37 (0.56)
		O	0.30 (0.10)	0.43 (0.56)	0.24 (0.23)	0.50 (0.59)	0.10 (0.08)
	0	I	**1.31** (1.91)	**2.16** (0.97)	**2.15** (1.97)	**2.88** (1.98)	**1.10** (0.87)
		M	0.34 (0.24)	1.05 (0.85)	2.43 (2.66)	1.86 (0.82)	1.07 (0.92)
		O	0.24 (0.13)	0.23 (0.29)	**1.67** (2.09)	0.42 (0.46)	**0.69** (0.78)
	150	I	0.45 (0.29)	**1.65** (2.24)	**2.12** (1.62)	**1.87** (1.72)	**2.54** (1.82)
		M	0.22 (0.07)	1.39 (2.47)	2.88 (3.32)	1.47 (1.43)	1.83 (1.66)
		O	0.29 (0.18)	0.43 (0.86)	**0.54** (0.86)	0.41 (0.49)	0.27 (0.28)
	300	I	0.23 (0.13)	0.30 (0.54)	0.49 (0.59)	**1.14** (2.03)	**14.16** (29.02)
		M	0.20 (0.06)	0.17 (0.16)	0.33 (0.34)	1.79 (3.13)	0.81 (0.90)
		O	0.16 (0.09)	0.10 (0.10)	0.11 (0.10)	**1.06** (1.77)	0.40 (0.46)
Rods plus Boracare	-300	I	**1.57** (1.80)	0.36 (0.25)	**0.51** (0.32)	0.20 (0.16)	0.15 (0.14)
		M	0.36 (0.20)	0.43 (0.37)	0.56 (0.28)	0.07 (0.10)	0.12 (0.10)
		O	0.23 (0.05)	0.16 (0.03)	**0.58** (0.59)	0.04 (0.06)	0.10 (0.04)
	0	I	**2.80** (1.86)	**7.59** (6.38)	**2.40** (1.51)	**5.68** (6.61)	**10.39** (9.85)
		M	0.32 (0.18)	4.77 (4.78)	1.34 (0.92)	5.03 (4.71)	0.78 (0.90)
		O	0.22 (0.05)	0.40 (0.39)	**0.87** (0.93)	**0.83** (0.91)	**0.53** (0.67)
	150	I	**4.35** (3.61)	**3.55** (1.22)	**4.13** (4.66)	**5.17** (3.72)	**3.14** (2.65)
		M	1.06 (1.10)	1.32 (1.67)	4.10 (4.50)	1.86 (0.97)	1.69 (1.72)
		O	0.50 (0.34)	0.49 (0.90)	0.40 (0.30)	**1.08** (1.85)	0.21 (0.23)
	300	I	**1.79** (1.16)	**1.22** (1.09)	**0.81** (1.05)	**2.27** (3.19)	**1.83** (1.29)
		M	1.16 (1.91)	0.33 (0.29)	0.89 (1.36)	4.23 (8.09)	0.89 (0.68)
		O	0.33 (0.19)	0.15 (0.18)	**1.00** (1.77)	**1.62** (2.88)	0.12 (0.06)
Rods plus Boracol 20	-300	I	**0.87** (0.71)	**0.69** (0.75)	0.50 (0.53)	0.26 (0.19)	**1.61** (1.06)
		M	0.49 (0.48)	0.29 (0.26)	0.26 (0.24)	0.22 (0.23)	0.99 (0.90)
		O	0.47 (0.49)	0.20 (0.21)	0.22 (0.15)	**1.62** (3.36)	0.13 (0.19)
	0	I	**4.51** (5.32)	**2.41** (0.73)	**3.93** (2.95)	**3.33** (1.95)	**2.22** (2.74)
		M	1.44 (2.09)	0.79 (0.53)	2.38 (2.32)	1.99 (1.25)	0.89 (0.58)
		O	0.32 (0.12)	**1.11** (2.11)	**2.96** (2.91)	**0.55** (0.63)	0.11 (0.11)
	150	I	**1.84** (0.95)	**3.64** (4.00)	**1.65** (1.79)	**3.69** (1.56)	**2.06** (1.47)
		M	0.73 (0.70)	1.00 (0.65)	3.39 (5.04)	1.85 (1.16)	3.86 (1.89)
		O	0.36 (0.23)	**0.93** (1.45)	0.30 (0.27)	0.44 (0.41)	0.27 (0.20)
	300	I	**2.87** (4.37)	**0.70** (0.72)	**0.93** (1.12)	0.36 (0.70)	**0.91** (1.22)
		M	0.67 (0.62)	1.09 (1.16)	0.58 (0.82)	0.27 (0.56)	1.04 (1.66)
		O	0.24 (0.07)	**1.37** (2.44)	0.20 (0.24)	0.40 (0.72)	0.20 (0.36)

treatment	height (mm)	depth	Boron (Kg/m^3 BAE)				
			year 1	year 2	year 3	year 5	year 7
Roda plus Boracol 40	-300	I	**2.49** (2.38)	**0.92** (0.63)	**0.71** (0.62)	**0.62** (0.73)	**1.32** (1.17)
		M	0.55 (0.41)	0.71 (1.09)	1.53 (2.57)	0.37 (0.36)	0.41 (0.34)
		O	0.21 (0.08)	**0.74** (0.99)	**1.36** (2.66)	0.07 (0.07)	0.14 (0.28)
	0	I	**11.15** (6.98)	**10.41** (9.50)	**5.82** (3.21)	**10.82** (9.22)	**5.86** (4.24)
		M	3.38 (2.69)	5.16 (3.23)	9.54 (10.73)	13.82 (10.66)	7.49 (3.73)
		O	0.45 (0.31)	**1.26** (1.47)	**2.65** (2.21)	**2.53** (1.85)	**0.53** (0.34)
	150	I	0.37 (0.24)	0.33 (0.30)	0.35 (0.30)	**0.63** (0.86)	**1.39** (1.58)
		M	0.22 (0.03)	0.44 (0.43)	0.41 (0.31)	0.33 (0.53)	0.47 (0.40)
		O	0.18 (0.11)	0.33 (0.28)	0.26 (0.08)	0.14 (0.27)	0.06 (0.04)
	300	I	0.18 (0.12)	0.10 (0.09)	0.08 (0.07)	0.03 (0.04)	0.37 (0.67)
		M	0.15 (0.10)	0.08 (0.05)	0.09 (0.08)	0.04 (0.05)	0.18 (0.17)
		O	0.15 (0.11)	0.07 (0.04)	0.08 (0.07)	0.02 (0.02)	0.04 (0.02)
Rods plus ethelyne glycol	-300	I	0.32 (0.29)	0.33 (0.20)	0.16 (0.13)	0.14 (0.21)	0.30 (0.24)
		M	0.19 (0.06)	0.18 (0.11)	0.07 (0.13)	0.04 (0.09)	0.10 (0.07)
		O	0.16 (0.10)	0.10 (0.11)	0.10 (0.13)	0.03 (0.05)	0.19 (0.31)
	0	I	**5.30** (8.91)	**3.71** (2.92)	**3.88** (3.84)	**2.84** (1.97)	**4.86** (3.37)
		M	0.97 (1.20)	0.61 (0.39)	0.67 (0.46)	2.81 (2.00)	5.17 (7.26)
		O	0.21 (0.16)	0.17 (0.17)	**0.68** (1.20)	**1.61** (1.90)	0.49 (0.46)
	150	I	**2.98** (3.50)	**5.02** (4.32)	**5.31** (1.72)	**2.77** (2.53)	**2.89** (1.34)
		M	1.34 (1.53)	1.09 (1.36)	2.34 (2.63)	6.53 (10.12)	3.08 (2.69)
		O	0.29 (0.22)	0.10 (0.08)	**1.45** (2.03)	**4.29** (7.08)	0.27 (0.18)
	300	I	0.17 (0.11)	0.24 (0.16)	**1.50** (1.83)	**1.57** (2.79)	**0.63** (1.10)
		M	0.19 (0.05)	0.18 (0.22)	0.56 (0.69)	3.44 (6.66)	1.16 (1.73)
		O	0.20 (0.04)	**0.61** (0.97)	**0.91** (1.72)	**2.33** (4.85)	0.43 (0.48)
Rods plus Timbor	-300	I	**0.83** (0.43)	**0.67** (0.37)	0.30 (0.22)	0.32 (0.39)	**1.12** (1.58)
		M	0.30 (0.07)	0.26 (0.11)	0.54 (0.37)	0.13 (0.22)	0.32 (0.33)
		O	0.33 (0.18)	0.14 (0.06)	**0.51** (0.60)	0.03 (0.04)	0.04 (0.06)
	0	I	**2.75** (2.36)	**2.68** (2.36)	**5.67** (4.81)	**7.58** (11.41)	**2.59** (2.46)
		M	0.32 (0.17)	1.84 (1.99)	1.46 (1.35)	1.54 (0.78)	0.85 (0.53)
		O	0.34 (0.23)	0.20 (0.17)	**0.54** (0.55)	0.47 (0.49)	**0.55** (1.10)
	150	I	**3.53** (3.44)	**2.89** (2.22)	**2.83** (2.85)	**2.22** (1.10)	**14.00** (21.75)
		M	6.60 (12.26)	1.42 (1.89)	1.74 (1.98)	6.15 (7.51)	2.51 (2.13)
		O	**0.72** (0.79)	0.35 (0.30)	**0.94** (0.74)	**1.13** (0.83)	**0.54** (0.43)
	300	I	**2.94** (5.56)	**1.74** (2.22)	**1.57** (1.91)	**3.38** (5.19)	**1.33** (1.30)
		M	0.38 (0.23)	0.40 (0.35)	1.84 (2.42)	0.68 (0.66)	1.00 (0.54)
		O	0.45 (0.32)	0.15 (0.07)	**3.14** (2.42)	0.34 (0.48)	0.22 (0.25)

5. Performance of fluoride rods in Douglas-fir poles:

Flouride has long been known to be effective against a variety of decay fungi and this chemical has been used in pressure treating formulations (as Fluor-Chrome-Arsenic-Phenol or FCAP) as well as in a variety of external preservative paste systems. It has also been used in rod form for arresting internal decay in the areas below railroad tie plates. While fluoride has been effective in all of these applications, there is little data on the efficacy of fluoride rods for arresting internal decay in utility poles.

