A COOPERATIVE POLE RESEARCH PROGRAM

CONSERVING ENERGY BY ENVIRONMENTALLY ACCEPTABLE PRACTICES IN MAINTAINING AND PROCURING TRANSMISSION POLES

EIGHTH ANNUAL REPORT

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by

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ABSTRACT

The eighth annual report details continued progress on each of the five objectives. In this year's report, Objectives II and III from previous reports have been combined to reflect the similarity of each effort.

Improved fumigants: The previously established field trials continue to demonstrate the superior performance of both chloropicrin and Vorlex after 18 years in poles and 13 years in piling. In addition, solid methylisothiocyanate (MIT) continues to protect Douglas-fir poles in a manner similar to Vorlex.

Along with evaluations of existing registered formulations, we continue to explore the use of novel solid fumigants for their ability to arrest decay in Douglas-fir heartwood. Laboratory studies indicate that both Mylone and sodium n-methyldithiocarbamate (NaMDC) can be pelletized to improve handling safety. Previous studies indicate that the rate of decomposition to produce MIT is often too slow for effective fungal control, but the incorporation of certain buffers or metallic salts can alter the rate and characteristics of chemical decomposition. In our tests, the levels of chemical release varied with pH; however, complete fungal control was not achieved. Further studies are underway to determine if other conditions can alter the rate of MIT production by these compounds. Both chemicals are registered for other, non-food uses and should be registerable for application to wood.

Efforts to better understand the properties of MIT, the major fungitoxic product of both Vorlex and Vapam, are also continuing. These efforts have led to the development of a preliminary model to describe fumigant movement through Douglas-fir heartwood. The goal of this work is optimize treatment dosage and application patterns for various pole sizes. In addition to the more theoretical studies, we are continuing our efforts to determine the

ability of fumigants to control decay fungi in poles containing large decay voids and to determine the levels of volatile emissions from fumigant treated wood.

Field treatment: The field tests to evaluate potential replacements for pentachlorophenol (penta) treatment of western redcedar sapwood were evaluated after 7 years using the Aspergillus bioassay. The results indicate that residual levels of chemical were detectable in the penta treatments, but the remaining test chemicals exhibited little evidence of residual fungitoxicity. Further decay tests are planned on material removed from these pole sections. In addition to the pole sections, the small-scale test blocks were also evaluated using the Aspergillus bioassay. The results indicate that several chemicals remained in the wood at fungitoxic levels after one year of accelerated weathering. Further decay tests are also planned on these samples.

The bolt hole study is now in its seventh year and the incidence of decay fungi in the test poles remains low. Variations in incidence from year to year have made it difficult to draw any useful conclusions from this study. To overcome this problem, a second test has been established which accelerates leaching and evaluates the ability of a test fungus to invade the field drilled bolt hole to cause wood weight loss.

Decay detection and residual strength: We continue to evaluate the use of lectins for detecting fungal colonization at the early stages. This past year, we completed a comparison of colonization by three common decay fungi over a 12 week period.

The search for small-scale methods for estimating residual strength is also continuing. Longitudinal compression measurements were used to determine residual strength of a pole involved in an automobile accident.

Finally, we have completed portions of a study to determine the effects of fungal colonization on wood strength. Four fungi, Poria carbonica, Poria placenta, Peniophora spp., and Haematostereum sanguinolentum were evaluated in this study. Results with P. carbonica and Peniophora spp. indicate strength effects lag behind fungal colony development in small beams. These results were similar to previous field studies and indicate that air-seasoning for 2 to 3 years should not produce significant strength losses. Further studies with these fungi are underway.

Initiation of decay in air-seasoning Douglas-fir: While the air-seasoning studies are now completed, we are continuing to evaluate the data from these tests. A detailed examination of the three year decay development study indicates that several fungi were typically found only in the heartwood or sapwood zones of the pole sections. In addition, the fungal flora at the four seasoning sites varied widely, with the greatest deviation occurring at the Oroville, CA. This site has the driest and warmest conditions, and would appear to be best site for seasoning. A detailed discussion of isolation frequency by position is presented for the eleven most common basidiomycetes.

Studies to prevent colonization by basidiomycetes during air-seasoning are also continuing using polyborate dips or sprays. Sodium octaborate tetrahydrate appears to reduce the level of colonization after one year of air-seasoning at both Oroville and Corvallis, OR. Dipping shortly after peeling appeared to produce the best results, although spraying at regular intervals also had some effect on colonization. This study will continue for an additional two years.

Determining the ability of existing pressure treatment cycles to eliminate fungi which colonize Douglas-fir poles during air-seasoning also remains a high priority. Only a few additional schedules were examined during

the past year, but efforts to develop more realistic heating curves are under way. In addition, several questions concerning the accuracy of the existing data were answered. Additional studies using the Cellon process and the longer steaming period for the ammoniacal copper zinc arsenate treatments are planned in the coming year.

While sterilization during preservative treatment is an important factor in pole longevity, questions have also arisen concerning the storage of poles for long periods after treatment.

A survey of poles which were treated with creosote, pentachlorophenol, chromated copper arsenate, and ammoniacal copper arsenate prior to storage for one to 15 years was conducted. While colonization varied widely between sites, the results indicated that storage of poles for long periods substantially increased the risk that the pole would be placed in service with an active decay fungus established somewhere along its length. Several suggestions are made for remedying this situation.

Effect of microfungi on Douglas-fir poles: A study was conducted to determine the effect of microfungi which commonly colonize fumigant treated Douglas-fir heartwood on the ability of P. carbonica and P. placenta to cause wood weight loss in fumigant treated wood. The results indicate that several isolates were associated with reduced weight losses by these fungi. The decreased weight losses suggest that the microfungi could be colonizing fumigant treated poles prior to the basidiomycetes and, once there, could help prevent reinvasion. This scheme may help explain the remarkable protection provided by fumigant treatment. Further studies are underway to explore this possibility.

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OBJECTIVE I

DEVELOP SAFE, ENVIRONMENTALLY ACCEPTABLE FUMIGANTS TO CONTROL INTERNAL DECAY OF DOUGLAS-FIR POLES

A. PREVIOUS ON-GOING AND RELATED RESEARCH

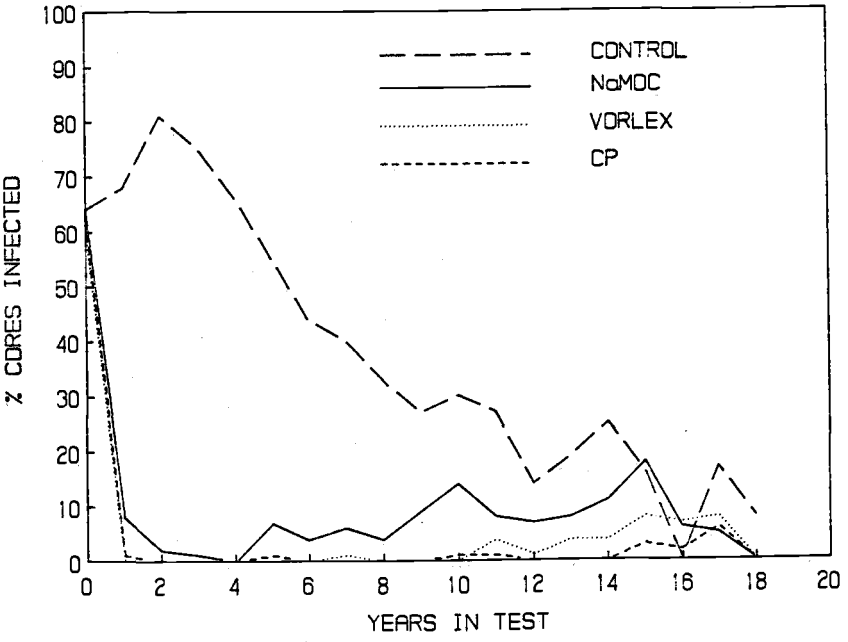
Douglas-fir poles treated in 1969 with chloropicrin, Vapam, or Vorlex

Poles in the Santiam-Toledo line originally treated in 1969 with 1 liter of chloropicrin, Vapam, or Vorlex or left untreated have been sampled on an annual basis by removing increment cores for culturing and closed tube bioassays ('84 Ann. Rept., pg. 1-2). Because the Vapam poles were experiencing a continually increasing level of fungal colonization, poles in this treatment group which contained viable decay fungi were retreated with 1 liter of Vapam last year. The chemical was applied to the existing treatment holes, which were replugged with new dowels.

Eighteen years after treatment, the levels of colonization appear to have decreased in both the Vapam, chloropicrin, and Vorlex treatments (Table I-1). Only one of the five poles retreated with Vapam contained viable decay fungi, while the single remaining untreated control was also colonized. These figures represent 6 and 8 percent of the Vapam retreated and untreated cores, respectively (Figure I-1). The relatively low levels of colonization in the untreated control once again reflect the difficulty of culturing from very badly decayed wood.

In spite of the low levels of colonization in the Vorlex, chloropicrin and Vapam treated poles, closed tube bioassays indicate that significant levels of fungitoxic vapors were only detectable at 1.2, 1.8 and 2.4 meters above the groundline in the chloropicrin treated poles or the groundline of the Vorlex treatments (Table I-2). These results continue to indicate a gradual decline in residual chemical protection; however, this decline has not resulted in significant fungal invasion. It is interesting to note that

Figure I-1. Population of decay fungi isolated from internally decaying pressure-treated Douglas-fir poles treated with Vapam, Vorlex or chloropicrin. Values represent the average of 12 cores removed annually from selected heights above and below groundline.



