ABSTRACT

Evaluations of previously established field trials indicate that chloropicrin, and Vorlex continue to provide protection to Douglas-fir poles, although the degree of protection is diminishing. Reapplication of Vapam 18 years after the initial application eliminated fungi which had recolonized the poles. Methylisothiocyanate (MITC) continues to protect Douglas-fir poles 12 years after application.

Gelatin encapsulation of MITC or chloropicrin appears to have no negative influence on fungitoxicity of these chemicals. Application of water to decompose the gelatin accelerated initial chemical release, but had no longterm effects on performance.

A series of laboratory trials have been established to evaluate the performance of sodium n-methyldithiocarbamate (NaMDC), the active ingredient of Vapam. This chemical decomposes more slowly than the liquid formulations and a number of additives are being evaluated to accelerated decomposition. Along with the solid NaMDC, a pelletized formulation of Vapam was evaluated which contained 15 or 40 % NaMDC. These evaluations indicated that the addition of water accelerates release, but the fungal survival in these tests was more variable. The results suggest that a dosage 2 times greater than the liquid formulation is required for effective fungal control; however, further tests are planned to confirm these results.

The evaluations of MITC-FUME in Douglas-fir and southern pine poles indicated that MITC has moved to a greater extent in Douglas-fir. Both closed tube bioassays and gas chromatographic analyses of ethyl acetate extracts of wood samples indicated that MITC was present at higher levels in Douglas-fir poles. Southern pine is far more permeable than Douglas-fir and MITC movement should be more rapid in this species. Further tests are planned to identify the nature of this delayed movement.

Evaluations of Dazomet, a crystalline solid which decomposes to produce MITC in wood, indicate that detectable levels of this chemical are present in virtually all of the treatment groups. The decomposition rate of this chemical is normally too slow for effective fungal control and these trials are examining the ability of various additives to accelerate decomposition. Further evaluations of pole sections treated with Dazomet and selected additives are underway.

A study to evaluate the effect of voids on fumigant effectivness suggests that voids do not adversely affect MITC movement through Douglas-fir pole sections. These results indicate that treatment of voids should be cost-effective if the chemical is not applied directly to the void and if the pole retains a sufficient degree of strength.

We continue to develop and refine a model for simulating the movement of MITC through Douglas-fir under varying temperature and moisture conditions. The model has been improved to permit three dimensional evaluations, but the times required for computation are still somewhat long. Further evaluations using a variety of environmental conditions are planned.

Evaluations of potential replacements for pentachlorophenol for treatment of western redcedar sapwood and field drilled bolt holes have identified several promising alternatives. These chemicals are now under study in several modified field and laboratory tests. Field trials of several potential treatments for field drilled bolt holes indicate that Boracol 40, disodium octaborate tetrahydrate and ammonium bifluoride provided excellent protection over an 8 year period. These formulations all are relatively safe and can be easily applied in the field.

A laboratory trial to evaluate the effects of selected basidiomycetes on strength of Douglas-fir sapwood and heartwood has concluded. Fungal density, measured as the average number of fungl colonies per beam, gradually increased in all of the beams while longitudinal compression strength (LCS), modulus of rupture (MOR), and modulus of elesticity (MOE) slowly declined. Of the measurements, LCS appeared to be most useful, probably owing to the increased number of sampling sites per beam. The results indicate that the degree of colonization was not a good indicator of wood strength effects.

The value of kerfing for decreasing post-treatment checking and improving the service life of Douglas-fir poles was evaluated using a series of inspection reports from a local utility. Kerfed transmission poles had substantially lower rates of internal decay and rejection, but there appeared to be little difference in the rate of decay between kerfed and non-kerfed distribution poles.

The evaluation of disodium octaborate tetrahydrate for preventing colonization of air-seasoning Douglas-fir pole sections has been completed. Spraying with a 10 % boric acid equivalent solution (BAE) at 6 month intervals provided the greatest degree of protection, although dipping in a 20 % BAE solution at the start of air-seasoning produced a similar degree of protection. As expected, fungal colonization was far lower at the dryer Oroville site and borate treatment had little influence on the degree of fungal colonization at this site. The results indicate that borate treatment at the start of air-seasoning is a viable method for limiting fungal colonization in moist air-seasoning sites west of the Cascade Mountains.

Evaluations of the tolerance of _Stereum sanguinolentum_ and _Peniophora_ spp. to elevated temperature exposures indicated that both of these fungi were extremely sensitive to elevated temperatures. The lack of long-term survival structures in these fungi probably accounts for this susceptibility to heat.

A series of trials which measured internal temperatures in Douglas-fir pole sections during treatment with ammoniacal copper arsenate were used to develop a model for predicting internal heating during steaming. The results indicated that previous heating curves were overly optimistic in their prediction of heating. A series of heating curves for various pole diameters and starting conditions are presented.

A number of externally applied groundline treatments are under evaluation in a field trial at Peavy Arboretum and a second trial will be established in the San Francisco Bay area. Seven formulations (including standards) are included. The Peavy site will be sampled in the next few months.

The performance of copper naphthenate in western wood species is being evaluated in a series of small western redcedar sapwood stakelets which have been treated to a range of retentions and exposed in the fungus cellar. The results will be used to help confirm the performance of copper naphthenate in this species.

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* Asterisk denotes funding. All supplied poles, hardware, or other assistance.

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OBJECTIVE I
DEVELOP SAFE, ENVIRONMENTALLY ACCEPTABLE CHEMICALS TO CONTROL
INTERNAL DECAY OF DOUGLAS-FIR POLES

A. EVALUATE PREVIOUSLY ESTABLISHED TESTS OF FUMIGANT PERFORMANCE IN DOUGLAS-FIR

The Cooperative Pole Research Program has installed a number of long-term field trials to evaluate the performance of the various fumigants in active utility lines (Table I-1). These trials provide valuable data on the rates of fungal recolonization and chemical depletion. This information can then be used to develop recommendations for the various treatments.

1. <u>Douglas-fir poles treated with Vapam, Vorlex, or Chloropicrin</u>: In 1969, a series of Douglas-fir poles were treated with 1 liter of Vapam, Vorlex, chloropicrin, or were left untreated to serve as controls. These poles have been sampled on an annual basis for the presence of decay fungi and the residual levels of fumigant. Fungal colonization has been determined by removing increment cores from three equidistant sites around the pole at the groundline as well as 1.2, 1.8, and 2.4 m above that zone. These cores are placed on malt extract agar in a petri dish and observed for evidence of fungal growth. Any fungi growing from the wood are examined for characteristics typical of basidiomycetes, a group of fungi which includes many important wood decayers. Residual chemical levels have been determined by removing additional cores from sites adjacent to those used for culturing. The treated shell is discarded and the next 2.5 cm as well as the inner zone corresponding to 12.5 to 15.0 cm of the core are used in a closed tube bioassay. Briefly, glass tubes containing slanted malt extract agar are inoculated with a test fungus, <u>Postia placenta</u>. The tubes are incubated until the fungus has begun to grow from the inoculum plug. The extent of growth is marked and the wood sample is added to the tube. The tube is incubated in an inverted position so that any vapors released from the wood move up and into the fungal culture where they can inhibit radial

Table I-1. Characteristics of fumigants currently registered by the Environmental Protection Agency for application to wood.

Trade Name(s)	Active Ingredient	Concentration %	Toxicity (LD_{50})	Source
Timber Fume (Chloropicrin)	Trichloronitromethane " "	96%	205 mg/kg	Osmose Wood Preserving, Inc. Great Lakes Chemical Company
Wood Fume	Sodium n-methyldithio-carbamate	32.1	1700-1800 mg/kg	Osmose Wood Preserving, Inc.
Pole Fume (Vapam)	" "			Kop-Coat, Inc.
Vorlex	20% methylisothiocyanate 80% chlorinated C_3 hydrocarbons	99%	538 mg/kg	NorAm Chemical Company
MITC-FUME	methylisothiocyanate	96%	305 mg/kg	Osmose Wood Preserving, Inc.

growth. Radial growth of the fungus is then used as a relative measure of residual chemical content. Core segments with high chemical levels generally prevent fungal growth. Average growth of the test fungus is reported as a percentage of growth of control tubes containing the fungus, but no wood. The closed tube bioassay is extremely sensitive to low levels of fumigant.

The results of inspection 20 years after treatment indicate that the levels of fungal colonization continue to increase in both the chloropicrin and Vorlex treated poles, although the percentage of cores containing decay fungi remains below 10 percent (Figure I-1). Vorlex provided nearly complete protection for 10 years and then colonization proceeded at a very slow rate. Chloropicrin prevented recolonization for 14 years, and poles treated with this chemical have only recently been recolonized. No decay fungi were isolated from the Vapam treated poles, which were retreated in 1986. Vapam is generally used on a 7 to 10 year retreatment cycle, and our results suggest that reapplication of Vapam to the original treatment holes will eliminate decay fungi which have reinfested the wood.

Closed tube bioassays of cores removed from locations near the culturing sites indicate the poles treated with Vorlex and chloropicrin continue to retain

% Cores Infested

Years in Test
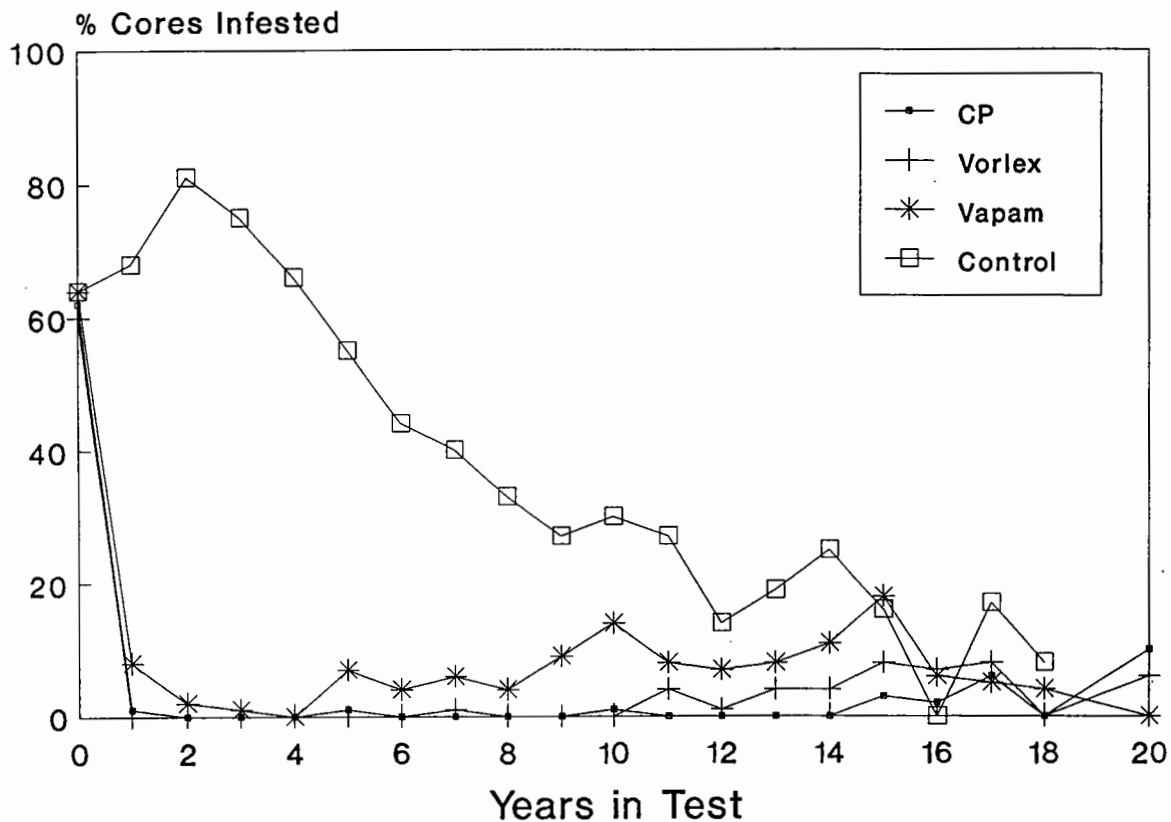
Figure I-1. Percentages of increment cores removed from Douglas-fir poles treated with Vapam, Vorlex, or chloropicrin which contain decay fungi, as determined by culturing on a nutrient media.

small amounts of residual toxicity, while the Vapam treated poles exhibited little evidence of residual volatile fungitoxicity (Table I-2). Previous tests have also shown that volatile decomposition products of Vapam do not remain in the wood for long periods. Low levels of chloropicrin and methylisothiocyanate appear to be highly effective for preventing fungal colonization. Most Basidiomycetes will likely enter the wood via spore germination in checks. Since spores are among the most sensitive stage of the fungal life cycle, low levels of chemical may be more than adequate for preventing recolonization.

The results of this test indicate that fumigants will provide a relatively long period of protection when applied to poles which already contain a well-treated preservative shell.

2. **Douglas-fir poles treated in 1977 with allyl alcohol, methylisothiocyanate, or Vorlex**: The ability of methylisothiocyanate (MITC) and allyl alcohol to arrest fungal colonization was evaluated by treating Douglas-

fir poles with 1 liter of allyl alcohol, 20 % MITC in diesel, or 100 % MITC ('86 Ann. Rept., pg. 7). MITC is a solid at room temperature that sublimes directly from a solid to a gas. This chemical is also the presumed fungitoxic breakdown product of Vapam and is the active ingredient in Vorlex. MITC can be applied in a highly concentrated form, maximizing the dosage for a given pole.

Table I-2. Residual fungitoxic residues in Douglas-fir poles 20 years after treatment with chloropicrin, Vorlex or Vapam as measured using a closed tube bioassay.

Modem above GL	Core location inside treated shell (cm)	Ave. growth of assayed fungus (as % controls)			
		Chloropicrin	Vorlex	Vapam	Retreated Vapam (86')
24	0-2.5	36	85	37	90
	12.5 - 15.0	55	88	50	98
18	0-2.5	53	54	75	43
	12.5 - 15.0	62	62	66	66
12	0 - 2.5	29	77	67	62
	12.5 - 15.0	36	56	17	58
0	0 - 2.5	66	55	0	73
	12.5 - 15.0	71	20	19	92

[a]Growth of controls = 31 mm

The poles have been sampled annually by removing increment cores from selected zones around the groundline. These cores have been cultured for the presence of decay fungi and used in the closed tube bioassay.

MITC continues to protect the poles from fungal reinvasion 12 years after treatment, while the Vorlex treated poles are experiencing a low level of recolonization (Figure I-2). At present, two 20 % MITC treated poles and 1 Vorlex treated pole contain viable decay fungi (Table I-3). The allyl alcohol treatments were ineffective and the poles in this group were retreated with Vapam to prevent any further damage. Similarly, the control poles were treated with

Vapam ten years after the test began to prevent further fungal attack. The continued performance of the 100 % MITC indicates that applications of this concentrated chemical should provide protection for a period similar to that experienced with Vorlex. While the 20 % MITC has experienced some fungal colonization, these levels remain relatively low.

Closed tube bioassays of increment cores revealed that fungitoxic vapors were present in Vorlex and MITC treated poles, but the levels continue to decline (Table I-4). As these levels decline, the poles should experience a slow, but continued increase in the degree of fungal colonization.

The results indicate the MITC can provide protection to Douglas-fir poles for at least 12 years, far longer than the routine maintenance cycles which are employed by most utilities. Thus, regular reapplication of MITC at 10 year intervals would minimize the risk of renewed fungal invasion and provide a highly reliable method for pole protection.
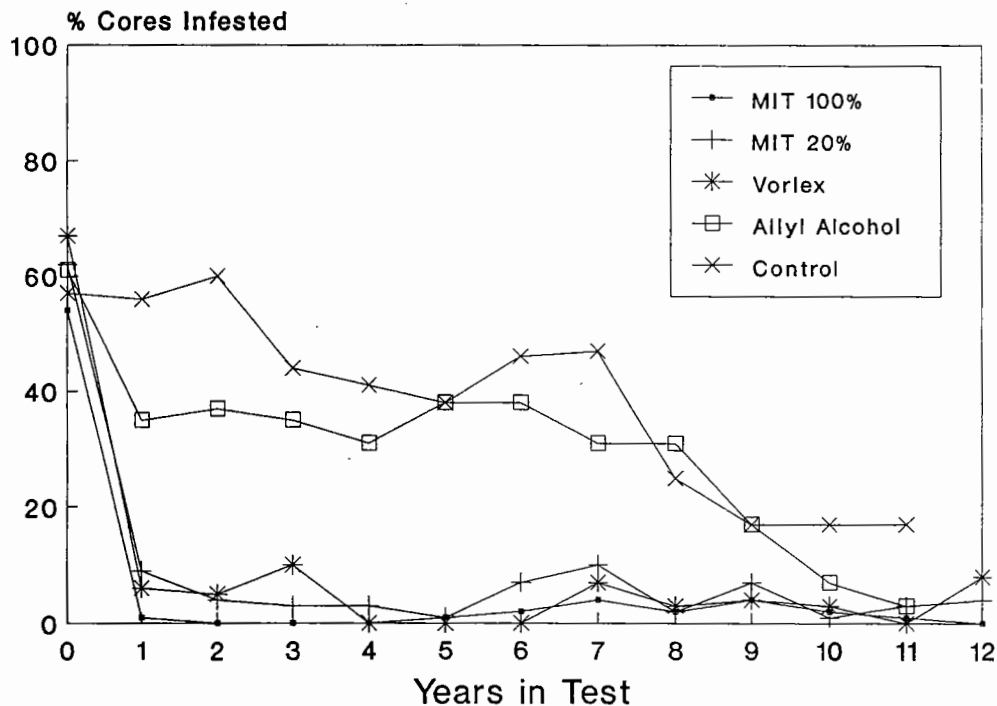
Figure I-2. Percent of cores removed from various sites on Douglas-fir transmission poles treated with Vorlex, 20% methylisothiocyanate in diesel oil, 100% methylisothiocyanate, or allyl alcohol/Vapam which contain Basidiomycetes, a class of fungi containing many important wood decayers.

Table I-3. Effectiveness of fumigants in Douglas-fir poles treated in 1977 as measured by culturing increment cores removed from the treated poles for the presence of decay fungi.[a]

		Number of poles containing decay fungi			
		Allyl		Methylisothiocyanate	
Year	Untreated	Alcohol/Vapam	Vorlex	20%	100%
1977	9	9	7	9	8
1978	9	9	3	6	2
1979	9	9	4	4	0
1980	9	9	3	3	0
1981	5[5]	6[6]	0[4]	1[5]	0[5]
1982	5	6	0	1	1
1983	5	6	0	3	2
1984	5	5	2	4	2
1985	4	5	1	2	1
1986	4	5	2	2	1
1987	3	3	2	1	2
1988	3	1[c]	0	2	1
1989	-[d]	-[d]	1	2	0

[a]Poles were treated with fumigants in 1977, and annually thereafter three cores were removed at five heights from the groundline and cultured for fungi. Superscripts denote poles remaining in test since 1981. Others were inadvertently treated with Vapam by a commercial applicator.
[b]Diluted in diesel oil.
[c]The allyl alcohol poles were re-treated with Vapam in 1987.
[d]These poles were not inspected in 1989.

Table I-4. Residual fumigant vapors in Douglas-fir poles twelve years after fumigant treatment as measured using a closed-tube bioassay.[a]

	Segment location	Growth of the assay fungus (as % of control)		
Meters above	from surface	Vorlex	Methylisothiocyanate	
ground	(cm)		20%	100%
2.4	0-2.5	81	70	-
	12.5-15	65	76	65
1.8	0-2.5	49	100	57
	12.5-15	62	89	59
1.2	0-2.5	32	86	29
	12.5-15	92	98	62
0	0-2.5	54	81	27
	12.5-15	68	57	73
Control	(no wood)	37 mm[c]		

[a]For the closed-tube bioassay, a core was removed at each height from four to six poles. A 2.5-cm-long core segment was sealed in a test tube below an agar slant inoculated with Postia placenta. Suppressed growth of P. placenta compared to growth of the fungus where no wood was present (control) indicates the presence of fungitoxic vapors. Lower percentages indicate increased inhibition.
[b]In diesel oil.
[c]Average growth in 7 tubes.

Table I-5. Frequency of decay fungi isolated from Douglas-fir poles treated with gelatin encapsulated methylisothiocyanate (MITC).

Sampling Date	Meters above Groundline	Cores with decay fungi (%)[a]		
		Dry	Moist	Wet
Sept. 1983	0	80	60	50
	0.9	100	100	83
	1.8	80	100	83
	2.8	60	67	67
	3.7	20	80	33
	4.6	20	40	17
Sept. 1984	0	60	0	20
	0.9	40	20	20
	1.8	0	20	0
	2.8	20	20	0
	3.7	40	20	40
	4.6	60	0	0
	5.5	20	20	40
Sept. 1985	0	0	0	0
	0.9	0	0	0
	1.8	0	0	0
	2.8	0	0	0
	3.7	0	0	0
	4.6	20	0	0
	5.5	0	0	0
Sept. 1986	0	-	-	-
	0.9	40	0	0
	1.8	0	40	60
	2.8	20	0	20
	3.7	40	0	20
	4.6	20	0	0
	5.5	40	0	0
Sept. 1987	0	0	0	0
	0.9	0	0	0
	1.8	0	0	0
	2.8	0	0	0
	3.7	0	0	0
	4.6	0	0	0
	5.5	0	0	10
Sept. 1988	0	0	0	0
	0.9	0	0	10
	1.8	0	0	0
	2.8	0	0	0
	3.7	0	0	0
	4.6	0	0	0
	5.5	10	0	0
Sept. 1989	0	0		
	0.9	0	0	0
	1.8	10	0	0
	2.8	0	0	0
	3.7	0	0	0
	4.6	0	0	10
	5.5	0	10	0

[a]The initial fungal estimates were based on culturing of shavings collected during treatment hole drilling. Subsequent data has been based on culturing increment cores removed from sites opposite from the treatment holes. Either 0 ml (dry), 40 ml (moist), or 70 ml (wet) of water was added to each treatment hole to aid in fumigant release from the gelatin.

Table I-6. Residual fumigant effectiveness in Douglas-fir utility poles following application of gelatin encapsulated methylisothiocyanate as measured by a closed-tube bioassay.

Meters above ground	Core location inside treated shell (cm)	Dry 1987	Dry 1989	Moist 1987	Moist 1989	Wet 1987	Wet 1989
		Growth of assay fungus (as % of control)[a]					
0	0-2.5	-	16	-	16	-	13
	12.5-15	-	16	-	0	-	6
0.9	0-2.5	8	0	8	19	24	19
	12.5-15	10	16	16	16	28	32
1.8	0-2.5	4	3	0	6	16	0
	12.5-15	3	13	17	22	16	9
2.7	0-2.5	18	0	0	13	8	6
	12.5-15	0	0	8	16	16	9
3.6	0-2.5	3	0	0	0	8	0
	12.5-15	4	0	0	0	8	0
4.5	0-2.5	24	0	0	0	10	0
	12.5-15	20	0	11	13	8	0
5.4	0-2.5	11	3	8	0	12	0
	12.5-15	13	13	4	0	0	0
Control[b]	(no wood)	31 mm					

[a] Treatments involved adding either 0 ml (dry), 40 ml (moist), or 70 ml (wet) to each treatment hole to aid in fumigant release from capsules. The closed tube bioassay uses 2.5 cm wood segments removed from the pole. These segments are placed into agar tubes inoculated with an assay fungus, Postia placenta. Fumigant effectiveness is then evaluated as the ability to inhibit radial growth of the fungus. Cores with lower numbers have higher fumigant levels.
[b] Average growth in 10 control tubes (no wood).

3. **New York field test of encapsulated MITC**: The evaluations of gelatin encapsulated MITC, begun in 1981, were not sampled this year, but will be resampled in 1991 to determine the performance of this formulation 10 years after installation.

4. **Treatment of Douglas-fir poles with encapsulated MITC--effect of moisture content on chemical release**: In 1983, a study was initiated to determine the effect of moisture on release of MITC from gelatin capsules. Poles were treated with 528 ml of gelatin encapsulated MITC. Each hole received 88 ml of MITC in 4 gelatin capsules along with 0 (dry), 40 (moist), or 70 (wet) ml of water. The poles have been sampled annually by removing increment cores from

selected sites around the poles from 0 to 5.5 m above the groundline. The cores have been cultured for the presence of decay fungi and evaluated using the closed tube bioassay.

The results indicate that all three of the MITC treatments are providing nearly complete protection to the poles, although there are limited isolations of decay fungi from poles in each treatment group (Table I-5). Initially, the moist and wet treatments appeared to provide more rapid decay control, but these differences disappeared upon longer sampling. The differences may; however, reflect reduced wood damage since the decay fungi would be active for shorter periods in the wet and moist treatments. The significance of this delay in control can not be determined from this test.

Closed tube bioassays of increment cores removed from the same poles indicate that significant levels of volatile fungitoxins remain in all of cores (Table I-6). Once again, there appears to be little difference in the level of inhibition between the three treatments.

The results indicate that the presence of a gelatin capsule has little influence on the overall effectiveness of MITC. Although the addition of water at the time of application accelerates the rate of chemical movement and the rapidity of fungal control, our results indicate that this effect is temporary. The residual moisture present in the poles, even above the groundline, is sufficient for gelatin breakdown and chemical release.

5. Treatment of through-bored Douglas-fir poles with gelatin encapsulated MITC or chloropicrin: In 1982, increment cores were removed from 16 Bonneville Power Administration poles located near Cottage Grove, Oregon. These cores were cultured for the presence of decay fungi, and six poles containing active infestations well above the groundline were selected for further testing. Three to six holes (1.9 cm in diameter by 40 cm deep) were drilled 0.6 to 4.2 m above

the groundline in these poles (Table I-7). Two 10 cm long and one 6.25 cm gelatin capsules containing either MITC or chloropicrin were placed into each hole. A small quantity of water was added to each hole before sealing with treated wood dowels.

Table I-7. Gelatin encapsulated treatments applied to Douglas-fir poles located in Cottage Grove, Oregon.

Pole #	% Infested Cores	Chemical Treatment	Dosage (ml)	Treatment Sites (m above groundline)
3/2-A	25	MITC	310	0.9, 1.5, 2.1, 2.7, 3.3
3/2-B	29	MITC	372	1.2, 1.8, 2.4, 3.0, 3.6, 4.2
4/6-A	44	MITC	372	1.2, 1.8, 2.4, 3.0, 3.6, 4.2
4/6-B	75	Chloropicrin	310	0.6, 1.2, 1.8, 2.4, 3.0
5/4-B	67	Chloropicrin	177.5	0.6, 1.2, 1.8
5/5-A	57	Chloropicrin	248	0.6, 1.2, 1.8, 2.4

The poles are somewhat inaccessible and have only been sampled 2 and 7 years after treatment. The poles were sampled by removing increment cores from sites 0.6 to 5.1 m above the groundline. These cores were used for culturing and the closed tube bioassay. The outer and inner 2.5 cm segments of the core were used for closed tube bioassays. Because of concerns about strength effects from repeated sampling above the ground, samples were removed from alternating quadrants of the pole at each time point. For example, the first samples might be removed from quadrants 1 and 4, while the second set was removed from quadrants 2 and 3. This sampling pattern more evenly distributed the strength effects.

The results 7 years after treatment indicate that fungitoxic levels of MITC are present in most of the samples, although there are apparent pockets of incomplete treatment (Table I-8). In earlier examinations, the capsules were found to be empty 2 years after application, suggesting that the small amount

of water incorporated at the time of application produced rapid chemical release. Both chloropicrin and MITC have strong affinities for wood and should remain in the poles for long periods. Culturing of increment cores removed from the same locations revealed that none of the chloropicrin treated poles contained viable decay fungi; however, one MITC treated sample contained was colonized. This core was removed from a site where the closed tube bioassay results indicated low levels of fungitoxic vapors. It is possible that minor wood defects in this zone interfered with chemical movement, leaving a pocket of unprotected wood.

The absence of decay fungi in the remaining cores and the presence of fungitoxic vapors suggest that these treatments will continue to protect the wood from some time to come.

6. Above ground treatment with gelatin encapsulated or pelletized MITC: In 1986, a series of 15 Douglas-fir poles were treated with 45 or 90 g of gelatin encapsulated or pelletized MITC. The gelatin encapsulated formulation was similar to that used for the New York poles. The pelletized MITC contained 65 % MITC on fumed silica pellets. These pellets were applied using a stainless steel closed application system. The MITC, which was physically trapped by the silica was released once the pellets were exposed to the atmosphere.

The formulations were applied 0.3 m below field drilled bolts hole used for crossarm attachments on a line located north of Eugene, Oregon. The bolt holes had not been retreated after drilling. A total of 45 or 90 g of chemical was applied to 1 or 2 holes, respectively, and the holes were sealed with tight fitting wood dowels. The gelatin encapsulated MITC was applied using 2 or 4 capsules. The poles were sampled annually from 1985 to 1987, and were resampled this past year, 6 years after treatment. Increment cores removed from sites 1.8 m below the treatment hole were used for culturing or the closed tube bioassay. Bioassays were performed on the outer and inner 2.5 cm segments of each core.

The results indicate that none of the cores sampled 6 years after treatment contain viable decay or non-decay fungi (Table I-9). The absence of decay fungi is consistent with the 3 year results and indicates that the chemical is providing a high degree of protection to the zone around the field drilled bolt hole. The absence of non-decay fungi in the cores is interesting since these fungi are among the first to recolonize the wood following fumigant treatment.

Closed tube bioassays of increment cores removed 1.8 m below the treatment holes indicate that all of the treatments are contain residual fungitoxic vapors, although the protective effect provided by the lower dosage of pelletized MITC appears to be declining (Table I-10).

The results suggest that relatively low dosages of MITC can provide protection to field drilled bolt holes above the groundline.