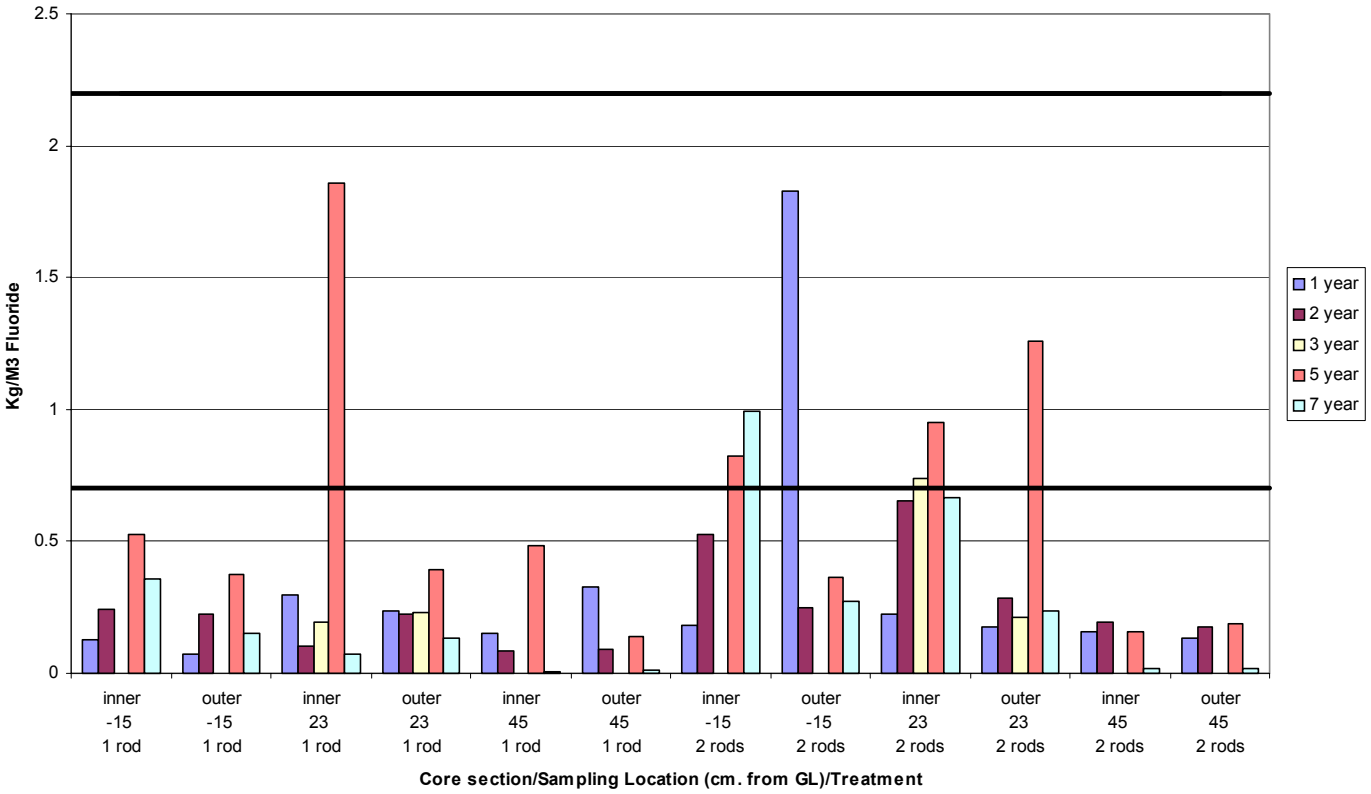
Pentachlorophenol treated Douglas-fir poles sections (250 to 300 mm in diameter by 2.4 m long) were set to a depth of 0.6 m at the Peavy Arboretum test site. Three 19 mm diameter by 200 mm long holes were drilled into the poles beginning at groundline and moving around the pole 120 ^{o} and upward 150 mm. Each hole received either one or two sodium fluoride rods, then the holes were plugged with tight fitting wood dowels. Each treatment was assessed on 7 or 8 poles for the first three years and then 5 poles at years 5 and 7. Fluoride movement was assessed by removing increment cores from 3 equidistant sites around each pole 150 mm below groundline as well as 225 mm above groundline and 150 mm above the highest treatment hole (450 mm above groundline). The outer treated shell was discarded, then the remainder of each core was divided into inner and outer halves. The halves from a given treatment and sample location were combined and ground to pass a 20 mesh screen. The samples were analyzed by Osmose Inc. on a blind sample basis. These analyses were initially performed according to AWPA Standard A2 Method 7 (AWPA, 2000); however, the most recent analyses were performed at OSU using a hot water extract procedure in place of the ashing. Previous trials indicate that the two methods are reasonably comparable.

For the purposes of our assessment, we used a fluoride threshold value of 0.70 kg/m^3. This value is slightly lower than the values suggested by Fahlstrom, (1964); however, repeated laboratory trials of decay fungi in non-soil contact exposures suggest that fluoride is highly effective in above ground exposures. We have also listed an upper threshold of 2.2 kg/m^3; however, we feel that level is more appropriate for fluoride performance in direct soil contact.

Fluoride levels remain very low at virtually all locations regardless of dosage 7 years after treatment (Figure I-26). While fluoride levels have been elevated at some locations over the test (particularly at the 5 year sampling). Most levels remained well below the lower threshold. While fluoride has been very effective in our laboratory trials, it is clear that the dosages used in this field test do not produce the chemical levels considered necessary to eliminate established decay fungi and restrict recolonization.

The poor movement of fluoride in these tests is perplexing. Fluoride has a long history of use in wood preservative and has been shown to move readily through a variety of wood species. Furthermore, a variety of laboratory tests indicate that it is highly effective against a range of decay fungi. Our results suggest that higher fluoride levels may be required to produce the desired chemical dosage in the treatment zone.

Figure I-26. Residual fluoride levels in Douglas-fir pole sections 1 to 7 years after application of 3 or 6 fluoride rods.



6. Effect of voids on movement of remedial treatments in above ground locations of Douglas-fir poles:

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 and we have continued to receive normal rainfall levels since that time. Although prior examination of the rods indicates that the materials have begun to diffuse into the wood (Figure I-27), the percentage of pole area occupied by the chemicals remains limited. (Table I-20). For example, boron was only detectable in 12 to 17 percent of the area in poles treated with either the B or Cu/B rods, respectively (Figures I-28 to 29). Similarly, fluoride was only detectable in 2 to 8 percent of the area in poles treated with the fluoride rods (Figure I-30). Interestingly, copper was detectable in 7 to 20 % of the area treated with the Cu/B rod, a finding that contradicts copper analyses of poles treated with this formulation closer to the groundline (See Objective I-B-3). MITC analysis of cores removed from the Basamid treated poles are still underway and will be reported in the next Annual Report.

The overall results still show that the rod treatments do not become uniformly distributed in the poles when applied above the groundline. The more variable distribution of moisture in these regions of the poles probably plays a major factor in this distribution. It may be possible that the chemical distribution coincides with the available moisture, which would also overlap with the areas where fungi might grow. If so, these treatments could still be effective in these above ground locations; however, we will need a much better understanding of seasonal moisture levels in poles before we could support this premise.

Figure I-27. Condition of fluoride, and copper/borate rods removed from poles two years after application. Fused borate rods in the same test have completely dissolved.

Figure I-28. Degree of boron movement in Douglas-fir pole sections two years after treatment 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-29. Degree of boron and copper movement in Douglas-fir pole sections two years after treatment 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-30. Degree of fluoride movement in Douglas-fir pole sections two years after treatment 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.

Table I-20. Degree of fluoride, boron or copper movement from remedial treatment rods applied to Douglas-fir pole sections that were then exposed for one or two years near Salem, Oregon.

Original Treatment	Rod Treatment	Degree of Treatment (% of Area)						
		Area (cm^2)	Fluoride		Boron		Copper	
			1 Yr	2 Yr	1 Yr	2 Yr	1 Yr	2 Yr
DF-Penta	Impel	2530	-	-	31	12	-	-
DF-Creosote	Impel	1860	-	-	64	12	-	-
WRC- Penta	Cobra	1390	-	-	4	15	18	7
DF-Penta	Cobra	1860	-	-	30	17	25	20
DF-Penta	Flurod	1860	47	8	-	-	-	-
WRC Creosote	Flurod	1860	4	2	-	-	-	-

7 Development of threshold values for boron and fluoride in non-soil contact applications:

Water diffusible fungicides such as boron and fluoride are excellent candidates for limiting fungal attack in the heartwood of species that are resistant to conventional preservative treatment (Becker, 1976; 1973; Cockcroft and Levy, 1973). Boron and fluoride are two examples of water diffusible compounds that are primarily employed where their ability to diffuse through water in wood can be used to deliver chemicals into wood that normally resists traditional preservative treatment using pressure processes. Boron has long been used in dip/ diffusion processes for treatment of building framing to prevent beetle attack, while fluoride has been used to treat wooden windows and door frames (Becker, 1976). In addition, both chemicals are used for remedial treatment of wood that is decaying in service (Dickinson et al., 1988; Dietz and Schmidt, 1988; de Jonge, 1986; Morrell and Schneider, 1995; Panek et al., 1961; Sheard, 1990). These compounds, applied as either rods or pastes placed into holes drilled into the structure, can move with moisture to the point where decay is occurring. Assessing the movement of either compound into the wood is relatively simple and can be accomplished using either chemical indicators or chemical extraction and analysis of the extracts. While chemical quantification is relatively simple, determining how much of each compound is required for protection against fungal attack is a much greater challenge.

The simplest way to assess toxicity is to expose fungi to the toxicant in agar or other growth media (Richards, 1924); however, this approach is extremely artificial and does not account for the potential interactions between the wood and the toxicant. The alternative is to treat wood blocks to selected retentions with the toxicant, then expose these blocks to fungal attack. The resulting weight losses are plotted against chemical loading and the point where weight losses are no longer considered to be of fungal origin is considered to be the threshold. The soil and agar block tests are the two most common methods for accelerated decay tests. These methods work reasonably well for chemicals that are relatively immobile in wood and that are intended for protecting wood in direct soil contact; however, they become more problematic with chemicals that remain mobile and are primarily used for protecting the interior of a wood product.

The estimated thresholds for wood protection determined using wood block exposures range widely for both boron and fluoride (Table I-21). The wide range of values reflects, in part, the array of conditions under which the tests were performed as well as differences between the woods and fungal isolates tested. For example, thresholds are likely to be much higher if the tests allowed for chemical leaching to occur. While this factor

would be important in applications where the chemically treated wood is directly exposed to soil or liquid water, boron and fluoride are used in rod forms that are intended for internal application. The risk of leaching is minimal under these conditions, making a leaching exposure threshold value suspect. The target chemical levels in wood become important when considering retreatment cycles. Remedial treatments are generally reapplied at regular intervals to provide continued supplemental protection to the wood, but the point at which re-application is necessary can be difficult to determine. Refining the retreatment cycles can produce considerable cost savings for electrical utilities if it allowed them to delay treatments. One approach for determining retreatment time has been to chemically analyze the wood to assess residual chemical levels, then reapply once the levels decline below a given level. Determining the re-application level, however, is difficult without more precise data on the threshold required for protection against fungal attack.

Table I-21. Thresholds of fluoride and boric acid against selected decay fungi as predicted in previous studies.

Fungas	Boron (kg/m3 BAE)	Souce	Fluoride (kg/m3)	Source
G.trabeum	0.5 to 0.7	Becker, 1959	1.13-1.36	Baechler and Roth, 1956
	1	Findlay, 1953	1.18-1.36	Fahlstrom, 1964
	1.6 to 2.4	Baechler and Roth, 1956; Fahlstrom, 1964		
	<3.1	Ruddick and Kundzewicz, 1992		
	2.9	Williams and Amburgey, 1987		
	4.7	Roff, 1969		
G. saepiarium	2.2	Edlund et al., 1983		
P. placenta	0.4 to 0.8	Baechler and Roth, 1956	1.13-1.31	Baechler and Roth, 1956
	1.0 to 1.4	Fahlstrom, 1964	1.31-1.45	Fahlstrom, 1964
	< 3.1	Ruddick and Kundzewicz, 1992		
	4.3	Roff, 1969		
N. lepideus	0.3	Findlay, 1953	0.63-0.95	Baechler and Roth, 1956
	0.5 to 1.4	Becker, 1959	0.86-1.08	Fahlstrom, 1964
	1.0 to 1.4	Fahlstrom, 1964		
	1.6 to 2.4	Baechler and Roth, 1956		
T. versicolor	0.6	Baechler and Roth, 1956	6.06-10.22	Fahlstrom, 1964
	2.2 to 3.6	Fahlstrom, 1964	6.10-10.22	Baechler and Roth, 1956
	4.7	Roff, 1969		
C. puteana	0.5 to 0.7	Becker, 1959	1.08-1.22	Fahlstrom, 1964
	1.0 to 1.4	Fahlstrom, 1964		
	3.9	Roff, 1969		

In this report, we describe tests to assess the thresholds for boron and fluoride against selected decay fungi under non-leaching conditions. The trials with each chemical were performed two times, but we report only the most recent trials which contained treatment levels that were low enough to allow us to estimate threshold levels for each chemical

Materials and Methods

Wood: Douglas-fir (*Psuedotsuga menziesii* (Mirb.) Franco) sapwood and heartwood wafers (5 by 10 by 30 mm long for the boron test and 12 by 12 by 40 mm long for the fluoride) were cut from lumber that was free of defects or visible evidence of microbial colonization. Slightly thicker specimens were employed with fluoride in an effort to improve moisture stability of the specimens, although this did not appear to have any substantial influence on moisture over the course of the test. A single, 0.5 mm diameter by 2 mm long hole was drilled into one wide face of each wafer to serve as a fungal inoculation point. The wafers were oven dried (54 C) to constant weight, then weighed (nearest 0.001 g). The wafers were allocated to groups for boron or fluoride treatment.

Preservative Treatment: For boron treatment, wafers were allocated to 7 groups of 15 blocks each. Solutions of disodium octaborate tetrahydrate (US Borax Inc., Valencia, CA) were prepared to produce boron levels of 0.13, 0.22, 0.40, 0.76, 1.03, or 1.61 kg/m^3 boric acid equivalent (BAE) for heartwood blocks and 0.0.13, 0.40, 0.94, 1.39, 1.43, 2.06 kg/m^3 BAE for sapwood blocks on a wt/wt % basis. Lower boron levels delivered into heartwood blocks because of the inherent resistance of this material to fluid ingress; however, we would also expect that the moderate durability of the Douglas-fir heartwood would require less boron to provide comparable protection than the non-durable sapwood of this species. The blocks were immersed in the desired test solutions, then a short vacuum (80 kPA) was applied to the blocks. The pressure was then raised to 800 kPa and held for 60 minutes. Following treatment, the blocks were wiped clean of excess solution and weighed to determine gross solution uptake.