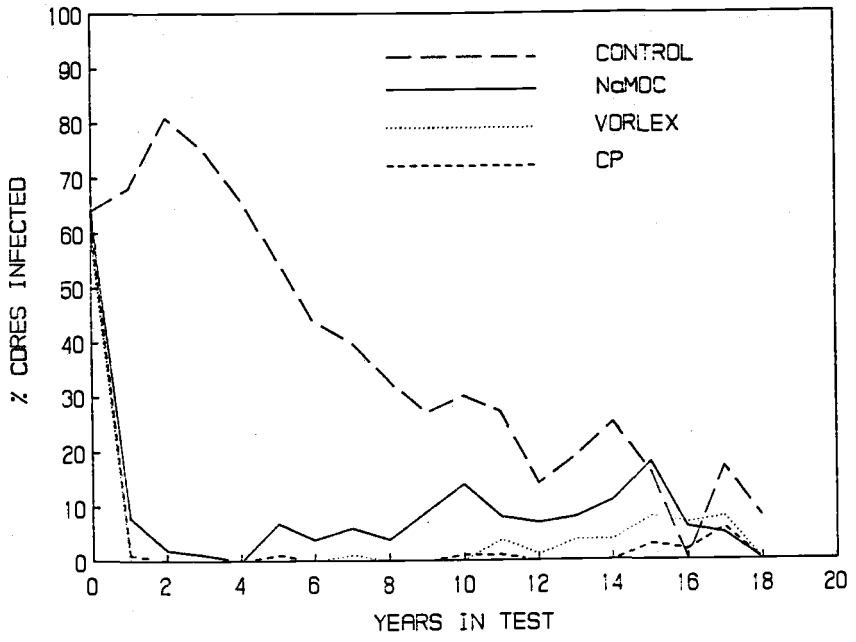


Figure I-2. Changes in the population of decay fungi isolated from internally decaying pressure-treated Douglas-fir poles treated with fumigants. Each value is based on 15 cores removed at -0.3 to 2.4 m from the groundline from the poles listed in Table 5.

Table I-1

EFFECTIVENESS OF FUMIGANTS IN DOUGLAS-FIR POLES TREATED WITH 1 LITER OF FUMIGANT AS DETERMINED BY CULTURING INCREMENT CORES REMOVED FROM THE TREATED POLES.[a]

		POLES CONTAINING DECAY FUNGI				
		VAPAM				
YEAR	CONTROL	WRAPPED	UNWRAPPED	RETREAT	VORLEX	CHLOROPICRIN
1968	8	8	8	-	8	8
1969			POLES TREATED			
1970	8	4	4	-	0	1
1971	8	1	1	-	0	0
1972	8	0	1	-	0	0
1973	8	0_{7}	0_{7}	-	0_{7}	0_{6}
1974	7	4^{7}	4^{7}	-	0^{7}	1^{6}
1975	7	1	0	-	1	0
1976	5	2	3	-	0	0
1977	5	2	1	-	0	0
1978	5	3	2	-	0	0
1979	5	3	2	-	2	1
1980	5	1	3_{6}	-	1	0
1981	3	2	2^{6}	-	1	0
1982	2	2	2	-	1	0
1983	2_{2}	2_{6}	2_{2}	-	1_{5}	0_{5}
1984	2^{2}	4^{6}	1^{2}	-	1^{5}	1^{5}
1985	1^{1}	3	2	-	2	1_{4}
1986	1	3_{2}	1	-	3	3^{4}
1987	1	0^{2}	-	1^{5}	0	0

[a] All poles contained decay fungi before the fumigants were applied. Superscripts denote the number of poles remaining in test; the missing poles were inadvertently removed from service. Vapam retreat poles were retreated with 1 liter of Vapam in 1986.

residual protection for the Vorlex poles remains highest at the groundline, while that of the chloropicrin treated poles remains highest above that zone. This variation may reflect differences in affinity with the wood structure which affect chemical movement. The Vapam retreated poles exhibited slight fungitoxicity in the groundline and 1.2 meters above that point; however, these levels did not approach those for the chloropicrin or Vorlex treatments. The volatile fungitoxic nature of Vapam appears to be considerably lower than the other fumigants, which may account for the differences noted in this study.

TABLE I-2

RESIDUAL FUMIGANT VAPORS IN PRESSURE-TREATED DOUGLAS-FIR POLES 18 YEARS AFTER FUMIGANT APPLICATION AS MEASURED USING THE CLOSED TUBE BIOASSAY.

METERS ABOVE GROUND	SEGMENT LOCATION FROM SURFACE (cm)	GROWTH OF THE ASSAY FUNGUS AS A % OF THE CONTROL[a]				
		NO FUMIGANT[b]	VAPAM	VAPAM RETREAT	VORLEX	CHLOROPICRIN
2.4	0-2.5	66	43	48	51	17
	12.5-15	51	40	71	54	0
1.8	0-2.5	48	66	60	54	20
	12.5-15	74	48	74	51	23
1.2	0-2.5	51	63	23	57	0
	12.5-15	100	66	26	69	31
0	0-2.5	66	40	40	69	57
	12.5-15	71	77	57	20	63
Control	(No Wood)	35 mm[c]				

[a] For the closed-tube bioassay, a core was removed at each height from eight poles. A 2.5-cm long segment of the core was sealed in a test tube below the agar slant which had been inoculated with Poria placenta. Suppressed growth of P. placenta compared to growth of the fungus where no wood was present (control) indicates the presence of fungitoxic vapors. The lower the percentage, the higher the concentration of fumigant vapors in the wood.

[b] Valves represent one pole.

[c] Average growth of the test fungus in 24 tubes.

TABLE I-3

DECLINE IN RESIDUAL FUMIGANT VAPORS IN DOUGLAS-FIR TRANSMISSION POLES AT SELECTED POINTS AFTER APPLICATION OF CHLOROPICRIN, VAPAM, OR VORLEX AS MEASURED BY THE CLOSED-TUBE BIOASSAY.[a]

METERS ABOVE GROUND	GROWTH OF THE ASSAY FUNGUS (AS % OF CONTROL) IN THE PRESENCE OF WOOD FROM POLES AT VARIOUS TIMES (YEARS) AFTER FUMIGANT TREATMENT.[b]																			
	CONTROL (NO FUMIGANT)				VAPAM					VAPAM RETREAT	VORLEX					CHLOROPICRIN				
	10	16	17	18	5	7	16	17	18	1	10	15	16	17	18	10	15	16	17	18
2.4	91	72	34	58	53	100	55	47	41	60	48	69	84	15	53	4	11	21	8	8
1.8	96	104	63	61	60	78	75	52	57	67	35	61	89	21	53	0	5	23	10	22
1.2	96	136	47	75	60	78	51	38	64	25	39	74	71	8	64	4	38	26	22	15
0	100	98	69	68	60	100	38	36	60	48	52	81	71	0	45	17	51	51	36	60

[a] Each pole was treated with 1 liter of the selected chemical applied to three holes 1 m above the groundline and four holes at the groundline.

[b] For the closed-tube bioassay, a core was removed at each height from eight poles. A 2.5-cm long segment of the core was sealed in a test tube below the agar slant which had been inoculated with Poria placenta. Suppressed growth of P. placenta compared to growth of the fungus where no wood was present (control) indicates the presence of fungitoxic vapors. The lower the percentage, the higher the concentration of fumigant vapors in the wood.

A comparison of closed tube results for cores removed at selected time points after treatment illustrates the gradual decline in residual fungitoxicity of each treatment (Table I-3). While the control and Vapam treatments have exhibited little fungitoxicity over the past 12 years, growth of the assay fungus, Poria placenta, in the presence of wood from the chloropicrin and Vorlex treatments has only recently begun to increase. Based upon the low existing rate of fungal colonization and the relatively slow rate of reinvasion, both the Vorlex and chloropicrin treatments should provide adequate protection for at least 20 years. This degree of protection is truly remarkable in light of the volatility of these same chemicals in other media, such as soil.

Douglas-fir poles treated in 1977 with allyl alcohol, methylisothiocyanate, or Vorlex

Tests to evaluate the ability of methylisothiocyanate (MIT) and allyl alcohol to protect Douglas-fir poles were begun in 1977, using Vorlex as a comparison chemical. Treatment conditions were previously described ('86 Ann. Rept., pg 7) and the poles have been sampled on an annual basis by removing increment cores for culturing to detect the presence of decay fungi and closed tube bioassays to detect residual fungitoxic vapors.

The results indicate that both the 20 and 100 percent MIT treatments continue to provide excellent protection, although poles treated with both of these formulations and Vorlex have experienced low levels of recolonization (Table I-4). The allyl alcohol treated poles and the controls continue to experience higher levels of colonization. The former poles were retreated with Vapam this past summer to prevent further deterioration. While the MIT and Vorlex treated poles have been reinvaded, the levels of colonization remain low, with rates of 3, 1, and 2 percent of cores removed from the

TABLE I-4

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	VORLEX	20%[b]	100%
1977	9	9	7	9	8
1978	9	9	3	6	2
1979	9	9	4	4	0
1980	9_5	9_6	3_4	3_5	0_5
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

[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.

Vorlex, 20 and 100 percent MIT treatments, respectively, containing viable decay fungi (Figure I-2). These results appear similar to previous results on the Santiam-Toledo line and indicate that fumigant treated Douglas-fir poles are reinvaded at very slow rates.

Closed tube bioassays of cores removed from the test poles indicate that very little volatile fungitoxicity remains in the wood (Table I-5). These results differ from previous reports ('87 Ann. Rept., pg 7) and suggest that the fumigants are moving out of the wood more rapidly. This variation may reflect differing degrees of decay in the test poles, since decayed wood with large voids would be expected to lose chemical more rapidly than sound wood.

Evaluation of fumigants for pile top decay control

In 1974, creosoted Douglas-fir piling in Florence, Oregon were treated with Vapam, Vorlex, or chloropicrin applied through steep-angled holes drilled

TABLE I-5

RESIDUAL FUMIGANT VAPORS IN DOUGLAS-FIR POLES NINE YEARS AFTER APPLICATION AS MEASURED USING THE CLOSED TUBE BIOASSAY.[a]

METERS ABOVE GROUND	SEGMENT LOCATION FROM SURFACE (cm)	GROWTH OF THE ASSAY FUNGUS AS % OF CONTROL				
		NO FUMIGANT	ALLYL ALCOHOL	VORLEX	METHYLISOTHIOCYANATE 20%[b]	METHYLISOTHIOCYANATE 100%
2.4	0-2.5	100	79	82	72	51
	12.5-15	100	74	97	79	72
1.8	0-2.5	97	87	49	79	64
	12.5-15	95	92	82	97	51
1.2	0-2.5	97	82	87	85	77
	12.5-15	100	92	85	77	77
0	0-2.5	100	92	85	77	77
	12.5-15	82	100	92	85	90
Control	(No Wood)	39 mm[c]				

[a] For the closed-tube bioassay a core was removed at each height from four to six poles (Table 5). A 2.5-cm long core segment was sealed in a test tube below an agar slant inoculated with Poria 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 8 tubes.

near the top of each pile. Twelve years after treatment, the piles remain relatively free of decay fungi, with low levels of colonization present in the Vapam treated poles and none present in the chloropicrin or Vorlex treatments (Table I-6). The excellent performance of these chemicals in piling closely parallels that found in utility poles.