B. EVALUATE NEW CHEMICALS FOR CONTROLLING INTERNAL WOOD DECAY

1. **Ability of solid chemicals to control decay fungi in Douglas-fir heartwood**: Vapam is the most commonly used chemical for fumigant treatment of wood poles; however, many users object to its caustic properties and liquid formulation. Workers often spill chemical on their shoes during application and later experience painful burns. _use rubber boots !_

Last year ('89 Ann. Rept., pg. 11-17), we discussed the use of a solid formulation composed of solid sodium n-methyldithiocarbamate with the water removed. These tests are continuing and will be discussed later in this section. In addition to the solid NaMDC, we are also evaluating a commercial formulation containing either 15 or 40 percent NaMDC (ICI Americas, Richmond, CA). This formulation was developed for application in warm climates where liquid Vapam

was rapidly lost from the soil. The pelletized Vapam delays volatilization in soil and this formulation would appear to be highly useful for wood application.

The efficacy of 15 and 40 % Vapam was evaluated using the small block fumigant test, wherein blocks (2.5 x 2.5 x 10 cm long) colonized by a decay fungus, <u>Antrodia</u> <u>carbonica</u>, were treated at the center with 0 to 500 mg of the chemical. The chemical was added alone or with 1.5 ml of water to accelerate

Table I-8. Effect of fumigant treatment with gelatin encapsulated MIT or Chloropicrin (CP) in transmission poles from Dorena-tap line seven years after treatment as measured using the closed-tube bioassay.

Treatment	Height Above GL (M)	Q1 Outer	Q1 Inner	Q2 Outer	Q2 Inner	Q3 Outer	Q3 Inner	Q4 Outer	Q4 Inner
MIT	5.1	100	0			0	0		
3/2-A	4.2	0	0.	0	0	0	0	0	0
	3.6	0	0	0	38	100	100	0	0
	3.0	0	0			0	0	0	0
	2.4			0	0			0	0
	1.8	0	0	0	0	0	0	0	0
	1.2			0	0			0	0
	0.6	0	0	0	0	0	0	0	0
MIT	5.1	27	36	0	0			46	0
3/2-B	4.2	39	0			0	0		
	3.3	0	0	0	0	0	0	0	0
	2.7			0	0			0	0
	2.1	0	0	0	0	0	0	0	0
	1.5			0	0			0	0
	.9	0	0	0	0	0	0	0	0
MIT	5.1			9	0			0	0
4/6-A	4.2			6	0			0	0
	3.6	0	0	19	0	0	0	0	0
	3.0	0	0			0	0		
	2.4	0	0	0	0	0	0	0	0
	1.8	0	0	0	0	0	0	0	0
	1.2	0		0		0			
CP 4/6-B	13 ~~3.9~~	100	21	0	0	15	0	0	0
	10 ~~3.0~~	0	0	0	0	0	0	0	0
	8 ~~2.4~~			0	0			0	0
	6 ~~1.8~~	0	0	0	0	0	0	0	0
	4 ~~1.2~~	0	0	0	0	0	0	0	0
	2 ~~0.6~~			0	0	100	A.D.*	0	A.D.*
CP 5/4-B	4 2.7	100	0			0	0		
	6 ~~1.8~~	0	0	0	0	0	0	0	0
	4 ~~1.2~~	0	0	0	0	0	0	0	0
	2 ~~0.6~~			0	0				
CP 5/5-A	~~3.3~~	0	0			0	0		
	8 ~~2.4~~	0	0	0	0	0	0	0	0
	6 ~~1.8~~	0	0	0	0	0	0	0	0
	4 ~~1.2~~	0	0	0	0	0	0	0	0
	2 ~~0.6~~	0	0			0	0		

Growth in unexposed controls = 33 mm
x = 2 6mm in 7 control tubes.
* = A.D. Advanced decay

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Table I-9. Fungal population near bolt hole attachments in Douglas-fir poles treated with encapsulated or pelletized MIT

TREATMENT	DOSAGE	CORES WITH DECAY/NON-DECAY FUNGI (%)[a]				
		1984	1985	~~1986~~	~~1987~~	1990
MIT Capsules	45 ml	33/33	0/70	11/1..	0/11	0/0
MIT Capsules	90 ml	0/50	0/67	17/1..	0/0	0/0
MIT Pellets	45 g	50/50	0/50			0/0
MIT Pellets	90g	0/20	0/46			0/0

[a] In 1984, chips from the original treatment holes were cultured. In 1985, cores were removed from site 0.6 m below the treatment holes. In 1986, cores were removed from sites 1.2 m below the treatment holes, while 1987 samples were removed 0.9 m below the treatment hole.

Closed-tube bioassay results

Table I-10. Presence of fungitoxic vapors at selected sites in Douglas-fir poles containing field-drilled bolt holes treated with pelletized or gelatin encapsulated MIT.

% Inhibition of p. placenta

Treatment (dosage)	Dosage	~~REPLICATES~~[b]	OUTER ZONE				INNER ZONE			
			1985	~~1986~~	~~1987~~	1990	1985	~~1986~~	~~1987~~	1990
MIT Capsules (45 ml)	45ml	~~6(3)~~	70	79	12	6	35	57	4	0
MIT Capsules (90 ml)	90ml	2(2)	40	37	5	0	30	0	0	0
MIT Pellets (45 g)	45g	5(4)	42	38	16	18	25	30	6	22
MIT Pellets (90 g)	90g	2(2)	28	17	17	0	40	0	18	0

Growth of control fungus 31 mm

[a] Percent inhibition as measured against the growth of the test fungus in the absence of wood, where 0 percent inhibition signifies the presence of toxic vapors, and 100 inhibition signifies the absence of fungitoxic vapors.
[b] Values in parenthesis represent number of poles remaining in test in 1990. The crossarm configurations in the other poles were altered, making the sampling sites inaccessible.

release. The blocks were incubated for 1 or 4 weeks, then three 0.5 cm thick
sections were cut from the ends of each block. The outer section was discarded
and the next two sections were cut into 16 equal-sized squares. The inner four
squares from the next section were placed onto potato dextrose agar and observed
for growth of the test fungus. Fungal survival was used as a measure of chemical
effectiveness. The cubes from the third section were extracted in ethyl acetate
and this extract was analyzed for MITC using gas chromatography.

As expected, increasing dosages of the solid Vapam produced increasing
amounts of MITC, although the levels of chemical declined in the 500 mg treatment
with 15 % Vapam without water (Figure I-3). The addition of water to the
treatment holes produced mixed effects in the 15 % Vapam treatments, decreasing
MITC production after one week and having no effect after four weeks.
Conversely, the addition of water was associated with lower MITC levels in the
40 % Vapam treatments after both 1 and 4 weeks. In all cases, examination of
the original treatment hole revealed that the pellets were completely dissolved,
suggesting that the addition of water may have dramatically accelerated the rate
of breakdown, and permitted the volatile MITC to move rapidly through the wood.
As a result, much of the chemical may have left the blocks prior to extraction.

While MITC levels varied in the blocks with time and water treatment,
cultural results indicated that dosages greater than 500 and 200 mg for the 15
and 40 % Vapam, respectively were capable of eliminating the test fungus from
the wood. In previous tests, approximately 100 mg of liquid Vapam was required
to control the same test fungus; however, the moisture contents of the blocks
used in earlier tests differed substantially from those used herein. Dry wood
sorbs higher amounts of MITC than wet wood. As a result, MITC would move through
the wood more slowly and be retained for a longer period in the dry wood,

potentially increasing treatment effectiveness. The moist wood in the current tests would lose MITC more rapidly, thereby reducing chemical effectiveness.

The results indicate that pelletized Vapam formulations can eliminate decay fungi established in Douglas-fir heartwood. These formulations will be further evaluated in a field trial to be established this summer.

2. **Effect of varying wood moisture content and the presence of additives on the effectiveness of solid NaMDC:** Last year ('89 Ann. Rept., pg 11-17) we reported on the ability of solid sodium n-methyldithiocarbamate (NaMDC) to eliminate decay fungi present in Douglas-fir blocks. NaMDC is the active ingredient of Vapam. The water can be removed from the Vapam, decreasing the risk of spills on applicators or in the environment surrounding the pole and increasing the percent of active ingredient from 32.1 to greater than 96 %. However, removing the water will reduce the rate of decomposition into MITC. One method for overcoming the reduced decomposition rate is to incorporate other chemicals into the powdered formulation. NaMDC decomposes best at basic pH's (>7), but most wood has a very low pH (Douglas-fir pH = 3-4). Chemicals which buffer the natural acidity of wood may be very useful as NaMDC additives. Earlier trials with the solid chemical evaluated various additives and time periods. These results suggested that the rates of MITC production from the decomposition of NaMDC could be controlled by simultaneous application of buffers or other additives; however, there were still many factors which needed to be more fully identified before the chemical could be tested in the field.

This past year we have begun a series of trials to determine the conditions necessary for optimum MITC production from NaMDC. In these trials, small Douglas-fir blocks (2.5 by 2.5 by 10 cm long) were oven-dried and weighed prior to being pressure-soaked with water. The blocks were then equilibrated to moisture contents of 10, 30, 60 or 100 %. As the blocks achieved their desired

MC, they were was dipped in molten wax to minimize further moisture losses and refrigerated for at least 2 weeks to permit equilibration of moisture within the block.

A 0.9 cm diameter hole was then drilled 2 cm into the center of each block and a measured amount of chemical was added to the hole. The hole was then plugged with a tight-fitting rubber serum cap. Blocks received 0, 50, 150, or 450 mg of chemical per block. The chemical was formed into 50 mg pellets for ease of handling and improved safety. The solid NaMDC was formulated with 5 % of pH 4, 7, or 10 buffer to determine the effect of pH on release rate from the pellets. The dry buffer salts were added to the powdered NaMDC, a small amount of water was added to the mixture and the pellets were formed using a specially adapted shotgun shell press. The dry pellets were stable and produced no significant odor. Each NaMDC/buffer combination was evaluated on 9 blocks. A small amount of water (1.5 ml/block) was added to each treatment hole to accelerate chemical release.

The blocks were incubated at room temperature (24-28 C) and three blocks from each treatment were examined 1, 4, or 8 weeks after treatment. Blocks were evaluated by cutting two 0.5 cm thick sections from each end of the block. The outer section was discarded and the next section on each end was cut into 16 equal sized squares. The inner four squares were placed into 5 ml of ethyl acetate and stored for 24 hours at room temperature. Additional sections removed from sites 0.5 cm away from either side of the treatment hole were also cut into 16 squares and the inner four squares were placed in ethyl acetate. The ethyl acetate extract was analyzed for residual MITC content using a Varian 3700 Gas Chromatograph equipped with a flame photometric detector with filters specific for sulfur. A glass column (3 m by 4 mm inner diameter) packed with 10 % Carbowax 20 M on 80/100 Supelcoport solid support was operated at the following
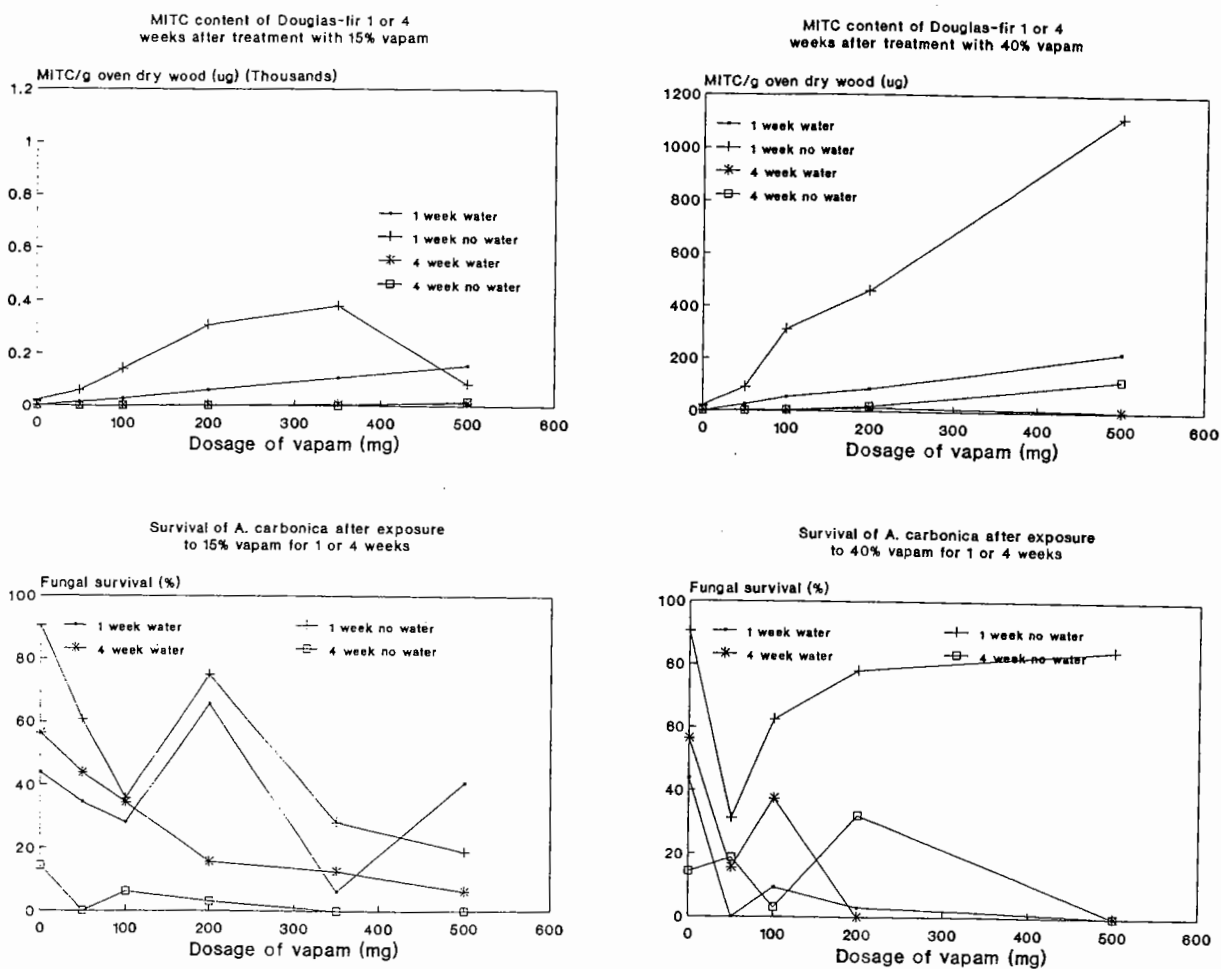
Figure I-3. MITC content and fungal survival in Douglas-fir heartwood blocks colonized by <u>Antrodia carbonica</u>, then treated with 0 to 500 mg of 15 or 40 percent pelletized NaMDC and incubated for 1 or 4 weeks at room temperature.

220°C, and nitrogen flow rate, 75 cc/min. The extracted wood was oven-dried following analysis and chemical content was reported as ug of MITC per oven-dry gram of wood.

In addition to the initial studies on the effects of pH on NaMDC decomposition, a series blocks treated with the optimum dosage and pH combination in the first study were used to evaluate the effects of other additives on MITC production. Blocks treated with the 150 or 450 mg of NaMDC and the optimum buffer combination will receive 1.5 ml of:

water	0.5 N NaOH
0.1 N NaOH	0.5 N HCl
0.1 HCl	1 % ethanol in water
10 % ethanol in water	1 % methanol in water
10 % methanol in water	No liquid

The blocks will be incubated for 1, 4, or 8 weeks prior to extraction and chemical analyses as in the previous tests.

These tests are on-going and the results of these trials will be used to identify the dosages and additive combinations which maximize MITC release at the various moisture levels found in wood in service. This data will be used to design a field test of NaMDC.

C. EVALUATE PROMISING FUMIGANT IN FIELD TRIALS

1. Evaluation of MITC-FUME in Douglas-fir and southern pine poles: The evaluations of MITC-FUME, a glass-encapsulated formulation of methylisothiocyanate are continuing. MITC-FUME is formulated in glass tubes containing 30 g of MITC. The tops of the sealed vials are punctured immediately before insertion into the treatment holes. Douglas-fir and southern pine poles

before insertion into the treatment holes. Douglas-fir and southern pine poles were treated with 60, 120, 180, or 240 g of MITC-FUME distributed in 1, 2, 3, or 4 holes, respectively. Each dosage was replicated on six poles per species. An additional group of poles of each species were treated with 500 ml of Vapam to serve as chemical controls. The poles were sampled after 6 and 12 months by removing increment cores from 3 equidistant locations 0.3, 0.9, and 1.5 m above the treatment holes. The outer and inner 2.5 cm (corresponding to 0 to 2.5 cm and 12.5 to 15.0 cm from the surface) of each core were placed into 5 ml of ethyl acetate which was stored for 48 hours at room temperature. The ethyl acetate extracts were then analyzed for residual MITC using a gas chromatograph equipped with a flame photometric detector. Additional cores removed from adjacent sites were evaluated for residual chemical content using the closed tube bioassay. The middle section from each core used for chemical analysis and closed tube bioassay was placed onto malt extract agar and observed for the presence of fungal growth. Any fungal growth was examined for characteristics typical of basidiomycetes.

In addition to the increment core samples, a series of three holes were drilled in the poles 120 degrees apart 0.3, 0.9, and 1.5 m above the groundline and doweling colonized by a decay fungus, Postia placenta, was inserted into these holes. The dowels were removed at six month intervals and placed on the surface of malt extract agar to determine if the fungus survived the exposure. Freshly colonized dowels were then placed into the empty holes. Survival of the test fungus was used as the measure of chemical effectiveness.

The six month results have been previously presented ('89 Ann. Rept., pg. 35-45). Chemical assays after one year indicate that MITC has become well-distributed throughout the Douglas-fir poles, extending up to 1.5 m above the original treatment hole (Table I-11). The highest chemical loadings were

generally found in the inner zone. The downward sloping treatment holes and presence of only one small diameter hole at the bottom end of the tube from which MITC could escape most probably contributed to this trend. Analysis of Vapam treated Douglas-fir poles indicated that MITC levels were similar to those found in the 60 g MITC-FUME treatment. While these results suggest that the treatments are comparable, MITC is just one of many potential decomposition products of Vapam. Thus, other decomposition products, such as carbonyl sulfide or carbon disulfide may contribute to the efficacy of Vapam. The consistent movement of MITC-FUME through Douglas-fir heartwood suggests that the configuration of the formulation tube may initially restrict chemical release; however, once the chemical moves out of the tube, it moves through the wood in the same manner as other MITC formulations.

While MITC moved well through Douglas-fir, movement through southern pine continued to be slower than expected (Table I-11). After 6 months, MITC was only detected in cores removed 0.3 m above the treatment holes. MITC was detected in cores removed from sites 0.9 m above the groundline one year after treatment; however, no MITC was detected above this zone. The delayed movement in this species is puzzling, since southern pine is far more permeable than Douglas-fir. Examination of Vapam treated southern pine indicated a similar trend, although no MITC was detected 0.9 m above the groundline. Once again the MITC levels present in the Vapam treated poles were similar to those detected in the 60 g MITC-FUME treatment.

Closed tube bioassays of samples removed from sites adjacent to those sampled for chemical analysis produced results similar to those for chemical assays (Table I-12). Fungal inhibition was generally greatest near the groundline in both wood species and declined with distance outward. Once again, inhibition declined more rapidly with distance from the groundline in the

southern pine poles and Vapam treatments in both wood species were approximately similar to the 60 g MITC-FUME treatment. The similarity in results once again highlights the reliability of the closed tube bioassay as a non-chemical indicator of residual fumigant protection.

Culturing of dowels infested with P. placenta and exposed in the poles for 6 months indicated that chemical levels in the Douglas-fir poles were only sufficient to kill the established decay fungus 0.3 m above the treatment hole, while the chemical levels above this region permitted some survival (Table I-13). Fungal survival was especially high in dowels exposed in Vapam treated poles, suggesting that the chemical levels present were inadequate for fungal control. Conversely, survival in 60 g MITC-FUME treatments were similar to those found with higher dosages of this chemical. The dowel survival is intended to provide a relative guide to chemical protection. Dowels exposed for 6 months in southern pine poles generally experienced far lower levels of survival in nearly all treatments, including the control. This low degree of survival makes it difficult to make statements concerning the relative merits of any particular treatment. Environmental conditions over the 6 month exposure play an important part in any test results and the period in question was characterized by particularly hot, dry conditions which may have contributed to the low fungal survival.

Culturing the center portion of each core removed for chemical and closed tube bioassays indicated that no decay fungi were present in the southern pine poles, but the poles were heavily colonized by non-basidiomycetes (Table I-14). In previous studies, several fumigant tolerant non-basidiomycetes have been shown to inhibit the activity of some basidiomycetes. Several cores removed from the 180g MITC-FUME treated Douglas-fir poles (as well as cores removed, Vapam treated, and control) poles contained viable basidiomycetes. The occurrence of

these isolates at positions well above the groundline is interesting. Although previous sampling failed to detect them, it is possible that these fungi were present at the time of installation and had survived the treatment process. As the poles are resampled in the coming weeks, these samples will be carefully observed to determine if the chemical treatments can effectively eliminate these fungi.

The results indicate that MITC-FUME is moving through poles of both wood species much in the same fashion as Vapam, the most commonly used chemical for fumigant treatment of wood poles. The seemingly slower rate of MITC movement in southern pine is puzzling. This delayed movement may be due to several possibilities. The higher resin content and the relatively dense summerwood bands in southern pine may combine to delay chemical movement through this species. Conversely, the more permeable nature of southern pine may result in accelerated radial and tangential diffusion, thus reducing the relative amount of chemical which diffuses upward. In related studies, researchers at the SUNY College of Environmental Science and Forestry found that the period of residual protection for Vapam and chloropicrin was much shorter in southern pine poles. Improved permeability and reduced chemical retention time may help explain this decreased performance. The results suggest that additional studies are required to more accurately quantify the effect of species variation on fumigant performance. These results can then be incorporated into the fumigant model being developed to predict the performance of each chemical in a particular wood species.

In addition to the field trials, a number of small scale laboratory trials have been established. Results from most of these studies were reported last year; however, our evaluation of the effect of temperature on MITC release rate into Douglas-fir poles continues. MITC-FUME tubes were applied to Douglas-

fir pole sections (25-30 cm in diameter by 0.9 m long) and the poles were exposed in a hot dry room (30 C), in a cold room (5 C), and to ambient environmental conditions in Corvallis, Oregon. Six poles were evaluated under each condition. The MITC-FUME tubes were removed from the poles at regular intervals and weighed to determine the rate of MITC release under the varying conditions. The pole sections have been exposed for nearly 2 years and clearly illustrate the effect of environment on chemical release. MITC has completely diffused from tubes in pole sections exposed under continuous hot conditions, while those exposed under cold conditions retain virtually all of the chemical (Figure I-4). Tubes in poles exposed to ambient environmental conditions have lost 67 % of the initial chemical present, but the rate of release slowed considerably 200 days after application. These results continue to confirm the slow rate of chemical movement under normal conditions, and suggest that some care should be exercised when performing any cutting on MITC-FUME treated poles which are removed from service.

Table I-11. Residual MITC content in increment cores removed from selected sites in Douglas-fir and southern pine poles one year after application of MITC-FUME.

CHEMICAL TREATMENT	DOSAGE (g)	RESIDUAL MITC CONTENT (μG/G OF OVEN DRY WOOD)									
		Distance from groundline (m)[a]									
		−0.3		0		+0.3		+0.9		+1.5	
		O	I	O	I	O	I	O	I	O	I
SOUTHERN PINE											
MITC-FUME	60	105	369	93	2031	38	239	T	T	0	0
	120	179	1534	147	2777	94	316	12	12	0	0
	180	170	1282	169	3009	30	212	13	9	0	0
	240	320	1644	275	3425	29	184	10	T	0	0
VAPAM	500	10	147	85	1986	9	96	0	0	0	0
DOUGLAS-FIR											
MITC-FUME	60	164	292	119	2525	26	128	34	24	5	T
	120	346	270	485	2879	12	349	94	198	T	7
	180	401	1327	280	3745	149	1052	25	26	T	T
	180[a]	303	1202	420	3014	8	320	54	205	T	T
	240	439	441	1500	3985	206	262	34	31	T	21
VAPAM	500	15	143	41	978	11	105	10	102	T	11

[a] Cores were taken from selected sites on the pole and the inner (I) and outer (O) 2.5 cm of each core were separately extracted in ethyl acetate. Each extract was analyzed for MITC content by gas chromatography.
b) The treating holes were flooded with water at the time of application

Table I-12. Closed-tube bioassays of increment cores removed from selected locations on douglas-fir poles treated one year with various dosages of glass encapsulated MITC-FUME

		\underline{P. placenta} Growth (as a % of the control)								
		Distance from the groundline (m)								
		-0.3		0		+0.3		+0.9		+1.5	
CHEMICAL TREATMENT	DOSAGE (g)	0	I	0	I	0	I	0	I	0	I
		SOUTHERN PINE									
MITC-FUME	60	12	0	16	0	80	40	100	60	100	100
	120	0	0	3	0	0	0	73	33	100	100
	180	0	0	11	0	21	0	95	92	100	100
	240	0	0	0	0	40	0	100	100	100	50
VAPAM	500	23	14	40	0	63	45	90	86	100	97
		DOUGLAS-FIR									
MITC-FUME	60	34	0	0	0	65	16	79	27	63	95
	120	25	12	0	0	32	12	64	26	100	100
	180	4	0	0	0	4	0	27	22	62	68
	180[b]	19	0	0	0	31	27	36	4	75	66
	240	0	0	0	0	0	0	19	8	48	50
VAPAM	500	77	49	10	0	67	15	70	39	86	84

[a] Values represent percentage growth of \underline{Postia placenta} in comparison to similar tubes containing no wood (0% equals complete inhibition). Bioassays were performed on the inner (I) and outer (0) 2.5 cm of each core.

[b] Water was added to the treatment holes at the time of chemical application.

Table I-13. Survival of <u>Postia Placenta</u> in dowelling one year after implantation at selected sites in fumigant treated poles.

Chemical Treatment	Dosage (g)	Wood Species	Fungal Survival (%)[a]		
			Distance Above the Groundline (m)		
			0.3	0.9	1.5
MITC-FUME	60	Southern Pine	0	17	6
	120	"	11	17	11
	180	"	0	0	11
	240	"	6	39	33
VAPAM	500	"	6	11	17
CONTROL (NONE)	0	"	6	0	6
MITC-FUME	60	Douglas-fir	0	11	33
	120	"	0	33	78
	180	"	6	22	28
	180[b]	"	0	44	67
	240	"	0	33	67
VAPAM	500	"	77	80	87
CONTROL (NONE)	0	"	100	100	100

[a]Wood dowelling infested with <u>Postia placenta</u> was implanted at 3 points (120° apart) around the pole 0.3, 0.9, or 1.5m above the highest treating hole. The dowels were removed after 6 months and cultured on malt agar/benlate plates.

[b]Water was added to the treatment holes at the time of chemical application.

Table I-14. Incidence of decay and nondecay fungi in Douglas-fir or southern pine poles one year after treatment with glass encapsulated MITC-FUME

CHEMICAL TREATMENT	DOSAGE (g)	Wood species	Cores containing decay nondecay fungi(%)[a]			
			Distance above the groundline (m)			
			0	0.3	0.9	1.5
MITC-FUME	60	Southern Pine	0^{67}	0^{100}	0^{100}	0^{100}
	120	"	0^{83}	0^{100}	0^{100}	0^{100}
	180	"	0^{30}	0^{100}	0^{100}	0^{100}
	240	"	0^{50}	0^{100}	0^{100}	0^{100}
VAPAM	500	"	0^{40}	0^{100}	0^{100}	0^{100}
CONTROL (NONE)	0	"	0100	0^{100}	0^{100}	0^{100}
MITC-FUME	60	Douglas-fir	0^{25}	0^{33}	0^{50}	10^{40}
	120	"	0^{29}	0^{71}	0^{64}	0^{71}
	180	"	0^{16}	0^{58}	0^{75}	30^{90}
	$180^{B)}$	"	0^{75}	12.5^{50}	12.5^{87}	25^{75}
	240	"	0^{29}	0^{25}	0^{8}	8^{75}
VAPAM	500	"	0^{60}	0^{40}	10^{50}	0^{40}
CONTROL (NONE)	0	"	0^{100}	0^{50}	8^{33}	0^{33}

[a] Values represent the percentage of cores containing decay fungi, while the superscript represents the percentage of nondecay fungi.

[b] The treating holes in these poles were flooded with water at the time of application to enhance chemical movement.
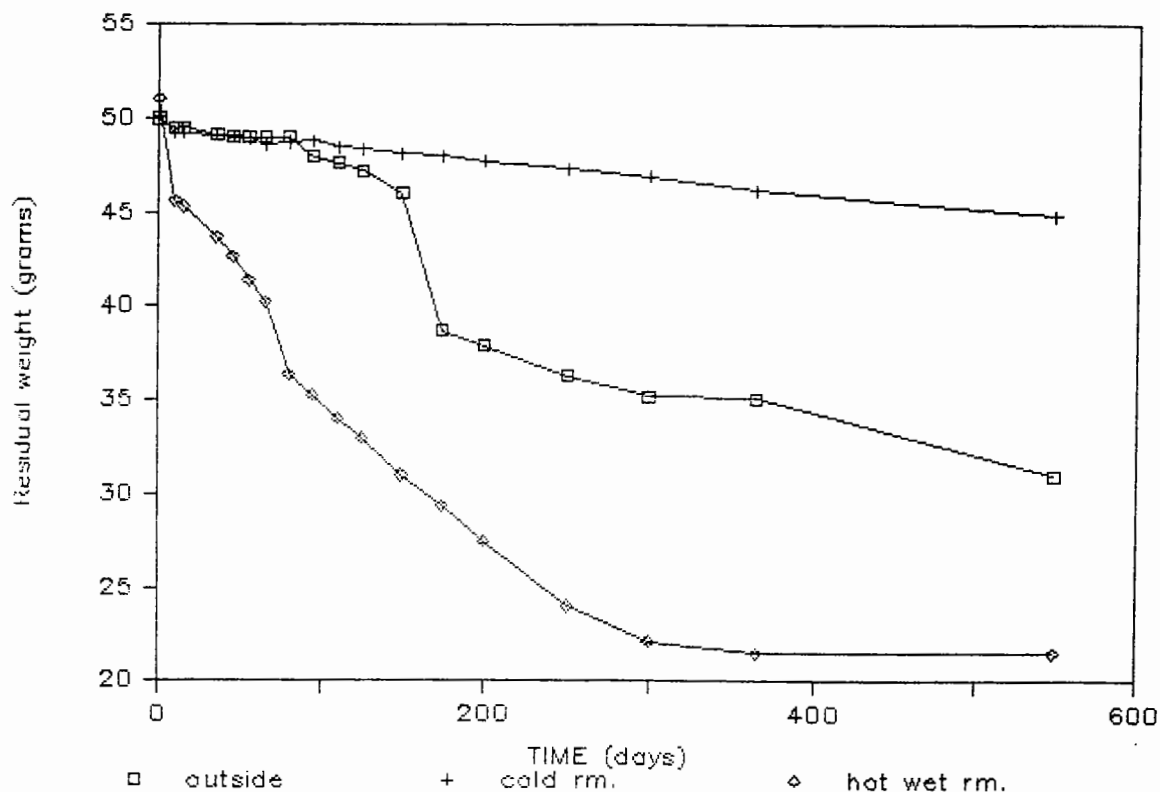
Figure I-4.   Rate of MITC release from MITC-FUME tubes placed into Douglas-fir pole sections exposed under hot, varying and cold conditions for 550 days.