For fluoride treatments, wafers were allocated to 8 groups of 21 sapwood or heartwood wafers. Wafers for a given group were immersed in treating solutions of sodium fluoride designed to produce 0.045, 0.090, 0.240, 0.360, 0.448, 1.12, and 2.24 kg/m^3 of fluoride by weight in the wood . The wafers were treated as described for the boron treatments, then weighed to determine net solution uptake.

Three blocks treated with each chemical were removed and retained for chemical analysis. The remainder were sealed in plastic bags and sterilized by exposure to 2.5 mrads of ionizing radiation from a cobalt 60 source.

Decay Chambers: Decay chambers consisted of 115 mm glass petri dishes containing three sheets of moistened filter paper. A single, u-shaped glass rod was placed on top of the filter paper and the plates were sterilized by heating at 121 C for 30 minutes. Sterile wafers from a given treatment group were the placed on the glass rods. The boron treated blocks were incubated individually on the rods, while the fluoride treated blocks were incubated in pairs with the faces with the inoculum holes abutting to reduce drying in the holes and encourage fungal attack.

Fungal inoculation: Wafers treated with boron were inoculated with a mycelial suspension of either *Gloeophyllum trabeum* (Pers:Fr) Murr (isolate Mad. 617) or *Trametes versicolor* (L:Fr) Pilat (Isolate R-105). Wafers treated with fluoride were inoculated with these same fungi along with *Postia placenta* ((Isolate Mad 698). The mycelial suspension was prepared by inoculating 1.5 % malt extract broth in 250 ml erlenmeyer flasks with agar discs cut from the actively growing edge of the appropriate test fungus. The flasks were incubated for 14 days on a rotary shaker at room temperature (20-23 C), then the resulting mycelium was collected by filtration and washed with sterile distilled water to remove residual media. The resulting mycelium was resuspended in sterile distilled water and blended for 10 seconds to fragment the mycelium.

Each wafer received 100 ul of the resulting mycelial fragment/spore suspension through the small hole drilled into the wood surface. The petri dishes were sealed with wax film to retard moisture loss, then the wafers were incubated at 28 C for 16 or 21 weeks for *G. trabeum*, *P. placenta* or *T. versicolor*, respectively. Each fungus/chemical level was replicated on 6 wafers.

The test methodology permitted exposure of moist boron or fluoride treated wafers to fungal spores and hyphae under nearly non-leaching conditions. The use of spores/mycelial fragments also helped to better recreate possible fungal exposure conditions. Internal decay is presumed to start via invasion by spores or mycelium along checks that develop in the wood rather than mass invasion from a mycelial mat. The spores in the pre-drilled holes might be compared to spores on a moist, untreated surface in a check within a timber or pole.

Chemical Analysis: Selected wafers from each treatment were dried, ground to pass a 20 mesh screen and analyzed for their respective preservative. Boron content was assessed using the azomethine H/carminic acid method as described in American Wood Preservers' Association Standard A2 Method 16 (AWPA, 2001a). Fluoride was analyzed by hot water extraction and analysis of the extract using a specific ion electrode following procedures described by Chen et al. (2003). Boron values are reported as kg/m^3 boric acid equivalent using the analytical results. Fluoride values reported are based upon net solution uptake. Fluoride analysis by the specific ion electrode method suggested that retentions were approximately one third of the target values at the lower retention. The analysis result came closer to the gage retention as the target increased. At the two highest retentions the analysis was in close agreement with the gage retention. because the specific ion electrode method is not accurate at the very low fluoride levels used in this test, the results are reported on the basis of gage retention.

Data analysis: The results were plotted as described in AWPA Standard E10 and these plots were used to estimate thresholds for fungal attack (AWPA, 2001b).

Results and Discussion

Hyphal growth became evident on the surfaces of untreated wafers with in 4 weeks for *G. trabeum* and *P. placenta* and within 8 to 10 weeks for wafers exposed to *T. versicolor*. In addition, wood moisture contents of the wafers at the end of the test were well above the fiber saturation point. These observations indicate that conditions were suitable for fungal growth despite the absence of supporting media or soil. Weight losses tended to be far lower than those typically found with soil or agar block tests, reflecting the limited inoculum potential and absence of any exogenous nutrients in our tests.

Boron threshold: Weight losses for untreated heartwood wafers were generally low for both fungi, reflecting the natural durability of this material (Scheffer and Cowling, 1966) (Table I-22). Weight losses tended to be higher with the brown rot fungus, regardless of wood substrate. This finding is consistent with the tendency for brown rot fungi to be more aggressive on softwood, while white rotters tend to cause more damage to hardwoods (Zabel and Morrell, 1992).

Table I-22. Effect of boron retention on weight losses in Douglas-fir heartwood or sapwood blocks exposed to decay fungi in a simulated above ground decay test. [a]

Retention	Heartwood Weight Loss (%)		Retention	Sapwood Weight Loss (%)	
(kg/m3 BAE)	G. trabeum	T. versicolor	(kg/m3 BAE)	G. trabeum	T. versicolor
0	9.6 (1.0)	0.2 (0.6)	0	21.6 (1.1)	7.3 (2.0)
0.134	9.1 (1.3)	0.3 (0.6)	0.134	19.7 (4.2)	5.2 (0.5)
0.224	2.6 (0.6)	1.0 (0.5)	0.4	2.5 (2.1)	2.0 (0.9)
0.4	1.0 (0.5)	1.0 (0.4)	0.94	1.6 (0.3)	1.2 (1.0)
0.76	1.2 (0.4)	0.9 (0.3)	1.39	0.9 (0.3)	0.2 (0.3)
1.03	0.9 (0.4)	1.9 (0.3)	1.43	0.8 (0.2)	0.0 (0.9)
1.61	0.9 (0.3)	1.0 (0.6)	2.06	0.5 (0.3)	-0.4 (0.6)

[A]Values represent means of 6 wafers per treatment. Figures in parenthesis represent one standard deviation

Weight losses for *G. trabeum* approached 10 % for heartwood wafers treated to 0.13 kg/m^3 BAE, then declined sharply with increased boron level. The results suggest a boron threshold of approximately 0.35 kg/m^3 BAE. Weight losses were negligible for all heartwood wafers exposed to *T. versicolor*, making it impossible to estimate any threshold for this fungus.

Weight losses in untreated sapwood were again higher with *G. trabeum* and declined rapidly with increasing boron content. Weight losses were negligible with either fungus at boron levels above 0.45 kg/m^3 BAE. The results suggest that the threshold for protection of Douglas-fir sapwood would be between 0.40 and 0.44 kg/m^3 BAE. Findlay (1953) reported a toxic threshold for *G. trabeum* of 1.0 kg/m^3 BAE, while Williams and Amburgey (1987) reported a threshold of 2.9 kg/m^3 BAE and Harrow (1950) reported a threshold between 2.2 and 4.0 kg/m^3 BAE. Our levels were well below the thresholds reported in other tests and illustrate the limited potential for spores and hyphal fragments to invade wood containing even modest amounts of biocide. This effect would be masked by procedures such as those used in the soil block test that expose the wood to large amounts of actively growing mycelium. Soil or agar block tests poorly represent invasion of single spores or hyphal fragments through exposed checks in larger timbers.

Fluoride Thresholds: As with the boron tests, weight losses in blocks exposed using our procedures tended to be far lower than those that would be expected in a typical soil block test, however, the differences were sufficient to allow us to delineate between treatments with the two brown rot fungi (Table I-23).

Table I-23. Effect of fluoride retention on weight losses in Douglas-fir heartwood or sapwood blocks exposed to decay fungi in a simulated above ground decay test. [a]

Retention	Heartwood Weight Loss (%)			Sapwood Weight Loss (%)		
(kg/m3 F)	*G. trabeum*	*P. placenta*	*T. versicolor*	*G. trabeum*	*P. placenta*	*T. versicolor*
0	-0.5 (0.1)	7.0(3.9)	0.1 (0.3)	8.9 (1.3)	27.6 (4.2)	5.3 (1.6)
0.045	-0.3 (0.2)	0.3 (0.2)	0.1 (0.4)	3.7 (0.7)	2.2 (1.9)	3.0 (0.2)
0.09	-0.2 (0.2)	0.4 (0.3)	0.4 (0.3)	1.8 (1.7)	1.2 (0.2)	2.4 (0.4)
0.224	-0.1 (0.2)	0.3 (0.2)	0.5 (0.1)	0.1 (0.1)	1.0 (0.1)	0.3 (0.4)
0.336	0.1 (0.3)	-0.2 (0.1)	-0.1 (0.4)	-0.2 (0.2)	0.2 (0.2)	-0.1 (0.2)
0.448	0.0 (0.1)	-0.1 (0.1)	0.1 (0.1)	-0.3 (0.1)	0.1 (0.2)	0.1 (0.2)
1.12	-0.1 (0.1)	-0.2 (0.2)	-0.1 (0.2)	-0.5 (0.1)	0.3 (0.1)	-0.2 (0.3)
2.24	-0.3 (0.2)	-0.5 (0.3)	-0.7 (0.3)	-0.5 (0.1)	-0.5 (0.1)	-0.3 (0.2)

[a] Values represent means of 6 wafers per treatment. Figures in parentheses represent one standard deviation.

Weight losses in untreated sapwood blocks exposed to *T. versicolor* were only barely above the background levels, while weight losses in blocks exposed to *P. placenta* approached 30 %. Weight losses were extremely low in heartwood blocks exposed to *G. trabeum* and *T. versicolor* while those in heartwood blocks exposed to *P. placenta* were nearly 25 % of those found with untreated sapwood. These results highlight the moderate durability of Douglas-fir heartwood as well as the adaptation of *P. placenta* for this wood. *Postia placenta* is a common inhabitant of Douglas-fir logs and lumber (Morrell et al, 1987).

Weight losses in blocks treated with fluoride were uniformly low in comparison to the untreated blocks. Weight losses in the 2 to 3 % range were noted in sapwood blocks treated to a target retention of 0.04 kg/m^3 fluoride. Thresholds for *G. trabeum* and *T. versicolor* on Douglas-fir sapwood appear to be in the range of 0.22 kg/m^3 fluoride. *P. placenta* appeared to have a similar initial sensitivity to fluoride, but still caused slight weight losses at 0.33 kg/m^3. Given the importance of this species in heartwood decay of Douglas-fir poles, the use of a 0.33 kg/m^3 threshold for internal fluoride treatments appears warranted. These values were nearly one fourth of those found for the same fungus in soil block tests (Table I-21). Weight losses in treated blocks exposed to *T. versicolor* were far lower than those reported on oak. This may reflect the use of a conifer in our tests as well as the use of mycelial fragments instead of well established mycelium

Weight losses in Douglas-fir heartwood blocks treated with any level of fluoride were within the error range of the test. These results suggest that relatively small amounts of boron can supplement the natural durability of Douglas-fir heartwood and also illustrate the relative sensitivity of fungal spores and mycelial fragments to low levels of toxicants.

Conclusions

Boron and fluoride were both highly effective at extremely low levels against the decay fungi tested. The higher sensitivity reflect the decay conditions and suggest that it should take relatively low levels of either compound inside a large wood member to prevent reinvasion. This knowledge should allow for more rational assessment of retreatment cycles for maintenance programs that employ either of these systems

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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 damage 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 holes, 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 bolt 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.

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)			
		Coper		Boron	
		Upward	Downward	Upward	Downward
Cop-R-Nap	1	2	2	-	-
	2	0	0	-	-
CuRap20	1	2	2	36	42
	2	7	10	6	5

Bolts treated with 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 amounts 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.

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 poles sections that were exposed at the Peavy Arboretum test site. Selected poles were split lengthwise around the bolt hole one and two years after treatment and the average and maximum degree of diffusion of the each paste component was measured after the wood had been sprayed with the appropriate chemical indicator.

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

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 300 mm in some samples (Table II-2). Maximum copper penetration tended to be greater in the Cu/F system than in the Cu/B system, although the average degree of penetration for copper was similar in both systems. Maximum distance may reflect the ability of the liquid to move for long distances in the wood along openings such as checks or splits. The copper naphthenate in the Cu/F system is oilborne, while the copper naphthenate in the Cu/B system is amine based. One disadvantage of the amine based system is that it becomes less mobile once the amine evolves from the complex, while the oilborne systems would remain soluble. This might allow the oilborne system to move further away from the bolt.