Two years after treatment of the bulkhead piles, a series of untreated marine piling at the same port were also treated with these same chemicals. The results from these tests were similar to those found with the bulkhead piling, although the levels of fungal colonization were slightly higher (Table I-7). The increased colonization of wood which does not contain an oil based preservative barrier is consistent with other studies of land-based poles ('87 Ann. Rept., pg 10-16) and indicates that untreated wood should be retreated at more frequent intervals.

TABLE I-6

FUNGAL POPULATION IN DOUGLAS-FIR BULKHEAD PILING TREATED WITH FUMIGANTS AS DETERMINED BY CULTURING INCREMENT CORES REMOVED FROM SELECTED LOCATIONS ON EACH PILE.[a]

	CORES CONTAINING DECAY FUNGI (%)													
CHEMICAL	'74	'75	'76	'77	'78	'79	'80	'81	'82	'83	'84	'85	'86	'87
VAPAM	73	2	0	0	2	8	12	8	12	7	6	5	8	3
VORLEX	72	2	0	0	2	4	0	1	0	5	1	0	7	0
CHLORO-PICRIN	59	4	0	0	0	3	0	1	0	0	0	0	2	0

[a] Five cores were removed from each pile, one each at 0.3, 0.6, 0.9, 1.2, and 1.8 m from the pile top.

TABLE I-7

PRESENCE OF DECAY FUNGI IN UNTREATED DOUGLAS-FIR MARINA PILES TREATED WITH FUMIGANTS AS DETERMINED BY CULTURING INCREMENT CORES FROM SELECTED LOCATIONS ON EACH PILE.[a]

	NUMBER OF PILES OR % CORES CONTAINING DECAY FUNGI												
CHEMICAL	75	76	77	78	79	80	81	82	83	84	85	86	87
	(Number)												
PILES													
Vapam	6	2	1	3	4	4	3	2	3	1	3	5	2
Vorlex	6	4	5	4	3	6	1	2	2	2	1	3	2
Chloro-picrin	6	3	0	3	2	3	1	0	4	0	0	1	2
	(%)												
CORES													
Vapam	32	4	7	6	13	15	8	7	12	2	6	15	9
Vorlex	37	6	3	5	11	12	1	3	6	5	2	8	5
Chloro-picrin	55	3	0	6	3	5	1	0	6	0	0	2	3

[a] Cores were removed from each pile at 0.3, 0.6, 1.2, 1.8, 2.4, and 3.6 m below the pile top.

B. EVALUATE NEW FUMIGANTS

Development of controlled release fumigant pellets

Last year, we reported the results of tests to control the release of volatile fungitoxic compounds from Tridipam and Mylone ('87 Ann. Rept., pg 17-25). These chemicals are both solids at room temperature and decompose at very slow rates to produce MIT. The natural rates of MIT production from these chemicals are generally considered to be too slow for effective decay control. In our tests, the addition of high pH buffers (pH >10) at the time of application accelerated the decomposition of these chemicals, suggesting that the rate of fungal control could be substantially enhanced by addition of buffer at the time of treatment. While this approach may be feasible, the powdery nature of both formulations increased the likelihood that applicators might breath dust particles. To eliminate this problem, we have evaluated pelletized versions of Mylone. Tridipam, which also appears promising, was not evaluated in these studies because it is not currently in commercial production and it was felt that the relatively small market for wood fumigants would make it difficult to register. Mylone is currently available under the trade name Basamid for non-crop applications and could be registered for wood use. In addition, we evaluated solid sodium n-methyldithiocarbamate (NaMDC), also pelletized, for its ability to control fungal infestations. NaMDC is the active ingredient in Vapam. When Vapam is dehydrated, the solid, crystalline sodium salt (NaMDC) is formed. Addition of small amounts of moisture permits formation into small pellets which can then be stored for long periods at relative humidities below 60 percent with little risk of chemical release.

The pellets were made by placing weighed amounts of each chemical into molds and pressing with a specially adapted shot gun shell press at 60 pounds. The finished pellets were then used in a number of experiments. In addition

to the efficacy of the pellets, we also evaluated the use of buffers, the use of starch as an additive, and the addition of small amounts of metallic salts to the pellet mixture. Previous studies suggest that metals can accelerate the decomposition of NaMDC.

The studies were conducted using the standard small block fumigant assay, in which Douglas-fir heartwood blocks (2.5 by 2.5 by 10 cm long) were infested with the test fungus, Poria carbonica, prior to addition of the test chemical to a hole drilled into the center of the block. The hole was plugged and the blocks were incubated for 1, 4, or 8 weeks at room temperature. At the end of the incubation period, three 0.5 cm thick slices were cut from each end of the block. The outer section was discarded and the next two sections were cut into 16 equal-sized squares. The inner four squares from the middle section were used for culturing on potato dextrose agar to determine if the fungus survived chemical exposure, while the inner four squares from the inner section were extracted in ethyl acetate and the extract was analyzed using the gas chromatograph to determine the residual levels of MIT present in the wood. In this manner, we could determine the degree of fungal control and the level of chemical required to achieve this control.

The parameters evaluated using these methods included dosage (0.15, 0.30, 0.5, 0.8 g/ block), pH (4, 7, 10, or 12), presence of starch (10 percent by weight), presence of copper (1.0 or 0.5 percent copper sulfate or copper oxide), and the degree of surface area (i.e same dosage in one or many pellets). Portions of these tests are still underway; however, the preliminary results provide some measure of the potential usefulness of these treatments.

While the degree of fungal survival has varied widely, there are several general trends in fungal survival which illustrate the effects of the various

additive on the performance of NaMDC and mylone. In general, the fungal survival results should only be used as a relative guide, since slight variations in initial degree of fungal colonization and environmental factors during the exposure period can substantially alter test results.

Performance of Pelletized NaMDC: Application of NaMDC pellets at dosages ranging from 0.1 to 0.8 g/block failed to completely control the test fungus, even after 8 weeks of incubation (Table I-8). However, the addition of buffers appeared to enhance the rate of MIT production, presumably producing eventual fungal control. The buffer effect was most noticeable at the 5.0 percent dosage, although there was a slight effect at the 1.0 percent buffer level. In last year's report, we described the effect of higher pH buffers ($\geq$ 7) which enhanced MIT production from Mylone. In the current tests, all of the buffers enhanced MIT production from NaMDC. The pH 10 buffer produced the most dramatic improvement, while the pH 4, 7, and 12 buffers were slightly less effective at enhancing MIT release from the NaMDC pellets.

While the MIT release rates were relatively high one week after treatment, these levels declined substantially 4 or 8 weeks after treatment. This decline suggests that the treatment initially produces a highly concentrated wave of chemical, whose concentration gradually declines. This wave may be enhanced by the water applied at the time of treatment. As this water is absorbed by the wood, the reactivity of the NaMDC pellets declines. In spite of this decline, long term exposure to low levels of chemical should eventually produce fungal control.

While complete fungal control was not consistently achieved, longer exposures to the test chemicals (4 and 8 weeks) produced more noticeable declines in fungal survival. This effect suggests that the pellets would eventually control the infestation. One factor which may have produced the

TABLE I-8

ABILITY OF SELECTED pH BUFFERS TO ENHANCE THE EFFECTIVENESS OF PELLETIZED NaMDC AFTER ONE, FOUR, OR EIGHT WEEKS OF INCUBATION IN DOUGLAS-FIR HEARTWOOD BLOCKS

		INCUBATION PERIOD[b]					
		ONE WEEK		FOUR WEEKS		EIGHT WEEKS	
DOSAGE g/BLOCK	pH[a]	MIT ug/g	SURVIVAL (%)	MIT ug/g	SURVIVAL (%)	MIT ug/g	SURVIVAL (%)
0.1	-	235	37	136	47	128	55
0.1	-	4163	43				
0.1	4@5.0	-	-	219	93	19	70
0.1	4@1.0	111	74	137	33		
0.1	7@5.0	174	85	151	33		
0.1	7@1.0	-	-	54	20		
0.1	10@5.0	365	93	192	40		
0.1	10@1.0	160	74	5	0		
0.1	12@5.0	-	-	339	13	6	30
0.1	12@1.0	241	30	0	0		
0.2	-	248	68	167	20		
0.2	-	1611	50				
0.2	4@5.0	-	-	158	7		
0.2	4@1.0	-	-	177	20		
0.2	7@5.0	1307	86	347	5		
0.2	7@1.0	-	-	315	47		
0.2	10@5.0	4217	68	198	9		
0.2	10@1.0	244	68	0	0		
0.2	12@5.0	-	-	290	47		
0.2	12@1.0	684	30	22	0		
0.3	-	320	53	136	47	108	4
0.3	4@5.0	944	30	273	20	76	48
0.3	4@1.0	373	100	35	43		
0.3	7@5.0	941	75	421	5		
0.3	7@1.0	283	100	7	67		
0.3	10@5.0	5306	53	287	14		
0.3	10@1.0	248	26	6	0		
0.3	12@5.0	804	8	382	9	20	15
0.3	12@1.0	476	33	507	0		
0.5	-	691	100	110	23	114	7
0.5	4@5.0	1323	22	140	57	59	30
0.5	4@1.0	619	100	18	7		
0.5	7@5.0	1652	50	515	5		
0.5	7@1.0	919	100	143	47		
0.5	10@5.0	1383	32	405	14		
0.5	10@1.0	231	21	317	50		
0.5	12@5.0	1382	3	361	28	99	30
0.5	12@1.0	793	20	122	70		
0.8	-	-	-	40	45		
0.8	4@5.0	-	-	109	15		
0.8	4@1.0	-	-	0	20		

[a] Values represent pH of buffer and percent of dry buffer added to each pellet.

[b] Based upon chemical analyses of the inner zones from eight blocks/value as measured by gas chromatographic analyses of ethyl acetate/wood extracts. Values represent ug of MIT per oven-dry gram of wood. Survival represents survival of Poria carbonica in blocks exposed to each chemical treatment adjusted against survival in control (untreated) blocks. Each value represents 32 isolation attempts.

high variation between the 1 and 4 week results was moisture content. After treatment, the blocks must be incubated in an open chamber to prevent the build-up of volatile fungitoxic compounds which might make a chemical appear more effective. As a result of the open incubation, the blocks have a tendency to dry out during the exposure. Dry wood retains fumigant differently and the fungi present in wood at lower moisture contents are less active, and, therefore, less sensitive to chemicals. As a result of this problem, the test method has been modified to permit incubation in closed chambers which are continuously flushed with a humidified airstream. This modification should limit the drying rate in the blocks and provide the test fungus with more uniform growth conditions over long incubation periods.