A final concern in the application of MITC-FUME is the fate of the glass vials once the chemical has moved into the wood. These tubes could be removed at the time of retreatment; however, we wondered whether the residual levels of MITC present in the empty tubes posed any hazard. To evaluate this prospect, visibly empty tubes from the pole sections exposed under hot conditions were extracted in 5 ml ethyl acetate and the extract was analyzed using the gas chromatograph.   The results indicate that there are trace amounts of MITC remaining in the tubes; however, there levels should rapidly dissipate once the tubes are exposed to air. Thus, disposal of empty tubes should not constitute a hazard.

2. Preliminary testing of the ability of Dazomet to decompose to produce MITC in Douglas-fir heartwood: In previous reports, we have described the attributes of Dazomet (also known as Mylone or Bassmid) for wood treatment. This

cyclic chemical is formulated as a dry powder, which can be pelletized for safe application to wood. Previous studies at the U.S. Forest Products Laboratory suggested that the decomposition rate of Dazomet to product MITC was too slow for commercial use. To overcome this limitation, we explored the use of high pH buffers to alter wood pH and stimulate breakdown. These studies indicated that high pH's improved the degree of fungal control. In 1987, a series of 9 Douglas-fir posts (1.8 m long) were treated with 75 g of Dazomet distributed among 3 holes at the center of the post alone or in combination with 100 ml of either pH 10 or 12 buffer. The poles were stored outdoors under cover for 3 years, and were sampled by removing three increment cores around the pole at 120 degree intervals 0.3 above and below the treatment holes.

The inner and outer 2.5 cm of each core were extracted in ethyl acetate and the extracts were analyzed for residual MITC content using gas chromatography. The results indicated that MITC was present at detectable levels above and below the treatment hole, at levels that were markedly greater than those found last year (Table I-15). These results suggest that the Dazomet is beginning to decompose to produce MITC and that this chemical is moving into the surrounding wood. The addition of pH 10 or 12 buffer solution produced slight improvements in the levels of chemical found in the inner zone, but had little effect on the levels present in the outer zone. This effect suggests that the differences between no buffer and buffer treatment reflect natural variations and not a definitive chemical effect. As a result, it would appear that application of buffer has a temporary effect on decomposition to produce MITC. This effect, however, may be critical for effecting rapid control of existing fungal infestations. Slower decompositon of the remaining Dazomet with time can then provide a chemical barrier against renewed infestations.

The results suggest that Dazomet can decompose at levels which will eventually effect fungal control in the wood, although the rate of chemical release is far slower than that associated with other wood fumigants.

Table I-15. Residual MITC content at selected heights above or below the treatment site in Douglas-fir pole sections treated with 75g of Mylone alone or in combination with pH 10 or 12 buffer as measured by gas chromatographic analysis of wood extracts.

Treatment	Dosage (g)	Total MITC (ug/oven dry g of wood)[a]			
		0.3m above		0.3m below	
		outer	inner	outer	inner
Mylone (dry)	75	14.31	16.65	11.95	13.36
Mylone (pH 10)	75	7.11	10.46	8.52	28.36
Mylone (pH 12)	75	11.80	17.33	22.85	29.67

[a]Outer zone represents 0 to 2.5 cm outer segment, while inner reflects 12.5 - 15 cm from the wood surface.

3. **Effect of selected additives on the decomposition of Basamid in Douglas-fir pole sections**: Last year, we reported on the installation of a field test to evaluate the effect of a number of additives on decomposition of Basamid to produce MITC ('89 Ann. Rept., pg. 30-32). Seventy five pole sections (25-30 cm in diameter by 1.5 m long) were treated with one of the following chemicals:

1. Control (no chemical)
2. Basamid
3. Basamid plus 1 % copper sulfate
4. Basamid plus 10 % glucose
5. Basamid plus 10 % lignin
6. Basamid plus 5 % boric acid
7. Basamid plus 50 ml acetone
8. Basamid plus 50 ml methanol
9. Basamid plus 50 ml ethanol
10. Basamid plus 50 ml water
11. Vapam

Each of the dry additives (2-6) was tested on five poles with or without 5 percent of a powdered pH 12 buffer. Seventy five g of dry chemical was applied to each of three treatment holes per pole.

The poles were evaluated 6 months after treatment for residual MITC content by removing increment cores from 3 equidistant locations around the pole, 15 cm above or below the original treatment holes. The outer and inner 2.5 cm of each increment core were individually placed into test tubes containing 5 ml of ethyl acetate. The tubes were stored for several weeks to permit complete extraction of any MITC present in the wood. The extracts were then analyzed for residual MITC using previously described gas-chromatographic procedures.

MITC was detected in all of the pole samples treated with Dazomet, although the levels were generally lower than poles treated with Vapam (Table I-16). Dazomet plus pH 12 buffer and 1 % copper sulfate appeared to improve the rate of Dazomet decomposition to the greatest extent, but MITC levels in these poles were only 50 % of those found in Vapam treated poles. The addition of copper sulfate alone had little effect, suggesting that the reaction was pH dependent. The addition of alcohol, which has been reported to stimulate Dazomet decomposition had little effect, possibly because the alcohol was rapidly absorbed by the wood surrounding the treatment hole and had little opportunity to influence decomposition.

The remaining additives, including water, also did little to alter the decomposition of Dazomet. These results suggest that contact and interaction with the wood play the major roles in decomposition. Further laboratory studies of other additives to Dazomet are planned.

4. **Ability of fused borate rods to move through Douglas-fir Heartwood:**

Previously established tests to evaluate the ability of boron to migrate from fused borate rods through Douglas-fir heartwood have been of limited value due

to the excessive preservative penetration of the test samples. As a result, the sampling zone for measuring boron penetration is limited. To overcome this problem, we established a second test in which Douglas-fir post sections treated

Table I-16. Effect of selected additives on the decomposition of Dazomet to MITC in Douglas-fir pole sections as measured by gas chromatographic analyses of wood samples extracted in ethyl acetate.

Chemical Treatment	MITC Levels (ug MITC/oven-dried g of wood)		
	Inner Zone	Outer Zone	Total
Vapam (500 ml)	184	108	147
Dazomet Plus:	(114)	(101)	(114)
$CuSO_4$ 1%	41	13	27
	(35)	(15)	(31)
$CuSO_4$ plus pH 12 buffer	119	30	75
	(77)	(60)	(82)
Glucose 10%	17	4	11
	(11)	(11)	(4)
Glucose plus pH 12 buffer	49	17	33
	(42)	(23)	(38)
Lignin 10%	14	1	8
	(17)	(4)	(14)
Lignin plus pH 12 buffer	34	4	19
	(29)	(7)	(26)
Boron 5%	26	14	20
	(26)	(25)	(26)
Boron plus pH 12 buffer	21	7	14
	(25)	(15)	(22)
Ethanol	9	2	5
	(10)	(6)	(10)
Methanol	11	2	7
	(12)	(6)	(11)
*Acetone	7	1	4
	(9)	(3)	(7)
*none	18	11	14
	(16)	(16)	(16)
water	9	1	5
	(12)	(2)	(10)
pH 12 buffer	71	20	44
	(62)	(28)	(56)

[a]Figures in parenthesis represent one standard deviation.

lightly with chromated copper arsenate to provide an external barrier were treated with varying dosages of boron rods.

Fifty Douglas-fir pole sections (1.05 m long by 25 to 30 cm in diameter) were surface dried and dipped for 5 minutes in a 2.0 percent solution of chromated copper arsenate Type C (CCA-C). The dipped samples were stored under cover for 24 hours to permit fixation reactions to proceed, then air-dried.

A 1.9 cm diameter hole was drilled through each pole section 40 cm from the top. A galvanized bolt with a slot cut perpendicular to the threads was then placed in each hole to simulate the presence of hardware in a field drilled bolt hole. A 1.9 cm diameter by 20 cm long hole was then drilled at a 90 degree angle in the poles 25 cm below the top.

The poles were treated with 40 or 80 g of fused borate rod per hole (1 or 2 rods per hole). Twenty pole sections were treated with each dosage. The holes were then plugged with tight-fitting wood dowels. The poles were capped with plywood to minimize water entry and simulate the center of a utility pole. These poles have been exposed on racks out of ground contact at the Peavy Arboretum or the Hilo, Hawaii test site.

The poles will be sampled annually for the presence of boron and fungal colonization by removing ncrement cores from three sites equally distributed around the pole 5, 25 or 40 cm above the field drilled bolt hole and 15, 30, or 45 cm below this site. These cores will be split lengthwise and one half will be stained with a curcumin/salicylic acid indicator for the presence of boron, while the remainder will be cultured on nutrient media for the presence of decay fungi.

At the end of the second year, five pole sections in each treatment at each exposure site will be destructively sampled using a chainsaw. The sections will be cut and stained with the boron indicator to determine the extent of boron migration. In addition, samples will be removed for culturing to assess the degree of fungal colonization in relation to boron distribution. Finally, sections cut from the poles will be returned to the laboratory for analysis of residual boron.

A preliminary examination of pole sections exposed at Peavy Arboretum indicate that boron has moved 15 cm from the application point in one pole treated with 40 g of fused borate rod. No boron, as measured using the curcumin/salicylic acid indicator, was present in any other samples.

D. EVALUATE FUNDAMENTAL PROPERTIES OF WOOD FUMIGANTS

1. **Effect of wood voids on movement of fumigant through Douglas-fir heartwood**: Fumigant application is a highly effective method for arresting decay in standing utility poles; however, several utilities have questioned the effectiveness of these chemicals when the pole contains large voids due to fungal or insect attack. Since many voids developed in association with a deep check which permitted the entry of moisture and fungal spores, chemicals applied in wood around these zones may diffuse more rapidly from these checks. To better quantify the effect of voids on chemical movement, a series of 2.4 m long Douglas-fir poles were pressure-treated with pentachlorophenol in P9 Type A oil. These poles were cut in half and a small void (5 cm in diameter by 15 cm long) was cut into the exposed cross section of each pole. The poles were reassembled and the edge between the two ends was sealed using an elastomeric paint to retard fumigant movement from the void. The poles were then treated with 80 or 160 ml of Vapam or chloropicrin applied to holes drilled above the void. The treated poles were exposed outdoors at the Forest Research Laboratory.

Closed tube bioassays of cores removed two years after treatment revealed that chloropicrin was well distributed around the voids, while no residual fungitoxic vapors were detected in the Vapam treated poles. These results suggest that the void had little impact on chemical distribution.

This past year, the poles were resampled by removing increment cores from 3 equidistant sites around the pole, 0.3 and 0.9 m above and below the void.

The inner and outer 2.5 cm of each core was placed in ethyl acetate for Vapam treatments or hexane for chloropicrin treatments and stored for 24 hours at room temperature. The ethyl acetate extract was analyzed for residual MITC, while the hexane extracts were analyzed for chloropicrin using a gas chromatograph equipped with flame photometric and electron capture detectors, respectively.

At present, results are only available for the Vapam treated poles. The results indicate that chemical distribution around the void differs little from that found in poles with no void (Table 1-17). In general, chemical levels were highest near the center of the pole. The high chemical levels near the center in poles containing voids is interesting since the void should presumably interfere with normal chemical movement in this zone. The results suggest that the void does not interfere with chemical movement. This effect may be explained by the relatively calm air present in the void. Under these conditions, the MITC vapor in the void would remain relatively constant and would provide a conduit between the wood above and below the void. Since wood has a strong affinity for MITC, the wood below the void would tend to selectively sorb MITC, creating a constant chemical gradient for continued MITC diffusion. The results suggest that voids do not interfere with the movement of fumigant, provided the internal air in the void does not rapidly exchange with that surrounding the pole. As a result, fumigant treatment of poles with voids should be economical provided the structure retains a sufficient degree of strength to support the design load.

Table I-17. Residual MITC concentrations at various sites above or below voids in Douglas-fir poles 3 years after treatment with Vapam as determined by gas chromatographic analysis of wood extracts.

Chemical Dosage (g)	Void (+/-)	MITC Content (ug/g wood oven dry basis)							
		-0.9 m		-0.3 m		+0.3 m		+0.9 m	
		0	I	0	I	0	I	0	I
80	+	3.65	2.95	9.67	15.88	12.40	11.00	4.19	3.44
160	+	4.22	10.45	13.12	32.35	8.84	20.02	-	5.27
80	-	-	2.49	8.06	13.45	9.44	15.11	-	3.85
160	-	2.08	4.45	15.42	30.32	20.38	28.14	3.43	3.88

2. Development of a three-dimensional model which simulates binding and diffusion of MITC through Douglas-fir poles: Fumigant treatment has developed through practical experimentation, with little regard for the basic properties of the various chemicals employed for this purpose and how they interact with the wood. As a result, application patterns, chemical dosages and retreatment schedules may be inappropriate or inefficient. In 1986, a project was initiated to use basic information obtained on the movement and interactions of MITC through Douglas-fir heartwood to develop a model which could be used to accurately predict the effects of various parameters on diffusion of a measured quantity of MITC. The first model was limited to a two-dimensional disk through the pole which included a treatment hole and a preservative treated barrier on the outer shell. This model was interesting, but of limited practical application because it did not account for movement up and down the pole.

Recently (with the assistance of P.E. Humphrey, Associate Professor in Wood Physics), we have begun to improve upon the model and incorporate three dimensional capabilities. The model, which uses Turbo Pascal 5.5, accounts for the sublimation and subsequent diffusion of MITC within a 180 degree section of timber. The program views the pole as a collection of horizontal layers, and each layer is viewed as a collection of smaller sections called sectors. Fumigant diffusion among all of the sections is calculated for small time increments and concentrations are then redefined in readiness for the next time increment. The model can incorporate MITC concentration and moisture dependent binding of MITC.

The change in concentration between any two adjacent sections of the pole over some time interval is given by the simple steady-state formula:

$$\underline{M= k(c_1-c_2)At} \ /L$$

where M= mass transferred

    k= the diffusion gradient between centroids

    $(c_1-c_2)/L$= the concentration gradient

    L= the conducting length between sectors

    A= the common surface area

    t= the time interval

Diffusion coefficients are implicitly corrected for flow direction (radial, tangential, or longitudinal), the presence of heartwood/sapwood, and wood moisture content. Pole length, diameter and characteristics such as moisture content, the depth of sapwood, chemical dosage and geometry of the treatment hole may be user defined. The results are output in a format which can be used to create graphic displays, reporting the concentration of MITC in the treatment hole and the amount of chemical bound in the various sectors. While the time requirements for running the program are long, this time factor can be reduced using more sophisticated systems (optimized programs and a faster computer).

A number of trial runs have been performed, but the model should be considered preliminary and needs confirmation to ensure that the predicted distributions accurately reflect those found in wood poles. These confirmational studies will be performed using data obtained from the MITC-FUME poles currently under evaluation at the Peavy Arboretum test site.

The model was used to predict MITC distribution in a Douglas-fir pole over a 50 day period (Table I-18). Because of computer memory limitations, only a 61 cm long pole section was examined. A dosage of 20 g of MITC was applied through a 1 cm diameter by 17 cm long hole drilled perpendicular to the longitudinal axis of the 30

cm diameter pole. A 2.5 cm long plug was then inserted into the hole. Although sloping holes are normally used to apply fumigants, the perpendicular hole simplified calculations for these initial runs. The model can account for sloping treatment holes and the effects of angle on movement of chemical. The model required 8 hours to simulate a 50 day diffusion period and indicated that MITC moved steady away from the treatment hole. The results were output as residual MITC levels at selected locations in each cross-section at a given height (Figure I-5). At the end of the 50 day period, 12.9 g of chemical had moved from the treatment hole and into the surrounding wood (Figure I-6).

Examination of MITC vapor levels predetermined points within the pole indicated that MITC diffused relatively slowly across the pole, moving only 1 cm longitudinally and tangentially from the treatment hole (Figure I-6). These levels seem somewhat low; however, the model evaluated very dry wood and MITC sorbs at high levels to dry wood. As we begin to manipulate the model, the effects of varying temperature and moisture

Table I-18. Conditions used to simulate MITC movement through a Douglas-fir pole section.

Days to simulate	50
Pole Height (cm)	61
Pole diameter (cm)	30
Height to center of treatment hole (cm)	1
Treatment hole angle	0
Treatment hole length (cm)	17
Treatment hole diameter (cm)	1
Plug length (cm)	5
Initial MITC mass (g)	20
Wood Density (kg/m^3)	0.441
Water volume (cc/cc of wood)	0.0
Heartwood Diffusion Coefficients:	
Adsorption	800
Desorption	900
Longitudinal diffusion	2.3000
Radial diffusion	0.0060
Tangential diffusion	0.0038
Sapwood Diffusion Coefficients:	
Adsorption	1200

Desorption	1500
Longitudinal diffusion	4.0000
Radial diffusion	0.0140
Tangential diffusion	0.0140

levels will be examined. The relatively small rate of longitudinal movement was also suprising in that the rate of longitudinal MITC diffusion is over 1000 times greater than tangential or radial diffusion. However, the measuring points employed in the model lie above and tangentially from the treatment hole. Thus, our measure of longitudinal movement included a tangential diffusion component. In previous laboratory trials, dosages of 1g of MITC were detectable 5 cm from the point of application in as little as one week after application.

The results indicate that MITC movement in Douglas-fir poles can be predicted using the model; however, the results and the model itself can be considered only a preliminary method. Further testing and refinement of the present model should permit more detailed evaluation of the effects of various treatment parameters on the performance of MITC in wood.
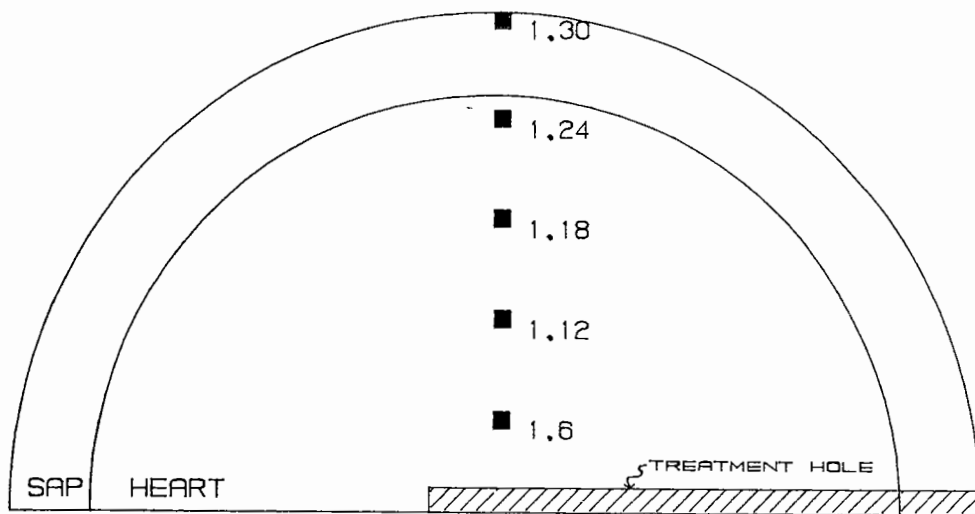

Figure I-5. Cross section showing location of sampling points along the transverse face of the pole.
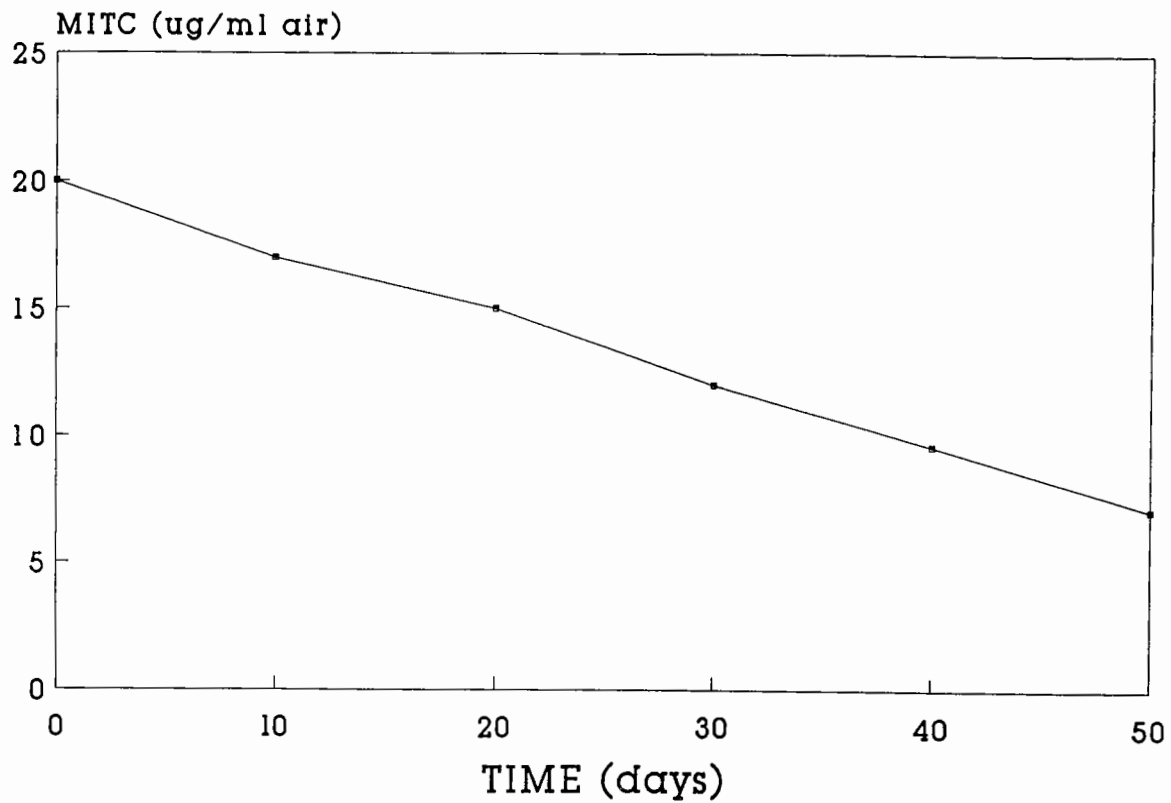
Figure I-6. Computer simulation of the rate of MITC movement from the treatment hole into the surrounding wood of a Douglas-fir pole over a 50 day period.
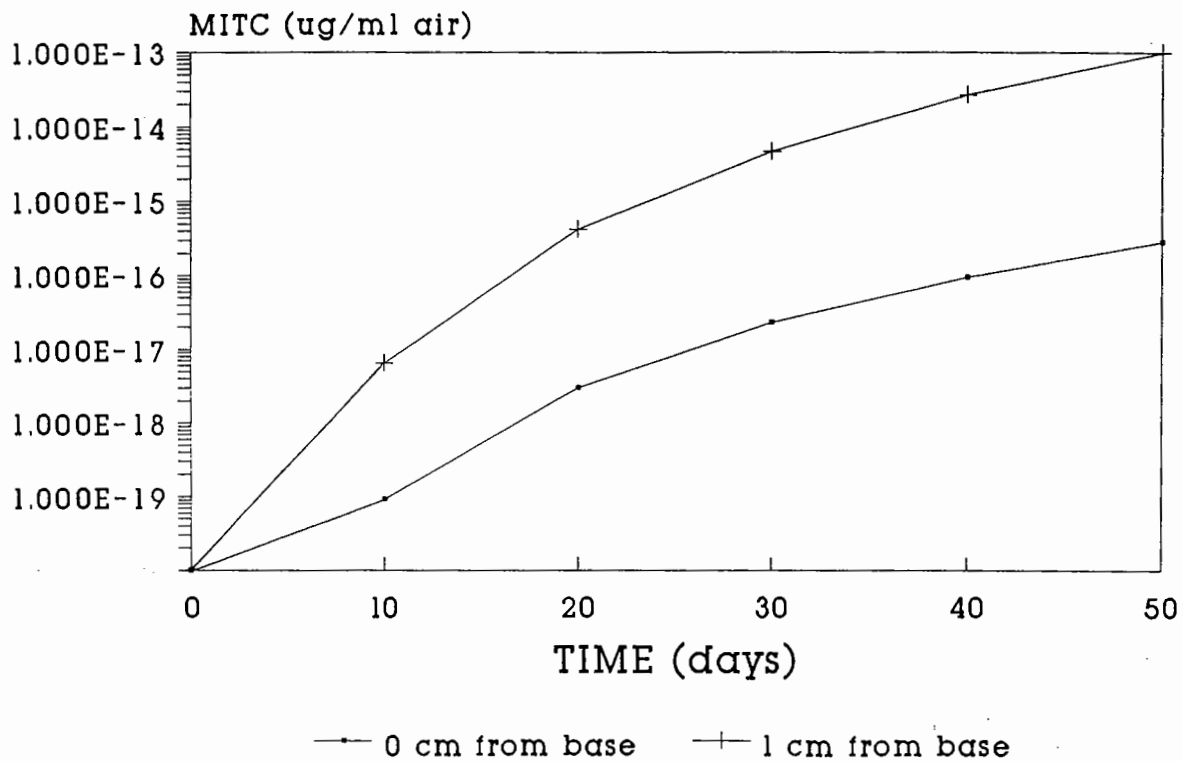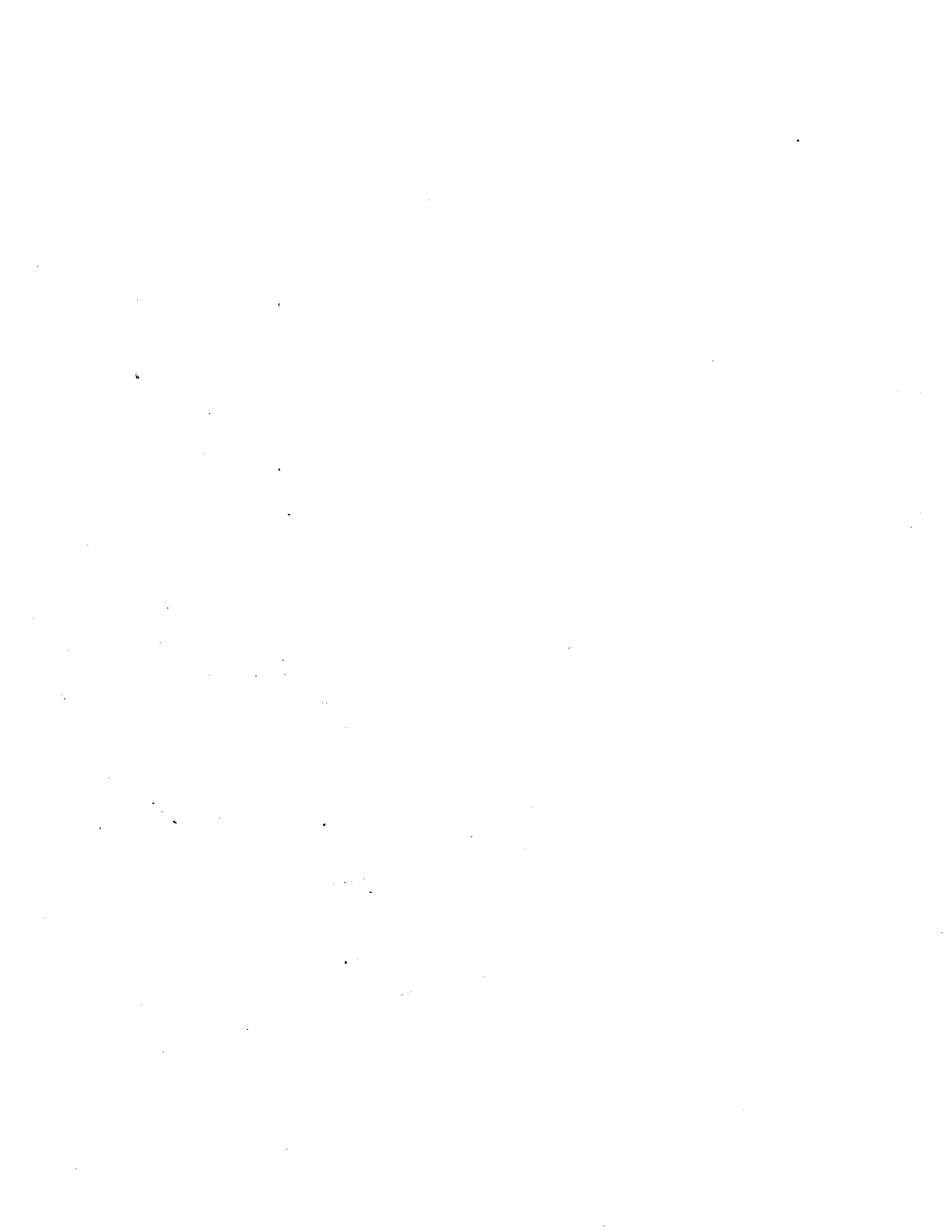
Figure I-7. Computer simulation of MITC levels at selected points in a Douglas-fir pole section over a 50 day period following application of 20 g of MITC.