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

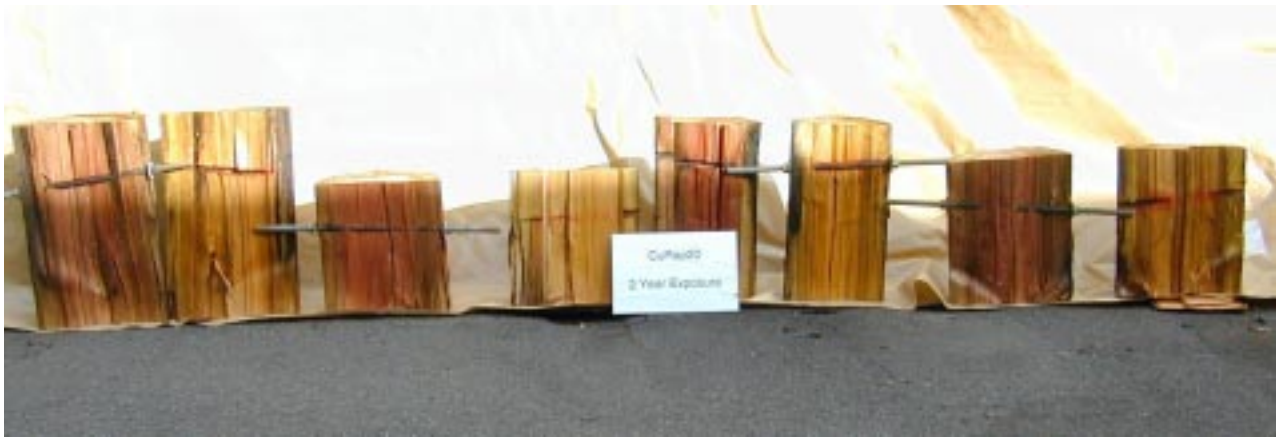
Treatment	Degree of Chemical Movement (mm)[a]							
	Coper				Boron or Fluoride			
	Average		Maximum		Average		Maximum	
	Yr 1	Yr 2	Yr 1	Yr 2	Yr 1	Yr 2	Yr 1	Yr 2
Cop-R-Plastic	<1	2.3 (1.3)	30 (29)	108 (74)	<1	2.0 (2.8)	118 (139)	108 (74)
CuRap 20	3 (1)	2.3 (0.5)	21 (10)	46 (29)	3 (1)	6.3 (3.4)	50 (11)	46 (29)

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

Average boron and fluoride diffusion were also somewhat limited 1 year after treatment, then increased in the second year (Table II-2, Figures II-2,3). The relatively slow rate of initial diffusion might reflect, in part, the presence of the brush-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-2. Degree of copper and fluoride movement away from the sites in Douglas-fir poles where Cop-R-Plastic coated galvanized rods were installed two years 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 two years earlier.



Average boron movement tended to be better 2 years after treatment than fluoride movement, although the maximum distance of fluoride movement was nearly two times higher. In most of our tests, fluoride has tended to move more slowly and at apparently lower levels than boron. Our results for average movement in these tests follow that trend, although it appears that, when conditions are suitable, fluoride can diffuse for considerable distances from the point of application.

The results show that the coated rods can deliver chemicals to a small area around the treatment hole. These results, coupled with previous trials of boron and fluoride sprays into field drilled bolt holes, suggest that treated bolts may represent one method for ensuring that field drilled wood is protected. This approach would allow utilities to specify specific treated bolts when other utilities occupy portions of the pole and must field drill for attachments. This approach would allow utilities to minimize the risk of decay in field drilled holes above the ground. As utilities continue to use internal and external treatments to protect the groundline zone, slow development of decay above the ground may threaten the long term gains provided by groundline treatments. This type of treatment could be used to limit the potential for above ground decay, allowing utilities to continue to gain the benefits afforded by aggressive groundline maintenance.

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. While it is clear that wood moisture contents in poles are sufficient for decay to occur, the relative moisture distribution in poles remains relatively poorly understood. In addition to its effect on fungal development, moisture can have important impacts on the effectiveness of some of the water diffusible remedial treatments as well as impact the material properties of the pole. Over the past 3 years, we have collected an extensive data base on seasonal moisture levels in poles in Western Oregon. The summary of these results was presented last year, but we will continue to work with these data to determine how they can be applied to the better understand pole performance.

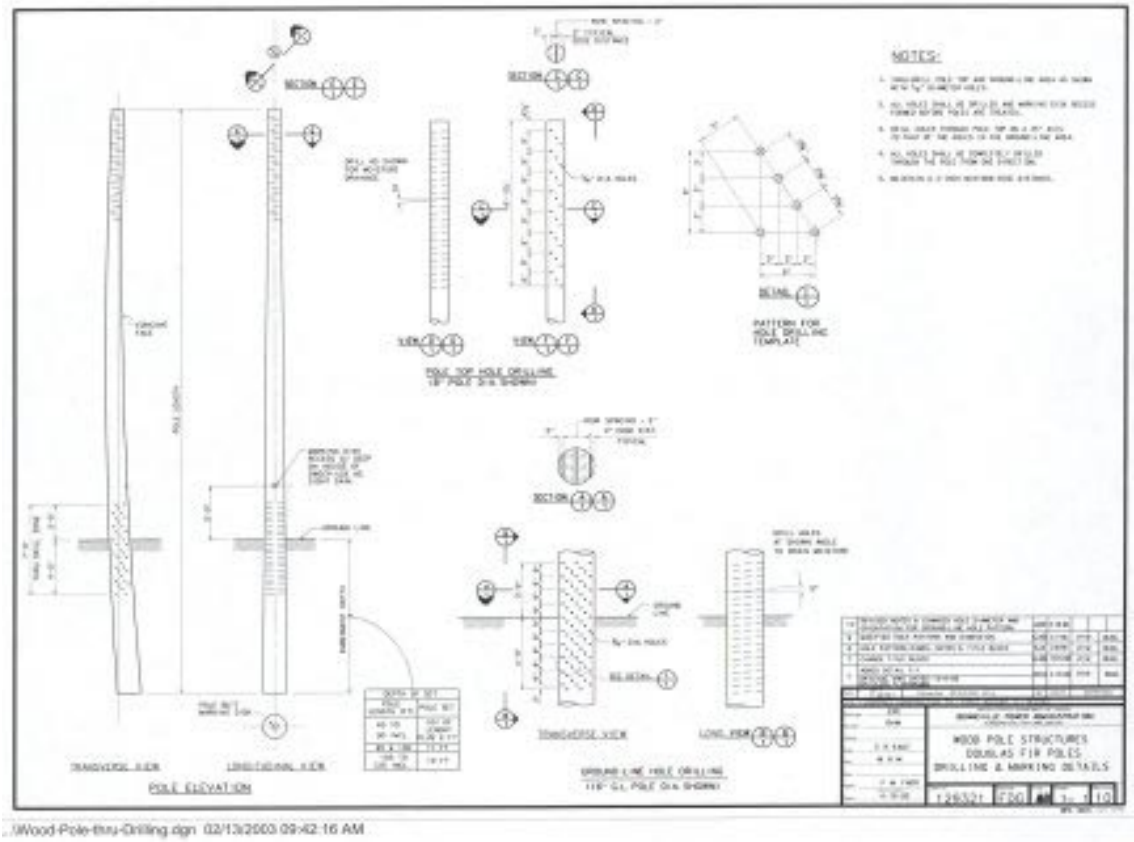
B. Effects of through-boring and radial drilling on pole strength properties

The use of either through-boring or radial drilling in the groundline region of Douglas-fir poles largely eliminates the potential for fungal attack in this zone and is a major contributor to the excellent pole service lives being observed in many regions of the country (Figure III-1). Over the past 10 years, we have performed a number of studies examining the degree of preservative penetration in the through-bored region of poles and found that poles with greater than 70 % preservative penetration in the through-bored zone were free of decay. Based upon this work, we also examined the potential for using more widely spaced patterns to reduce the amount of wood removed from any given cross section and these data were used, in part, to increase hole spacing in poles specified by Bonneville Power Administration, Portland General Electric and Pacificorp. In addition to this work, we examined the effects of full length through boring on pole bending properties and found that the process caused approximately a 10 % reduction in modulus of elasticity or modulus of rupture. The number of poles tested, however, was relatively small.

The question of how much strength is lost when a pole is through-bored has long troubled engineers who object to the loss of any wood fiber. There is no question that through-boring or radial drilling remove some wood in the critical bending zones that provide pole wood strength, but the loss of wood is considered to be offset by the subsequent high degree of protection against fungal attack in this zone. As a result, these groundline boring processes have long been viewed as giving up some initial strength to provide more uniform pole performance.

The body of data supporting either through boring or radial drilling is rather limited. Both strategies were developed in the 1960's in response to severe early failures of Douglas-fir poles due to internal decay. Two through-boring patterns and one radial drilling pattern emerged from a series of utility tests involving fewer than 20 full length poles. While no significant effects on bending strength were observed and the poles all broke above the drilled zone at their predicted bending moment, the overall number of poles tested for each of the processes remains low. Conversely, through-boring and radial drilling have been used to protect the groundline zone of millions of Douglas-fir poles with little or no evidence that the process produces weaker poles.

Figure III-1. Example of through boring pattern used to enhance treatment of the groundline zone in a Douglas-fir pole.



Despite the widespread success of through boring and radial drilling, over the past two years, we have examined several through-bored poles that had failed at the groundline under extreme wind loads. In one case, the pole was in a H-frame structure, while the others were in a transmission line of single poles. In the case of the single pole line, a series of poles cascaded under an extreme wind load. In this case, the line contained both through-bored and older non-through-bored poles and both types of poles failed at groundline. In addition, a large heavy duty steel pole acting as a tangent buckled and another was pulled out of its foundation. These actions attest to the severity of the weather event and suggest that no line could have withstood the forces applied. These failures, however, have also caused a number of utility engineers to ask for additional data on the effects of through boring and radial drilling on pole strength.

This past summer, we were fortunate to recruit a new Master's student who is pursuing a dual civil engineering/ wood science degree to work on this problem. The goal of this work is to identify possible effects of various through boring and radial drilling patterns on pole strength with the ultimate goal of identifying a unified patters for each process that minimizes strength effects while maximizing treatment. These patterns would then be presented to ANSI for possible inclusion in ANSI 05. The first step in this process, was to calculate the effects of various common through boring and radial drilling patterns on section modulus in comparison to no groundline preparation.

The previously employed BPA pattern resulted in the largest loss in section modulus of the 5 patterns examined (Table III-1). Section modulus was reduced over 10 % in this pattern. This loss of section molecules occurred because, over the years, the treater had substituted larger drill bits for the process. While this reduced drifting of bits during drilling and undoubtably reduced breakage, it also increased the possible effects of the process on section modulus. The results of this calculation (performed by Scott Kent, an OSU Graduate Student) led to changes in BPA specifications. The new pattern using smaller bits has a slightly lower reduction in section modulus. Spreading the pattern even further such as the widely spaced pattern used in full length through bored poles tested in cooperation with BPA, PGE and Pacificorp, produced 4 to 4.5 % loss in section modulus.

Table III-1. Effect of through-boring or radial drilling on section modulus of Douglas-fir poles.

Boring Pattern[a]	Axis	Calculated Section Modulus (in^3)	Reduction (%)
None	X-X	402	-
	Y-Y	402	-
Original BPA	X-X	328	10.4
	Y-Y	336	8.2
New BPA	X-X	372	7.5
	Y-Y	381	5.2
Simplified Radial	X-X	379	5.8
	Y-Y	379	5.8
Newbill Pattern	X-X	386	4
	Y-Y	384	4.5

[a] Values based upon a pole 15.5 inches in diameter at goundline for the old BPA pattern and 16 inches for all others. Newbill pattern is from full length through-bored poles.

In all instances examining through boring, the loss in section modules was directional since the through boring holes are only applied on one side of the pole. As a result, section modulus reductions tended to be slightly lower perpendicular to the through boring direction. One outcome of these findings, which were confirmed by previous tests on through bored lodgepole pine, is the need to alternate poles to avoid a directional effect in the line. This is relatively simple to accomplish for BPA, since all poles are through bored in the cross arm zone so they can be field drilled. It becomes more problematic, however, for utilities that use pre-boring for attachments (a highly recommended practice) since the treater must alternate through boring and pre-drilling patterns to create poles where these holes line up and where they are 90 degrees around from one another. This may not be feasible on a field basis and it will be important to determine if the 2 % gain in section modulus is really worthwhile given the wide variations in wood properties and the safety factors that are already applied to poles.