One factor which may influence the effectiveness of the pelletized fumigants is surface area. In powdered formulations, the surface area is limitless, providing a high probability that the chemical will react with moisture or the wood to decompose. In the pellets, the compressed chemicals have a lower probability of interacting, suggesting that the rate of MIT production will also decline. One method for overcoming this limitation is to increase surface area by making many small pellets. Our results indicate that increasing the number of pellets at the same relative dosage did improve the rate of MIT production, although the maximum levels of chemical released did not differ (Table I-9). Instead, the results were more uniform, providing a higher degree of reproduceability. In addition, the levels of fungal control were improved one week after treatment. This increased fungal control continued after 4 weeks, but the levels of MIT present in the wood declined to a greater degree in multiple pellet treatments. This effect suggests that the concentration of the initial chemical wave in the multiple pellet treatments was larger than that found in the single pellet group producing more rapid

fungal control. The effect of the more rapid release on long term fungal control remains unclear. The large surface to volume ratio of the test blocks encourages chemical migration from the wood. This migration would be considerably slower in full size test material, and the slower dissipation of the chemical could enhance fungal control.

TABLE I-9

EFFECT OF SURFACE AREA ON MIT PRODUCTION AND CONTROL OF Poria placenta FOLLOWING APPLICATION OF NaMDC AND SELECTED BUFFERS

			INCUBATION PERIOD[c]			
			ONE WEEK[c]		FOUR WEEKS[c]	
DOSAGE (g)	pH[a]	# PELLETS[b]	MIT ug/g	SURVIVAL (%)	MIT ug/g	SURVIVAL (%)
0.15	-	1	612	87	35	12
0.15	4	1	448	65	0	35
0.15	7	1	542	65	102	0
0.15	10	1	676	33	35	29
0.15	12	1	671	33	0	85
0.45	-	3	1195	39	39	0
0.45	4	3	1386	30	17	40
0.45	7	3	1211	43	126	0
0.45	10	3	2086	55	43	0
0.45	12	3	1250	4	0	35
0.75	-	5	1323	30	32	4
0.75	4	5	2956	35	17	15
0.75	7	5	1060	17	32	0
0.75	10	5	2270	26	34	100
0.75	12	5	1620	7	0	20

[a] Buffers added at 5 percent by weight.

[b] Each pellet weighed 0.15 g.

[c] Values for MIT represent 8 gas chromatographic analyses of ethyl acetate/wood extraction. Figures represent up of MIT per oven-dry gram of wood. Values for survival represent 32 attempts to reisolate P. carbonica.

Performance of Pelletized NaMDC with Additives

Previous studies have suggested that copper ions can enhance the decomposition of NaMDC in soil; however, the levels of MIT present in blocks treated with NaMDC pellets containing 0.5 or 1.0 percent of copper sulfate or 1.0 percent of cupric oxide suggest that these ions have little effect in wood (Table I-10). Conversely, fungal survival in blocks treated with these same

pellets suggests that fungal control was enhanced by the presence of copper. The inverse relationship between fungal survival and MIT content suggests that copper may alter the decomposition pathways of NaMDC. This compound decomposes to produce a multitude of potential fungitoxic compounds. In general, fungal survival, which was not consistently affected one week after treatment with pelletized NaMDC alone, was consistently lower in the copper

TABLE I-10

EFFECT OF COPPER SULFATE AND COPPER OXIDE ON MIT PRODUCTION AND SURVIVAL OF P. CARBONICA IN DOUGLAS-FIR HEARTWOOD BLOCKS FOLLOWING TREATMENT WITH PELLETIZED NaMDC.

			INCUBATION PERIOD[c]					
			ONE WEEK		FOUR WEEKS		EIGHT WEEKS	
DOSAGE g/BLOCK	pH[a]	ADDITIVES[b]	MIT ug/g	SURVIVAL (%)	MIT ug/g	SURVIVAL (%)	MIT ug/g	SURVIVAL (%)
0.2	-	CUS@0.5	546	25	105	58		
0.2	7@5.0	CUS@0.5	405	36	271	17		
0.2	12@5.0	CUS@0.5	189	78	74	75		
0.2	-	CUS@1.0	384	68	67	100	0	0
0.2	4@5.0	CUS@1.0	-	-	-	-	15	0
0.2	7@5.0	CUS@1.0	819	83	129	25	-	-
0.2	12@5.0	CUS@1.0	599	61	102	45	29	3
0.2	7@1.0	CUS@0.5	-	-	170	58		
0.2	12@1.0	CUS@0.5	-	-	259	33		
0.5	-	CUS@0.5	2016	3	367	58		
0.5	7@5.0	CUS@0.5	745	18	359	58		
0.5	12@5.0	CUS@0.5	746	14	-	-		
0.5	-	CUS@1.0	-	-	107	40	22	0
0.5	4@5.0	CUS@1.0	-	-	-	-	37	3
0.5	7@5.0	CUS@1.0	1462	26	173	15	-	-
0.5	12@5.0	CUS@1.0	1238	35	120	40	88	11
0.5	7@1.0	CUS@0.5	-	-	318	17		
0.5	12@1.0	CUS@0.5	-	-	335	58		
0.2	-	CUO@1.0	809	43	-	-	50	7
0.2	4@5.0	CUO@1.0	-	-	-	-	30	36
0.2	7@5.0	CUO@1.0	807	52	-	-	-	-
0.2	12@5.0	CUO@1.0	738	56	-	-	45	21
0.5	-	CUO@1.0	1421	26				
0.5	12@5.0	CUO@1.0	1732	30				

[a] Values represent percentage of each pH buffer in each pellet.

[b] Copper sulfate or copper oxide were added to pellets at rates of 0.5 and 1.0 percent by weight.

[c] Values for MIT represent 8 gas chromatographic analyses of ethyl acetate/wood extracts. Values for fungal survival represent survival of P. carbonica.

containing treatments. This effect was most noticeable in the pellets which did not contain buffer, suggesting that the presence of buffer masks the effect of the copper on NaMDC decomposition.

Performance of Pelletized Mylone: While NaMDc pellets produced abundant quantities of MIT in most treatments, the Mylone pellets produced MIT more slowly. As a result, the degree of fungal control with Mylone was far lower than that found with the NaMDC (Table I-10). In previous tests using powdered Mylone, complete fungal control was achieved after 4 weeks exposure when a pH 12 buffer was added at the time of treatment. In the more recent tests, higher pH buffers enhanced MIT production, but the presence of Mylone and 5 percent of a pH 12 buffer in a pellet had no effect on fungal survival 4 weeks after treatment. The variation in results would appear to reflect the decreased surface area in the pellets (Table I-11). The pellets also repelled water, further slowing reactivity. Increasing the surface area of the pellets by applying several smaller pellets to achieve the same dosage level did not appreciably alter the levels of MIT found in the blocks. This lack of surface area effect suggests that the inability of moisture to penetrate the pellets was a major limiting factor in the effectiveness of Mylone.

Effect of Metallic Salts on Performance of Mylone: The presence of metals has been reported to enhance decomposition of dithiocarbamates and related compounds; however, addition of copper, zinc, or magnesium salts had little effect on MIT production or fungal survival after one week (Table I-12). Both the zinc and magnesium salts appeared to retard MIT production, while the copper salt had no effect. These results indicate that the addition of metals to Mylone will not enhance performance.

Following the initial tests using metallic salts, the effect of copper compounds was further evaluated using copper sulfate and copper oxide at 0.5

TABLE I-11

EFFECT OF pH ON MIT PRODUCTION AND DEGREE OF CONTROL OF P. carbonica PRODUCED BY PELLETIZED MYLONE IN DOUGLAS-FIR HEARTWOOD BLOCKS 1, 4 OR 8 WEEKS AFTER TREATMENT.

		INCUBATION PERIOD[b]					
		ONE WEEK		FOUR WEEKS		EIGHT WEEKS	
DOSAGE g/BLOCK	pH[a]	MIT[b] ug/g	SURVIVAL (%)	MIT ug/g	SURVIVAL (%)	MIT ug/g	SURVIVAL (%)
0.15	-	18	75	24	71		
0.15	4@5.0	23	100	23	71		
0.15	7@5.0	32	19	28	77		
0.15	10@5.0	25	0	28	96	4	100
0.15	12@5.0	94	100	32	68		
0.15	4@2.5	60	100	22	74		
0.15	7@2.5	46	35	24	80		
0.15	10@2.5	33	19	21	80		
0.15	12@2.5	80	0	21	68		
0.30	-	20	100	22	87		
0.30	4@5.0	45	95	23	100		
0.30	7@5.0	20	48	26	100	14	100
0.30	10@5.0	102	22	21	92	12	100
0.30	12@5.0	137	100	62	52		
0.30	4@2.5	61	94	24	61		
0.30	7@2.5	56	56	15	92		
0.30	10@2.5	71	16	21	85		
0.30	12@2.5	138	50	50	36		
0.55	-	35	100	18	77		
0.55	4@5.0	59	100	28	77	18	100
0.55	7@5.0	43	35	25	69	13	100
0.55	10@5.0	117	64	35	81	11	100
0.55	12@5.0	205	69	57	56		
0.55	4@2.5	47	70	24	87		
0.55	7@2.5	75	80	25	100		
0.55	10@2.5	81	0	30	61		
0.55	12@2.5	167	100	50	68		
0.85	-	37	100	19	100		
0.85	4@5.0	82	90	37	100		
0.85	7@5.0	172	100	35	100		
0.85	10@5.0	218	100	53	100		
0.85	12@5.0	152	100	51	100		
0.85	4@2.5	52	66	27	100		
0.85	7@2.5	89	38	32	100		
0.85	10@2.5	318	100	31	100		
0.85	12@2.5	191	75	34	100		

[a] First value represents pH while second value represents percent (by weight) of buffer added to each pellet.

[b] Value for MIT represents ug/oven dried gram of wood as measured by gas chromatographic analyses of ethyl acetate/wood extracts. Survival represents 32 isolations attempts of wood from the test blocks.

TABLE I-12

EFFECT OF COPPER 1 PERCENT SULFATE, ZINC SULFATE AND MAGNESIUM SULFATE ON MIT PRODUCTION AND FUNGAL CONTROL BY PELLETIZED MYLONE ONE WEEK AFTER TREATMENT OF DOUGLAS-FIR HEARTWOOD BLOCKS.