OBJECTIVE II
IDENTIFY ENVIRONMENTALLY ACCEPTABLE CHEMICALS FOR
PROTECTING WESTERN REDCEDAR SAPWOOD
AND FIELD DRILLED BOLT HOLES

A.   ACCELERATED FIELD TRIALS OF POTENTIAL PENTACHLOROPHENOL REPLACEMENTS FOR PROTECTING WESTERN REDCEDAR SAPWOOD

Western redcedar has a naturally durable heartwood, but the sapwood of this species has little natural decay resistance. Over the years, this species has been extensively used by utilities either untreated or butt treated to protect the groundline from decay. Unfortunately, the untreated sapwood above the groundline has no natural decay resistance and this zone experiences substantial surface decay. The decayed wood is subjected to shelling, particularly when line personnel climb the poles to perform routine maintenance or repairs. Many utilities controlled sapwood decay by spraying the sapwood with 10% pentachlorophenol (penta) in diesel oil at regular 10 to 15 year intervals. Recently,the practice of open-air penta spraying has raised increasing concerns leading to the substitution of copper naphthenate for this purpose. While copper naphthenate has performed well in ground contact, there is little or no data on the performance of this chemical above ground when applied using a spray process. Furthermore, the choice of copper naphthenate as a replacement has been primarily dictated by the ready availability of this chemical in the marketplace. To better determine the efficacy of the many biocides which could be potentially applied to protect western redcedar sapwood, a series of pole sections treated with various chemicals have been installed at the Peavy Arboretum test site. In addition, a lengthy series of laboratory trials have been performed to identify chemicals which might be suitable for field testing.

While a number of promising replacements for pentachlorophenol for controlling decay of western redcedar sapwood are under evaluation at our Peavy Arboretum test site, we continue to screen new chemicals and search for improved methods for accelerated testing of these chemicals. In 1987, a series of small blocks (15 by 15

by 10 cm in length) were cut from the surface of a western redcedar pole section which had been removed from service. The poles were tested to ensure that no prior chemical treatment had been applied to the wood surface. Each section contained a 15 by 15 cm sapwood face. All of the remaining faces were sealed and the sapwood face was treated with one of the test chemicals (Table II-1). After drying, the blocks were exposed on a test fence in Corvallis and were subjected to daily watering during the summer months to stimulate microbial growth and chemical leaching.

The exposed blocks were sampled after 1 or 2 years by removing increment cores and plugs from the exposed sapwood surface. In the first year, only increment cores were removed and evaluated for residual chemical using the Aspergillus niger test. The results of these tests have been presented in an earlier report (88 Ann. Rept., pg 59-61). The plugs were cut into sections corresponding to 0 to 3, 3 to 6, 6 to 9, and 9 to 12 mm from the wood surface. The decay resistance of these wafers was evaluated using a soil block test with Postia placenta as the test fungus. Wood weight loss, as compared with that found in non-chemically treated controls, was used as the measure of residual chemical protection.

The results indicate that several chemicals are providing protection comparable to pentachlorophenol (penta) at 2 years after treatment, including isothiazolone, tributyl tin oxide (TBTO), Amical 48, and N-100SS, a quaternary ammonium compound (Table II-2). All four chemicals were oilborne formulations, reflecting the improved penetrability of oilborne formulations into the cedar sapwood. While waterborne formulations have certain advantages due to reduced solvent costs and safety, the high surface tension of waterborne formulations reduces preservative penetration. This factor becomes especially important in the cedar pole, since a sufficient amount of chemical must be sorbed as the formulation floods down the pole. The performance of TBTO is interesting since this chemical frequently does well in laboratory trials, but fails in field trials. The remaining chemicals have performed well in previous

Table II-1. Chemicals tested as potential pentachlorophenol replacements in western redcedar.

Chemical	Source	Carrier	Concentration
Azaconazole	Janssen Pharm.	water	0.15/0.30
ACAR 86013		water	1.0
86013		water	1.0
Copper-8-quinolinolate	Chapman Chem. Co.	oil	0.12 (Cu)
Copper-8-quinolinolate	Nuodex	water	0.3 (Cu)
Copper naphthenate	Tenino Wood Presv.	oil	2.0
CWP 44	Chapman Chem. Co.	water	10.0
Diiodomethyl-paratolyl sulfone	Akzo Chemie	oil	1.0
Dodecyl dimethyl	Nuodex	oil	8.0
ammonium salt		water	8.0
3-iodo 2-propynyl butyl	Troy	water	2.0
carbamate (IPBC)	Beecham (DAP)	oil	0.5
Isothiazolone	Rohm and Haas	oil	1.0
Methylene bisthiocyanate (MBT) plus	Buckman Laboratories	water	4.0
Thiocyanomethylthio Benzothiazole (TCMTB)			2.0
TCMTB	Buckman Laboratories		4.0
Trimethylcocammonium chloride (TMCAC)	Akzo Chemie	water	5.0
Zinc naphthenate (a)	Mooney Chemical	water	4.0
			2.0
Zinc naphthenate (b)	Mooney Chemical	water	4.0
Pentachlorophenol	Chapman Chem. Co.	oil	10.0
Tributyltinoxide		oil	5.0
IPBC/Busperse 47 (B-47)	Troy-Buckman	oil	1.0/5.0
Isothiazolone/B-47	Rohm & Haas/Buckman	oil	1.0/5.0
TMCAC/IPBC	Akzo Chemie/Troy	oil	4.0/2.5
TCMTB/B-47	Buckman	water	4.0/5.0
			2.0/2.5
(MBT/TCMTB)/B-47	Buckman	water	4.0/5.0
			2.0/2.5
Isothiazolone/TMCAC	Rohm & Haas/Akzo Chemie	oil	3.5/6.0

Table II-2. Decay resistance of western redcedar wafers treated with selected chemicals and exposed for 2 years in Corvallis, OR as measured using a modified soil block test.

Chemical Treatment	Conc. (%)	dispersant	(%) Weight loss of wafer by location from surface (MM)			
			0-3	3-6	6-9	9-12
Isothiazolone	1	oil	8	5	8	8
TBTO	5	oil	7	7	8	
Amical 48	1	oil/acetone	9	8	11	8
Penta	10	oil	10	9	8	10
Isothiazolone + busperse 47	1/5	oil	11	8	9	9
Isothiazolone + Arquad C-50	3.5/6	oil	9	9	15	19
Nuodex 100SS	8	oil	11	10	21	18
Busan 1009 + Busperse 47	4/5	water	8	17	27	26
Busan 1009 + Busperse 47	2/2.5	water	12	17	31	28
Cu Naph	2 (as metal)	oil	13	18	29	27
Busan 1009	4	water	15	17	18	16
Arquad C-50	5	water	22	23	22	20
Busan 1030 + Busperse 47	4/5	water	15	23	24	25
Busan 1030	4	water	16	21	31	26
Busan 1030 + busperse 47	2/2.5	water	16	27	40	35
Cu-8-10	.12 (as metal)	oil	20	17	34	34
Zn Naph M-553	4	water	24	29	31	28
Zn Naph M-553	2	water	33	34	25	34
Zn Naph M-550	2 (as metal)	water	32	33	36	38
CWP 44	10	water	25	29	39	37
3-Iodo-2-(IPBC)	2	water	26	30	35	23
IPBC Woodlife	0.5	oil	28	27	30	31
IPBC + busperse 47	1/5	oil	37	35	37	32
Nuodex 100 WD	8	water	27	36	42	42
Busan 1009	2	water	33	30	32	35
Azaconazole	0.3	water	32	36	28	36
Azaconazole	0.15	water	33	35	37	47
Arquad C-50/ IPBC	4 2.5	oil	34	29	29	31
Cu-8-10 (Nuodex)	.3 cu (as metal)	water	31	27	45	36
Busan 1030	2	water	33	40	33	47
ACAR #86013	1	water	37	36	33	30
ACAR #86032	1	water (>130°F)	28	27	34	30

laboratory and field trials, suggesting that they should also perform well in this application. A second group of chemicals provided a slightly lower level of protection. These chemicals provided some degree of protection to the outer zones, but exhibited little evidence of chemical penetration into the inner zones. A third group of chemicals provided little protection to the sapwood after the two year exposure. A number of these chemicals, such as zinc naphthenate and iodo-propynyl butyl carbamate (IPBC) are used in other above group applications, but the severe leaching exposures used in the current tests evidently limited the efficacy of these chemicals.

The four most promising chemicals will be evaluated in more practical field tests using cedar poles in service.

B. EVALUATE TREATMENTS FOR PREVENTING DECAY IN FIELD DRILLED BOLT HOLES

Preservative treatment of wood produces a protective shell surrounding a core of wood that is susceptible to attack by insects and fungi. As long as the treated shell remains intact, the untreated internal portion of the wood remains protected. Unfortunately, holes or cuts must be made in treated wood in many applications. For example, although many utility companies specify that holes for attachments such as guy wires or cross arms be drilled in utility poles before they are treated. It is often necessary to drill holes for other attachments after treatment. In most utility systems, linemen are required to spray preservative into a field-drilled hole to provide a thin barrier of protection to the exposed wood. Until recently, 10-percent pentachlorophenol (penta) in diesel oil was was the chemical most commonly used for that purpose; however, increasing environmental concerns and classification of penta as a "restricted use" pesticide have increased the use of 2-percent copper naphthenate in diesel oil. Unfortunately, many linemen avoid these oily formulations. The

failure to protect the untreated wood can result in extensive aboveground decay that weakens the pole around the attachment.

The ideal bolt-hole treatment would be safe, simply to apply, and protective for the entire life of a pole. To identify better methods for protecting field-drilled bolt holes, we performed the following test.

Twenty-eight poles of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) 5.4 m long and 60 to 70 cm in circumference were treated with pentachlorophenol in P9 Type A oil by Boultonizing them for 8 hours and then releasing the vacuum and draining the preservative solution. The treatment produced a thin shell of preservative surrounding an untreated heartwood core.

Eight holes 2.5 cm in diameter were then drilled through each pole at 45-cm intervals in a spiral pattern descending at a 45-degree angle from 45 cm below the top to 60 cm above the groundline. One of four chemical treatments--10-percent pentachlorophenol in oil, 40-percent boron in ethylene glycol (Boracol 40[R]), powdered sodium octaborate tetrahydrate (Timbor[R]), and powdered ammonium bifluoride (ABF)--was applied to the eight holes in each of four poles. The holes in four poles were not given a chemical treatment, but leathery washers (Patox[R] washers) containing 37.1 percent sodium fluoride, 12.5 percent potassium dichromate, 8.5 percent sodium pentachlorophenate, 1 percent sodium tetrachlorophenate and 11 percent creosote were used on the bolts. Eight poles received no chemical treatment and served as controls.

Bolts were inserted in each treatment hole. Half of the holes on each pole were given metal gain-plates on both sides and half plastic gain plates. The poles were set 1.2 m into the ground in Corvallis, Oregon, and watered from above during the dry summer months to simulate leaching and to accelerate fungal colonization.

In the first 5 years, the same four control poles were sampled annually by removing increment cores 15 cm long directly below each bolt-hole gain plate on one side of the pole and directly above the washer on the opposite side. Each hole was plugged with a tight-fitting wood dowel. The cores were cultured on nutrient media for the presence of Basidiomycotina, a class of fungi containing many important wood decayers. Non-decay fungi present in the cores were also noted. Beginning 6 years after installation, all poles were sampled in the same manner. After 7 years, bolts from each treatment were removed and visually examined for evidence of metal corrosion, then reinserted in their respective holes.

Decay fungi were isolated from five of the eight poles containing untreated field-drilled bolt holes, but the decay process was relatively slow, and only 17 percent of the cores from these poles contained decay fungi after 8 years (Table II-3). All chemical treatments appeared to have reduced the level of fungal colonization, although the degree of control baried. Bolt holes receiving pentachlorophenol or Patox[R] washers had only half the incidence of decay fungi that was found in the controls, and bolt holes treated with Timbor[R], ABF, and Boracol[R] were entirely free of decay fungi 8 years after treatment. The latter three water-soluble preservatives have the ability to migrate into the wood with moisture and have been shown to be highly effective in specific applications to Douglas-fir. These chemicals are better able to move into the freshly exposed wood as checks open around the bolt hole.

The inability of pentachlorophenol to protect the bolt hole completely may reflect its inability to migrate into the wood. The resistance of Douglas-fir heartwood to fluid penetration results in a relatively shallow barrier on the surface of the bolt hole. Any checks that penetrate beyond this barrier will eventually permit entry by decay fungi.

Patox[R] washers were the simplest system of preservation but were also unable to protect the bolt holes completely. These proprietary washers were cut from preservative-soaked pads, and the chemicals were apparently unable to move with moisture into the wood. Furthermore, the pads had to be placed outside the bolt hole on the pole surface so that the chemical had to diffuse from the pad into the wood to protect the exposed surface. While the water-soluble components in Patox[R] are recognized fungicides, external application decreases the effectiveness of this system as most of the chemical tends to run down the pole rather than into the bolt hole.

During application, Timbor[R] and ABF tended to fall out as the bolt was driven into the hole; however, this problem could be overcome by using the chemicals in a thick past or slurry. The use of pastes would also reduce the possibility of exposing the applicator to chemical dust. Boracol[R] was formulated in a viscous slurry that was difficult to apply, a problem that would be reduced by an applicator gun.

One disadvantage of water-diffusible chemicals is that they eventually need to be reapplied. As moisture carries the chemical further from the bolt hole, chemical levels decline below the threshold for fungal growth. The time required for this depletion process was not determined, but it would appear that despite this, the rate of fungal invasion is still slower than that found in the oilborne treatments.

Examination of bolts removed from the poles showed that none of the chemicals tested corroded the metal, a finding particularly important for ABF, a chemical that has been reported to be corrosive at higher dosages.

The increasingly common practive of using the lower portions of electric-distribution poles to support cable or phone networks raises the risk of fungal invasion in field-drilled bolt holes. The results indicate that preservative

application to a field-drilled bolt hole reduces that likelihood. Although they are not currently used for this purpose, water-soluble chemicals appear to be effective. Application of water-soluble preservative pastes at the time of drilling would reduce the risk of decay in these holes and significantly prolong pole service-life.

C. RAPID EVALUATION OF REMEDIAL TREATMENTS FOR PROTECTING FIELD DRILLED BOLT HOLES

Although the field tests established in 1981 to evaluate the performance of chemicals for preventing decay in field drilled bolt holes are now providing valuable information, the time period required has been extremely long. In this period, a number of new chemicals have emerged on the market and the rules which govern chemical usage in wood poles have changed dramatically. As a result, we saw a need to develop a more rapid method for evaluating the efficacy of field treatments under controlled conditions.

Initial trials involved the use of Douglas-fir heartwood blocks which had been dipped in 1% Chromated copper arsenate (CCA) then field drilled. The field drilled hole was then treated with the appropriate chemical and the block was exposed to a 3 or 6 month weathering period. The blocks were then inoculated with a decay fungus and weight loss was used as the measure of chemical performance. Unfortunately, the natural durability of Douglas-fir heartwood inhibited significant weight losses on the controls, even after 9 months of exposure, and the test was discontinued.

A second test was initiated in which small holes were drilled in the radial face of Douglas-fir heartwood and ponderosa pine sapwood blocks (3.8 by 8.8 by 3.8 cm long). These holes were treated with one of 15 potential bolt hole decay

control chemicals or were left untreated (Table II-3). Each chemical was evaluated on 9 blocks per species. The chemical was applied by plugging one end of the hole with a rubber stopper and flooding the hole with 2 ml of chemical. The other end of the hole was plugged and the block was agitated for 5 seconds to evenly distribute the chemical along the walls of the hole. The plugs were

Table II-3. Basidiomycetes and other fungi found in preservative-treated Douglas-fir poles 6, 7, and 8 years after bolt holes were drilled and treated in the field, as shown by cultures from increment cores.

Field treatment	Percentage of cores containing --					
	Basidiomycetes			Other fungi		
	6 yr	7 yr	8 yr.	6 yr	7 yr	8 yr.
Ammonium bifluoride (n - 32)	0	2	0	5	2	16
Boracol^R 40 (in = 32)	0	2	0	18	27	33
Patox^R washer (in	5	5	8	12	22	31
Pentachlorophenol (in = 32)	2	2	8	25	17	25
Timbor^R (n = 32)	0	0	0	11	25	25
Control (n = 64)	3	9	17	3	9	17

removed and the blocks were air-dried for 1 week prior to exposure in an accelerated weathering device.

The blocks were subjected to 2 or 4 months of continuous heating (30 C) with alternating periods of water spraying (8 hours). Six blocks from each treatment were weathered while the remaining three samples served as unweathered controls.

At each time point, three blocks from each chemical treatment/species group were removed and evaluated in a modified soil block test. Each block was cross cut in half to create two 3.8 by 4.4 by 3.8 cm long blocks each containing half of the original bolt hole. These blocks were then oven dried (54 C) and weighed prior to being steamed for 20 minutes at 100 C. The sterilized blocks were exposed to _Postia_ _placenta_, a brown rot fungus, in a soil block test. The decay

chambers were incubated for 12 weeks at room temperature, then the blocks were removed, scraped clean of adhering mycelium and oven-dried (54 C). The blocks were then weighed to determine weight loss during the fungal exposure. The dry blocks were then cut in half across the bolt hole and the zone of protection around each bolt hole was measured.

The results indicate that several chemicals provided a reasonable protective zone around the bolt hole (Table II-5). While none of the chemicals completely protected the block against the established decay fungus, this degree of protection was not required. In practice, bolt holes would be colonized by fungal spores which land on the surface and must germinate out of soil contact. The decay test used in this evaluation was designed to provide a much harsher exposure.

Wood weight losses of blocks containing chemically treated bolt holes differed little from those which received no chemical treatment (Table II-4). In general, wood weight losses were greater in the pine blocks, reflecting the low decay resistance of this species. The results suggested that none of the treatments were capable of protecting the wood; however, examination of the zone around the bolt hole revealed that several chemicals provided small zones of protection around the hole. In general, the size of this zone was greater in pine blocks, reflecting the more permeable nature of this species. Of the chemicals tests, pentachlorophenol (penta) in oil appeared to provide some protection against decay and produced the greatest zone of protection around the bolt hole. These results reaffirm the excellent performance of penta. Nearly all of the remaining chemicals produced measurable zones of protection in non-weathered blocks; however, this protective effect was lost upon prolonged weathering. After 4 months, only Arquad C-50, Busan 1009, Busan 1030, and Oxine copper produced measurable zones of protection around the bolt hole sin Douglas-

fir blocks. Leach resistance is an important factor in performance, since continued water exposure as rain water flows down the pole and into the bolt hole along checks can rapidly deplete surface deposits of chemical.

Copper naphthenate, the chemical most commonly used for treating field-drilled bolt holes, appeared to provide no measurable zone of protection in Douglas-fir, even immediately after treatment. The absence of a measurable zone

Table II-4. Chemicals evaluated for protection of field-drilled bolt holes

TRADE NAME (CHEMICAL)	SOLVENT	CONCENTRATION A.L. (%)
1. Amical 48 (diiodomethyl-paratolyl sulfone)	diesel/acetone	1.0
2. Arquad C-50 (3-trimethyl-cocammonium chloride)	water	5.0
3. Busan 1009 (methyl bisthio-cyanate/2) (thiocyano-methythio) benzothiazole (MBT/TCMTB)	water	4.0
4. Busan 1030 (TCMTB)	water	4.0
5. Rodewood SC-5033 (Azaconazole)	water	0.3
6. Copper 8 quinolinolate	water	1.0[a]
7. Copper naphthenate	diesel	4.0[a]
8. Polyphase (3-iodo 2 propynyl (butylcarbamate) (IPBC)	water	2.0
9. Woodlife (IPBC)	diesel	0.5
10. Kathon 930 (Isothiazolone)	diesel	1.0
11. N-100-WD (Dodecyl dimethyl ammonium salt of naphthenic acid) (DDBAN)	water	4.0
12. Pentachlorophenol	diesel	10.0
13. M-Gard 553 (Zinc naphthenate)	water	4.0[a]
14. Koppers NP-1	water	1.0
15. TIMBOR (disodium octaborate tetrahydate)	water	10.0[b]

[a]Chemical active ingredient is on a metal basis (copper or zinc).

[b]As boric acid equivalent.

Table II-5. Effect of chemical treatments or protection of field drilled bolt holes as measured using soil block tests and visual estimation of the zone of protection after 0, 2 or 4 months of artificial weathering.

Test Chemical (trade name)	Wood Species	Weight loss (%)[a]			Zone of Treatment (ZOT) (mm)[b]		
		0	2 mo.	4 mo	0	2 mo.	4 mo.
Amical 48	P. pine	35.4	41.5	36.3	1.4	2	2
	DF	24.0	24.6	25.6	1	1	0
Arquad C-50	P. pine	31.0	36.3	27.6	3	3	3.6
	DF	25.2	23.2	22.4	1	1	3.6
Busan 1009	pine	46.5	43.7	39.33	2.5	2	4
	DF	28.7	29.0	29.4	4	2.5	9.4
Busan 1030	pine	48.2	45.2	41.5	3.5	3.4	3.7
	DF	23.6	28.2	31.5	2	1.3	2.8
Rodewood SC-503	pine	39.4	42.0	23.5	2.5	1.7	2.2
	DF	25.6	25.1	25.4	1	1	0
Copper-8-quinolinolate	pine	39.8	39.3	29.9	2.5	2.7	4
	DF	25.7	26.3	23.1	1	1	1
Copper naphthenate	pine	46.7	47.0	36.0	0.3	0.5	0
	DF	26.2	27.3	23.8	0	0	0
Polyphase	pine	38.2	43.3	34.88	2.7	2.7	0
	DF	32.0	29.2	25.8	1.2	1.2	0
Woodlife	pine	41.8	37.3	36.63	1	1.3	2.5
	DF	30.2	31.8	23.6	0	0	0
Isothiazolone	pine	32.8	36.3	35.83	0.7	1.5	1.5
	DF	28.3	25.8	20.8	1	1	0
N-100-WD (DDBAN)	pine	38.3	38.8	37.65	2	1.7	1
	DF	28.0	27.1	28.1	0	0	0
Penta	pine	23.3	23.0	26.24	8	8.5	8.6
	DF	21.3	16.0	21.2	7.8	8	10
Zinc naphthenate	pine	38.5	40.3	29.5	1.3	1.2	0
	DF	25.5	26.8	24.9	1	1	0
NP-1	pine	37.0	38.4	32.2	1	1	0
	DF	27.8	24.7	26.4	0	0	0
Timbor	pine	-[a]	-[a]	36.3	-[a]	-[a]	0
	DF	*	31.2	31.6	0	0	0
Control (no treatment)	pine	32.7	35.7	40.85	0	0	0
	DF	24.3	25.8	28.8	0	0	0

[a] As measured in a modified soil block test using P. placenta as the test fungus

[b] The protective zone around each bolt hole.

does not necessarily mean that this chemical provides no protection to the field drilled wood; however, the shallow nature of this treatment can be easily negated by development of small checks in the bolt hole surface. The requirements for protection from decay fungi in environments such as that characterized by the bolt hole differ substantially from those for wood in ground contact. Bolt holes represent an above ground exposure where fungal colonization will most often begin by the germination of a spore or growth of a hyphal fragment that somehow finds its way into the untreated wood exposed in this zone. The spore generally represents the most susceptible portion of the fungal life cycle. Thus, biocides which normally fail in ground contact, may provide excellent protection under the less hazardous exposure. In addition, surface coatings of biocides may be acceptable, provided no checks or splits penetrate beyond this thin shell of protection. In practice, movement of the bolt or fastener over the course of service does create small checks which can penetrate beyond the shell. Our results would suggest that four chemicals show promise for protecting bolt holes. Of these, three (Busan 1009, Busan 1030, and Oxine copper) are registered for wood use. Oxine copper has certain advantages in that it is considered to be extremely safe and is the only chemical approved for the treatment of wood in direct contact with food. This chemical is also oilborne, while the the remaining three chemicals are waterborne formulations. The results of these trials will be used to establish field trials; however, previous studies suggest that useful field data will require long test periods.

OBJECTIVE III

DETECT EARLY DECAY AND ESTIMATE RESIDUAL

STRENGTH OF POLES IN SERVICE

A. EFFECT OF FUNGAL COLONY SIZE AND DENSITY ON RESIDUAL STRENGTH OF DOUGLAS-FIR
   SAPWOOD AND HEARTWOOD

Colonization of wood products by basidiomycetous decay fungi is generally associated with the substantial losses in mechanical properties of the material. These losses range up to 60 percent for some properties with as little as 5 percent mass loss. While these losses suggest that fungal colonization of wood is immediately detrimental, mechanical testing of beams cut from Douglas-fir pole sections which had been air-seasoned over a 3 year period indicated that strength losses were gradual over this period, despite high levels of fungal colonization. These tests suggest that there may be a lag between fungal colonization of the wood and loss of structural integrity. This possibility becomes particularly important in commodities where air-seasoning exposes structural material, such as poles, to colonization by wood decaying fungi.

The effects of fungal colonization on wood properties are generally evaluated by exposing wood samples to a given fungus, either growing on an artificial media or in soil under optimal conditions. In practice, the environment in wood out of ground contact is characterized by wide fluctuations in moisture which limit microbial growth. Thus, decay tests performed under optimal conditions for fungal growth may not accurately reflect the real risk of degradation. One approach for assessing the risk of fungal colonization is to determine the relationship between the size and density of a fungal colony

and the effects of this colony on wood strength in the absence of large quantities of fungal inoculum.

This approach was used to study two fungi, Stereum sanguinolentum and Postia placenta, which commonly invade Douglas-fir poles during the air-seasoning process.

Douglas-fir sapwood and heartwood beams, 1.27 by 1.27 by 20 cm long (0.5 by 0.5 by 8 in.). were cut from one fresh, debarked log. A 2 mm (0.081 in.) diameter hole was drilled through each beam at mid-span from one radial face to within 1.6 mm (0.063 in.) of the opposite radial face (Fig. III-1). The beams were water-soaked in a vacuum-pressure cycle to moisture contents above fiber saturation. Each beam was placed into a 15 by 30 cm (6 by 12 in.), 1.25 mil thick, polyethylene bag and sealed using a thermal impulse sealer. Twelve beams were placed in a larger bag, sealed, and autoclaved for 30 minutes at 100 C, without pressure, on three consecutive days. No more than 4 bags were cooled and refrigerated until needed.

Fungal inoculum was prepared by removing several 4 mm diameter disks from the advancing perimeter of each selected test fungus growing on nutrient media. The disks were added to 125 ml of 1.5% malt solution and incubated for 7 to 10 days at room temperature (23-25 C) on a shaker revolving at 80 rpm. Each flask of inoculum was then filtered and rinsed with 300 ml sterile distilled water (SDW) to remove sugars. The residual mycelium and spores were macerated with 250 ml SDW in a sterile Waring blender at high speed for 1 minute.

Twenty-four hours before beam inoculation, the bags were removed from the refrigerator to attain room temperature. Beams were removed from the larger bags and inoculated, in sets of 12, in a laminar flow hood to prevent contamination.

Douglas-fir heartwood beams were inoculated with Postia placenta (Fr.) M. Lars. & Lomb. [Madison isolate FP94267R], while Stereum sanguinolentum Alb. & Schw.:Fr., [Forest Research Lab isolate 42M from Scappoose, OR] was inoculated into sapwood beams. Control beams were not inoculated. For each set of 12, a hole was pierced in the bag directly over the pre-drilled inoculation hole in each beam using a flamed dissecting needle. Twenty ul of blended inoculum was pipetted into the inoculation hole and the hole was resealed with the thermal impulse sealer. Each bag was numbered with the inoculum batch number and a small amount of the remaining inoculum was distributed on growth media. Subsequent fungal growth was monitored during the week for contamination. The blender was sterilized between batches in the autoclave or rinsed with a dilute bleach solution, followed by a rinse with SDW.

Inoculated beams were stored in sterile crispers and incubated at 28 C for 1 to 12 months. Sterile water was placed in the incubator to maintain humidity. At selected time points, two control beams and twenty beams inoculated with each test fungus were removed and tested for residual strength and degree of fungal colonization.

Bending tests - Ten inoculated beams and one control beam were tested in three point loading perpendicular to the inoculation hole over a 17.8 cm (7 in.) span and at a speed of 0.1 cm/min. to determine modulus of rupture (MOR), work to maximum load (WORK), and modulus of elasticity (MOE) (Fig. III-1). Since bending strength is most affected by changes near the beam mid-point, the progressive colonization of the beam by the fungus was monitored by cutting a series of 18 cross-sections, each 0.3 cm (1/8 in.) thick, from the center 8.4 cm (3.3 in.) of each beam tested in bending. The two outermost sections were used to measure moisture content, while the remaining sixteen sections were cut

into 4 equal sized pieces, surface-flamed, and plated on growth media to detect fungal colonization. Sections from beams inoculated with P. placenta were plated on Difco Bacto Potato Dextrose Agar (39 g/liter SDW), while sections from beams inoculated with S. sanguinolentum were plated on 1.5% malt extract/1% agar media. To discourage the growth of Fungi Imperfecti, 10 ppm active Benomyl was added to the molten media.