Calculations of section modulus loss applied to radial drilled poles using 4 inch long holes every 45 degrees around the poles (i.e. 8 holes around the pole in a given cross section) showed that section loses were 5.8 % in comparison with the non-bored pole. These values are slightly greater than those found with the Newbill pattern, but lower than those found with either BPA pattern. The radial drilling effect is uniform around the poles, reflecting the presence of holes on all faces.

It is important to note that these calculations are extremely preliminary and are intended to bring together the parties for a discussion about how to develop better information on the effects of groundline boring on pole properties. The goal of this work will be to identify patterns that can potentially be used as national standards. One possible benefit of this process would be the chance to automate the boring practice. This could reduce costs and increase uniformity.

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 Table IV-1. The primary goals of this objective are to assess the laboratory and field performance of external preservative systems for protecting the below ground portions of wood poles.

Table IV-1. Preservative systems available for external groundline treatment.

Trade name	Components	Paste or Wrap	Manufacturer
Cobra Wrap	copper naphthenate	wrap	Genics Inc., Spruce Grove, Alberta.
			Redesigned/Packaged CuNap Wrap
CopR-Plastic	copper naphthenate, sodium fluoride	paste	Osmose Utilities Services, Inc.
			Buffalo, NY
CuBor	copper hydroxide, boron	paste	Pole Maintenance Co. Columbus, NE
CuNap Wrap	copper naphthenate	wrap	No longer on the market.
CuRap 20	copper naphthenate, sodium tetraborate	both	ISK Biocides, Inc., Memphis, TN
OsmoPlastic	creosote, sodium fluoride	paste	Osmose Utilities Services, Inc.,
			Buffalo, NY (Retired 1/1/04)

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

The field test in California is now completed. The final results were provided in the 2002 annual report.

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-1). The poles were sampled 2, 3 and 4 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 AWPA Standard A23-94.

Figure IV-1 Douglas-fir poles at the Corvallis test site treated with selected external preservative systems.

The poles in this test experienced extremely rapid decay below ground. The decay rates were much more rapid than we have observed in previous tests and have resulted in the decision to terminate this test after 4 years. We attribute the more rapid decay rates to the location of the test on the hill above the previous test site. The new site was better drained than our earlier test site, which tended to be extremely wet during the winter. The excess moisture levels undoubtably limited fungal activity during certain parts of the year. In the final year of the test, the condition of the wood also forced us to combine assay zones from inner and outer halves of the plugs. This reduced our sensitivity, but allowed us to reduce the risk of sample loss due to the degree of decay in some cores. Copper levels in poles treated with the Cu/F/B system tended to vary over the first two years.

Copper levels in the outer 4 mm were nearly double the threshold two years after treatment, but were only 2/3 of the threshold 2 years later (Table IV-2). Copper levels further from the surface declined precipitously, suggesting that the copper in this system was relatively immobile. Copper levels in the Cu/F/B system fell by more than 50 % by the fourth year after treatment in the outer zone and were largely below the detection limit in the inner zone. Copper is not supposed to move for long distances from the surface in this treatment, so these results are not surprising. Boron levels in the Cu/F/B system tended to be uniform, but relatively low at all sampling times at all 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 4. 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/F/B system at all sampling times for the outer three sampling depths (Table IV-2). Copper levels associated with the Cu/B system were far in excess of those required for protection against fungal attack for the first 2 years, then declined to just the threshold four years after treatment. Copper levels in the inner zone 4 years after treatment were at the detection limit, again indicating the limited mobility of this component of the system. Boron levels in these 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 and were well below the threshold this past year. Boron is sensitive to moisture and our site is characterized by very high winter moisture levels that should encourage rapid loss. The absence of a preservative treated shell should further accelerate this process.

Propiconazole levels near the surface were extremely high and far in excess of the levels required for fungal protection (Table IV-2). Chemical levels dropped sharply in the 4 to 10 mm assay zone, indicating that the propiconazole formulation had relatively little ability to move inward. The samples for this year's inspection are still under evaluation. The results will be provided in a future report.

Table IV-2. Levels of copper, fluoride, boron and propiconazole in wood beneath the groundline of Douglas-fir pole stubs treated with selected external preservative systems.

Treatment	Assay Zone	Residual Chemical Loading (kg/m^3)[a]																					
		Copper						Fluoride						Boron						Propiconazole			
	(mm)	Yr. 2		Yr. 3		Yr. 4		Yr. 2		Yr. 3		Yr. 4		Yr. 2		Yr. 3		Yr. 4		Yr. 2		Yr. 3		Yr. 4	
Cu/B	0-4	**3.69**[b]	(1.04)	**4.06**	(1.88)	**2.57**	(1.46)							**3.43**	(2.51)	**1.73**	(0.88)	1.09	(0.48)						
	4-10	**1.20**	(0.86)	0.33	(0.24)									**3.17**	(1.72)	1.00	(0.57)								
	10-16	0.25	(0.34)	0.09	(0.06)	0.02	(0.01)							**2.97**	(2.04)	0.92	(0.46)	0.98	(0.39)						
	16-25	0.00	-	0.02	(0.01)									**1.56**	(1.37)	0.76	(0.48)								
Cu/F/B	0-4	**1.14**	(0.39)	0.43	(0.20)	0.45	(0.25)	0.52	(0.19)	0.31	(0.15)	0.19	(0.11)	0.11	(0.10)	0.27	(0.29)	0.14	(0.07)						
	4-10	0.15	(0.24)	0.14	(0.09)			0.35	(0.11)	0.19	(0.11)			0.16	(0.18)	0.19	(0.11)								
	10-16	0.00	-	0.06	(0.07)	0.02	(0.03)	0.36	(0.18)	0.16	(0.11)	0.09	(0.06)	0.15	(0.14)	0.17	(0.09)	0.17	(0.06)						
	16-25	0.00	-	0.02	(0.02)			0.32	(0.14)	0.14	(0.09)			0.17	(0.10)	0.17	(0.07)								
Propiconazole	0-4																			**1.06**	(1.18)	**8.02**	(18.8)	-	-
	4-10																			0.05	(0.04)	0.10	(0.17)	-	-
	10-16																			0.03	(0.04)	0.01	(0.01)	-	-
	16-25																			0.02	(0.03)	0.03	(0.06)	-	-

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

C. Effectiveness of Selected Groundline Treatments in Western Redcedar and Southern Pine Poles in Binghamton, New York

The field test was established in distribution poles in Binghamton New York. Western redcedar and southern pine distribution poles ranging from 13 to 69 years old, were treated with CuNap Wrap, CuRap 20, or Pole Wrap. These systems contain copper naphthenate, copper naphthenate plus boron and sodium fluoride, respectively. The poles were sampled 2, 3, 4, and 8 years after treatment by removing plugs or increment cores from the three equidistant points around each pole 150 mm below groundline. In some cases, sampling on a given pole was limited by obstructions such as sidewalks. The cores were cut into zones corresponding to 0 to 4 mm, 4 to 10 mm, 10-16 mm and 16-25 mm from the pole surface. Samples from the same treatment and location were combined for the poles in each treatment group prior to being ground to pass a 20 mesh screen. The resulting wood dust was first analyzed for copper by x-ray fluorescence, then for fluoride or boron by the appropriate American Wood Preservers' Association method.

Copper levels in the poles treated with CuNap wrap were all below the threshold (0.6 kg/m^3) for the entire 8 year test (Figure IV-2). Levels did approach the threshold in the first 4 years after treatment in the outer zones for both wood species, but then declined well below that level 8 years after treatment. Copper also appeared to move better through southern pine than western redcedar, reflecting the deeper, more permeable sapwood in the former species.

Copper data for the CuRap 20 samples 8 years after treatment is temporarily unavailable due to the loss of our x-ray fluorescence unit. These data will be incorporated in the next annual report. Boron levels in the CuRap 20 treated poles were above the threshold for the first 4 years after treatment at all depths for both species, but then declined sharply over the next four years. At this point, only the innermost zone in the western redcedar poles still contains sufficient levels of boron to provide protection against attack (Figure IV-3). Boron levels in the zones nearer the surface in this species also contained higher boron levels than those in southern pine 8 years after treatment. The higher boron levels may reflect the less permeable nature of western redcedar which might make this species less likely to lose chemical over time..

Fluoride levels in the Pole Wrap treated samples were at or above the upper threshold in the outer zone of the southern pine test poles over much of the test period, including the 8 year sampling point (Figure IV-4). Fluoride levels in pine declined inward from the surface, although the levels 10 to 16 mm from the surface were still above the lower threshold 8 years after treatment. Fluoride levels near the surface of western redcedar were lower than those found with pine and tended to remain close to the lower threshold value over the 8 year test period. Levels further in from the surface were above the threshold for the first 3 years after treatment, then declined. These results contrast with those for boron, although the reasons for these variations in chemical behavior are unclear.

Figure IV-2. Residual copper levels at selected distances from the wood surface below the groundline in western redcedar and southern pine poles 2 to 8 years after treatment with CuNap wrap.

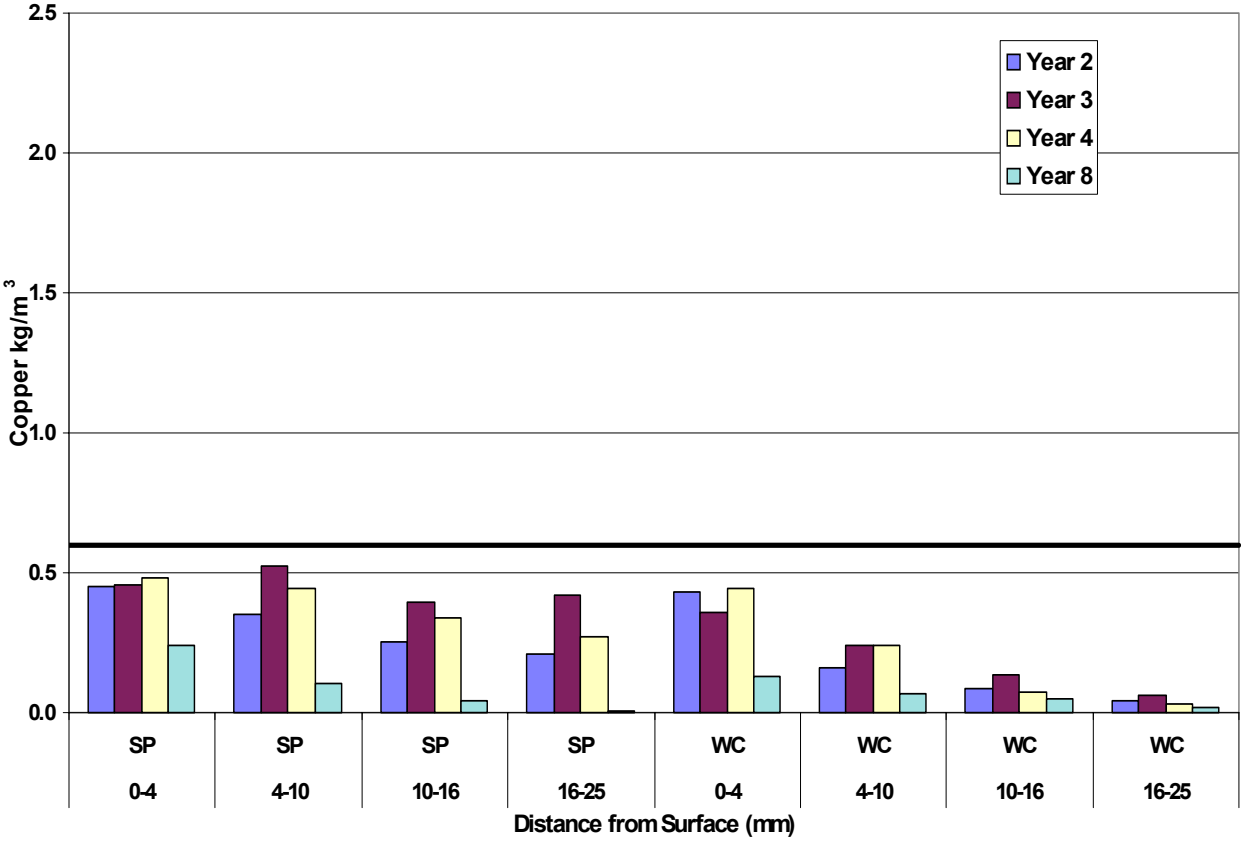


Figure IV-3. Residual boron levels at selected distances from the wood surface below the groundline in western redcedar and southern pine poles 2 to 8 years after treatment with CuRap 20 paste.