		CHEMICAL ADDITIVE[b]							
		NO ADDITIVE		$CuSO_4$		$ZnSO_4$		$MgSO_4$	
DOSAGE (g)	pH[a]	MIT ug/g	SURVIVAL (%)	MIT ug/g	SURVIVAL (%)	MIT ug/g	SURVIVAL (%)	MIT ug/g	SURVIVAL (%)
0.15	4	35	50	89	62	20	100	20	100
0.15	12	57	12	50	100	29	100	25	100
0.45	4	99	94	132	100	13	100	34	100
0.45	12	125	56	114	100	56	100	53	47
0.60	4	112	44	113	100	14	60	38	100
0.60	12	194	100	143	100	64	100	59	7

[a] Buffers were added at a rate of 5 percent by weight.

[b] MIT values represent 8 gas chromatographic analyses of ethyl acetate/wood extracts. Figures represent ug of MIT per oven-dry gram of wood. Values for survival represent 32 attempts to reisolate P. carbonica from treated wood. Chemical additives were applied at a rate of 1.0 percent by weight.

or 1.0 percent, by weight. The results indicate that neither copper compound influenced fungal control to a significant degree, although the production of MIT was slightly enhanced. This effect was most noticeable after four weeks, when the MIT levels in the copper-free treatments declined much more than similar copper-containing treatments (Table I-13). This effect may prove useful, since the levels of fungitoxic compounds following treatment would remain at higher levels for a longer time period. Although the MIT levels were still below those found with Vapam or the NaMDC pellets, long-termexposure to low levels of MIT may prove as effective for fungal control. Furthermore, slow release over long time periods may permit less frequent retreatments, thereby decreasing maintenance costs.

Effect of Starch on Performance of Mylone: Since the decomposition of Mylone is enhanced by the presence of organic compounds, inclusion of an organic molecule in the pellet may enhance chemical performance. To evaluate this prospect, pellets containing 10 percent starch were formulated at 0.15, 0.30, 0.55 and 0.85 g. The pellets also contained 5 percent of pH 4, 7, or 12 buffer. An additional set of starch containing pellets were formulated without buffer.

TABLE I-13

EFFECT OF COPPER SULFATE AND CUPRIC OXIDE ON MIT PRODUCTION AND CONTROL OF *P. carbonica* IN DOUGLAS-FIR HEARTWOOD BLOCKS FOLLOWING APPLICATION OF PELLETIZED MYLONE.

			INCUBATION PERIOD[c]					
			ONE WEEK		FOUR WEEKS		EIGHT WEEKS	
DOSAGE g/BLOCK	pH[a]	ADDITIVES[b]	MIT ug/g	SURVIVAL (%)	MIT ug/g	SURVIVAL (%)	MIT ug/g	SURVIVAL (%)
0.15	10@5.0	CUS@1.0	-	-	-	-	15	100
0.30	4@5.0	CUS@1.0	24	84	46	74		
0.30	4@2.5	CUS@1.0	114	80	68	0		
0.30	7@5.0	CUS@1.0	-	-	-	-	14	5
0.30	10@5.0	CUS@1.0	178	93	80	21	27	100
0.30	10@2.5	CUS@1.0	118	35	68	29		
0.30	4@5.0	CUS@0.5	54	84	71	55		
0.30	4@2.5	CUS@0.5	37	92	62	71		
0.30	10@5.0	CUS@0.5	48	100	67	74		
0.30	10@2.5	CUS@0.5	46	100	44	97		
0.55	4@5.0	CUS@1.0	92	93	231	4		
0.55	4@2.5	CUS@1.0	113	70	91	8		
0.55	7@5.0	CUS@1.0	-	-	-	-	31	28
0.55	10@5.0	CUS@1.0	180	100	71	8	27	100
0.55	10@2.5	CUS@1.0	182	85	91	42		
0.55	4@5.0	CUS@0.5	77	80	61	55		
0.55	4@2.5	CUS@0.5	40	100	59	77		
0.55	10@5.0	CUS@0.5	97	100	84	55		
0.55	10@2.5	CUS@0.5	57	100	60	74		
0.30	4@5.0	CUO@1.0	75	100				
0.30	7@5.0	CUO@1.0	-	-	-	-	17	19
0.30	10@5.0	CUO@1.0	-	-	-	-	11	67
0.55	4@5.0	CUO@1.0	90	80	64	42		
0.55	10@5.0	CUO@1.0	186	60	122	42	20	14

[a] Values represent pH of buffer followed by weight percentage of buffer/pellet.

[b] Copper Sulfate (Ce 5) of Cupric Oxide were added to pellet at the rate of no 0.5 or /.0 percent by weight.

[c] MIT values represent ug of MIT per oven dried gram of wood as measured by 8 gas chromatographic analyses of ethyl acetate/wood extracts, while survival values represent 32 attempts to reisolate *P. carbonica* from the treated wood.

Starch had little effect on the levels of MIT found in the blocks one week after treatment, but MIT levels were generally higher in starch treatments four weeks after incubation (Table I-14). Similarly, fungal survival did not appear to be affected by the presence of starch in the pellets. The exception to this occurrence was the pH 12 treatment, where

fungal survival was always lower when starch was included in the treatments. These results suggest that the presence of starch will enhance decomposition and fungal control at higher dosages in the presence of high pH buffers; however, the starch occupies volume in the pellets which decreases the maximum level of chemical applied. Decreased dosage may reduce the long-term treatment effectiveness, suggesting that the slight enhancement of MIT production does not justify addition of starch.

TABLE I-14

EFFECT OF STARCH (10%) ON MIT CONTENT AND CONTROL OF Poria carbonica IN DOUGLAS-FIR HEARTWOOD BLOCKS TREATED WITH MYLONE PELLETS AND INCUBATED FOR ONE OR FOUR WEEKS.

		INCUBATION PERIOD[b]							
		ONE WEEK				FOUR WEEKS			
		STARCH		NO STARCH		STARCH		NO STARCH	
DOSAGE (g)	pH[a]	MIT ug/g	SURVIVAL (%)	MIT ug/g	SURVIVAL (%)	MIT ug/g	SURVIVAL (%)	MIT ug/g	SURVIVAL (%)
0.15	-	27	100	18	75	36	71	24	71
0.15	4	25	100	23	100	67	90	23	71
0.15	7	38	96	32	19	22	100	28	77
0.15	12	84	100	94	100	68	53	32	68
0.30	-	39	25	20	100	37	84	22	87
0.30	4	23	100	45	95	38	97	23	100
0.30	7	41	96	20	48	55	100	26	100
0.30	12	81	100	137	100	50	41	62	52
0.55	-	-	-	35	100	52	90	18	77
0.55	4	37	125	59	100	41	71	28	77
0.55	12	200	96	205	69	52	12	57	56
0.85	-	68	75	37	100	62	100	19	100
0.85	4	55	100	82	100	56	87	37	100
0.85	7	83	76	172	100	68	84	35	100
0.85	12	197	100	152	100	93	12	51	100

[a] Buffers were added at a rate of 5 percent by weight.

[b] MIT values represent up of MIT per oven-dry gram of wood as measured by 8 gas chromatographic analyses of ethyl acetate/wood extracts. Values for survival represent 32 attempts to isolate P. carbonica from the treated wood. Starch was added as 10 percent by weight.

Future of Pelletized Formulations: While the current tests have not produced complete fungal control, they indicate that the rate of chemical release can be controlled by careful use of various additives. In addition, pellets offer

enhanced safety and ease of handling, making application more attractive to utility users. Further studies are now underway to explore the variation in results and to better quantify the relationship between wood moisture content at the time of treatment, MIT level in the wood and fungal control. The use of pelletized NaMDC appears particularly promising, since the levels of MIT production are higher than those found with Mylone, and the active ingredient is already registered for wood use.

Ability of Fused Borate Rods to Eliminate Fungi from Douglas-fir Heartwood

While fumigants have performed well, there are other technologies for controlling decay of large wood structures. Fused borate rods represent one such technology. These rods, which are made of sodium octaborate tetrahydrate fused into a glass-like material, are extensively used in Europe for remedial decay control of windows, door frames and building timbers. Applied to the same types of holes used for fumigant application, the rods break down in the presence of water to release boron, which migrates with moisture through the wood. While these chemicals do not appear to be capable of the appreciable upward movement typical of fumigants, previous studies on dimension lumber indicate that they can migrate well through Douglas-fir heartwood. Generally, wet wood treats better than dry. Judicious application of the rods could protect the groundline region. The main advantage of the borate rods is their safety. Borates are very low toxicity compounds which lack the volatility of conventional wood fumigants.

The ability of fused borate rods to control decay fungi established in Douglas-fir heartwood was examined using the small block test described above. Because borates migrate more readily through moist wood, one set of blocks were pressure soaked prior to introduction of the decay fungus. Normally, blocks used for the small block test begin at a moisture content of 50 to 60

percent, while moisture contents of pressure-soaked blocks ranged from 80 to 100 percent. Blocks were treated by placing weighed samples of small fused borate rods (0.5 cm diameter) into the same hole used for fumigant application. The rods were applied at rates of 50, 125, 250, 500, and 1000 mg per block to four conventional and four pressure-soaked blocks, and 1.5 ml of water was added to accelerate chemical release. These dosages correspond to 1, 2, 4, 8, or 10 kg/m^3 or 0.2, 0.5, 1.0, 2.0, or 4.0 percent (by weight) respectively. Following treatment, the blocks were incubated for 2 or 6 weeks at room temperature. Since volatile emissions were of little concern, the chambers were incubated with the lids on to retain moisture over the test period.

At the end of each incubation period, the blocks were removed and a series of three 0.5 cm thick sections were cut from each end. The outer section was discarded, while the middle section was cut into 16 equal size squares and the inner four squares were placed onto potato dextrose agar and were cultured for the presence of the test fungus, Poria carbonica, which was used as a measure of chemical efficacy. The inner section was stained with a tumeric extract/salicylic acid stain which is sensitive to the presence of boron at levels greater than 0.15 percent by weight. The indicator turns red in the presence of boron. The degree of boron penetration in the blocks ends was then measured. These sections will be retained for later chemical analyses.