Compression tests - Residual wood strength in each beam at selected distances from the inoculation point was measured by cutting 1.27 cm (1/2 in.) cubes from selected locations along the length of ten fungal inoculated beams and one control beam (Fig. III-1). The cubes were tested wet for longitudinal compression strength (LCS) (Fig. III-1) by compressing them parallel to grain between two platens at a head speed of 0.2 cm/minute. After LCS testing, moisture content was determined and five 1.27 cm (1/2 in.) cubes were aseptically cut from five locations in the beam (Fig. III-1). Each cube was surfaced flamed, then cut along its tangential plane into two pieces. Four 30u sections were microtomed from early wood from a freshly cut surface. These sections were macerated with 16 ml SDW in a blender for 15 sec. at high speed. This solution was poured into a bottle containing 60 ml of molten PDA or malt agar with benlate. The contents of the bottle were distributed equally among five petri dishes. An additional 120u section from each cube was cut and plated on growth media to monitor for fungal viability. The blender was washed with alcohol and rinsed with SDW before processing the next cube. Petri dishes were labeled, stored at room temperature, and fungal colonies appearing in the media over a four week period were counted. Fungal colonies per section was then used as a measure of the degree of colonization.

An analysis of variance was performed on the data and mean separations were performed using Neuman Kuel's method at α = 0.05.

Stereum sanguinolentum, a white rotter that commonly invades the sapwood of downed timber, was associated bending strength losses in MOR and WORK after 1 month incubation, but caused no significant changes in MOE (Table III-1). After 12 months, average MOR had been reduced by 29% from 6,110 to 4,325 psi, while work had declined 50% to 6 in.-lbs. from an initial value of 12 in.-lbs. These strength reductions were rapid between 1 and 5 months, then stabilized with continued incubation. Colonization of the beams was rapid as evidenced by isolation of the test fungus from the entire 8.4 cm (3 in.) mid-section of inoculated beams at every time point.

The combination of longitudinal compression strength testing and colony density measurements was designed to examine the importance of not only colony size, but also colony density on wood strength. As with bending MOR, average LCS of samples from beams inoculated with S. sanguinolentum declined after 1 month of incubation (Table III-3). After 12 months, average LCS dropped 22%, from an average of 417 kg for controls to 325 kg. Although radial compression strength is a better indicator of incipient decay, LCS does appear to be useful for following the course of degradation and can be correlated with bending properties. An inconsistency between LCS and bending test results was that LCS gradually declined from 3 to 12 months while MOR and WORK measurements showed no significant decreases over the same period. LCS, however, is probably a more accurate strength predictor of overall fungal effects than MOR or WORK, since LCS was measured at eight points along the length of each beam, while bending only evaluated the beam at mid-span. Average colony counts of S. sanguinolentum in the beams increased after one month incubation (Table III-3), then stabilized

over the remainder of the test period. Examination of LCS by position in the beam (Figure III-2) showed that LCS declined uniformly throughout the beams between 1 and 5 months then declined at a slightly faster rate towards the initial inoculation point at the beam center. Fungal density, examined by position in the same beams increased uniformly by beam position during the first 5 months (Figure III-3); however, upon longer incubation fungal density was greatest at beam ends and lowest at the beam inoculation point. This decline may reflect exhaustion of available nutrients near the inoculation point. These results suggests that fungal density is a poor predictor of potential strength losses.

The relationship between fungal density and decay activity may be quite complex. Many fungi produce large quantities of diffusible enzymes which migrate for long distances through the wood causing substantial strength effects while the quantity of fungal biomass remains quite small. Other fungi cause more gradual strength losses as they slowly move through the wood. Conversely, some fungi produce large quantities of spores or other propagules which can artificially increase the number of isolations in a density procedure like that used here. Compounding these effects is a trend for mycelial density of many fungi to decline in a given area as readily available substrates are utilized, making them more difficult to isolate. Stereum sanguinolentum is a common colonizer of fallen timber and must rapidly colonize the wood to compete with other pioneering colonizers. As the readily available nutrients present in the sapwood are exhausted, colony density declines and the remaining biomass must utilize less easily degraded structural components of the wood cell wall.

One factor which undoubtedly increased the impact of S. sanguinolentum on wood properties was moisture content, which was above 50% throughout the test.

In practice, peeled Douglas-fir poles attain sapwood moisture contents ranging from 11-24 percent in the outer 5.0 cm of shell within one year, depending on the climate at the seasoning site. The moisture content in a majority of the pole cross-sections after 1 year of seasoning is too low to permit extensive fungal growth. Temperature variations outside the range for optimal growth would further decease the impact of this fungus in a natural environment. Thus, while S. sanguinolentum is capable of causing significant strength losses under optimal conditions, it is unlikely that an air-seasoning pole represents these conditions.

The Postia placenta colonized Douglas-fir heartwood beams were only evaluated over a 7-month period because of lack of test material. Average strength values for MOR and MOE declined after 3.6 months and 1 month incubation, respectively (Table III-2). At the 5-and 7.4-month sampling points, it became apparent that the fungus was not causing strength loss in all of the beams. After seven months, some beams had no strength loss compared to controls while others had as much as 41% loss in MOR and 72% loss in work. This large variation in strength values caused average strength values to increase or remain the same after 5 months incubation. P. placenta colonized the middle 8.4 cm (3.3 in.) of the beams more slowly than S. sanguinolentum over the first month of incubation, however this entire mid-section was completely colonized in all beams upon longer incubation. Complete colonization, together with the fact that beam moisture content throughout the test was at or above 60%, which is ideal for colonization of Douglas-fir by P. placenta, indicated that test conditions did not inhibit the decay fungus. The absence of strength loss in some beams may reflect the presence of heartwood extractives in the beams. Douglas-fir heartwood is classified as moderately durable in ground contact and durable in

above ground exposures. Air-seasoning should be considered as an above ground exposure. While P. placenta is commonly isolated from Douglas-fir heartwood, it still must overcome the presence of heartwood extractives in the absence of readily available nutrients. Thus, it is likely that the initial effects of colonization of Douglas-fir by this fungus are minimal. Conversely, the level of colonization of heartwood by competing microorganisms is far lower than sapwood, reducing the need for a fungus to rapidly occupy the substrate to exclude competition. Under prolonged exposure, P. placenta may develop a sufficient biomass to begin attacking the wood structure and exert considerable effects on strength as evidenced by its association with internal decay of Douglas-fir heartwood in service. This delayed effect on strength properties is reflected by the finding that Douglas-fir pole sections, although heavily colonized by decay fungi after 2 years of air-seasoning, only begin to experience significant heartwood strength losses after the third year of seasoning. This delayed effect makes it difficult to accurately assess the significance of fungal isolation from wood in service in relation to wood properties.

The effects of P. placenta on longitudinal compression strength were similar to effects of the fungus on MOR, declining after 3.6 months incubation (Table III-3). Average fungal density in the beams increased after 1 month, remained steady, then declined after 5 months. Reduced fungal activity in many of the beams after 5 months incubation caused a wide variation in LCS values at the 7 month test point. Some LCS samples had the same strength as controls, while others experienced up to 27% strength loss resulting in slight increases in average beam LCS after 5 months incubation. There was a uniform decline in LCS throughout the beams after 3.6 months and an increase after 5 months, with strength loss near the inoculation site evident only at 7 months (Figure III-

4). Average fungal density along the length of the beams (Figure III-5) was initially high at mid-beam, and gradually decreased during the 7 month incubation period. Average fungal density at other positions in the beam gradually increased during incubation, becoming uniform throughout the beam after 5 months. The relatively high average 7-month colony count at mid-beam resulted from one beam having a colony count of 83 at mid-beam, while the other beams had counts ranging from 0 to 5 colonies at this position. This range illustrates the natural variation inherent in fungal colonization of wood.

Comparing the rates of colonization of the two fungi tested, S. sanguinolentum colonized Douglas-fir beams more rapidly than P. placenta. S. sanguinolentum was isolated from the entire length of every beam at all time points, while P. placenta was isolated from the inoculation point at mid-beam at every time point but didn't colonize the entire beam until after 3.4 months incubation. Fungal density patterns were also different for the two fungi. Density of S. sanguinolentum increased uniformly throughout the beams during 5 months incubation, then decreased at the inoculation point and increased at beam ends. P. placenta colonies, on the other hand, were initially very dense at the inoculation point and sparse at beam ends, eventually becoming uniform throughout the beam after 5 months of incubation. Comparing mean strength losses caused by the two fungi, S. sanguinolentum caused a greater percentage of strength loss compared to controls than P. placenta at nearly all time points. Also, S. sanguinolentum caused a proportionally greater strength loss than P. placenta when comparing the lowest strength value in the group with mean control values.

The results illustrate the differing effects and colonization strategies of the fungi tested. Stereum sanguinolentum colonizes Douglas-fir sapwood, a substrate relatively rich in nutrients, and must rapidly occupy the substrate

to utilize these nutrients before competing fungi colonize the wood. As a result, colony density and the resultant effects on wood properties occur more rapidly. <u>Postia</u> <u>placenta</u> colonizes the moderately durable heartwood and faces far less competition for nutrients or space. Fungi in this environment must be capable of growth in the presence of heartwood extractives. As a result of these microniche conditions, <u>P</u>., <u>placenta</u> grows more slowly through the wood and affects wood properties at a slower rate.

Conversely, moisture conditions near the wood surface remain suitable for fungal growth for only a short time, while those deeper in the wood remain conducive to fungal growth for much longer periods. Thus, the potential for damage by <u>S</u>. <u>sanguinolentum</u> exists, but rapid drying of the outer wood shell should minimize this potential.

The variations between fungal growth and effect on wood properties demonstrate the need for careful evaluation of fungal isolation data to distinguish between potential and actual risk of decay.

A

bending test
direction

drilled hole for
fungal inoculation

B

lcs test
direction

D

C

beam position: LE L4 L3 LM L2 L1 MM R1 R2 RM R3 R4 RE

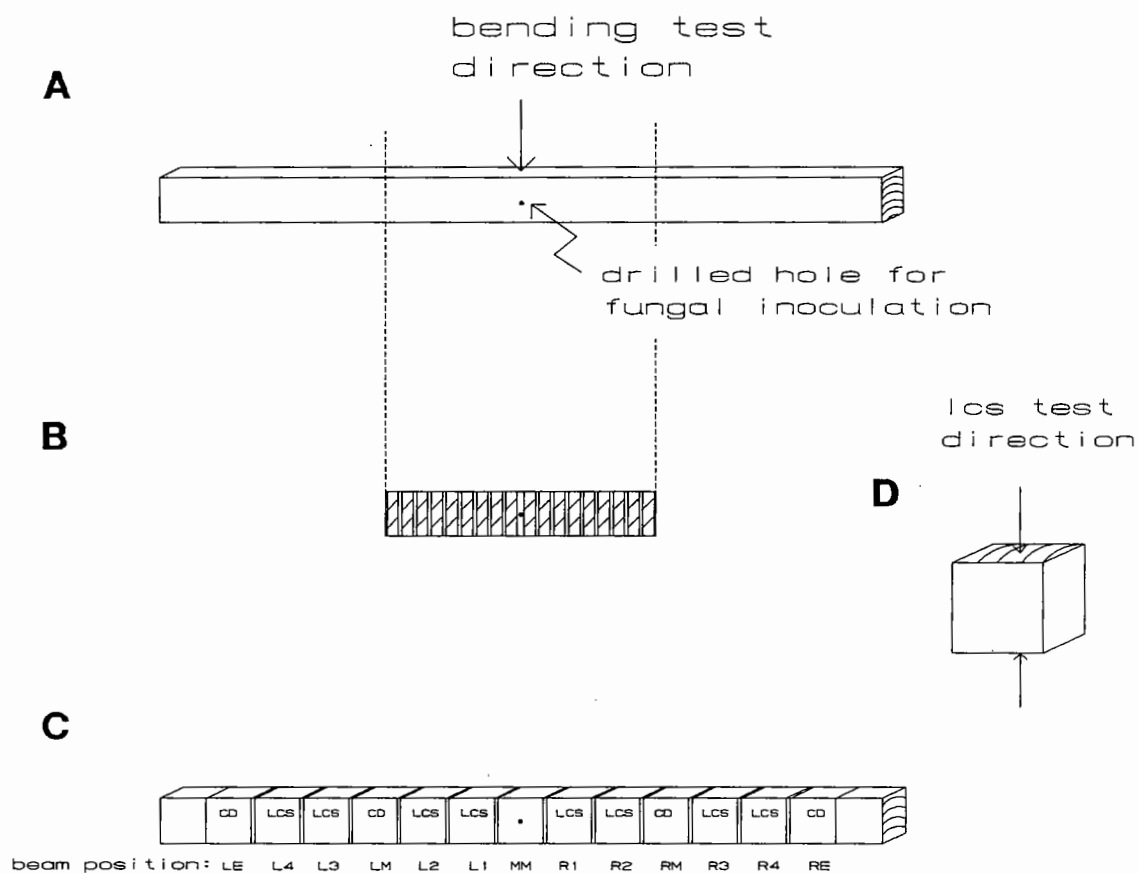CD LCS LCS CD LCS LCS · LCS LCS CD LCS LCS CD

Figure III-1. Douglas-fir beams showing (A) inoculation site on radial face, ring orientation, and application of bending load to tangential face, (B) cutting pattern for sections to measure growth of the fungal colony in bending beams, (C) cutting pattern for cubes to measure longitudinal compression strength (LCS), moisture content, and colony density in LCS beams, and (D) orientation of LCS cube during the LCS test.
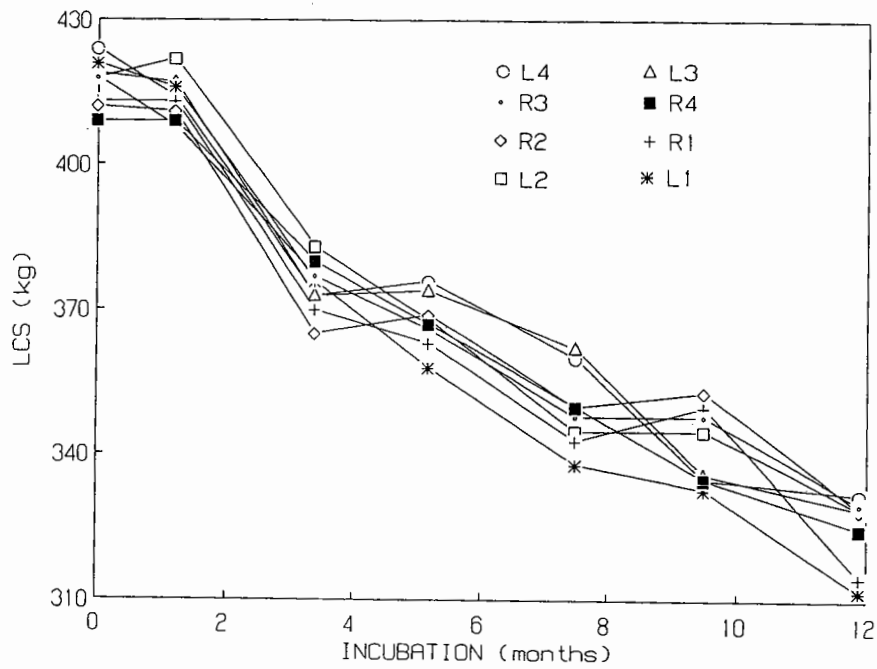
Figure III-2. Longitudinal compression strength (LCS) at selected points along Douglas-fir sapwood beams 0 to 12 months after inoculation at mid-span with a mycelial suspension of <u>Stereum</u> <u>sanguinolentum</u>.
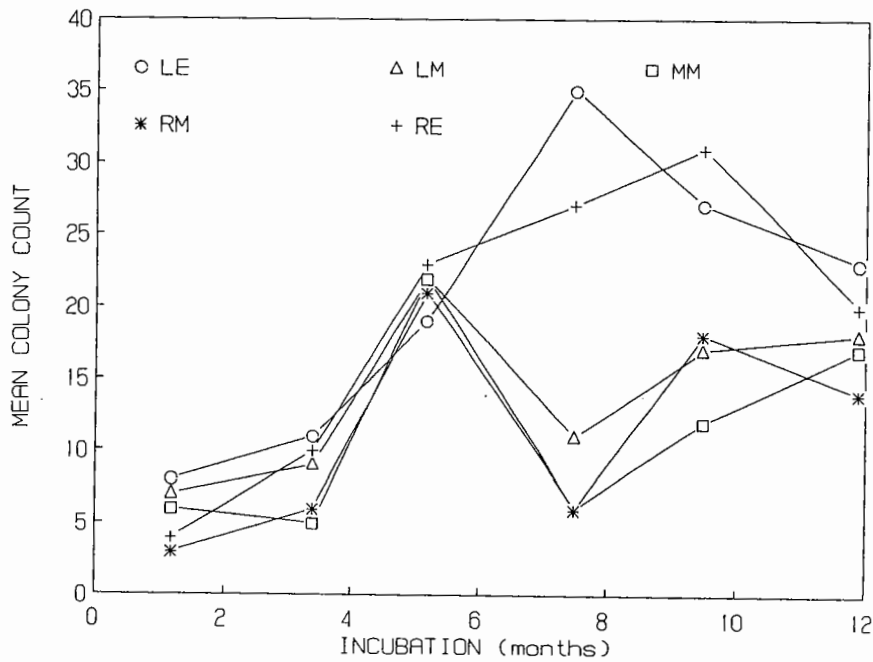

Figure III-3. Fungal density at selected points along Douglas-fir sapwood beams 0 to 12 months inoculation at mid-span with a mycelial suspension of <u>Stereum</u> <u>sanguinolentum</u>.
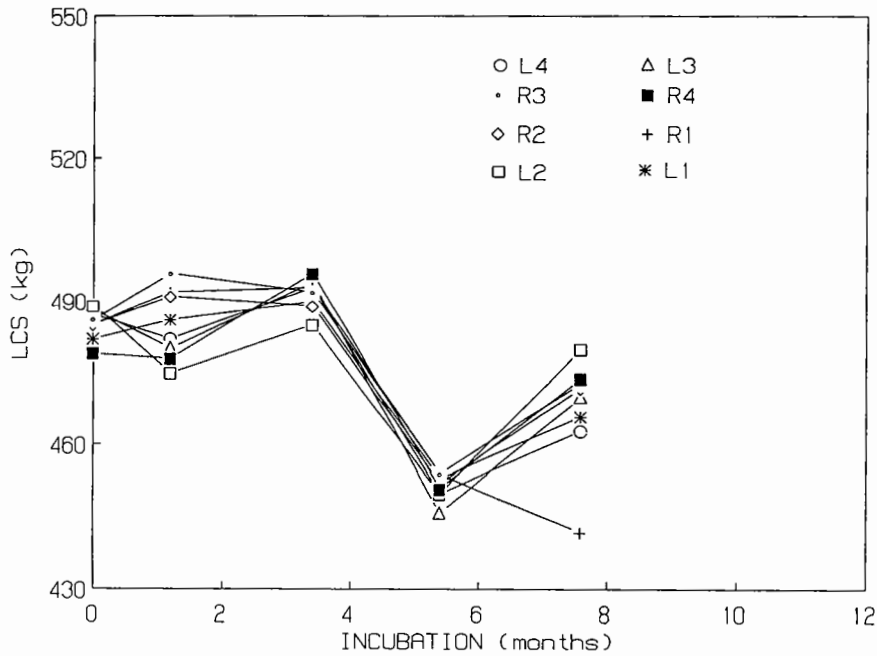
Figure III-4. Longitudinal compression strength (LCS) at selected points along Douglas-fir heartwood beams, 0 to 7 months after inoculation at mid-span with a mycelial suspension of Postia placenta.
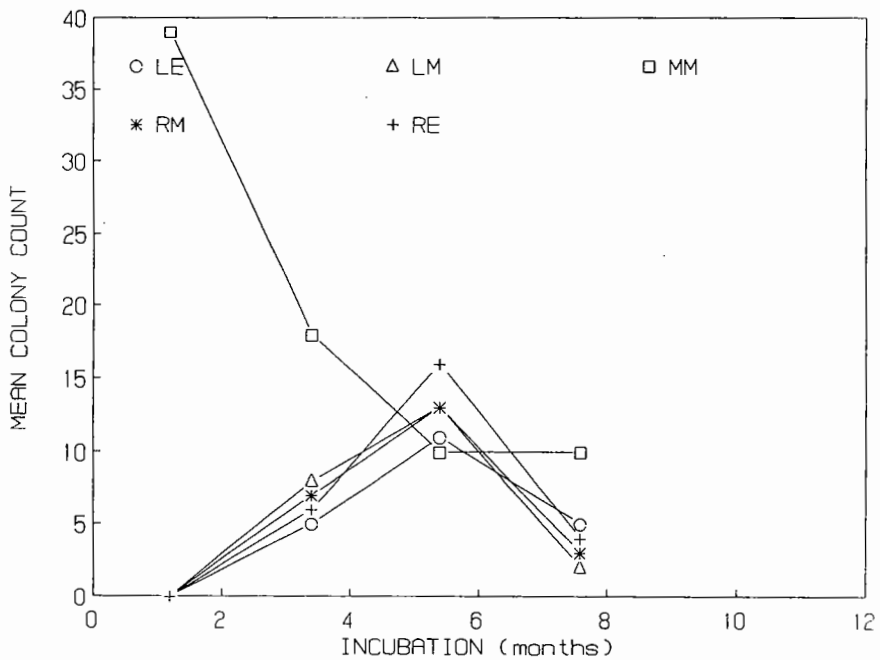

Figure III-5. Fungal density at selected points along Douglas-fir heartwood beams 0 to 7 months after inoculation at mid-span with a mycelial suspension of Postia placenta.

Table III-1. Modulus of rupture (MOR), modulus of elasticity (MOE), and work to maximum load (WORK) of Douglas-fir sapwood beams 0 to 12 months after inoculation with a mycelial suspension of <u>Stereum sanguinolentum</u>.

	MOR, psi		MOE, psi x 1000		WORK, in.-lb.	
	Average	Coefficient Variation,%[2]	Average	Coefficient Variation,%	Average	Coefficient Variation,%
Control	6110(342) a[1]	5.6	1409(222) a	15.8	12(2) a	13.4
Month: 1	6163(593) a	9.6	1360(191) a	14.0	11(3) a	26.1
3	5245(303) b	5.8	1163(182) a	15.6	8(2) b	29.6
5	4402(421) c	9.6	1235(197) a	15.9	6(1) b	24.4
7	4213(525) c	12.5	1140(207) a	18.2	7(3) b	46.5
10	4157(377) c	9.1	1102(142) a	12.9	6(2) b	40.9
12	4325(539) c	12.5	1267(221) a	17.5	6(2) b	26.8

[1] Values in parentheses are standard deviation. If followed by the same letter, average strength values in the same column are not significantly different (p = 0.05), Neuman - Keuls method.
2 Coefficient of variation is the ratio of the standard deviation to the average.

Table III-2. Modulus of rupture (MOR), modulus of elasticity (MOE), and work to maximum load (WORK) of Douglas-fir heartwood beams 0 to 7 months after inoculation with a mycelial suspension of <u>Postia placenta</u>.

	MOR, psi		MOE, psi x 1000		WORK, in.-lb.	
	Average	Coefficient Variation,%[2]	Average	Coefficient Variation,%	Average	Coefficient Variation,%
Control	7575(259) a[1]	3.4	1703(131) a	7.7	13(2) a	12.1
Month: 1	7488(557) a	7.4	1438(50) b	3.5	15(4) a	29.0
3.6	7266(477) ab	6.6	1314(109) b	8.3	13(4) a	28.2
5.1	6447(592) b	9.2	1498(145) ab	9.7	9(2) a	24.3
7.4	6431(1080)b	16.8	1539(178) a	11.6	10(5) a	48.4

[1] Values in parentheses are standard deviation. If followed by the same letter, average strength values in the same column are not significantly different = 0.05), Newman - Keuls method.

[2] Coefficient of variation is the ratio of the standard deviation to the average.

Table III-3. Longitudinal compression strength (LCS) and fungal density of Douglas-fir sapwood from beams 0 to 12 months after inoculation with a mycelial suspension of <u>Stereum sanguinolentum</u>.

	LCS		Fungal Density (# of colonies)	
	Average	Coefficient of Variation, %[2]	Average	Coefficient of Variation, %
Control	417(24) a[1]	5.7	0(0) a	0
Month: 1	414(24) a	5.8	5(5) ab	92.1
3	375(21) b	5.7	8(5) b	60.8
5	368(15) bc	4.1	21(9) c	43.9
7	350(19) bcd	5.3	17(6) c	34.4
10	342(25) cd	7.4	21(8) c	37.8
12	325(19) d	5.8	10(6) c	30.1

[1] Values in parentheses are standard deviation. If followed by the same letter, average strength values in the same column are not significantly different (p = 0.05), Newman-Keuls method.
[2] Coefficient of variation is the ratio of the standard deviation to the average.

Table III-4. Longitudinal compression strength (LCS) and fungal density (CC) of Douglas-fir heartwood from beams 0 to 7 months after inoculation with a mycelial suspension of _Postia placenta_.

	LCS		Fungal Density (# of colonies)	
	Average	Coefficient of Variation, %[2]	Average	Coefficient of Variation, %
Control	485(13) a[1]	2.7	0(0) a	0
Month: 1	485(10) a	2.0	8(4) b	50.8
3.6	492(9) a	1.7	9(5) b	58.8
5.1	451(25) b	5.4	13(7) b	53.8
7.4	467(19) ab	4.0	5(7) ab	147.0

[1] Values in parentheses are standard deviation. If followed by the same letter, average strength values in the same column are not significantly different (p = 0.05), Newman-Keuls method.

[2] Coefficient of variation is the ratio of the standard deviation to the average.

B. EFFECT OF KERFING ON PERFORMANCE OF DOUGLAS-FIR UTILITY POLES IN THE PACIFIC NORTHWEST

Preservative treatment of round wood using pressure processes under the standards of the American Wood Preserver's Association (AWPA) generally produces a shell of treated sapwood surrounding an untreatable heartwood core (AWPA). The treated shell varies in thickness depending upon the wood species and sapwood thickness, with southern or ponderosa pine producing wide shells and Douglas-fir, Lodgepole pine, or western redcedar producing the shallowest. Poles are often treated while the inner core of the pole is at a moisture content greater than it will be once placed in service. Because of the times required, seasoning of poles to in-service moisture levels prior to treatment is not economical. Following treatment, this inner core continues to dry, creating internal drying stresses which lead to the development of deep checks. These checks often extend beyond the depth of initial preservative treatment, permitting the entry of moisture, fungi, and insects into the untreated heartwood core. Under most conditions, a large percentage of poles will develop some degree of internal decay.

In the early 1960's, the problems associated with deep checking and subsequent internal decay of Douglas-fir poles threatened the continued use of this species and encouraged a number of Pacific Northwest utilities to explore methods for preventing deep checking. The research identified three methods for improving the performance of this pole species; deep incising or radial drilling to improve the uniformity of preservative treatment, through boring to completely treat specific high decay hazard zones, and kerfing to relieve drying stresses prior to treatment. Of these approaches, only kerfing actually reduces the degree of checking, while the remaining treatments increase the degree of preservative penetration to overcome the impact of checking and internal decay.

Kerfing involves making a sawcut to the pith of the pole along one face, normally from the butt to some point above the groundline prior to preservative treatment (Figure III-6). A chainsaw is normally used for this process and the costs are quite low. The kerf results in some treatment of the heartwood, but its primary function is to relieve drying stresses and limit the development of other, deep checks. Previous research has shown that the kerf shrinks and swells seasonally with changes in moisture, and that kerfed poles have significantly lower degrees of checking. In one field test, kerfed poles were found to have significantly lower levels of fungal colonization 20 years after installation; 2.5% of kerfed poles experienced internal decay while 12% of non-kerfed poles were internally decayed. Despite this excellent performance, only one utility in the United States employs kerfing in their pole specifications. This utility, Consumer's Power, Inc. (Philomath, OR) adopted kerfing for all poles longer than 15m in 1966, and recently completed an inspection of kerfed and non-kerfed poles within their system. All poles longer than 15m are kerfed to the pith center

from the butt to a point 1.5m above the groundline and two 5 cm deep by 0.45m long saw kerfs are cut into the pole top 80 degrees apart. Four years ago, this specification was broadened to include all poles purchased regardless of length. Previous reports have demonstrated that performance of through-bored poles, but there are no reports on the field performance of kerfed poles.

Douglas-fir poles (Psuedotsuga menziesii (Mirb.) Franco) treated with either pentachlorophenol in AWPA Standard P9 Type A oil or creosote were inspected after 0 to 25 years in service. Poles of all lengths were inspected, including both kerfed and non-kerfed poles. The poles were exposed in the Willamette Valley in Northwestern Oregon. The climate in this valley is maritime, with rainfall ranging from 112.5 to up to 250 inches per year, with most of the precipitation occurring during the winter months.

A series of steep angled, 1.875 cm diameter holes were drilled into the pole beginning at the groundline and progressing upward at 0.3m intervals and spiraling about the pole 90 degrees. The presence of internal voids was noted by either the torque release of the electric drill or by examination of the drilled hole using a shell depth indicator. The extent of any decay pocket was noted and, where necessary, additional holes were drilled around the void to more completely assess the extent of decay. Each hole was subsequently treated with Vapam or chloropicrin to control any existing fungal attack or to prevent the possibility of future invasion.

The inspection data was recorded along with pertinent data on pole class, length, and circumference. Some poles also experienced termite or Buprestid beetle attack, but some degree of fungal attack was almost always associated with the damage and these poles are included in the total percentage of poles containing internal decay. Because a comparable set of non-kerfed poles of the

same ages and classes was not available within the Consumer's Power system, a set of data from Douglas-fir utility poles owned by other utilities in the Willamette Valley and inspected by Osmose Wood Preserving, Inc. was used for comparison. These inspection results were available by years of service, but pole length and class were not included in this data. The extent of decay varied widely in poles, and any pole which contained a detectable decay pocket was counted as decayed.

The results of inspections of 1791 kerfed poles in the Consumer's Power system revealed that only 2.8% of these poles contained internal decay voids (Table III-5). This figure represents 50 poles, four of which contained pockets of a size warranting replacement. In some instances, these decay pockets appeared to have begun above the kerfed zone, then progressed downward. Above ground decay is a common problem in poles in the Willamette Valley, owing to the wet winters and high frequency of wind driven rain which creates conditions conducive to fungal growth.