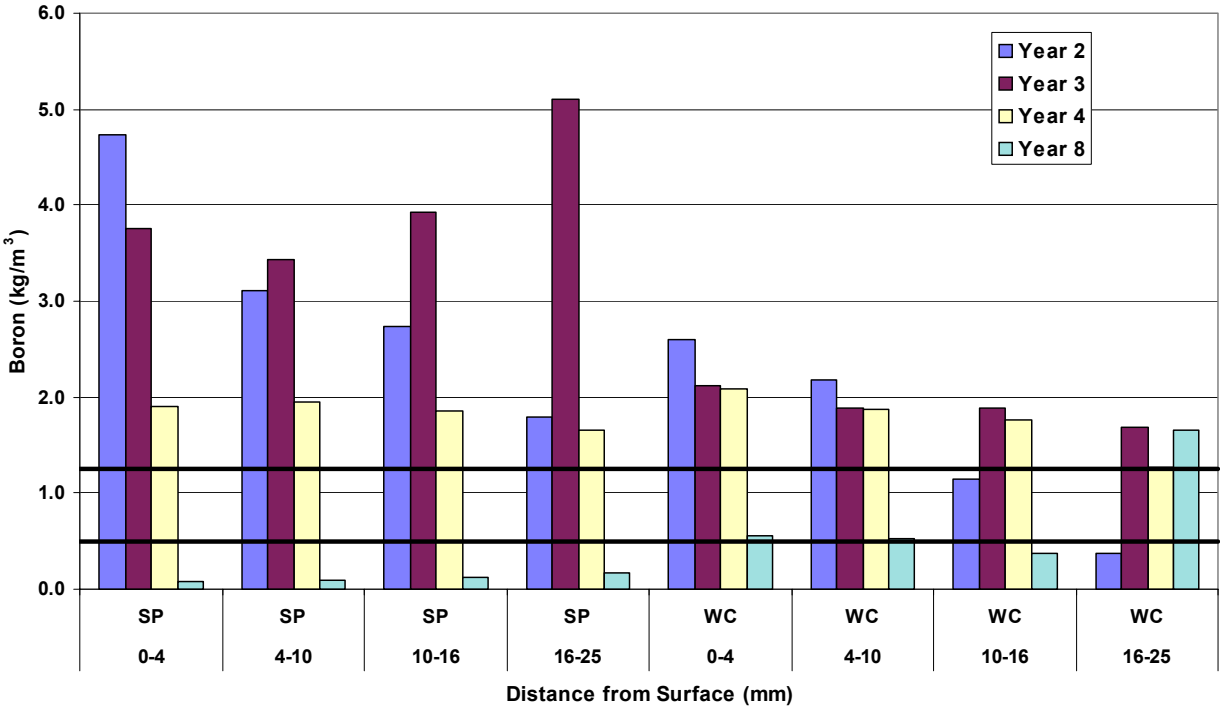
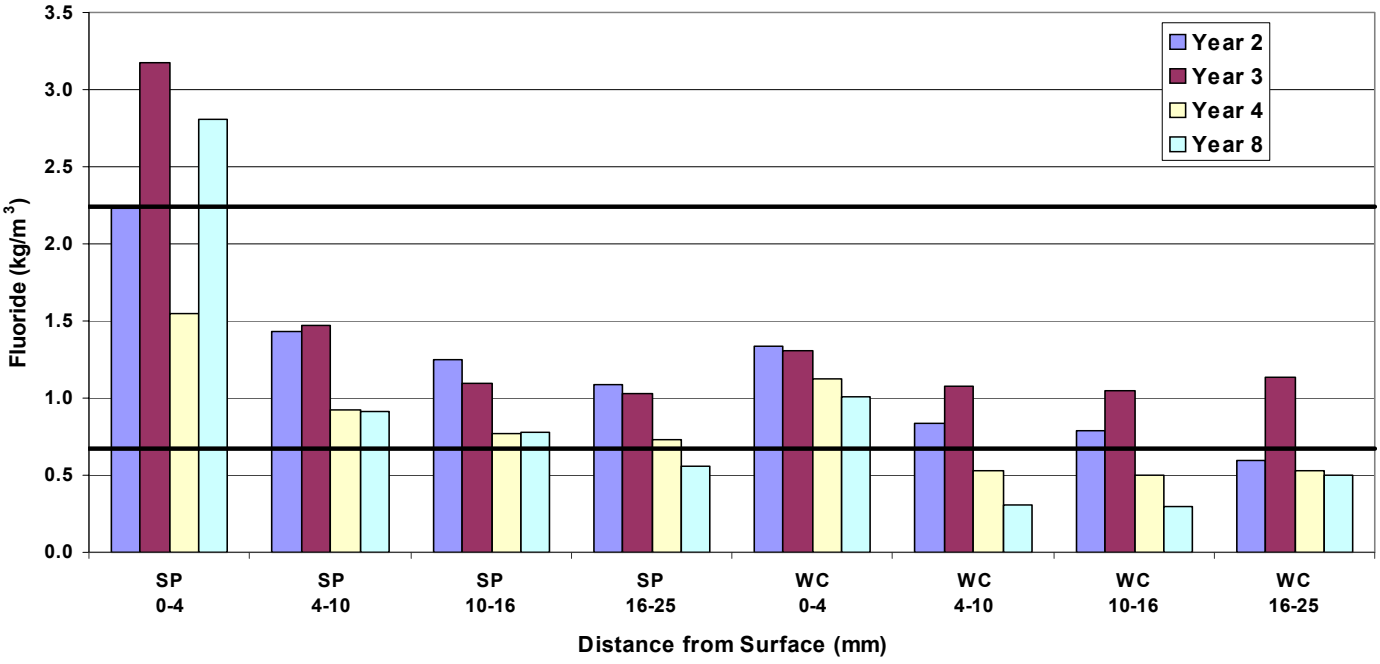


Figure IV-4. Residual fluoride levels at selected distances from the wood surface below the groundline in western redcedar and southern pine poles 2 to 8 years after treatment with Patox II paste.



D. Performance of External Treatments for Limiting Groundline Decay in Southern Pine Poles Near Beacon, New York

Seventy southern pine transmission poles in the Central Hudson Electric and Gas system were selected for study. The poles were randomly allocated to groups of 10 and received one of the following treatments:

Osmose Cop-R-Plastic
Osmose PoleWrap
BASF Wrap with Cu/F/B
BASF Wrap with Cu/B
Genics Cobra Wrap
Genics Cobra Slim
Triangle Laboratories Biological Treatment

The treatments were applied 0 to 450 mm below the groundline, then the soil was backfilled. The total amount of chemical applied to each pole was determined by weighing containers before and after chemical application or by measuring the total amount of prepared wrap applied. An additional set of ten poles served as untreated controls.

The poles were sampled 2 years after treatment by removing increment cores from selected locations below groundline. The cores were cut into two different patterns, depending on the remedial treatment chemical

involved. For copper based systems, the cores from a given treatment were cut into zones corresponding to 0-6 mm, 6-13 mm, and 13-25 mm. These assays zones were kept nearer the surface in recognition of the limited ability of copper to move into the wood. The samples from poles treated with systems containing either boron or fluoride were divided into zones corresponding to 0-13 mm, 13-25 mm, 25-50 m and 50-75 mm from the surface, in recognition that these chemicals are capable of moving rather deeply into the wood with moisture. Multiple cores were removed from poles treated with systems containing both copper and a water diffusible component. In addition, chips from the outer surface of each pole were cultured for the presence of fungi by placing them on malt extract agar and observing for evidence of fungal growth. Any fungi were examined under a microscope and identified using the appropriate keys. The poles were sampled in August and culturing and identification is currently underway.

Copper levels in the poles were well below the threshold for this chemical 2 years after treatment except for the poles treated with the Cop-R-Plastic (Figure IV-5). Copper levels in the remaining treatments were all less than one half of the threshold. Copper levels in all treatments declined away from the surface. The steepest declines occurred with the Cop-R-Plastic, but these lower levels largely reflect the much higher surface levels of copper in this treatment. Copper levels in the CobraSlim treated poles were approximately 1/3 those in the normal wrap, demonstrating the effects of reducing overall preservative level in a wrap on subsequent chemical deposition.

Fluoride levels in the BASF Cu/F/B wrap as well as in the Cop-R-Plastic and Pole Wraps varied widely (Figure IV-6). The lowest levels of fluoride were found in the Cu/F/B system, although the fluoride levels were approaching the lower threshold in the very outermost zone (0 to 13 mm). The fluoride levels in the outer zones of the two other treatments were 2 to 3 times the upper threshold for protection against fungal attack. The systems differ markedly in their construction. The Cu/F/B system is a dry material, while the other systems are more paste-like. Paste-like materials are clearly a bit more difficult to apply, but they may have an advantage in movement into the wood because of the more intimate contact they have with the pole. The Cu/F/B system must be in direct contact with the wood in order for the chemical to diffuse directly from the wrap into the wood. While the soil around the pole will encourage wrap/wood contact, there are still likely to be gaps that slow overall fluoride movement.

Boron was only present in the two BASF systems (Figure IV-7). Boron levels were just below the lower threshold levels in the Cu/B wrap two years after treatment. Boron levels were highest 25 to 50 mm in from the surface, although differences in chemical levels differed little among the four assay zones. Boron levels in the Cu/F/B system were all lower than those found in the Cu/B wrap and were all below the threshold.

As with previous trials, the interpretation of these data can be difficult owing to the lack of information on the degree of interaction between each preservative component. For example, both fluoride and boron were present in the Cu/F/B wrap at sub-threshold levels, but, in combination with the copper, may still be effective. We have made a number of unsuccessful attempts to assess these interactions under controlled laboratory conditions, but developing a better understanding of these interactions would help us to better interpret the results.

At present, the results show that the systems are moving into the wood, however, further testing will be necessary to better understand the relative differences in performance of the systems.

Figure IV-5. Residual copper at selected distances inward below the groundline in southern pine transmission poles 2 years after application of various external preservative systems.

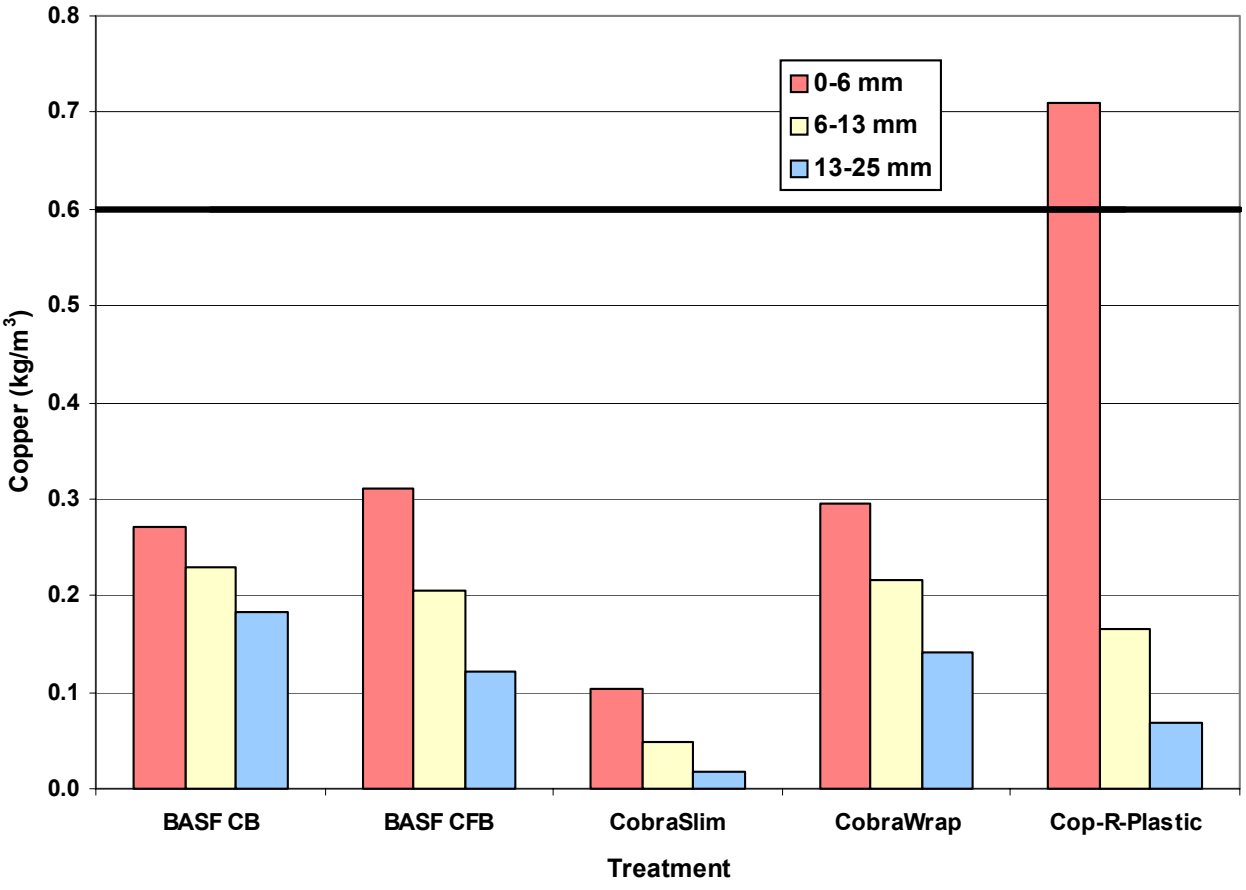


Figure IV-6. Residual fluoride at selected distances inward below the groundline in southern pine transmission poles 2 years after application of various external preservative systems.