The results indicate that short term exposures to borate had little effect on fungal survival, while longer incubation periods provided more effective fungal control (Table I-15). These results are not unexpected since previous tests evaluating the migration of boron into freshly sawn lumber indicate that 4 to 10 weeks are required for complete diffusion. Longer

incubation periods markedly enhanced the performance of the rods, particularly at application rates greater than or equal to 250 mg per block. The effect was most noticeable in the pressure-soaked blocks, where the higher moisture contents provided a medium more conducive to borate diffusion. Previous tests at the University of Minnesota have indicated that a minimum dosage of 3 kg/m^3 is required to control established decay fungi in spruce-pine-fir (SPF) lumber. Our results in the high moisture content blocks seems to reflect this treatment level. It is important to note that the diffusion period for the SPF lumber was 10 months, while our tests only lasted 6 weeks. Longer diffusion periods might provide more effective control at lower dosages, particularly in wet wood.

The results indicate that fused borate rods may have a role in decay control under certain regimes. As a result of these tests, field trials using small pole sections will be established at the Peavy Arboretum test site, at Hilo, Hawaii, and in a fungal cellar in Charlotte, North Carolina.

TABLE I-15

ABILITY OF FUSED BORON RODS TO ELIMINATE Poria carbonica FROM DOUGLAS-FIR HEARTWOOD BLOCKS AS MEASURED BY CULTURING 2 OR 6 WEEKS AFTER TREATMENT

DOSAGE (MG/BLOCK)	FUNGAL SURVIVAL (%)[a]			
	LOW MOISTURE CONTENT		HIGH MOISTURE CONTENT	
	2 WEEKS	6 WEEKS	2 WEEKS	6 WEEKS
CONTROL	100	25	94	100
50	100	25	100	-
125	-	-	100	-
250	-	-	62	25
500	94	16	-	0
1000	-	-	-	0

[a] Values based upon 32 attempted isolations from each treatment. Locations with a "-" denote tests that are in-progress. Low moisture content blocks ranged from 50 to 60 percent MC, while high moisture content blocks were pressure soaked to MC ranging from 80 to 100 percent.

C. EVALUATE THE MOST PROMISING FUMIGANTS IN POLES

Preinstallation fumigation of Douglas-fir poles

Fumigant treatment at the time of installation should provide the optimum protection to the pole. To evaluate this procedure, thirty-eight Douglas-fir poles ranging from 16.5 - 24 m in length were fumigant-treated with encapsulated MIT in the service yard prior to installation. The pattern of treatment started near the top and spiraled at 90^{0} intervals down the pole at 1.2 m intervals, avoiding both pre-drilled and field bolt holes.

Fifteen months after installation, ten poles were sampled by removing increment cores from the upper, middle, and lower portion of the poles. The upper and middle cores were taken between treatment holes or approximately 0.6 m from a given treating hole. Cores from the lower section were removed from sites 1.2 m below the lowest treatment hole. These cores were cultured for the presence of decay fungi by placing on malt extract agar and observing the wood for fungal growth over a one month period. In addition, a 2.5 cm segment from each core was extracted in ethyl acetate for gas chromatographic analysis.

Cores removed from the treated poles were completely free of decay fungi one year after treatment (Table I-16). This is not unexpected since the combination of Boulton seasoning prior to pressure-treatment with pentachlorophenol and fumigant treatment should completely eliminate decay fungi. In addition to the lack of fungi, detectable levels of MIT were present in all but two core samples (Table I-17). The latter two samples were removed from the outer zones from the lower portion of two poles. In general, fumigant levels were lowest near the groundline and near the outer shell. Previous tests indicate that the outer zones are normally the last to be protected by the fumigant. Below the treating hole (1.2 m), the fumigant

moved slower across the grain (from inside to outside) than along it (up and down). The lack of protection below the last treating hole, nearest the groundline, suggests that decay fungi could attack this zone under ideal conditions; however, continued chemical migration should protect this zone.

TABLE I-16

FUNGAL POPULATION OF PRESSURE-TREATED DOUGLAS-FIR POLES FUMIGANT-TREATED ABOVE GROUNDLINE WITH ENCAPSULATED MIT PRIOR TO INSTALLATION AS DETERMINED BY CULTURING INCREMENT CORES REMOVED 15 MONTHS AFTER TREATMENT

	CORES CONTAINING DECAY/NON-DECAY FUNGI (%)[a]		
Pole Number	Lower	Middle	Upper
G171/11	0^1	0^0	0^0
G171/2	0^0	0^0	0^1
G171/4	0^1	0^0	0^0
G084/1	0^0	0^0	0^0
G084/8	0^0	0^0	0^0
G054/3A	0^0	0^0	0^0
G054/3B	0^0	0^0	0^0
G054/3C	0^0	0^0	0^0
G053/19A	0^0	0^0	0^0
G053/19B	0^0	0^0	0^0
Total	0^2	0^0	0^1

[a] The number represents cores with decay fungi, and the superscript denotes micro fungi. While lower, middle, and upper columns refer to the portion of the poles sampled.

The results indicate that the fumigant has become well distributed and should prevent decay fungi from colonizing wood above groundline or around bolt holes. As a result, service life should be significantly extended and this pole will retain the maximum strength values over its service life. Preinstallation fumigant treatment was readily performed on these test poles in the utility's storage yard prior to treatment. The recent registration of glass-encapsulated MIT would make these treatments simple and cost effective.

TABLE I-17

LEVELS OF MIT IN CORES REMOVED FROM DOUGLAS-FIR POLES TREATED WITH GELATIN-ENCAPSULATED MIT MEASURED BY EXTRACTING IN ETHYL ACETATE AND ANALYZING EXTRACTS USING GAS CHROMATOGRAPHY.

POLE NUMBER	SAMPLING SITE (METERS ABOVE GL)	MIT LEVELS[a] OUTER ZONE	MIT LEVELS[a] INNER ZONE
G171/2	0.6	18	142
	3.6	118	512
	6.0	92	386
G053/19B	0.6	234	127
	3.6	494	865
	6.0	202	1,074
G171/11	0.6	0	62
	3.6	165	1,052
	6.0	64	61
G053/19A	2	13	351
	4.2	738	1,169
	6.6	31	716
G084/8	2.4	26	279
	5.4	135	810
	7.8	154	525
G054/3A	2.4	30	308
	5.4	196	967
	7.8	150	436
G054/3B	2.4	17	145
	5.4	94	724
	7.8	218	685
G054/3C	2.4	33	278
	5.4	131	534
	7.8	9	600
G171/4	3.0	0	386
	6.0	94	925
	8.4	180	1,051
G084/1	4.2	17	128
	7.2	100	775
	9.6	77	150

[a] Total ug MIT extracted per oven-dried gram of wood. Core zones correspond to 0 to 2.5 cm and 12.5 to 15 cm from the pole surface.

New York field test of encapsulated MIT

In 1981, twenty-four 9 year old chromated copper arsenate treated poles were remedially treated with gelatin encapsulated MIT (475 or 950 ml) or non-encapsulated Vapam (950 ml). These poles have been sampled on an annual basis by removing increment cores for culturing for the presence of decay fungi and closed tube bioassays for the presence of residual fungitoxicity. The sampling scheme for these tests was previously described ('86 Ann. Rept., pg. 25-28).

The poles continue to remain relatively free of decay fungi, although one pole in the lower MIT treatment was lightly colonized 0.6 meters (2 ft.) above the groundline (Table I-18). The continued isolation of low levels of decay fungi suggests that isolated pockets have not been protected by the treatment. These treatment voids may represent zones adjacent to small checks or zones where defects above or below the sampling site interfere with chemical migration. The small size and the low frequency of these isolations suggests that they should not affect long term treatment efficacy.

Closed tube bioassays continue to indicate the presence of fungitoxic vapors in all treatments except the Vapam treated poles (Table I-19). This result is not unexpected, since Vapam usually can not be detected within 2 to 3 years after treatment. Despite the absence of volatile fungitoxicity, the Vapam treated poles continue to remain free of decay fungi.

The remaining treatments retain considerable fungitoxicity, although wood from the low dosage MIT treated poles and the outer zone of the Vorlex treated poles did not completely inhibit growth of the test fungus, Poria placenta. The results of the MIT treatments closely parallel those with non-encapsulated MIT and Vorlex, and indicate that this treatment should perform as well as the aforementioned chemicals.

TABLE I-18

INCIDENCE OF DECAY FUNGI IN DOUGLAS-FIR POLES IN NEW YORK STATE PRIOR TO AND AFTER TREATMENT WITH VAPAM OR GELATIN ENCAPSULATED METHYLISOTHIOCYANATE (MIT).[a]

SAMPLING DATE	METERS ABOVE GROUNDLINE	CORES WITH DECAY FUNGI (%)			
		NO FUMIGANT[c] (VORLEX) 950 ML	VAPAM 950 ML	ENCAPSULATED MIT[B] 475 ML	ENCAPSULATED MIT[B] 950 ML
June 1981	0	83	61	78	78
	0.6	61	72	61	56
Oct. 1981		Poles Treated With Fumigants			
July 1982	0	94	22	22	6
	0.6	67	17	0	6
	1.2	22	6	6	6
July 1983	0	44	6	0	0
	0.6	61	11	0	6
	1.2	33	0	0	0
July 1984	0	67	0	0	0
	0.6	78	0	0	0
	1.2	33	0	0	0
July 1985[c]	0	39	0	0	6
	0.6	61	0	11	0
	1.2	28	17	6	0
July 1986	0	6	0	0	0
	0.6	0	0	6	0
	1.2	0	17	11	6
July 1987	0	0	0	0	0
	0.6	0	0	6	0
	1.2	0	0	0	0

[a] A total of 18 cores (three per height) were removed from six poles for each sampling date.

[b] About 450 ml of water per pole was added along with the capsules for the 475 ml MIT treatments, and about 900 ml of water was added with capsules for the 950 ml treatments.

[c] Control poles were retreated with gelatin encapsulated Vorlex after the 1985 sampling.

TABLE I-19

CLOSED-TUBE BIOASSAYS OF CORES REMOVED FROM NEW YORK POLES AFTER TREATMENT WITH VAPAM, GELATIN ENCAPSULATED MIT OR VORLEX.[a]

CHEMICAL	DOSAGE (ML)	YEAR SINCE TREATMENT	SAMPLING HEIGHT (FEET)	AVERAGE GROWTH OF P. PLACENTA (AS A % OF CONTROL) CORE ZONE[b] OUTER	INNER
MIT	475	6	0	24	14
			0.6	5	17
			1.2	7	0
MIT	950	6	0	0	0
			0.6	0	0
			1.2	0	0
VAPAM	950	6	0	57	77
			0.6	77	54
			1.2	70	69
VORLEX	950	2	0	18	0
			0.6	13	0
			1.2	22	0
Control tubes (no wood): Avg = 8.3 mm[c]					

[a] The close tube bioassay uses a 1 inch wood segment removed from the pole. These segments are placed in agar tubes preinoculated with an assay fungus, Poria placenta. Fumigant effectiveness is then evaluated as the ability of a wood sample to inhibit radial growth of the fungus and cores with lower numbers have higher fumigant levels.