The rate of internal decay in kerfed poles appeared to increase with service life, peaking at 5.8% in poles between 16 and 20 years of age, but remaining extremely low for the first 15 years. Most utilities perform their first maintenance inspection between 10 and 15 years years after installation. By judicious application of fumigants at the time of the first inspection and at 10 year intervals thereafter, our results suggest that a utility could virtually eliminate the possibility of internal decay in the groundline zone of kerfed Douglas-fir poles.

The degree of internal decay in kerfed poles appeared to increase with increasing pole diameter or class. Class 1 poles experienced nearly twice the rate of internal decay found in class 2, 3, or 4 poles. Class 4 poles contained

the lowest levels of internal decay (0.5%). The effects of pole size on the rates of internal decay can be clearly illustrated by the performance of non-kerfed distribution poles within the Consumer's Power system. These poles (in classes 3 through 6) experienced internal decay rates which were similar to those found with the kerfed poles, suggesting that kerfing was not necessary (Table III-6). However, it is more likely that smaller diameter poles are less likely to check as deeply, that these poles are drier at the time of treatment, and that the checks are less likely to penetrate beyond the treated shell.

The data supplied on non-kerfed transmission poles exposed in the Willamette Valley clearly illustrated the benefits of kerfing larger diameter poles (Table III-7). Over 19 percent of the transmission poles in the non-kerfed comparison sample contained evidence of internal decay, with nearly 9.6 percent of these having decay voids sufficient for rejection. Although it was not possible to delineate pole age or class to the same degree, non-kerfed poles experienced a decay rate which was nearly 7 times that found with kerfed poles.

Kerfing provides a simple, but highly effective means for controlling the development of deep checks which penetrate beyond the depth of initial preservative treatment. As such, kerfing is an excellent method for limiting the development of internal decay, particularly in larger diameter poles. Kerfing does not, however, prevent internal decay above the kerfed zone. Full length kerfing has been tested but has not been advocated because the kerf presents a climbing hazard to linemen. This risk can be minimized by limiting the kerf to a zone extending 1.5m above groundline. While kerfing can be used on all poles, the inspection results from this survey suggest that the benefits are greatest in larger diameter poles.

Table III-5. Condition of kerfed pentachlorophenol or creosote treated Douglas-fir transmission poles (>15 m long) 0 to 25 years after installation, as determined by coring above and below the groundline.

Pole Class[a]	Pole Length (m)	Percentage of Poles with Internal Decay[b]					
		0-5 yrs	6-10 yrs	11-15 yrs	16-20 yrs	21-25 yrs	TOTAL
1	15.0	–	–	0.0 (1)	33.3 (3)	0.0 (1)	20.0 (5)
	16.5	–	–	–	0.0 (1)	–	0.0 (1)
	18.0	–	0.0 (5)	–	16.7 (30)	0.0 (12)	11.1 (47)
	19.5	–	0.7 (144)	0.0 (3)	12.8 (39)	0.0 (9)	3.1 (195)
	21.0	–	0.0 (31)	0.0 (3)	15.0 (20)	0.0 (11)	4.6 (65)
	22.5	–	4.2 (24)	0.0 (1)	33.3 (6)	0.0 (1)	9.4 (32)
	24.0	–	0.0 (22)	0.0 (2)	0.0 (4)	–	0.0 (28)
	25.5	–	0.0 (3)	–	0.0 (2)	–	0.0 (5)
	27.0	–	0.0 (2)	–	–	–	0.0 (2)
	28.5	–	–	–	0.0 (2)	–	0.0 (2)
2	13.5	0.0 (3)	–	0.0 (3)	0.0 (1)	–	0.0 (7)
	15.0	–	–	0.0 (3)	0.0 (23)	2.4 (42)	1.5 (68)
	16.5	–	–	0.0 (6)	0.0 (84)	0.0 (16)	1.9 (106)
	18.0	0.0 (1)	0.0 (43)	5.5 (18)	0.0 (103)	8.9 (45)	1.9 (210)
	19.5	–	0.0 (8)	0.8 (120)	4.9 (162)	0.0 (32)	2.8 (322)
	21.0	–	3.7 (27)	0.0 (56)	10.0 (50)	0.0 (11)	4.2 (144)
	22.5	–	0.0 (10)	0.0 (20)	5.5 (18)	0.0 (2)	2.0 (50)
	24.0	–	0.0 (2)	0.0 (18)	100.0 (1)	–	4.8 (21)
3	12.0	–	0.0 (1)	–	–	–	0.0 (1)
	13.5	0.0 (3)	0.0 (2)	0.0 (1)	–	0.0 (8)	0.0 (14)
	15.0	0.0 (39)	0.0 (16)	0.0 (90)	2.7 (36)	7.8 (38)	1.8 (219)
	16.5	0.0 (3)	0.0 (1)	0.0 (9)	9.5 (21)	0.0 (5)	5.1 (39)
	18.0	–	0.0 (1)	0.0 (1)	22.2 (9)	–	18.2 (11)
	19.5	0.0 (4)	0.0 (1)	0.0 (1)	–	–	0.0 (6)
4	12.0	0.0 (35)	–	0.0 (2)	0.0 (1)	0.0 (2)	0.0 (40)
	13.5	0.0 (6)	0.0 (4)	0.0 (2)	0.0 (3)	0.0 (14)	0.0 (29)
	15.0	0.0 (12)	0.0 (2)	0.0 (14)	1.3 (75)	0.0 (2)	1.0 (105)
	16.5	–	–	–	0.0 (13)	0.0 (4)	0.0 (17)
TOTAL		0.0 (106)	0.6 (349)	0.5 (374)	5.8 (707)	3.5 (255)	2.8 (1791)

[a] Pole classes and lengths as per ANSI.
[b] Values in parentheses represent the number of poles inspected.

Table III-6. Condition of non-kerfed pentachlorophenol or creosote treated Douglas-fir distribution poles (<15 m long) 0 to 25 years after installation, as determined by coring above and below the groundline.

Pole Class[a]	Pole Length (m)	Percentage of Poles with Internal Decay[b]					
		0-5 yrs	6-10 yrs	11-15 yrs	16-20 yrs	21-25 yrs	TOTAL
3	10.5	0.0 (1)	0.0 (1)	0.0 (1)	0.0 (1)	-	0.0 (4)
	12.0	-	-	-	0.0 (7)	100.1 (1)	12.5 (8)
	13.5	0.0 (3)	0.0 (3)	-	0.0 (3)	0.0 (8)	0.0 (17)
4	10.5	-	0.0 (2)	0.0 (4)	0.0 (11)	0.0 (1)	0.0 (18)
	12.0	0.0 (35)	1.0 (99)	2.2 (357)	4.5 (402)	9.7 (144)	4.0 (1037)
	13.5	0.0 (12)	2.2 (46)	1.6 (188)	3.4 (207)	4.3 (47)	2.6 (500)
5	7.5	-	-	0.0 (2)	-	0.0 (1)	0.0 (3)
	9.0	-	0.0 (2)	0.0 (6)	0.0 (7)	0.0 (4)	0.0 (19)
	10.5	0.0 (3)	0.0 (19)	0.0 (33)	0.0 (24)	0.0 (8)	0.0 (87)
	12.0	0.0 (66)	0.0 (102)	1.3 (316)	1.9 (641)	9.0 (210)	2.6 (1337)
	13.5	0.0 (7)	0.0 (14)	4.8 (21)	0.9 (22)	12.5 (24)	6.8 (88)
6	7.5	-	0.0 (1)	-	-	-	0.0 (1)
	9.0	0.0 (60)	1.6 (61)	0.4 (252)	3.2 (441)	4.9 (82)	2.2 (896)
	10.5	0.0 (7)	0.0 (6)	0.0 (4)	9.1 (11)	-	3.6 (29)
	12.0	-	0.0 (2)	0.0 (1)	0.0 (6)	-	0.0 (9)
7	9.0	-	-	-	0.0 (1)	-	0.0 (1)
	10.5	-	-	-	0.0 (1)	-	0.0 (1)
TOTAL		0.0 (194)	0.8 (357)	1.4 (1186)	3.0 (1785)	5.1 (513)	2.9 (4055)

[a] Pole class as per ANSI specifications.

[b] Values in parentheses represent the number of poles inspected.

Table III-7. Incidence of internal decay in Douglas-fir transmission poles exposed for 0 to 25 years in the Willamette Valley in Northwestern, Oregon.

Years in service	% Poles Containing Internal Decay[a]
0-5	1.3 (229)
6-10	4.8 (396)
11-15	17.6 (694)
16-20	20.6 (1121)
21-25	26.8 (1115)
TOTAL	19.0 (3555)

[a] As determined by drilling a series of holes from groundline upward. Values in parentheses represent number of poles inspected.
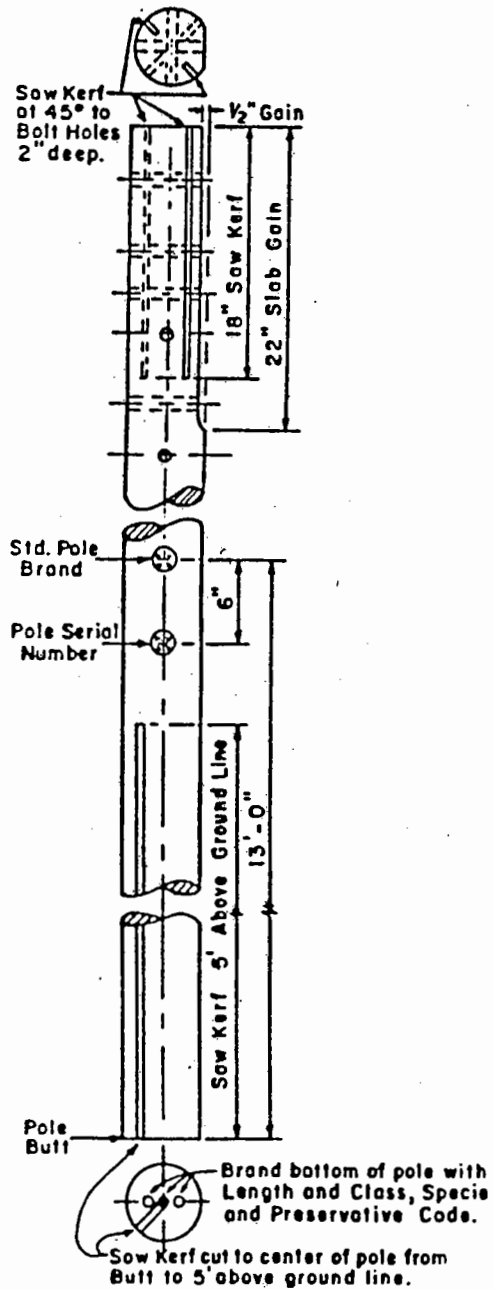
Figure III-6.   Schematic of kerfing specification used prior to preservative treatment of Douglas-fir poles.

OBJECTIVE IV
EVALUATE THE POTENTIAL FOR DECAY DEVELOPMENT DURING
AIR SEASONING AND IDENTIFY CONTROL STRATEGIES

A. EVALUATE THE POTENTIAL FOR INFECTION AND DECAY DEVELOPMENT
IN AIR-SEASONING DOUGLAS-FIR POLES.

1. <u>Basidiomycete Colonization of Douglas-fir poles following dip or spray
treatments with sodium octaborate tetrahydrate:</u> Air-seasoning is commonly used
to remove moisture from the sapwood of poles and large timbers prior to
treatment. Bark provides an excellent barrier against fungal invasion and its
removal at the start of air seasoning exposes a large volume of wood to fungal
colonization. Previous studies indicate that virtually all Douglas-fir logs
exposed in air-seasoning yards are colonized by Basidiomycetes within one year
and that the incidence of fungi colonization steadily increases between 1 and
3 years. While these fungi have only minimal effects on wood strength, their
presence creates the need to insure that treatment temperatures are sufficient
to kill any fungi which become established during air-seasoning. As an
alternative, flooding the freshly peeled logs with concentrated solutions of
ammonium bifluoride has sharply limited fungal colonization, but industry
concerns about leaching of fluorides into the soil and the absence of an
applicable label from the Environmental Protection Agency have prevented
application of this technique. One approach to overcome this problem is the use
of sodium octaborate tetrahydrate (borate). This chemical has extremely low
mammalian toxicity, can diffuse through wet wood and should be capable of moving
into the wood to checks as they open. Borates are used worldwide to protect
freshly sawn timber from insect and fungal attack, but their use in the United
States has been limited. The ability of borates to protect air-seasoning
Douglas-fir logs was evaluated in the following study.

One hundred twenty freshly peeled Douglas-fir (Psuedotsuga menziesii) (Mirb.) Franco) pole sections (25-30 cm in diameter by 2.4 m long) were obtained from commercial preservative treating companies located in the Willamette Valley of Northwestern Oregon. Increment cores were removed at 15 cm intervals around the circumference 30 cm in from each end of the pole section. These cores were placed on 1.5% malt extract agar (MEA) and observed for the presence of basidiomycetes, a subdivision of fungi containing many important wood decayers. The outer 30 cm on each end of the pole was removed and the freshly cut ends were sealed with an elastomeric paint. The pole sections were then subjected to one of a series of dip or spray treatments with disodium octaborate tetrahydrate (Table IV-1). Sprayed pole sections were flooded on the upper surface with 10% boric acid equivalent solution of borate, while dipped samples were submerged for 3 minutes in 20% boric acid equivalent of borate. Each treatment was replicated on 5 pole sections per time point per test site. Thirty pole sections were left untreated to serve as controls. The pole sections were exposed, above ground, for one, two, or three years at Corvallis, Oregon. A second set of Timbor dipped and untreated control poles were exposed at Oroville, California. The Corvallis site represents a typical Willamette Valley test site, with cool moist winters and warm dry summers. The Oroville site experiences lower precipitation and warmer temperatures. Previous tests indicate that basidiomycete colonization is significantly lower at the Oroville site.

At each time point, five pole sections from each treatment group were sampled at each exposure site. The sections were sampled by removing increment cores at 15 cm intervals around the circumference every 15 cm along the length of each section. These cores were plated on 1.5% MEA. The plates were observed

Table 1. Schedule for treatment of Douglas-fir pole sections with sodium octaborate tetrahydrate

Treatment[a]	Months of Air-Seasoning[b]						
	0	6	12	18	24	30	36
spray	X		Sample	-	-	-	-
spray	X	X	Sample				
spray	X	X	-	-	Sample		
spray	X	X	-	-	-	-	Sample
spray	X	X	X	X	Sample		
spray	X	X	X	X	X	X	Sample
spray	-	X	Sample				
spray	-	X	-	-	Sample		
spray	-	X	-	-	-	-	Sample
control	-	-	Sample	-	Sample	-	Sample
spray	X	-	-	-	Sample		
spray	X	-	-	-	-	-	Sample
spray	X	-	X	-	Sample		
spray	X	-	X	-	X	-	Sample
spray	X	X	-	X	Sample		
spray	X	X	-	X	-	-	Sample
dip	X	-	Sample	-	Sample	-	Sample

[a]Spray treatments were applied as 10 percent boric acid equivalent (BAE) solutions of Timbor, while dip treatments involved 3 minute immersions in 20 percent BAE solutions.

[b]"X" denotes treatment and "-" denotes no treatment. Five poles per treatment were removed at each sampling date.

for the presence of basidiomycetes. Particular attention was paid to the presence of Antrodia carbonica, an important decayer of Douglas-fir heartwood. Initial levels of fungal colonization in poles from the various treatment groups ranged from 0 to 34% at the time of treatment. Since the borate treatments must be applied when the pole sections are as wet as possible and culturing of increment cores took a minimum of 1 month, the initial levels of fungal colonization could not be uniformly distributed among the various treatments. As expected from previous studies, the untreated sections exposed

at Corvallis were increasingly colonized over the three year period, while those at Oroville experienced little or no fungal attack (Table IV-2). Oroville has very dry summers coupled with elevated temperatures which make extensive fungal attack unlikely. In general, application of borates at some point during the air-seasoning period reduced the incidence of Basidiomycete colonization in nearly all treatments exposed at Corvallis, although the effects were sometimes small. In one treatment, poles sprayed 6 months after peeling experienced levels of colonization which were greater than the untreated controls. Borates diffuse best through wet wood, and any delay between peeling and treatment could reduce wood moisture content and limit diffusion. Delaying spraying 6 months undoubtedly reduced surface moisture contents and limiting subsequent boron diffusion.

Of the chemical treatments, dipping or regular spraying with borate at 6 month intervals were associated with the lowest levels of fungal colonization over the test period. The effects of regular retreatments appeared to be temporary, as evidenced by the increased colonization within one year after treatments were stopped. Although some solution collected in the checks, the majority of chemical from the spray treatments ran off the surface and onto the ground. Thus, relatively little chemical was left to diffuse into the wood as seasoning checks opened. Regular spraying at 6 month intervals replenished the surface coating, providing additional chemical for diffusion in the wood. It was interesting to note that the incidence of A. carbonica steadily increased in all treatments but those which received continued spray treatment (Table IV-3). While dipping provided a reservoir of chemical on the wood surface, the loadings were apparently not sufficient to protect checks which opened as the pole

Table IV-2.   Basidiomycete colonization of Douglas-fir pole sections treated with borates and air seasoned for one to three years at Oroville, CA or Corvallis, OR.

Treatment Schedule	Percent Cores Colonized[a]		
	Exposure Period (years)		
	1	2	3
Corvallis Site			
Spray (Mo. after peeling)			
Control	23(12)	59(10)	87(11)
0	13(16)	48(25)	69(5)
6	14(9)	63(13)	83(13)
0-6	19(23)	43(13)	61(19)
0-12	-	34(13)	-
0-6-18	-	39(34)	61(7)
0-12-24	-	-	43(25)
0-6-12-18-24-30	-	-	24(14)
DIP			
0	9(0)	47(0)	30(3)
Oroville Site			
Control	9(5)	1(5)	9(2)
DIP 0	5(9)	1(5)	3(5)

[a]Numbers in parentheses are the isolation frequencies from the same poles before treatment.

Table IV-3. Incidence of <u>Antrodia</u> <u>carbonica</u> in Douglas-fir pole sections dipped or sprayed with sodium octaborate tetrahydrate and seasoned for one, two, or three years in Corvallis, Oregon.

| Chemical Treatment | % of cores infested with <u>A</u>. <u>carbonica</u> | | |
| | Years after peeling | | |
	1	2	3
Control	0.4	10.8	17.6
Spray Schedule (Months after peeling)			
0	1.1	3.4	10.1
6	0.2	4.8	15.7
0,6	0.2	0.9	13.1
0,12	-	3.9	-
0,6,18	-	3.4	8.3
0,6,12,18	-	0.7	-
0,12,24	-	-	3.3
0,6,12,18,24,30	-	-	1.7
DIP	0	4.7	13.0

seasoned. <u>Antrodia</u> <u>carbonica</u> and a second organism, <u>Postia</u> <u>placenta</u>, are important decayers of Douglas-fir products and preventing their colonization will reduce the risk that these fungi will survive subsequent treating cycles. In this regard, even dipping delayed colonization by <u>A</u>. <u>carbonica</u> for one year, reducing the risk that any wood damage will occur during seasoning.

While chemical treatments of poles exposed at Oroville reduced the levels of colonization, both the controls and treated pole sections were sparsely colonized after 3 years. Poles at Oroville rarely need more than 1 year of air-seasoning and the sparse colonization of untreated controls suggests that dipping in borate would not be cost effective at this site.

The results suggest that dipping poles shortly after peeling or regular spraying of the upper surface of air-seasoning poles with concentrated borate solutions provides a barrier to invasion by many decay fungi. The concentrated boron would then diffuse from the surface and protect checks as they open in the wood. Boron diffusion into the heartwood may provide additional benefits by increasing the decay resistance of the wood, although this possibility was not directly addressed in this study.

In light of the labor involved in spraying and the need to carefully control the release of any pesticides in the pole yard, dipping freshly peeled logs would appear to be the most practical method for limiting fungal invasion during air-seasoning. Boron treatments should reduce the incidence of basidiomycetes, but do not completely prevent colonization. Thus, poles must be sterilized at some point during the treatment cycle to insure that any fungi present are eliminated.

B.   ABILITY OF CURRENT TREATMENT PRACTICES TO ELIMINATE DECAY FUNGI WHICH BECOME ESTABLISHED DURING AIR-SEASONING OF DOUGLAS-FIR

1. **Survival of decay fungi in Douglas-fir blocks exposed to elevated temperatures:** The variety of fungi which colonize air-seasoning Douglas-fir poles place added importance on the need to adequately heat the pole at some point during the treatment process. Generally, a temperature of 65.6°C for at least 75 minutes at the pith center has been proposed for eliminating decay fungi which become establish between the time of cutting and treatment. This value was based upon laboratory tests

performed on fungi colonizing southern pine and may not accurately reflect the conditions necessary for eliminating fungi colonizing Douglas-fir.

The ability of the four fungi most commonly isolated from air-seasoning Douglas-fir poles was evaluated by inoculating Douglas-fir heartwood and sapwood blocks (2.5 by 2.5 by 5 cm long) with one of four fungi. The fungi tested were Postia placenta, Antrodia carbonica, Peniophora spp., and Stereum sanguinolentum. The former two fungi were tested on heartwood, while the latter two species were tested on sapwood. The colonized blocks were sealed in plastic bags which were immersed in a water bath maintained at the desired temperature. A thermocouple inserted in the center of one block was used to monitor internal temperature. Blocks were exposed for periods varying from 15 minutes to 48 hours at the target temperature. Each block was then cut in half and a 0.5 cm thick section was cut from the center zone. The section was cut into 16 equal sized cubes which were placed onto potato dextrose agar and observed for evidence of fungal growth which was used as the measure of temperature tolerance.

Last year, we reported on the results with A. carbonica and P. placenta, illustrating that both fungi were able to survival fairly long exposures to lower temperatures, but succumbed to elevated temperatures (65.6 C) after one hour of exposure ('89 Ann. Rept., pg. 103-105). Longer exposures to moderate temperatures (60 to 62.8 C) were also capable of eliminating these fungi, suggesting that the longterm heating at lower temperatures associated with some treatments may be sufficient for sterilization.

Both Peniophora spp. and S. sanguinolentum were far more sensitive to elevated temperatures than the heartwood colonizing fungi, succumbing to exposures to 54.4 C for as little as 15 minutes (Table IV-4, Figure IV-1). Stereum sanguinolentum appeared to be slightly more temperature tolerant than Peniophora; however, both species exhibited little evidence of temperature tolerance. Even short term exposures to the

lowest temperature tests dramatically reduced fungal survival. Neither of these fungi produces survival structures such as chlamydospores. Chlamydospores are thick-walled structures which some fungi produce under adverse environmental conditions. These structures permit the fungus to survive until conditions for growth are more favorable. Both P. placenta and A. carbonica produce chlamydospores in wood. The absence of these structures in the two sapwood colonizing species apparently renders these fungi highly sensitive to environmental extremes. In the natural environment, these fungi are characterized by rapid colonization of freshly exposed sapwood and remain active only while readily available carbohydrates are present in the wood. Under these circumstances, the production of longterm survival structures is of little use, since the wood substrate would no longer support the fungus once conditions again became favorable for growth.

The results indicate that neither of the fungi which most commonly colonize sapwood in air-seasoning Douglas-fir poles are capable of surviving the treatment process when elevated temperatures (>48.9 C) are employed. The evaluations of all four fungi indicate that heating the pith center of the wood to temperatures equal or greater to 65.6 for as little as one hour should eliminate these species from the wood.

Table IV-4. Effect of elevated temperature exposure on survival of Postia placenta, Antrodia carbonica, Peniophora spp. or Stereum sanguinolentum in Douglas-fir heartwood or sapwood blocks.

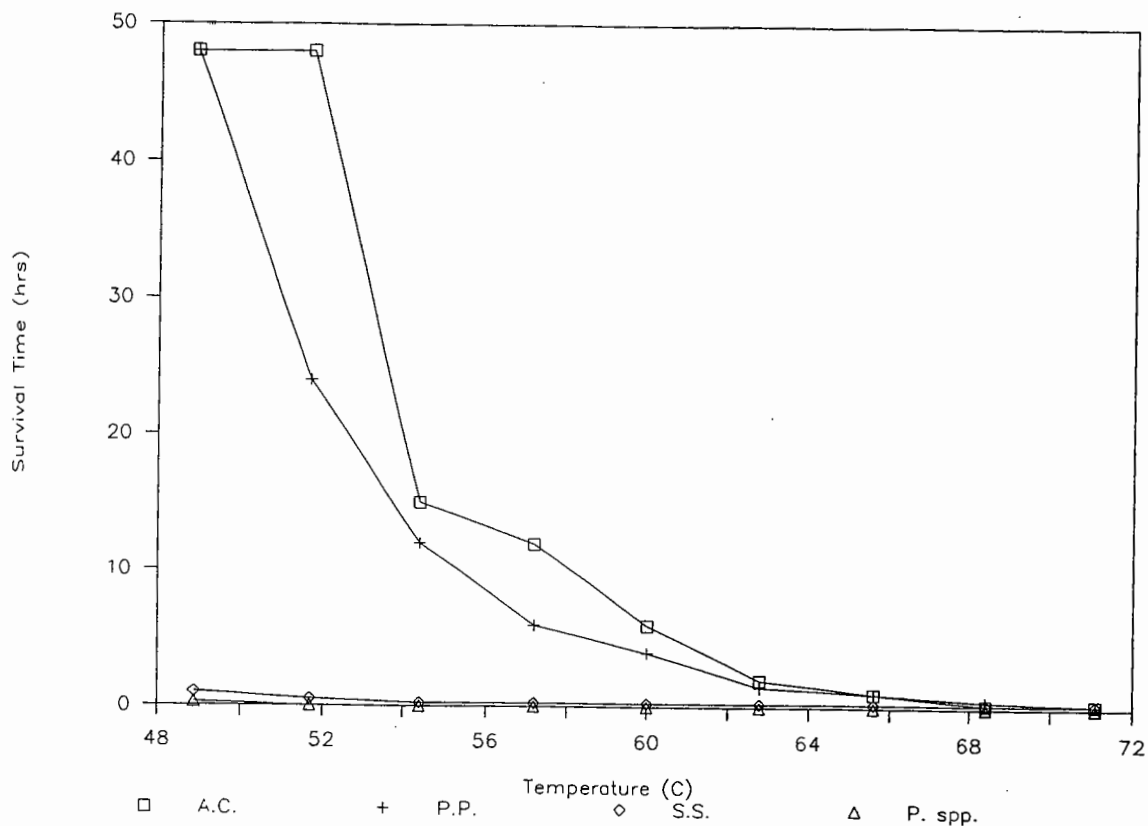| Exposure Temperature (c)	Exposure Period for killing (hrs)			
	A. carbonica	S. sanguinolentum	P. placenta	Peniophora spp.
48.9	48	1.0	48	0.25
51.7	48	0.5	24	0
54.4	15	0.25	12	0
57.2	12	0.25	6	0
60.0	6	0.25	4	0
62.8	2	0.25	1.5	0
65.6	1	0.25	1	0
68.4	0.25	0.25	0.5	0
71.1	0.25	0.25	0.25	0

Figure IV-1. Ability of <u>A</u>. <u>carbonica</u>, <u>P</u>. <u>placenta</u>, <u>Peniophora</u> spp. or <u>S</u>. <u>Sanguinolentum</u> established in Douglas-fir heartwood or sapwood blocks to survive exposure to temperatures ranging from 48.9 to 71.1°C.

2. <u>Survival of basidiomycetes in Cellon-treated Douglas-fir heartwood:</u> Until recently, the Cellon process, which uses liquified petroleum gas as a preservative carrier, was commonly used to treat utility poles with pentachlorophenol, and for a brief time, with copper naphthenate. Poles treated by this process must be dry before treatment and are first either air-seasoned or kiln dried. In Douglas-fir (<u>Pseudotsuga</u> <u>menziesii</u> (Mirb.) Franco), this seasoning period presents the opportunity for colonization by basidiomycetes, which must then be eliminated during the treatment process. While sterilization is generally assured by treatment cycles using Boulton-seasoning or conditioning with the heavy oil solvents specified under the American Wood-Preservers'

Association Standard P9 Type A, the less severe treatment conditions of the Cellon process have been thought to present the opportunity for fungal survival.

Although the Cellon process is no longer commercially used, more than 1 million poles treated by this process remain in service. We wondered if these poles were of higher risk of developing internal decay because of survival of fungi that colonized the wood during the air-seasoning process. To examine this problem, we evaluated internal temperature development during the Cellon process and the effects of various components of the cycle on elimination of basidiomycetes from the wood.

Internal temperatures during the Cellon process were monitored in two 2.4-m-long Douglas-fir pole sections (45 cm in diameter) that were end sealed with an epoxy resin. Six holes 0.95 cm in diameter were drilled perpendicular to the grain to depths of 7.5, 12.5, and 20.5 cm along the upper surface of each pole, at least 60 cm from the ends. Copper-constantin thermocouples were then placed in a lengthwise notch in one set of 2.5-cm-long dowels. The notched dowels were driven to the bottom of the holes, which were filled with Dow Corning silicone rubber to within 3.75 cm of the surface. The center-drilled dowels were then driven into the holes, and the remaining 1.25 cm was filled with a two-part epoxy resin. The sealants were allowed to cure at least 24 hours before the poles were exposed in a commercial treatment cylinder. Thermocouple wires threaded from the cylinder through Teflon-lined stainless-steel fittings in a specially constructed flange were connected to a CR 21X Micro Data Logger that recorded temperature every 10 seconds and average readings every 15 minutes. This arrangement permitted monitoring of internal wood temperature during the pressure process. The poles were evaluated in one commercial charge under the following conditions: vacuum (15 minutes), purge (10 minutes), vacuum (35 minutes), fill

and begin pressure (2 hours), pressure period (9 hours @ 82.2°C), empty cylinder (3 hours @ 82.2°C), vapor recovery (3.5 hours @ 82.2°C), and vacuum (3 hours). An oil wash was then applied by filling the cylinder (1 hour), raising the oil temperature to 82.2°C, and pumping out the oil (1.5 hours). The conditions were then: vacuum (30 minutes), steam (4 to 5 hours @ 110°C), vent (30 minutes), and final vacuum (1.5 hours). The entire cycle covered 80 hours.