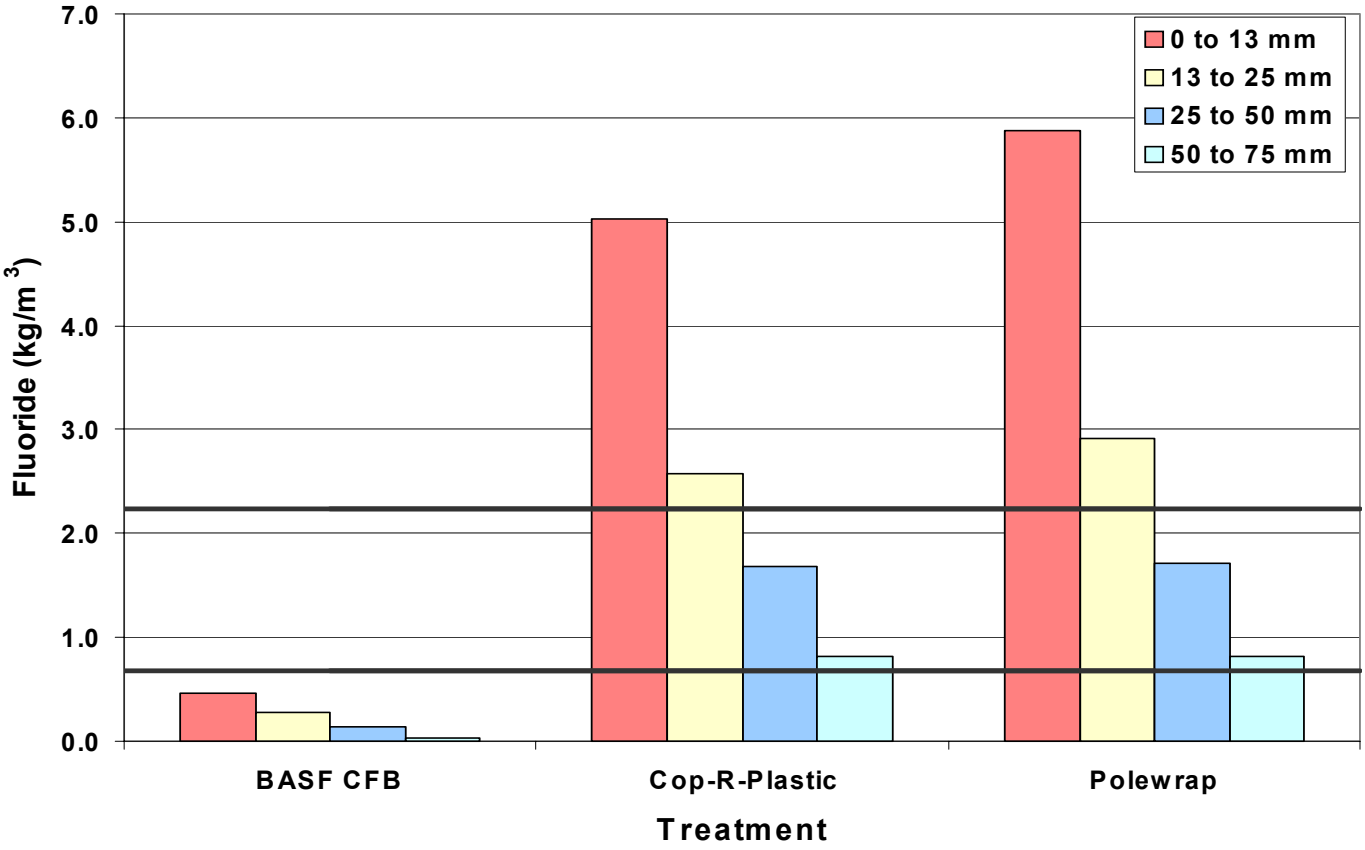
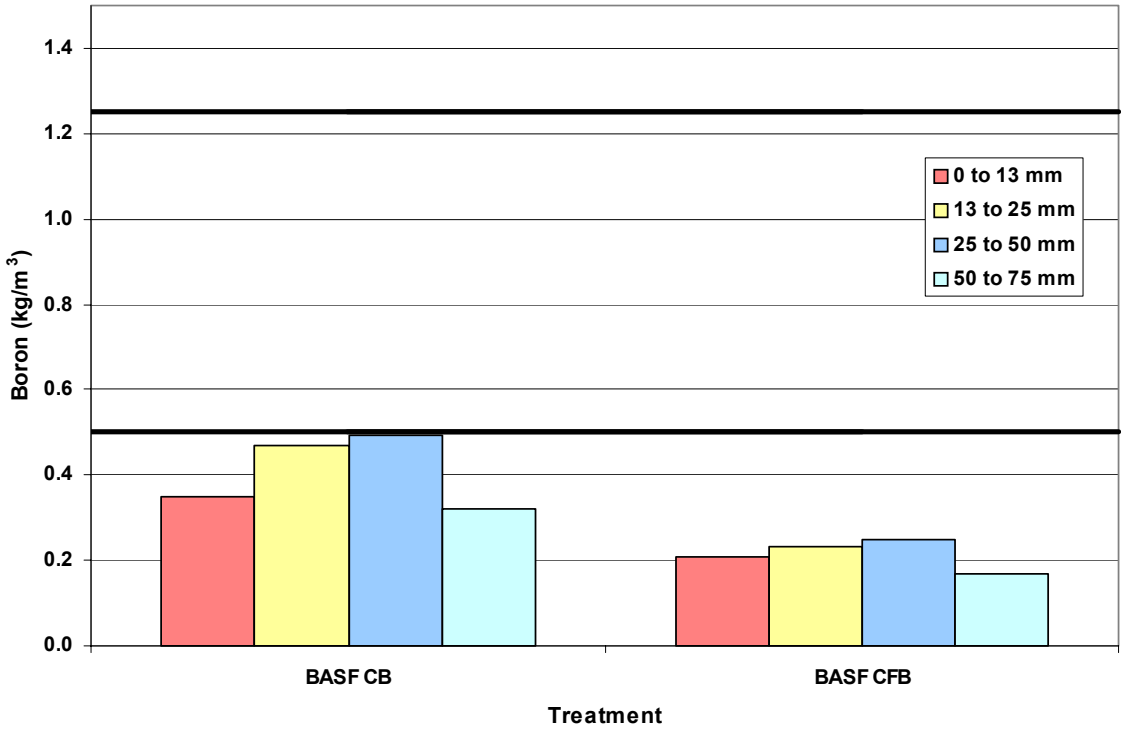


Figure IV-7. Residual boron at selected distances inward below the groundline in southern pine transmission poles 2 years after application of various external preservative systems.



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, or from 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 diluted in diesel oil to produce target retentions of 0.8, 1.6, 2.4, 3.2, and 4.0 kg/m^3. Each retention was replicated on 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 10 (completely sound) to 0 (completely destroyed).

The stakes cut from freshly sawn sapwood continue to out-perform 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 8.2 and 9.6 after 162 months of exposure, while stakes treated with diesel alone rated approximately 3.8. 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 162 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 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 162 months.

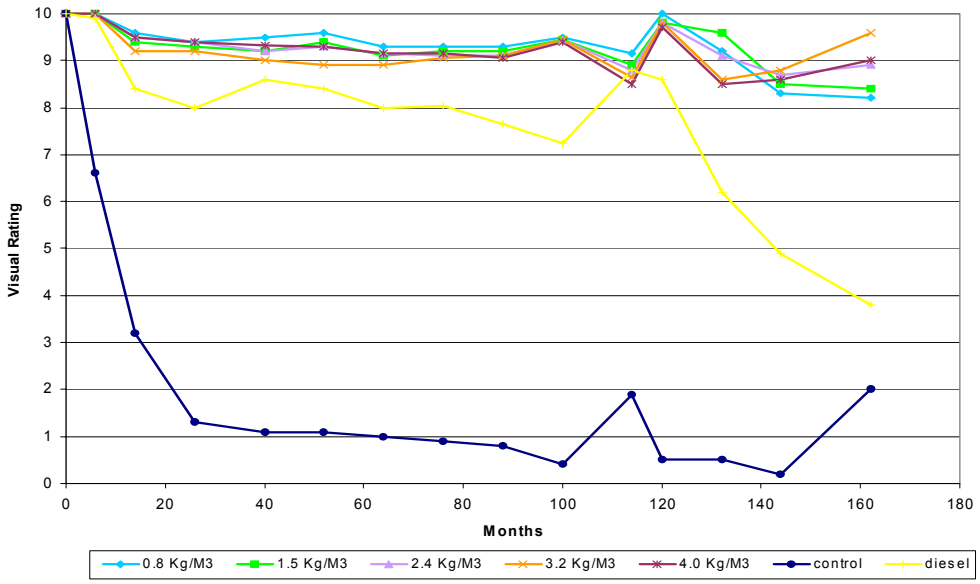
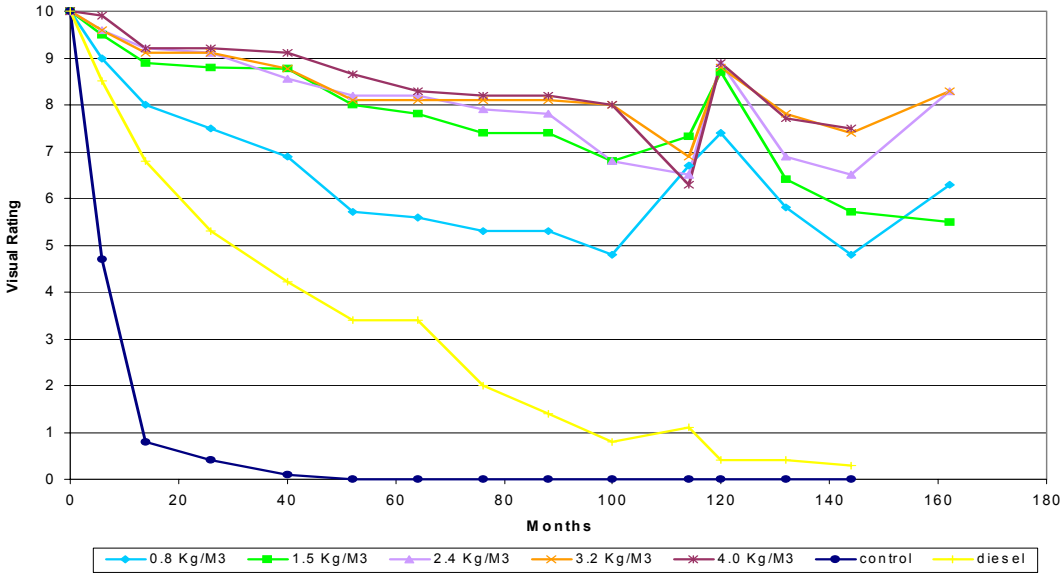


Figure V-2 Condition of weathered western redcedar sapwood stakes treated with selected retentions of copper naphthenate in diesel oil and exposure in a soil bed for 162 months.



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 is 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 (PCP) 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. 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, while still allowing 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 held together with 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.

Two extractions were required for the separation of PCP from an oil contaminated aqueous environment. The aqueous sample, or filter solid, was first adjusted to a high pH with sodium hydroxide to form 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 μ/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 μ/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 performed 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.