[b] Increment cores were divided into three segments, 0-2.5 cm, 2.5 to 12.5 and 12.5-1.5 cm. The middle segment was used for and the outer (0-2.5 cm) and inner 12.5-15 cm) segments were used for closed tube assays.

[c] Control tubes showed poor growth, ranging from only 5 mm to 20 mm after 7 days growth.

Treatment of Douglas-fir poles with encapsulated MIT: effect of moisture on chemical release.

In 1983, a study was begun to evaluate the effect of moisture addition at the time of treatment on gelatin encapsulated MIT ('86 Ann. Rept., pg. 30-32). Poles were treated by drilling holes in a spiral pattern offset by 90 degrees at intervals of 1 meter up the pole, from 0 to 5 meters from groundline. Each treatment hole received 0 (dry), 40 (moist), or 70 ml (wet) ml of water to determine the effect of excess moisture on gelatin breakdown and chemical release. The poles have been sampled on an annual basis by removing increment cores from sites beginning near the groundline and continuing up to 5.5 meters

above this zone. These cores have been used for culturing and closed tube bioassays.

Although last year's sampling indicated that some of the poles were being recolonized ('87 Ann. Rept., pg. 29), the most recent data indicates that the levels of colonization have fallen dramatically (Table I-20). This variation may reflect continued chemical migration through the pole. Only one zone, the 5.5 meter site in the wet treatment, contained viable decay fungi.

Closed tube bioassays of these same poles indicated that volatile fungitoxic vapors were present in all of the samples (Table I-21). Very few of the cores completely inhibited growth of the test fungus, but all produced inhibitions greater than 75 percent.

While initial results indicated that the wet and moist treatments produced more rapid fungal control, the present data indicate little difference between the treatments. Continued fungitoxicity indicates that these treatments should perform as well as the non-encapsulated treatments established in 1977.

TABLE I-20

FREQUENCY OF DECAY FUNGI ISOLATED FROM DOUGLAS-FIR POLES TREATED WITH GELATIN ENCAPSULATED METHYLISOTHIOCYANATE (MIT).

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

[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.

TABLE I-21

RESIDUAL FUMIGANT EFFECTIVENESS IN DOUGLAS-FIR UTILITY POLES FOLLOWING APPLICATION OF GELATIN ENCAPSULATED METHYLISOTHIOCYANATE AS MEASURED BY THE CLOSED TUBE BIOASSAY.

METERS ABOVE GROUND	CORE LOCATION INSIDE TREATED SHELL (cm)	GROWTH OF ASSAY FUNGUS (AS % OF CONTROL)[a]		
		DRY	MOIST	WET
0	0-2.5	-	-	-
	12.5-15	-	-	-
0.9	0-2.5	8	8	24
	12.5-15	10	16	28
1.8	0-2.5	4	0	16
	12.5-15	3	17	16
2.8	0-2.5	18	0	8
	12.5-15	0	8	16
3.7	0-2.5	3	0	8
	12.5-15	4	0	8
4.6	0-2.5	24	0	10
	12.5-15	20	11	8
5.5	0-2.5	11	8	12
	12.5-15	13	4	0
Control	(no wood)	40 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, Poria placenta. Fumigant effectiveness is then evaluated as the ability to inhibit radial growth of the fungus. Cores with lower numbers have higher fumigant levels.

D. IDENTIFY PROPERTIES OF FUMIGANTS IN RELATION TO PERFORMANCE

Preliminary Modeling of Methylisothiocyanate Movement through Douglas-fir Poles.

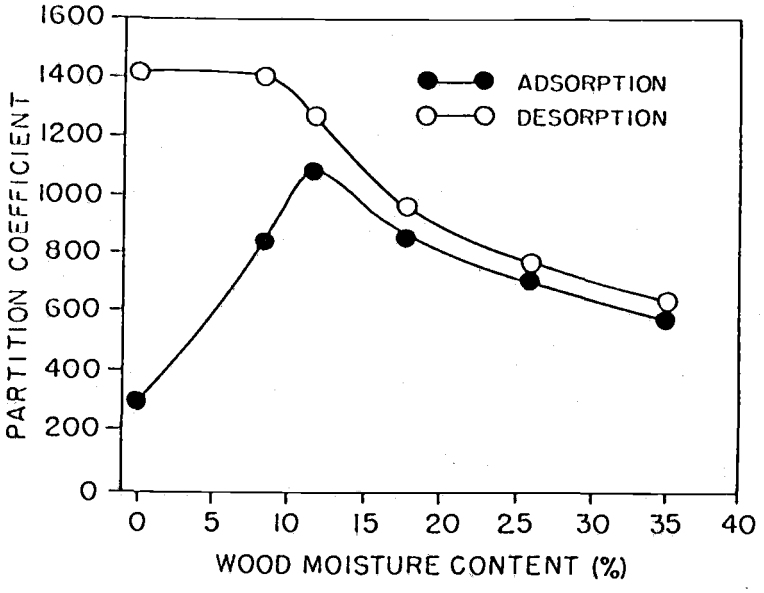
Fumigants can effectively control decay fungi within large wooden structural members and extend their service lives. Field studies have shown that MIT effectively controls decay fungi in wood poles and pilings, with vapors persisting for at least 10 years after treatment. Current fumigant treatment practices, including drilling pattern, formulation, quantity of fumigant used, and retreatment schedules depend more on "rules of thumb" estimated from field experiments rather than on an understanding of how the fumigant interacts with wood and fungus to control internal decay.

Information has recently been developed on MIT interactions with, and rates of diffusion through Douglas-fir wood (Figure I-3, Tables I-22, I-23) as well as the MIT concentrations required in the wood to effectively control the decay fungus P carbonica. This information provides insight into the MIT-wood interactions that govern the movement and effectiveness of fumigant treatments involving MIT as the active ingredient.

While there are gaps in our current understanding of how wood moisture content (MC), temperature, and preservative treatments interact to govern MIT movement, the existing knowledge is sufficient to develop basic models describing MIT movement through wood poles under specific treatment conditions. These models can be used to estimate fumigant behavior and effectiveness in wood products under different treatment conditions, and should aid in optimizing MIT treatment practices.

The MIT steady-state diffusion and equilibrium partition coefficients (sorption data) suggest patterns for the expected relative movement of MIT through poles under different treatment conditions (Figure I-4). MIT diffusion coefficients are considerably greater in the longitudinal than lateral dimensions, while the radial coefficient exceeds that for the tangential direction. Wood moisture content also has a strong influence on both diffusion coefficients and MIT sorption. Under certain conditions, these effects oppose one another in controlling overall MIT movement. For example, increasing wood moisture content reduces the MIT diffusion coefficient, but also lowers MIT sorption. These effects would restrict the total MIT moving through the wood, but allow greater MIT vapor concentrations to develop within a given region. These opposing effects make it difficult to intuitively determine the overall influence on chemical movement. Numerical modeling provides a viable alternative for assessing chemical movement.

Figure I-3. The relationship between the moisture content of Douglas-fir heartwood blocks and MIT partition coefficients for wood adsorbing and desorbing fumigant. Partition coefficients (bound/ vapor) describe the relationship between sorbed MIT (per g oven dry wood) and vapor concentrations of MIT (per cc air) at equilibrium.



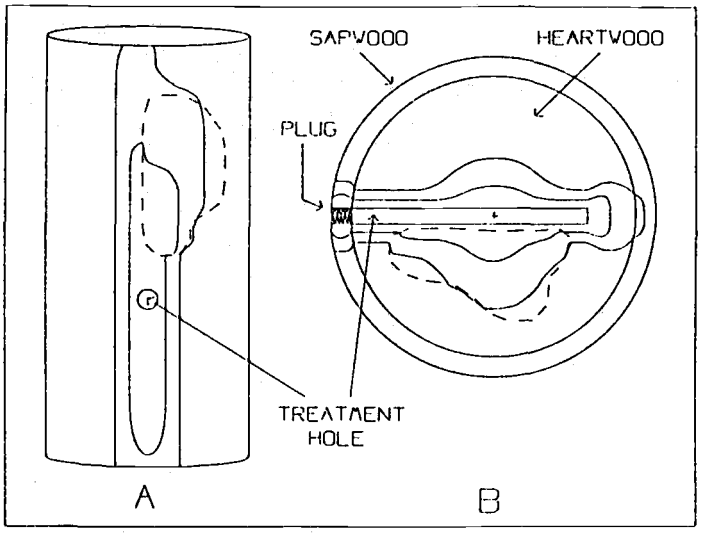


Figure I-4. Anticipated distributions of MIT in longitudinal (A) and transverse (B) directions through a low moisture content (14%) pole with a high moisture content (70%) pocket. Based on measured steady-state diffusion coefficients (Tables 1 and 2) and adsorption partition coefficients (Figure 1). Regions enclosed by dashed lines represent high moisture content pockets, while solid lines represent relative MIT concentration contours.

TABLE I-22

DIFFUSION COEFFICIENTS DESCRIBING THE RATE OF METHYL-ISOTHIOCYANATE MOVEMENT THROUGH DOUGLAS-FIR HEARTWOOD WAFERS.

Wood Moisture Content (%)	Diffusion Coefficients by flow direction[a]		
	Longitudinal	Radial	Tangential
13 -16	1.4	0.0019	0.00047
21 -24	2.3	N.A.	0.0038
35 -47	1.7	0.0062	0.0043
73 -91	0.84	N.A.	0.0040

[a] Diffusion coefficients (cm^2/min) were calculated using MIT concentration to describe the gradient (Zahora and Morrell,in review).

TABLE I-23

INFLUENCE OF PRESERVATIVE TREATMENTS ON RADIAL DIFFUSION AND SORPTION OF METHYLISOTHIOCYANATE (MIT) IN DOUGLAS-FIR SAPWOOD WAFERS EQUILIBRATED AT 76% RH (ABOUT 15% MC).