Fungal survival was evaluated in three trials. First, two Douglas-fir poles treated by the Cellon process were sampled by removing 34 increment cores every 62.5 cm along the length of each pole before and after the treatment. These matched cores were cultured for the presence of Basidiomycotina, a group of fungi containing many important wood decayers, in order to establish the extent of initial colonization during air-seasoning and survival after treatment.

Second, fungal survival was evaluated in an experimental retort during a modified Cellon process. We inserted 5-cm-long dowels colonized by the decay fungus, Postia placenta , in the center of 18 Douglas-fir pole sections 0.35 m long by 20 cm in diameter, plugged each hole with a small wood spacer, filled the hole with silicone, and stopped it with a second wooden dowel. The ends of each section were end-coated with epoxy and cured for 24 hours. The pole sections were treated with butane/isopropyl ether solvent in nine charges under various combinations of vacuum and pressure (Table IV-5). Samples in charge 9 were treated with copper naphthenate in butane/isopropyl ether to determine if the chemical penetrated the dowels along the epoxy seals. The dowels were removed following treatment, aerated to release residual chemical vapors, and cultured on 1-percent malt extract agar (MEA). The extent of fungus survival was used as the measure of treatment effectiveness.

Third, survival was investigated by exposing dowels infested with P. placenta over 50 ml of Cellon cosolvent isopropyl ether in small glass jars at room temperature for as long as 108 hours. Three dowels were removed at selected time points and cultured on 1-percent MEA. The extent of fungus survival was again used as the measure of treatment effectiveness.

The second and third trials were undertaken also to determine if the cosolvent contributed to treatment effectiveness.

Internal temperature in the two Douglas-fir poles receiving the Cellon treatment never exceeded 60°C at the pith center (Fig. IV-2); however, the wood at the pith center remained at or above 48.9°C for approximately 8 hours. Cultures of cores removed before treatment revealed that 18 percent from one pole and 50 percent from the other contained Basidiomycotina, while no cores removed after treatment contained active fungi.

The effects of long exposure to elevated temperature on fungus survival in Douglas-fir are poorly understood; however, preliminary laboratory tests suggested that P. placenta could survive at least 48 hours at 48.9°C. According to American Wood-Preservers' Association Standard M1-88, the pith center of a wood pole should be heated to at least 65.5°C for a minimum of 1 hour to ensure elimination of decay fungi. Our results suggest that, while internal temperatures fail to reach levels considered necessary for eliminating fungi during the Cellon process, factors other than heat enhance sterilization.

Although the preservative does not penetrate to the pith center, the volatile solvent or cosolvent may penetrate beyond the zone of preservative treatment and provide some measure of sterilization. Poles treated by the Cellon process commonly retain some solvent, as shown by the odor when an older pole is cut up many years after treatment. Results of the modified Cellon treatment

indicated that a 1- to 4-hour pressure period at 60.0°C to 62.8°C, even without preservative, eliminated nearly all of the test fungi. Although the small dimension of the samples and the higher temperatures may have influenced the results, the test fungi were also eliminated from dowels in all test pieces exposed at 51.7°C (charges 5, 6, 7, 8, Table IV-5), which suggests that the solvent played a key role in sterilization. No evidence of epoxy failure was detected in any charge.

Culturing of the dowels infested with P. placenta revealed that the test fungus survived the maximum exposure period (108 hours) to isopropyl ether at room temperature. The absence of pressure and heat may have influenced the results.

Results of the three evaluations suggest that, while internal temperatures during the Cellon treatment process fail to reach those generally considered to be necessary for sterilization, the combination of solvent under pressure and lower temperatures appear to be sufficient for eliminating decay fungi from the wood. Sterilization is important for ensuring long service life of wood poles, and combined with pretreatment steps such as through-boring or kerfing to limit the development of checks, it can substantially improve the performance of wood poles.

3. **Modeling internal temperature changes of timber poles during ACA treatment**: Sterilization is generally considered achieved when all of the wood has been heated to at least 65.5°C for 75 minutes; however, the precise periods required to achieve these temperatures remain poorly defined. To overcome this problem, the specifications of the Rural Electrification Administration require that poles be heated to 65.5°C for 2 hours. This presents little problem when the treatment

Table IV-5. Survival (+) or death (-) of <u>Postia</u> <u>placenta</u> in dowels implanted in Douglas-fir pole sections treated with butane/isopropyl ether by a modified Cellon process.

Charge[a]	Pressure (psi)	Time (hr)	Temperature (°C)	Fungal survival or death[b]
1	110	1	62.8	-/-
2	110	2	62.8	-/-
3	100	3	60.0	+/-
4	100	4	60.0	-/-
5	80	1	51.7	-/-
6	80	2	51.7	-/-
7	80	4	51.7	-/-
8	80	6	51.7	-/-
9	80	3	51.7	-/-

[a]All cycles had a 30-minute initial vacuum and a 1-hour final vacuum. charges 1 and 2 had a 2.5-hour vapor recovery phase at 20 psi; all others a 2-hour recovery phase at 20 psi.
[b]Survival or death of the test fungus was determined by culturing dowels from two pole sections per charge: "+/-" represents survival in one of two dowels.
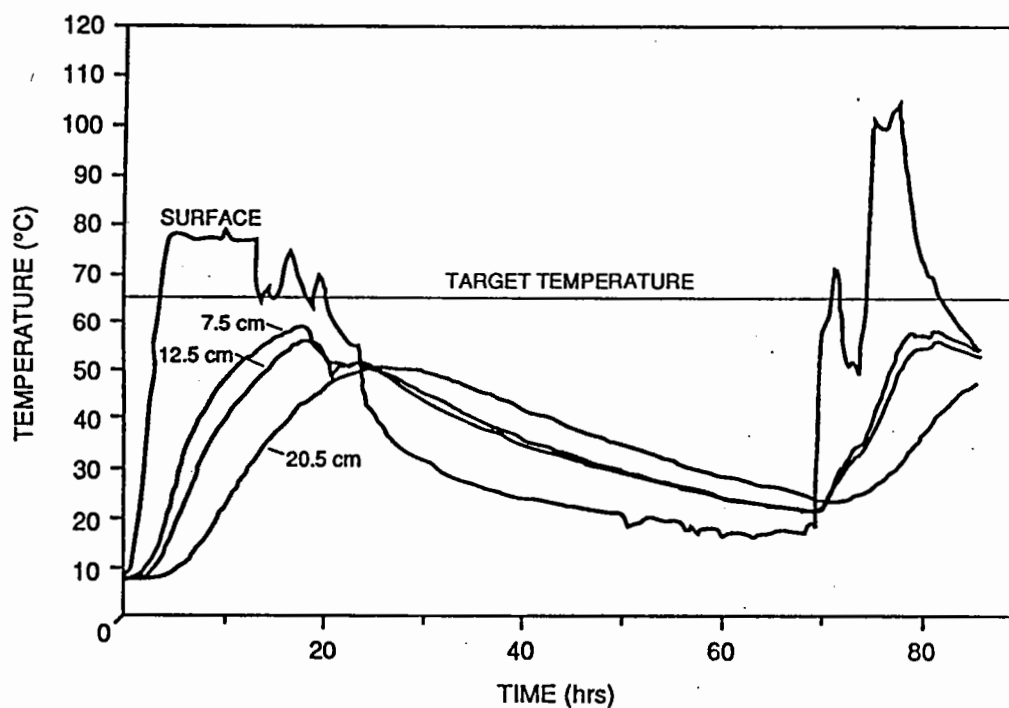
Figure IV-2. Surface temperature and internal temperatures measured by thermocouples at 7.5-cm, 12.5-cm, and 20.5-cm depth in two Douglas-fir pole sections during treatment with pentachlorophenol by the Cellon process.

cycles necessary to achieve adequate treatment are long and involve high temperatures (88 - 93°C), but causes some concern when the cycles involve only short heating periods. For example, the American Wood Preservers' Association recommendations for treatment with ammoniacal copper zinc arsenate (ACZA) or ammoniacal copper arsenate (ACA) formerly limited the steaming period to 6 hours (since increased to 8 hours). Although heated solution often is used after steaming, the solution temperature is generally lower than that required for sterilization and probably plays only an insulating role in the treatment process. Several recent studies suggest that the heating schedules initially developed by MacLean predict much faster heating rates than are actually recorded in poles. Improving the heating predictions used in these treatment systems would help insure that inadequately sterilized material does not reach the market.

Data of internal temperatures in Douglas-fir poles during treatment with ammoniacal copper arsenate previously collected during several commercial charges was examined in cooperation with E. Sahle-Demesse and Dr. K. Levien, Graduate Student and Assistant Professor, respectively, in the Department of Chemical Engineering. The sizes and moisture contents of the poles used in the experiments are given in Table IV-6. The moisture contents of the poles before steaming were low and ranged from 16 to 24%.

The results were reviewed to eliminate data from thermocouples whose leads had been severed during the treatment process or those which had been located too near checks in the wood. Since the model is not designed to predict temperatures near checks, these data sets were not used in the analysis.

The qualitative patterns of the initial temperature increases were as described in the literature. When steam was discontinued and the initial vacuum

was applied, the surface temperature suddenly decreased. Interior temperatures, however, continued to increase until the early pressure period, i.e., for an additional 3-4 hours after steaming was stopped. The length of this period of temperature rise depended on the size of the poles and the maximum surface temperature reached before the start of the vacuum period. In some cases the center temperature never reached 65.5°C, the sterilization temperature proposed by Chidester.

At positions near deep checks the temperature increased very sharply and dropped sharply during the vacuuming period, resembling temperature changes seen near the surface.

Analyses of data and model formulation: Developing a model that mathematically represents the physical phenomena of preservative treatments which rely on relatively short heating periods enables us to study how the main properties of the poles and the treatment variables are related. Although much work has been previously done in mathematical modeling preservative treatments, the accepted methods of treatment fail to bring the interiors of large diameter wood poles to the required temperature. Surface temperature was observed to decrease linearly with time, after steaming is stopped (Figure IV-3). As previously noted, the interior temperature of poles during the treatment process reaches its maximum early in the pressure period, some time after steaming has been stopped, and then decreases gradually. It is therefore important to determine the temperature -time-location relationships over the entire process. Previous modeling work considered only the steaming period. In order to extend the results to the entire treatment process, it was assumed that operational changes result in step changes in the surface temperatures of poles. However, actual measurements indicated that there is a lag between a change in an

operating condition and its observed effect on the surface temperature of the poles. This lag time is due to the thermal capacity of the process equipment and was found to be an important model element for accurate temperature prediction.

The initial heating-up time and the rates of surface temperature decrease during the initial vacuuming period and the first part of the pressure period were incorporated as model parameters. The resulting model was found to fit the measured data significantly better than previous models or other proposed models.

Prediction equations for time-temperature-location relations: Using the model with the mean estimated parameters, we can demonstrate important relations and make predictions. Based on the commonly used pressure treatment schedule for Douglas-fir poles with waterborne ammoniacal copper arsenate (ACA), the following recommendations were obtained using the results of modeling.

One of the objectives in modeling was to determine whether the treatment cycle resulted in sterilization. The minimum steaming time required to reach a maximum temperature of 65.5°C at various radial positions in the poles with diameters of 22.86, 30.48, 38.1, 45.72, 53.34, 60.96 cms. (9, 12, 15, 18, 21, 24 in.) are shown in Figure IV-5. These results indicate that the times required to reach 65.5°C at a depth of 15.24 cm (6 in.) were about 6.8, 12, 14.3 hours for poles with diameters of 30.48, 45.72, 53.34 cm respectively. Thus, for the same depth in poles of varying diameter, the minimum steaming time required to reach 65.5°C varies by a factor greater than 2. This result indicates that, in general, the previously presented time-depth relationship does not include the diameter of a pole as a variable and, thus, would predict the same required time of 9 hours to reach the desired temperature at given depth in all of the poles.

The minimum required steaming times to heat specific sites in poles to 65.5°C for two hours are plotted as a function of pole diameter for an assumed initial pole temperature of 18°C and a steam temperature of 115°C in Figure IV-6. An approximate equation for this relationship was obtained by using linear regression analysis after a logarithmic transformation of the power function. It is very important to note that, due to the various assumptions made, all prediction equations given here have about a $\pm$ 15 percent accuracy.

$$t_{stm} = 0.0039 \ D^2 \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ (1)$$

where

t_{stm} = the minimum required steaming time to achieve two hours with the center line temperature above 65.5°C [hr].

D   = diameter of the poles [cm].

There was relatively little effect on internal temperature of poles when the treatment solution was heated to 60°C (Figure IV-7). The warmer solution reduces the heat loss from the pole but did not increase the internal temperature already achieved during steaming (Figure IV-6). Previous research suggests that heated solutions merely act as an insulator, thereby delaying the loss of heat from the pole surface.

While predictions based on an assumed initial pole temperature of 18°C are useful, poles are treated under a variety of temperature conditions (0°C to 40°C). To explain these effects, the effect of initial temperature on the required steaming time was evaluated. Figure IV-8 shows the minimum required steaming time to achieve two hours of the center line temperature above 65.5°C when the treatment used wood at various temperatures. The following relation was developed from Figures IV-5 and 8.

$$t_{stm} = 0.0039 \ D^2 + (0.095 - 0.00464 \ D)(T_o - 18)\ldots\ldots\ldots\ldots(2)$$

where T_o = the pole initial temperature, [°C]

The effect of the steam temperature on the required steaming period is shown on Figure IV-9. As the steam temperature increases the required steaming time decreases. The following equation relates steaming time to steam temperature (100-130°C) and pole diameter:

$$t_{stm} = 0.0335 \ D^{1.73} - 0.00037 \ D^{1.57} \ T_{bath}\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where T_{bath} = the steam temperature [°C]

The above results were obtained using a mean thermal diffusivity of 8.18 cm^2/hr. The values of the minimum steaming time or the time required to reach 65.5°C may be corrected for a different thermal diffusion coefficient using:

$$t = t^* \ \frac{8.18}{\alpha} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

where   t = is either the minimum steaming time or the time required to reach 65.5°C calculated using equations 1 to 3, [hr]

t^* = the corrected time [hr].

α = true thermal diffusivity of pole [cm^2/hr].

The time the center line temperature remains above 65.5°C versus the diameter of the poles which are initially at 18 °C which were steaming for 6 or 8 hours and treated with preservative solutions at 20 or 60 °C were also examined (Figure IV-7). The time the center of the poles remained above 65.5°, above, first increases, because the thermal capacity of the pole increases with size

and then decreases sharply. For example, for a 6 hour steaming period, poles exceeding 37.5 cm diameter may not be steamed long enough to remain above 65.5°C for 2 hours. Similarly, 45 cm is the critical pole diameter for the 8 hour steaming period.

The maximum temperatures obtainable at various locations when the center line is heated to 65.5°C are shown in Figure 9 for various pole diameters. It was observed heating the center until it reaches 65.5°C, less than 75 percent, by volume, of the pole was heated above 100°C. Excessive heating of wood can lead to severe strength losses, particularly when the wood was a higher moisture content.

Modeling temperature-time-location relationships in cylindrical timbers during heat sterilization and pressure treatment is a complex, poorly understood problem. This complexity makes it difficult to tailor a single treatment program suitable for various operational and climatic conditions. Bearing in mind these limitations, the present method of analysis nevertheless brings some interesting facts to light.

1. A six hour steaming period, was found insufficient to heat large diameter poles (greater than 40 cm) to the conditions required for sterilization. Therefore, longer steaming times are highly recommended using the estimates provided by Equations (2) and (3).

2. The time-depth relation recommended by Dost (1984) seems too restrictive since it does not include the effect of the pole diameter.

3. Most of the early research work was done without computers, making it essential to make assumptions to simplify the computation involved. These assumptions were poorly correlated with the actual measurements and limit

the accuracy of the results. Including elements in the model that account for heating-up period and gradual cooling rates improves the prediction.

4. The large number of factors that are necessary to evaluate the required steaming time make it difficult to show all these effects on charts. Therefore, it is important to develop process simulation software to help engineers to predict adequate treatment cycles for the material being treated.

Recommendations for possible future work: Although this study was based on a large set of data taken using industrial equipment, the poles used for the study had low moisture contents in a narrow range. The effect of higher moisture content on the model parameters are not well-known. Additional data for poles with a wide range of moisture content are needed to understand and characterize these effects.

Research efforts are also needed to better understand the mechanistic process involved in using different heating media; for example, heating with steam, air or hot plates. At present only a qualitative comparison of the different heating media have been made.

Another important point which seems to be overlooked in all the modeling work is the collective effect of the pile of poles; i.e., the geometry, number and sizes of poles in a single charge. There needs to be a more fundamental approach to characterize these collective effects of poles as well as differences related to the type or size of cylinder used.

Table IV-6. Pole sizes and moisture contents used in the experiment.

Trial	Pole Number	Pole (cm) Diameter		Moisture % at depth	
		Minimum	Maximum	2.5 cm	5 cm
ACA1	3	30.8	33.7	22	----
	4	30.5	33.0	21	----
ACA2B	5	31.8	34.3	20	----
	6	33.7	34.3	21	----
ACA3	7	31.1	32.4	12	21
	8	31.75	34.3	20	21
ACA4	9	29.8	31.8	18	21
	10	30.5	32.4	17	20
	13	37	34.29	17	20
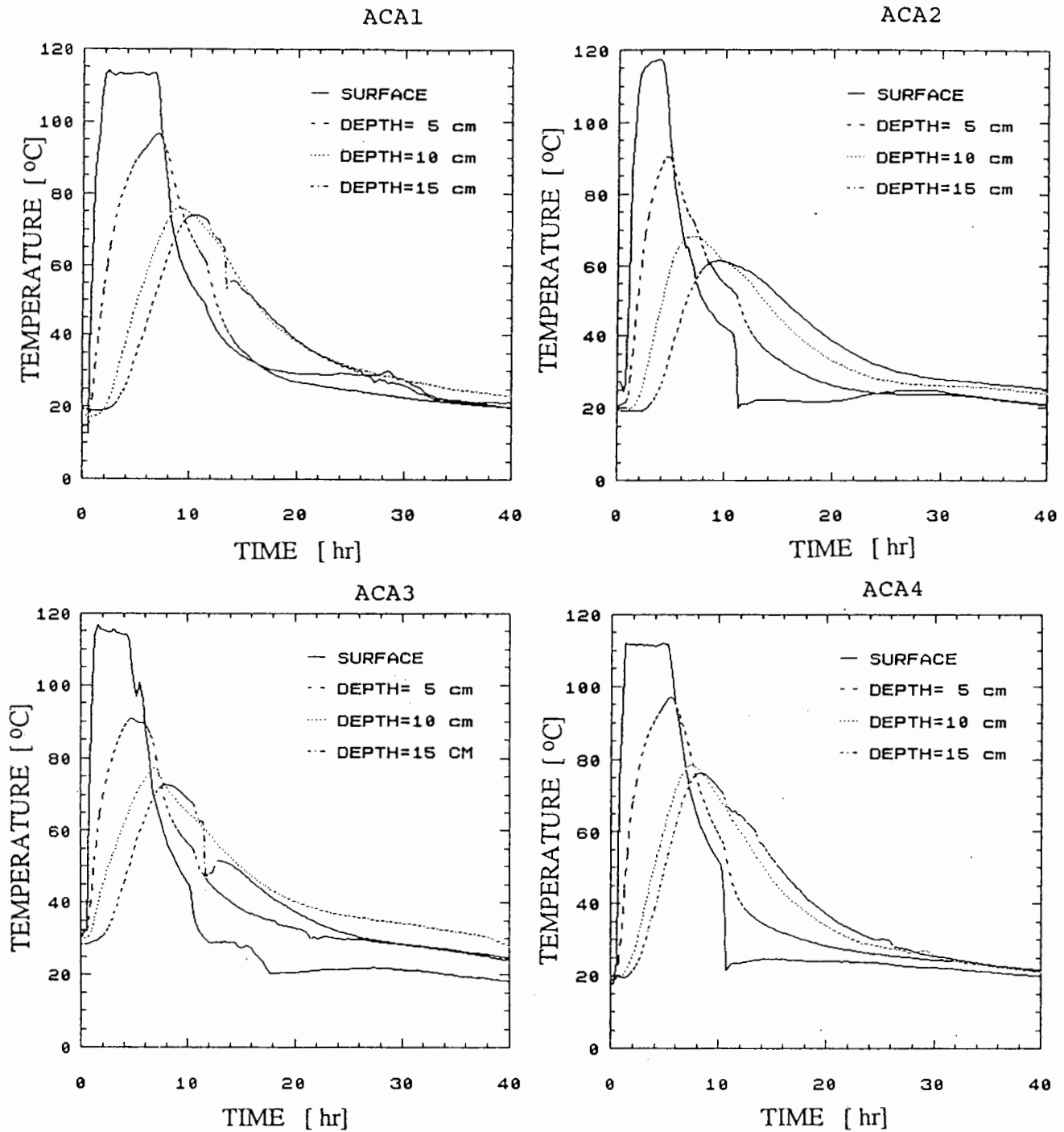
Figure IV-2. Temperature time relationships in Douglas-fir poles sections during preservative treatment with waterborne ammoniacal copper arsenate for steaming periods of 6.25, 4.25, 4.5 and 5.75 hours for Figures a, b, c, and d, respectively.
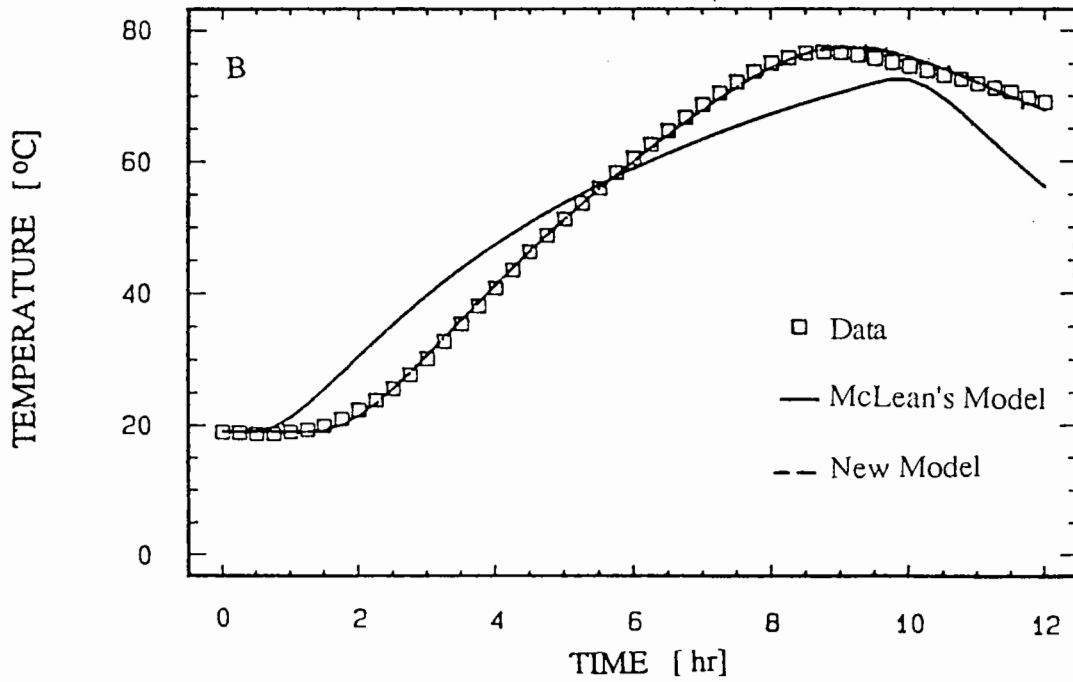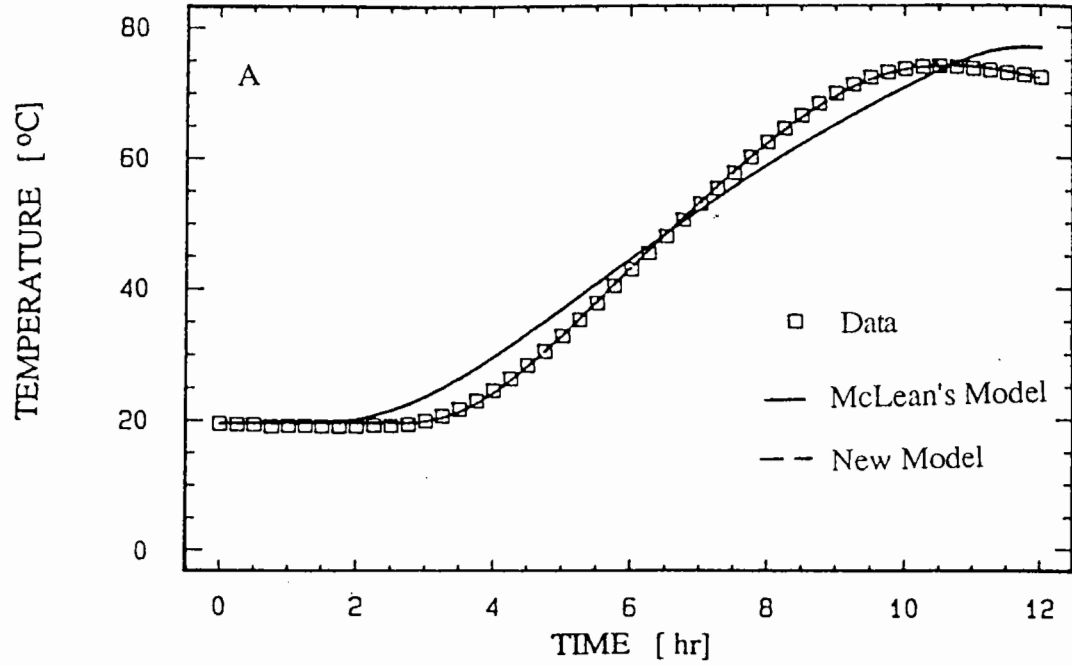
Figure IV-3. Comparison of experimental and predicted temperatures at the center of the poles for MacLean's model and the new model.
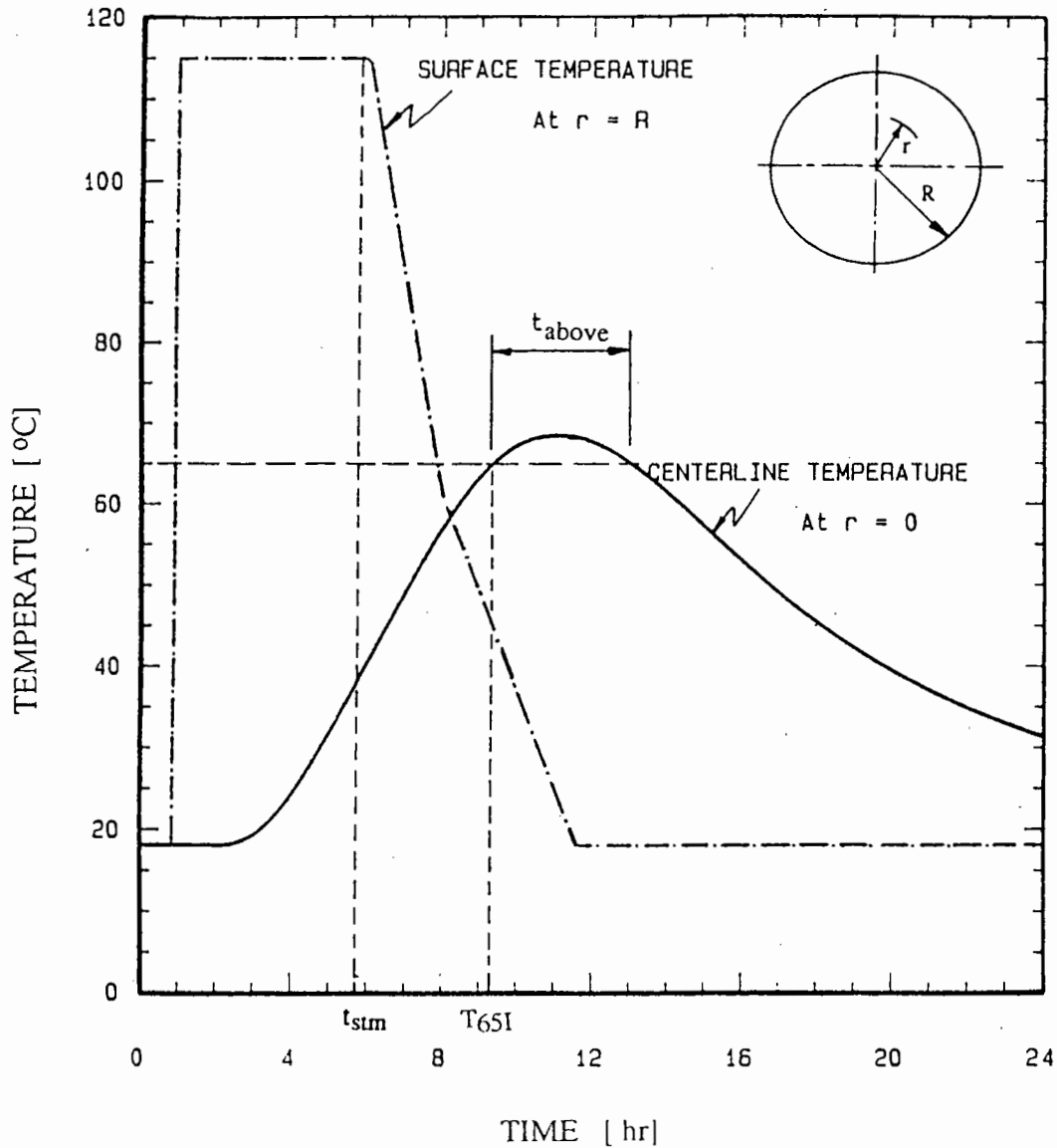
Figure IV-4. Temperature versus time relation for the center line and the surface of a pole. t_{stm} = steaming time, t_{65I} = time required to first each 65.5°C.
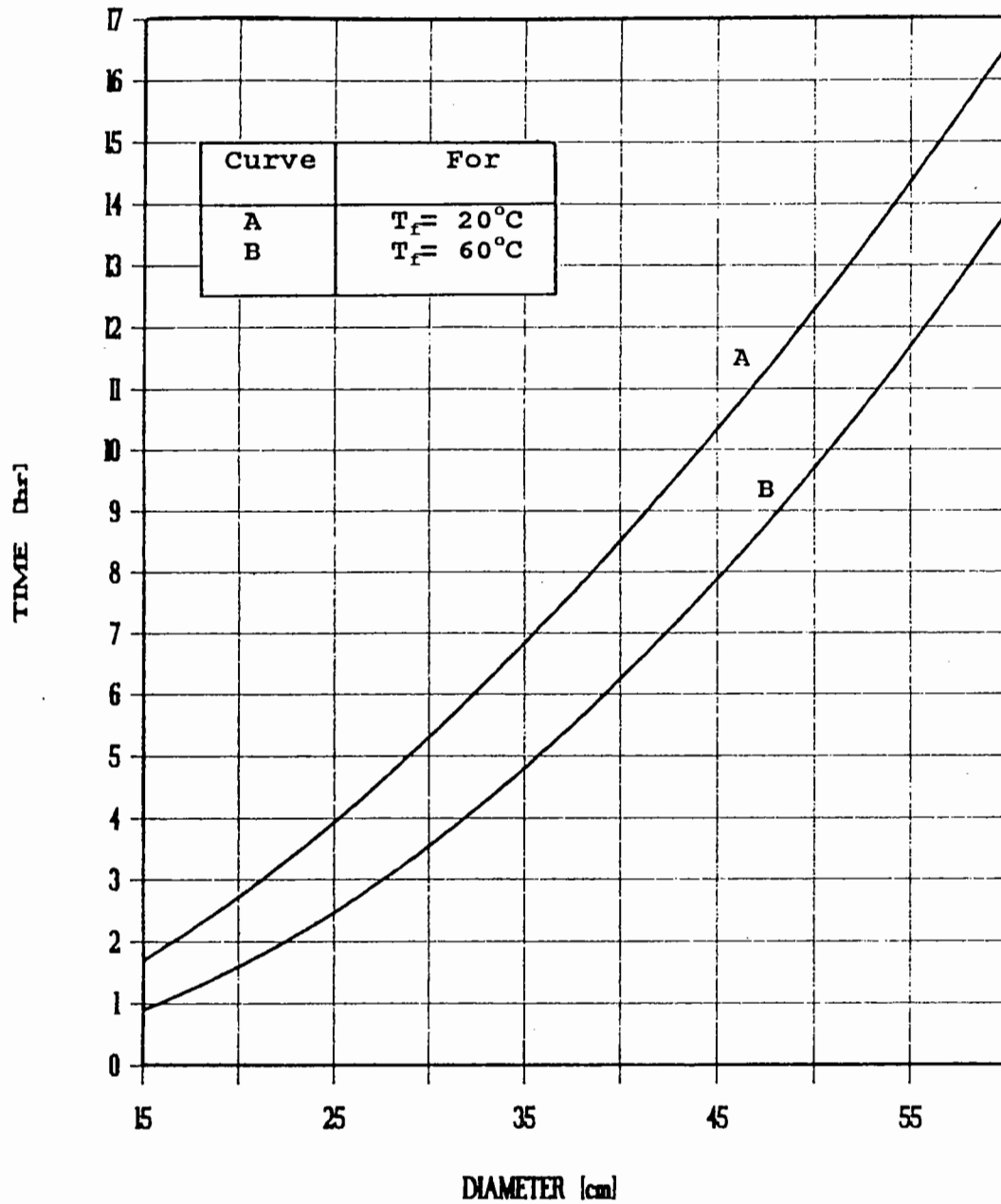
Figure IV-5. The minimum required steaming time to achieve two hours of the center line temperature above 65.5°C versus the diameter of the poles, treated with waterborne ACA and for assumed initial temperature of 18°C, steam temperature of 115°C and final preservative temperature of 20 or 60 °.
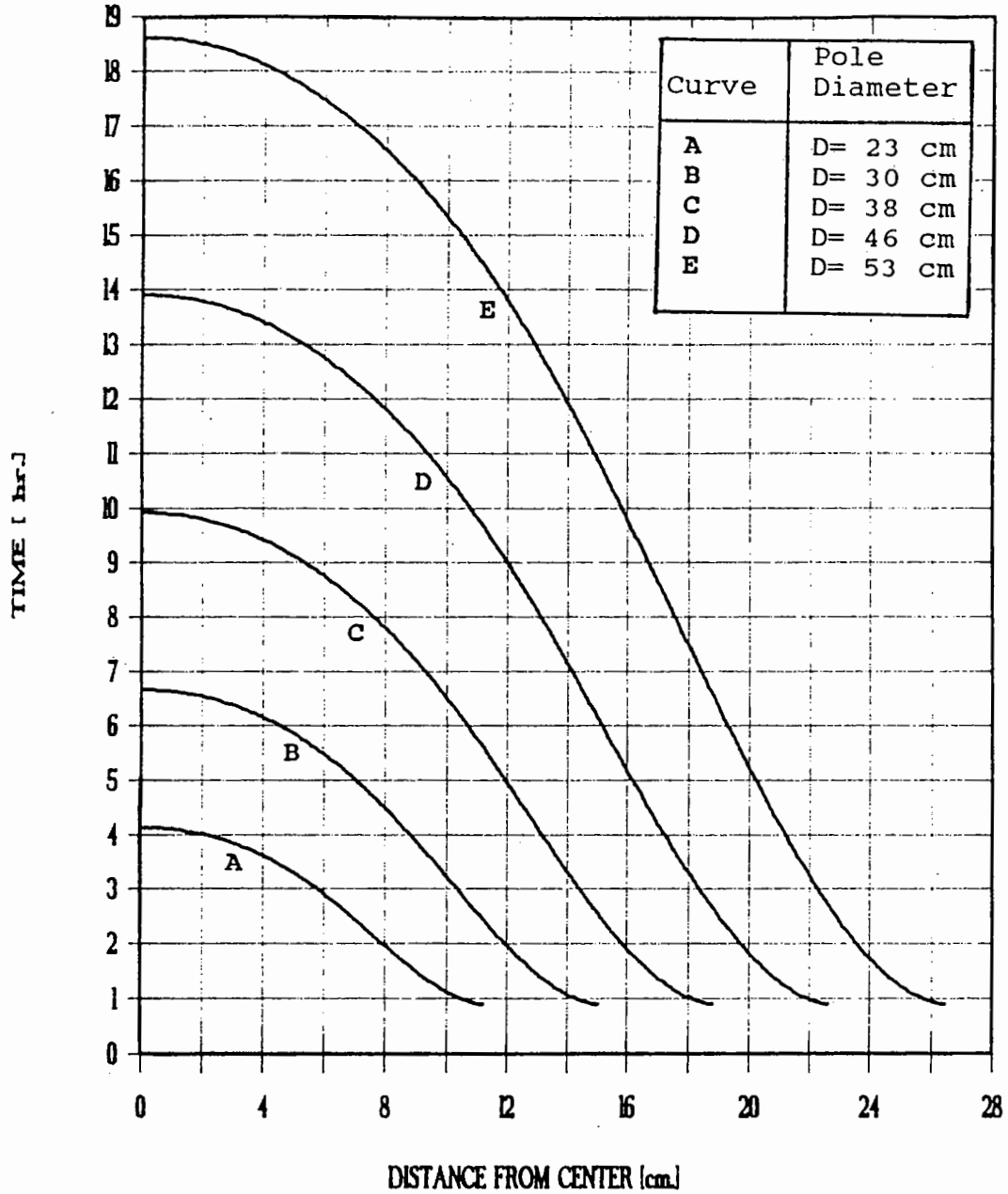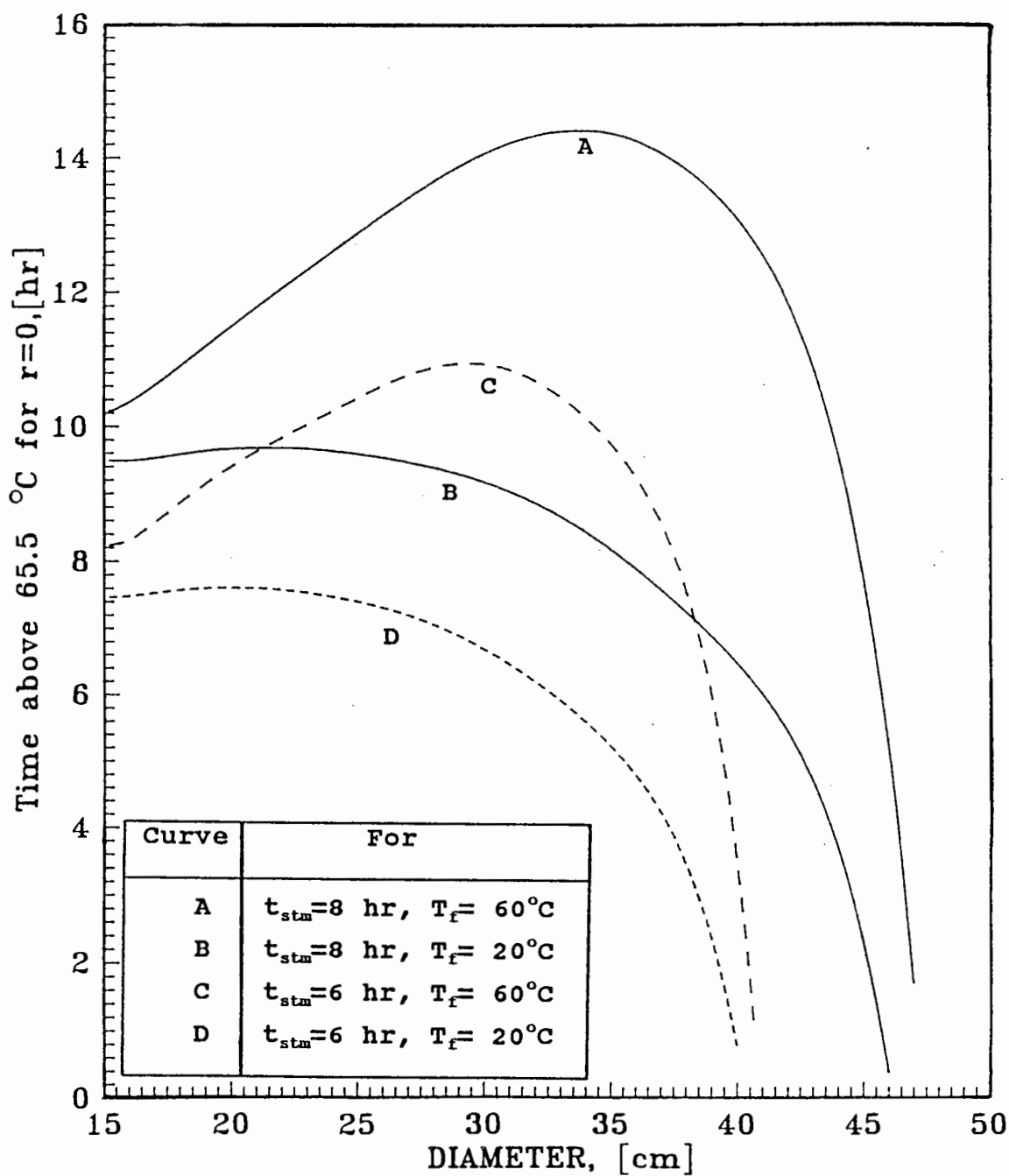
Figure IV-6. Steaming time required to reach T_{max} = 65.5°C at various distances from the center of a pole treated with waterborne ACA and for assumed initial temperature of 18°C, steam temperature of 115°C and final preservative temperature of 20°C.