Penta levels in runoff from the stored poles tended to range between 1 and 2.5 ug/ml of water over 62 rainfall events (Figure VI-1). Penta levels in the runoff from the first 6 rainfall events were lower than almost all other samples; however, there was a delay in analysis of these samples and we believe the lower levels were due to storage time. The remainder of samples were processed within 24 hours of collection, limiting the potential for degradation or loss in storage. Furthermore, the total amount of rainfall did not appear to affect the runoff concentration. Instead, increased rainfall was associated with an overall increase in total penta migration, but the runoff concentrations did not vary (Figure VI-2). These results suggest that migration from the poles is a function of water contact with the pole and penta solubility in the rainwater. The similarity in runoff concentrations over time suggests that losses can be predicted based upon the rainfall amounts and total surface area exposed to direct rainfall.

Another factor that was assessed was whether time between rainfall events affected penta concentrations in the runoff. Long term storage in the absence of precipitation might allow chemical to migrate to the surface, where it would be more prone to migration. Once again, however, the time between rainfall events appeared to have little effect on runoff concentration (Figure VI-3). This effect is clearly illustrated by the final sampling in September where the previous measurable rainfall event was 5 months prior to the sampling, yet runoff concentrations were similar to those found in the wet season. These results suggest that penta migration from poles is more affected by the exposed surface area and total rainfall than other environmental factors such as temperature.

Figure VI-1. Penta concentrations as a function of sampling date in leachate collected from penta treated Douglas-fir poles following rainfall events over a 1.5 year exposure period

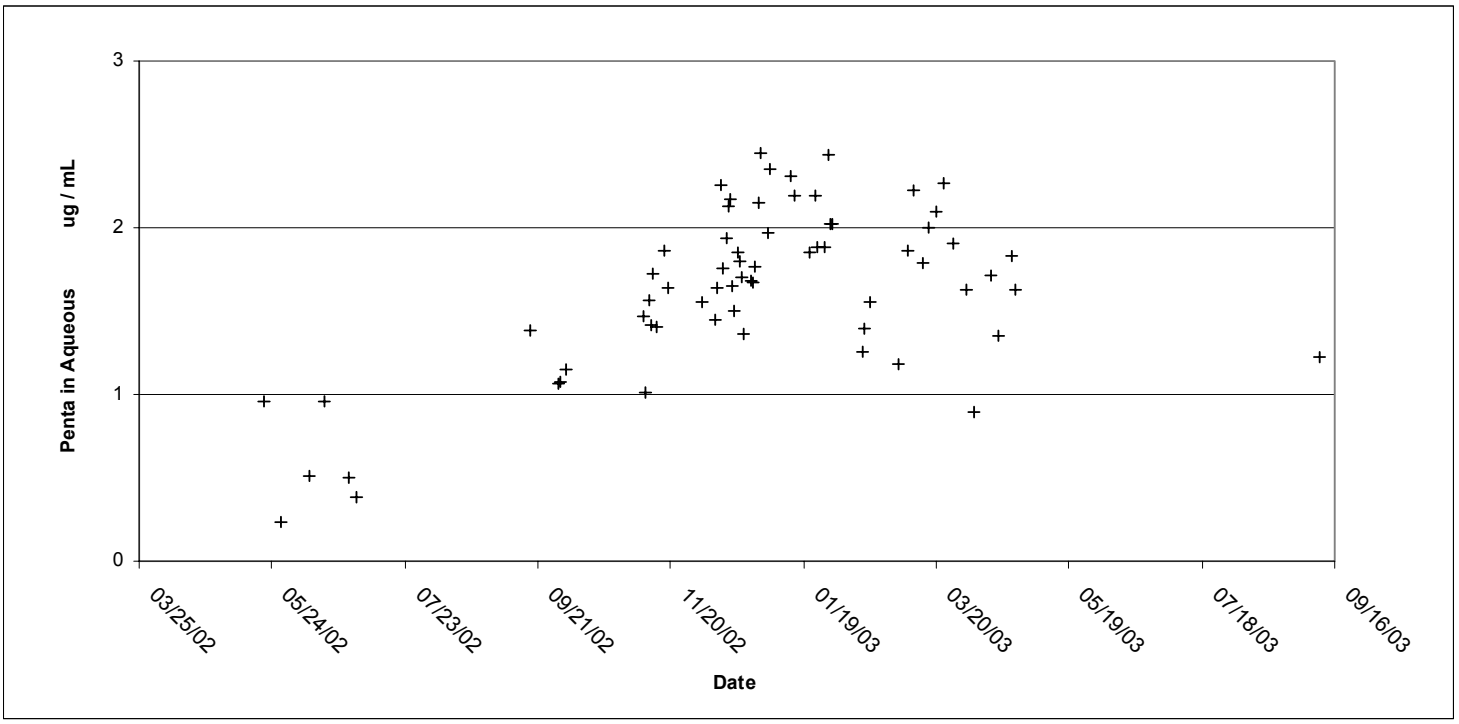


Figure VI-2. Penta concentrations as a function of total amount of rainfall collected in leachate from penta treated Douglas-fir poles following rainfall events over a 1.5 year exposure period.

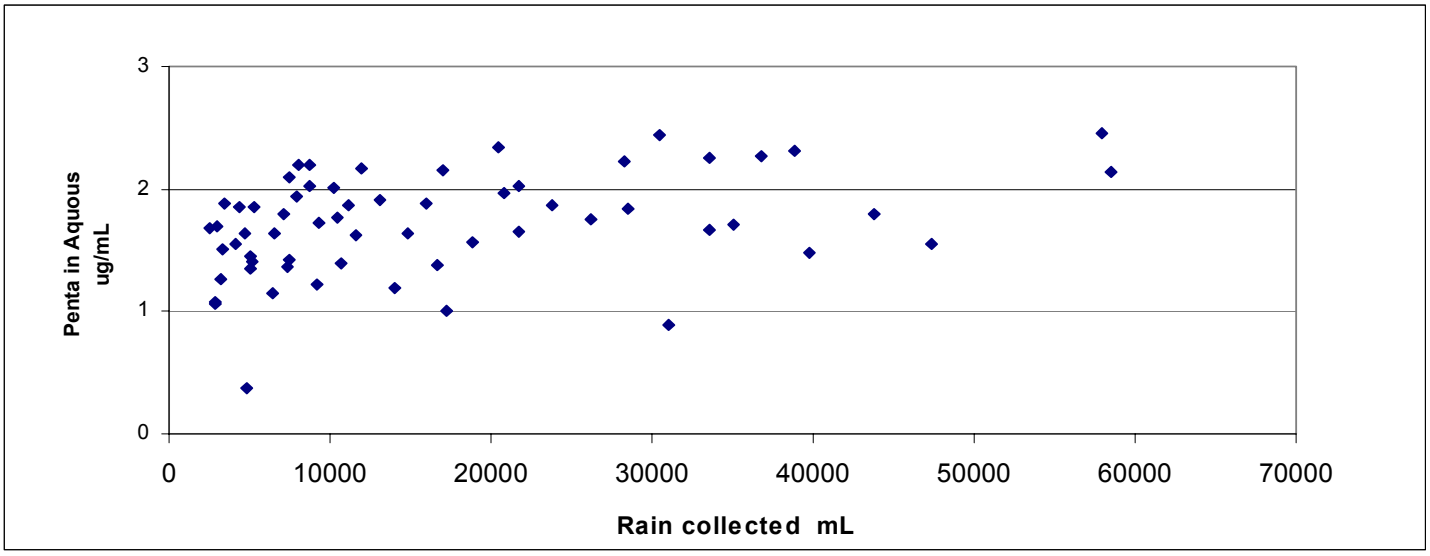
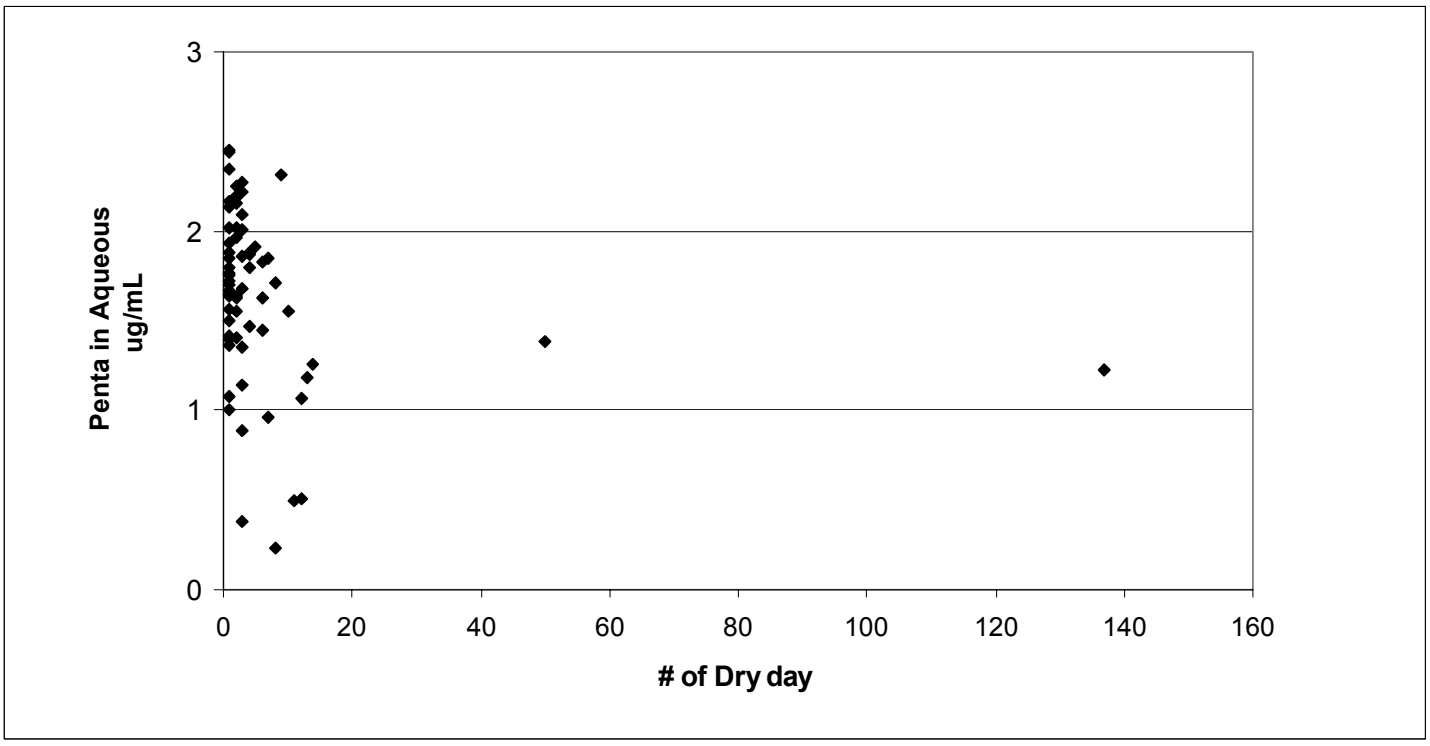


Figure VI-3. Penta concentrations as a function of intervals between collections (# of dry days) in leachate collected from penta treated Douglas-fir poles following rainfall events over a 1.5 year exposure period.



The total area exposed on the pole sections was approximately 6.21 square meters including the ends. A large proportion of this surface was on the underside of the poles and was not actually exposed to rainfall. While small streams of water flowed over these under-surfaces, the actual area exposed to potential rain contact was estimated to be approximately 5.3 square meters. If we convert our five short pole sections to 5 Class 4 forty foot poles, we would multiply our total penta losses by approximately 12 to arrive at the amount of migration from these poles. We collected a total of 1910 mg of penta from all of the rainfall events. This would translate to a total of 22.9 g of penta for the poles over the past year. A typical Douglas-fir pole would contain approximately 2.89 kg of penta and the five poles would contain 14.44 kg of penta. This translate to a loss of 0.016 % of the total available penta in the approximately 1.5 year exposure period.

An additional factor to consider in these calculations is the potential flow paths on poles in solid piles. In our tests, the poles were stacked in tiers which tended to protect the lower poles from wetting. In a larger stack, this protective effect would be even greater. Thus, it may be possible to examine the potential for loss on the basis of the exposed upper portions of the stack rather than considering all poles in an individual stack. We plan further tests of poles stacked in different configurations to determine which storage practices minimize the potential for loss of chemical.

The initial evaluations clearly show that penta can migrate from stored poles, a finding supported by previous studies in aquatic environments. Unlike aquatic environments, however, the migrating chemical winds up in the soil beneath the poles where it can be trapped and slowly degraded. As a result, the loss of chemical should have minimal impact on the surrounding environment. We will continue our tests using other poles and different storage configurations to better understand the primary factors that affect migration. These data will be used to develop more accurate storage recommendations to minimize potential releases of chemical into the environment.