Figure IV-7. The time the center line temperature remains above 65.5°C for 6 or 8 hours steaming versus the diameter of the poles which are initially at 18°C, treated with waterborne ACA at 20 or 60°C.
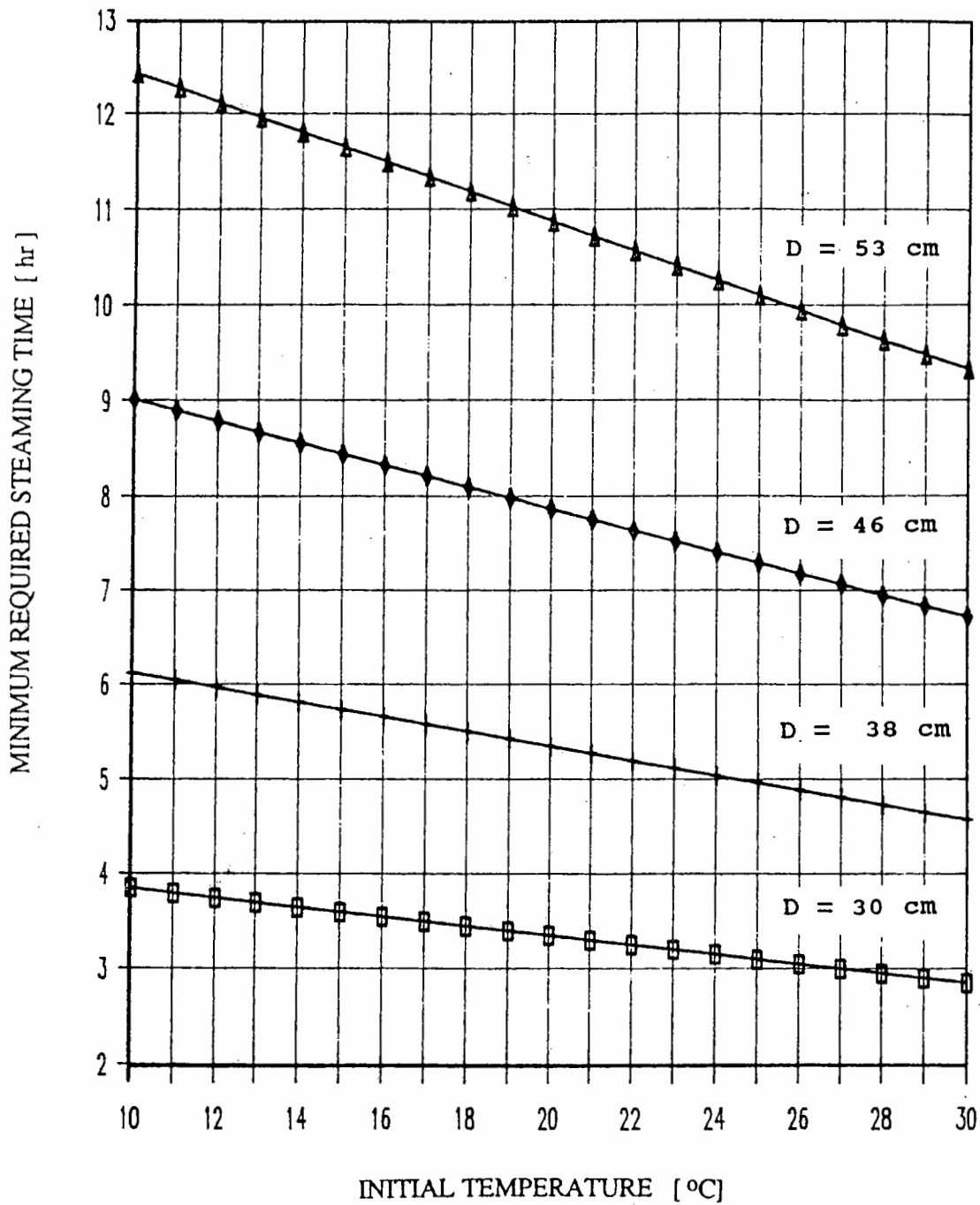
Figure IV-8. The minimum required steaming time to achieve for hours of center line temperature above 65.5°C versus initial temperature of poles treated with waterborne ACA, for steam at a temperature of 115°C and final preservative temperature of 20°C.
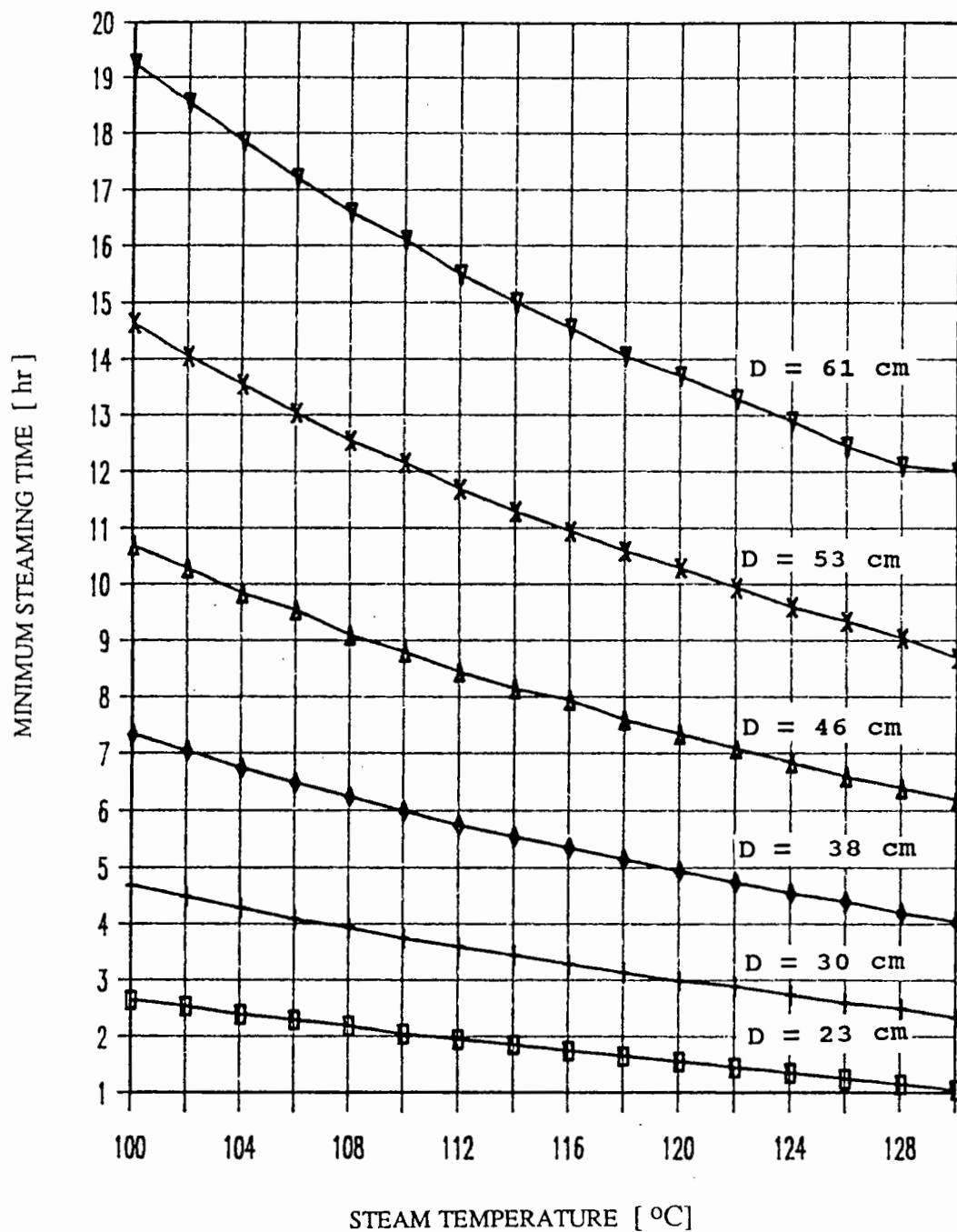
Figure IV-9. The minimum required steaming time to achieve two hours of center line temperature above 65.5°C versus the steam temperature for poles which are initially at 18°C and are treated with waterborne ACA.
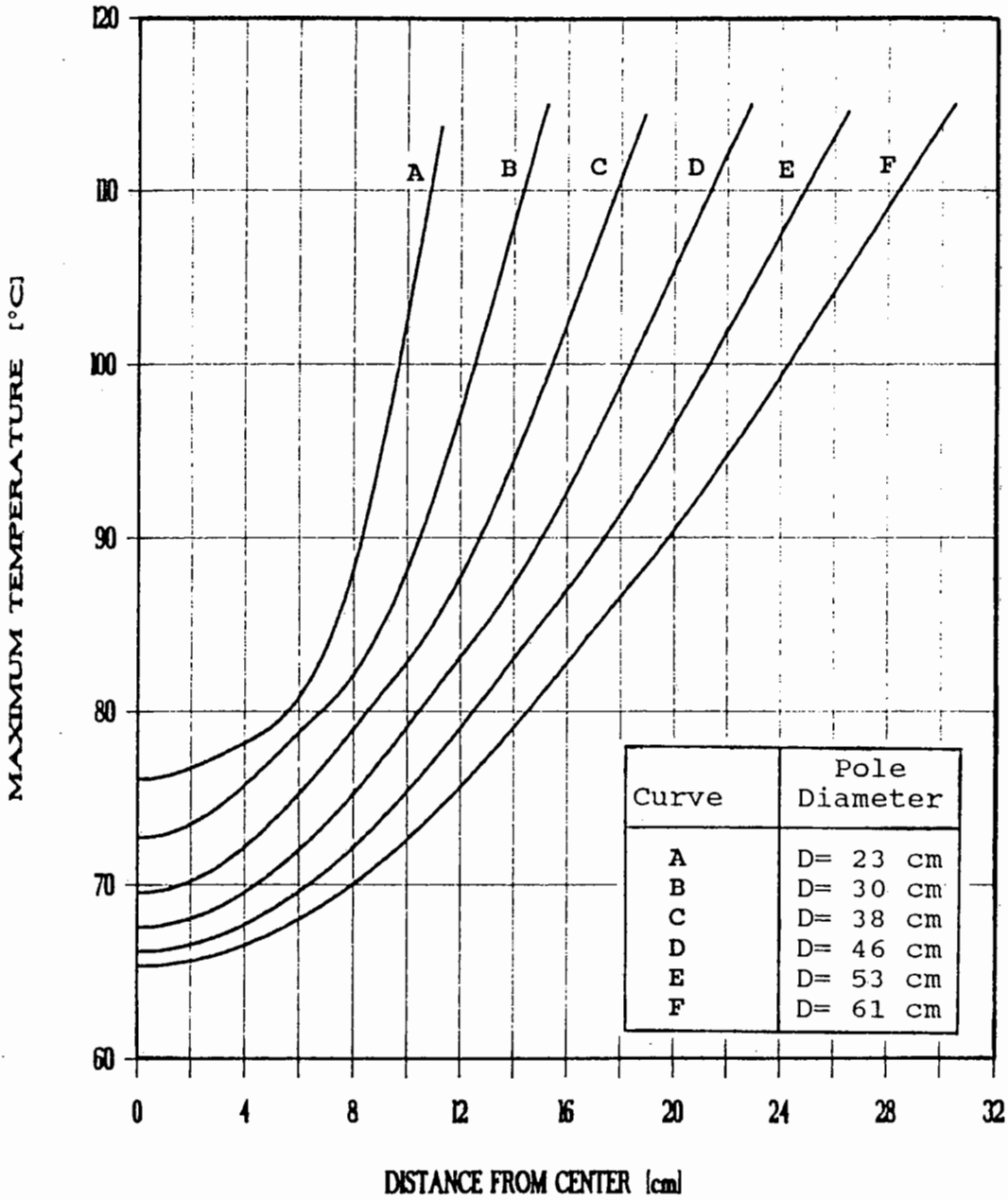
Figure IV-10. The maximum temperature reached in the interior of poles with diameters changing from 23 to 61 cm which are heated until the center line temperature remains two hours above 65.5°C for 2 hours using assumed initial and steam temperatures of 18°C and 115°C, respectively.

OBJECTIVE V

PERFORMANCE OF MODIFIED GROUNDLINE PRESERVATIVE SYSTEMS ON
UNTREATED DOUGLAS-FIR SAPWOOD

1. Efficacy of modified groundline wraps on untreated Douglas-fir pole sections: For many years, the chemicals employed in remedial groundline preservative formulations were relatively constant; however, the recent listing of pentachlorophenol and creosote as restricted use pesticides have encouraged utilities to seek remedial treatment chemicals which do not fall into this category. The result has been a proliferation of groundline treatment systems containing copper naphthenate, boron and sodium fluoride. With the exception of sodium fluoride, there is little data on the performance of these chemicals in this application. Last year, we described the installation of a field test to evaluate the performance of groundline preservatives on Douglas-fir post sections. The test is now installed and will be evaluated shortly. The chemicals in test include:

1. CUNAP-WRAP (Tenino Wood Preservatives, Inc.): a copper naphthenate solution (2.0 % as Cu) on an absorbant pad protected by a plastic barrier.

2. CUNAP-WRAP II (Tenino Wood Preservatives, Inc): the same formulation as formulation # 1 but on a more absorbant pad.

3. CuRap 20 (Chapman Chemical Co.): a paste containing 40 % borax (disodium octaborate tetrahydrate) and 18 % copper naphthenate.

4. PolNu 15-15 (Chapman Chemical Co.): a mixture containing 12.9 % pentachlorophenol, 15.5 % creosote, and 1.5 % chlorinated phenols to serve as a standard.

5. PolNu (Chapman Chemical Co.): a grease containing 10.2 % pentachlorophenol and serving as a standard.

6. Cop-R-Rap (Osmose Wood Preserving, Inc.): 19.25 % copper naphthenate paste (2.0 % as Cu).

7. CRP-82631 (Osmose Wood Preserving, Inc.): a paste containing copper naphthenate (2.0 % as Cu) in 45 % sodium fluoride.

8. Untreated control pole sections.

2. Migration of preservatives from groundline wraps into preservative treated Douglas-fir and western redcedar poles in service: A properly treated wooden utility pole provides long, reliable service when properly treated and maintained; however, some poles require special maintenance procedures to maximize service life. Poles can experience either surface or internal decay at some point in their useful life. Internal decay can be readily controlled by the application of fumigants, while external decay has generally been prevented by application of groundline wraps containing combinations of oil and water soluble preservatives.

Until recently, groundline wraps were composed of creosote, pentachlorophenol, sodium fluoride, sodium dichromate, arsenic pentoxide, and dinitrophenol; however, environmental concerns have encouraged a shift away from these compounds. In their place, copper naphthenate, sodium fluoride and borates have emerged as the two most commonly employed chemicals in modified groundline formulations. While both chemicals are excellent fungicides, their efficacy in groundline wraps remains largely untested.

To better answer questions concerning the performance of groundline wrap systems, the following test will be established.

Douglas-fir and Ponderosa pine poles treated with pentachlorophenol using the Cellon process and western redcedar poles treated with pentachlorophenol in

P9 Type A oil which have been in service for varying periods of time will be selectively sampled by removing 5 cm long plugs (9 mm diameter) from 3 sites (spaced 120 degrees apart) 15 cm below the groundline. These plugs will be divided into zones corresponding to 0 to 3 mm, 4 to 9 mm, 10 to 15 mm, and 16 to 25 mm from the surface. Each zone will be analyzed for residual chemical content by the appropriate analytical method. The analyses will then be used to segregrate the poles into treatment groups so that each group contains the same relative distribution of preservative retention.

Each treatment group of 9 poles per species will then receive one of three groundline wraps. The wraps will be applied to the zone extending from 8 cm above the groundline to 45 cm below the ground. The soil will be replaced around the poles, taking care not to disturb the wrap. Treatments to be evaluated will include: CuRap 20 (Chapman Chemical Co.), Patox II (Osmose Wood Preserving), and Cu-Nap-Rap (Tenino Chemical Co.).

The movement of chemical into each pole will be assessed by removing plugs near the original sampling sites on three of the poles in each treatment group 1, 3, 5, 7, and 10 years after installation. Sampling will rotate among the poles so that poles which are sampled in year one will be resampled 7 years after treatment. Those sampled at 3 years will be sampled 10 years after treatment. This pattern reduces the mechanical effects of repeated sampling on a given pole.

The plugs will be dissected in the same manner as described for the initial sampling and each segment will be analyzed to determine relative levels of copper (for copper naphthenate), fluoride, and boron. The results should provide a relative measure of the depth of chemical distribution from the wood surface, and, in conjunction with existing toxicity data, should provide a relative guide

to the efficacy of the various wraps at selected depths in the poles. The tests should also provide a companion set of data to tests already underway at Oregon State University which are evaluating the movement of additional groundline systems on Douglas-fir pole sections.

OBJECTIVE VI

PERFORMANCE OF COPPER NAPHTHENATE IN WESTERN WOOD SPECIES

Copper naphthenate has seen increasing application for initial treatment of Douglas-fir and western redcedar poles. This chemical has provided reliable service in field stake tests on southern pine, but there is limited data on its performance of western wood species. To help develop data, a series of western redcedar sapwood stakes (1.25 by 2.5 by 15 cm long) were treated with graded solutions of copper naphthenate in diesel oil using a modified full cell process. The stakes were weighed before and after treatment to determine gross solution absorption and additional stakes were treated for later chemical analysis. The target retentions for these tests ranged from 0.8 to 4.0 kg/m^3 (as copper). Untreated stakes were included for comparative purposes. The stakes have been exposed in the OSU Fungus Cellar which simulates more tropical conditions (28 C, 90 % relative humidity). The stakes will be rated on a scale from 10 (sound) to 0 (completely destroyed) beginning at 6 months and at 3 month intervals thereafter to determine the performance of copper naphthenate on this wood species.