CHEMICAL TREATMENT		SORPTION[a]	DIFFUSION[b]
TYPE	(KG/M^3)	(mg MIT/g WOOD)	COEFFICIENT
None	---	16	0.014
P-9 oil	245	121	0.007
CCA	16	14	0.014

[a] The average MIT sorption at an average MIT vapor concentration of 18 ug/cc air (35 to <1 ug/cc air across the wafer length).

[b] Average diffusion coefficients (cm^2/min) were calculated using MIT vapor concentration for the gradient.

In previous tests, MIT diffusion through the sapwood shell was greater than through the heartwood, but treatment of the shell with P-9 Type A oil (carrier for oil-borne preservatives) restricted diffusion as compared to a CCA or untreated shell (Tables I-22, I-23). Oil treatment also increased MIT sorption by the sapwood, which may increase MIT movement into the shell by maintaining higher vapor concentration differences between the heartwood and oil-treated shell. The relative importance of sorption and diffusion influences on the overall movement of MIT through wet pockets and the sapwood shell can be most easily estimated by the use of models.

Our current knowledge of chemical application patterns and MIT/wood interactions suggests that the central column of a pole should receive the highest concentrations of fumigant. It is common practice to drill multiple radial treatment holes in a spiral pattern around the pole. These holes overlap in the central core of the pole, and the relatively poor rate of tangential diffusion may result in excessive treatment at the very center of the pole in comparison to the outer heartwood. This may be especially important in dry wood. The lack of an accurate mathematical model to describe MIT movement makes it impossible to accurately estimate how the differences in longitudinal, radial, and tangential diffusion rates will influence the MIT concentrations within areas of a wood pole.

This report details preliminary results of a basic model which incorporates the current knowledge of MIT diffusion and sorption in wood to simulate MIT movement within a cross-section of a Douglas-fir pole. This model can be used to determine the influence of variations in specific treatment parameters on MIT movement and effectiveness.

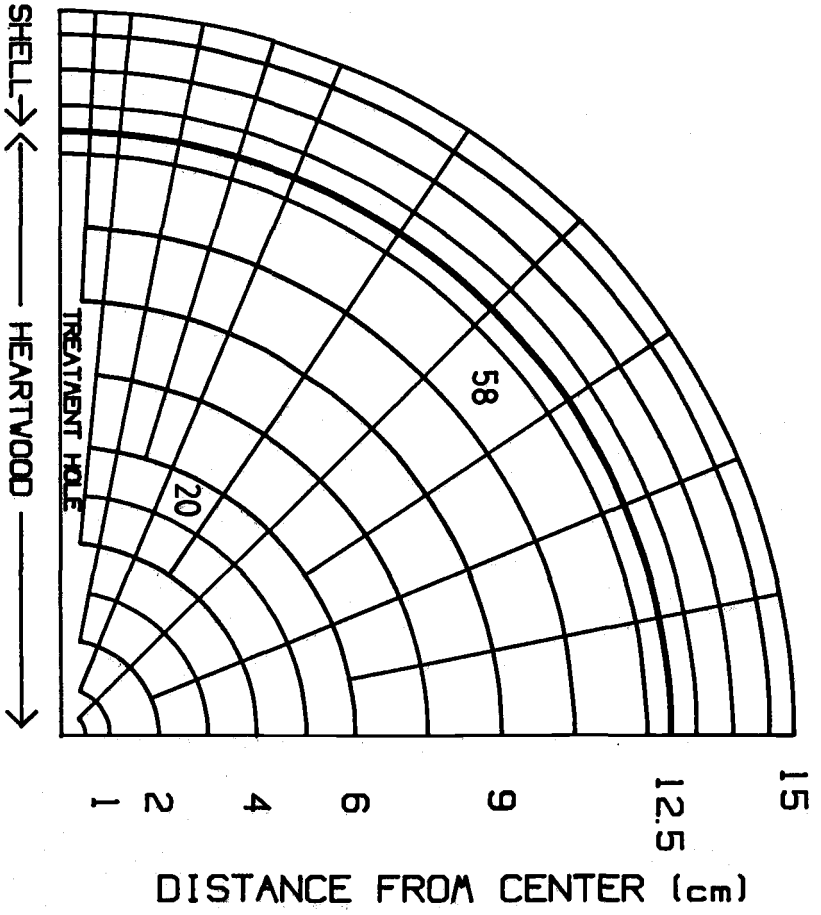
MATERIALS AND METHODS: The ideal mathematical model would account for all of the contributory physical and chemical processes operative in the system and

accurately draw on these to predict observed changes in the distribution of MIT throughout the wood. Prerequisites of such a model would be an understanding of how diffusion coefficients are affected by all the conditions that vary in the system, how MIT sorption and diffusion combine to govern fumigant movement under the selected conditions and how the system can be mathematically integrated. Unfortunately, MIT diffusion in wood depends on both bound and vapor components, each of which may be dependent on MIT concentration, wood moisture content, and whether wood is adsorbing or desorbing fumigant (hysteresis effect). At present, we lack information for many of these factors. In addition, we lack data on complicating factors such as the variable delay in reaching sorption equilibrium.

Sufficient information is, however, available to develop a preliminary model to estimate MIT movement, persistance, and effectiveness under specific environmental conditions. An appropriate numerical modeling scheme has been successfully formulated to simulate heat and moisture transfer with phase change in wood-based composites during hot pressing (Humphrey and Bolton, in press). The approach is based on numerical methods of mathematical analysis, wherein nonsteady-state diffusion is modeled in three-dimensions and time using a combination of steady-state diffusion coefficients and equilibrium sorption data.

Our preliminary model, which will be briefly described here, was limited to two-dimensional MIT movement through a horizontal cross-section of a standing wood pole. The circular pole section was broken into a series of discrete regions (Figure 5), with each region relating to its neighbors either radially or tangentially. In our model, the pole section was 30 cm in diameter, with a fumigant treatment hole of 0.5 cm diameter drilled radially through the center to within 3 cm of the opposite side. The treatment hole

Figure I-5. Grid system used to divide one quadrant of a pole cross-section for computer modeling. MIT vapor concentrations in discrete regions 20 and 58 are discussed in the results section.



was assumed to be sealed so that it was identical to the opposite side of the cross-section (diametrically symmetrical). This symmetry meant that predictions for one gradient of the pole section was representative of MIT movement in the entire cross-section.

The gradient was divided into 116 discrete regions, each with its own diffusion and sorption properties based on wood type (sapwood, heartwood, oilborne preservative treatment) and moisture content. These characteristics determine the specific diffusion coefficients in each diffusion direction (radial and tangential), and the equilibrium partition ratios between MIT in the vapor phase, adsorbed to solid wood, and taken up by the free water

present in that region. Three boundaries were considered within the model: between the treatment hole and the heartwood; between the heartwood and sapwood; and between the sapwood and the outside of the pole. Near these transition boundaries, smaller discrete increments were used than in areas farther away from boundaries.

Movement of MIT from one zone to the other was calculated based on Fick's first law using the equation:

$$m = D(C)*A*C*t / L$$

where:
- **m** = MIT flow (ug)
- **D(C)** = Diffusion Coefficient (cm^2/min)
- **A** = X-sectional area for flow (cm^2)
- **C** = MIT concentration difference driving diffusion over length L (ug/cm^3 air)
- **t** = Time of flow (min)
- **L** = Length in flow direction (cm)

The driving force for MIT diffusion was the associated equilibrium MIT vapor concentration difference between a discrete region and each of its neighbors. The diffusion coefficients combined both vapor and bound diffusion components into a single term (Table I-22). Equilibrium sorption and steady-state diffusion conditions were assumed in each region at any given point in time. The model was continually updated over a series of short time increments to estimate longer-term movement under nonsteady-state conditions. At the end of each time increment, the fumigant conditions were updated for each discrete pole region. The total MIT content was partitioned between vapor, wood and water phases, to determine the MIT vapor concentration in that region.

This method depends upon approximations that utilize sufficiently small time increments and flux of diffusant that does not significantly alter the gradient. Gradients are re-defined in response to preceding flux in readiness for the next time step. Clearly, choice of time step duration and size of regions will effect the accuracy of the predictions as well as the stability

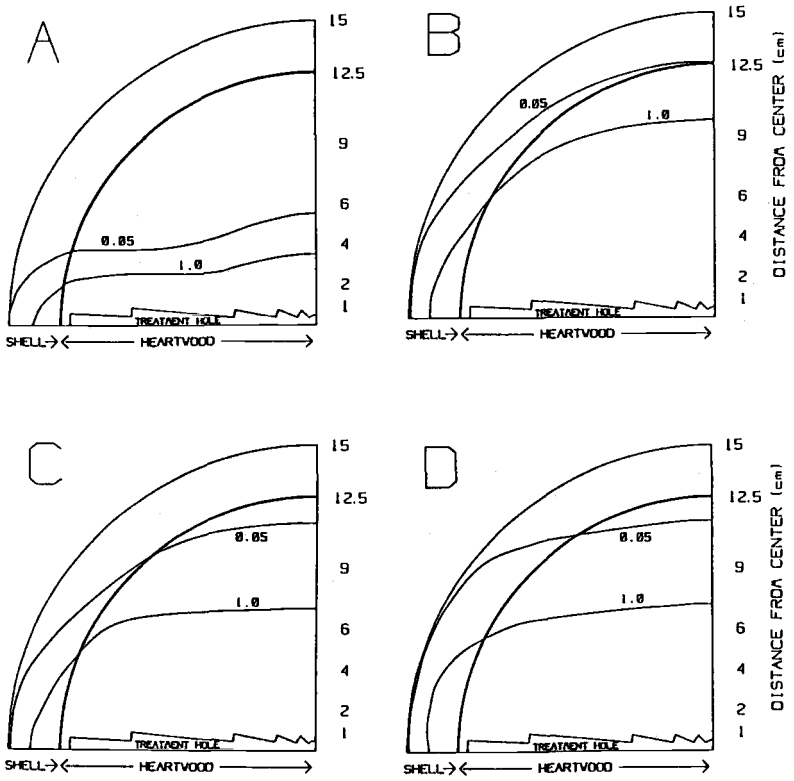
and convergence of the algorithm. In this preliminary form of the model, these parameters have been selected by trial and error. Future work will include derivation of criteria for more precise parameter selection.

The fumigant treatment parameters defined in preliminary runs of the model were: 0.2 g MIT in the treatment hole, moisture content of the heartwood section of the pole was either 14, 22, or 40 percent, and the sapwood zone of the pole section was either treated with an oil-based preservative or was left untreated. The latter condition would produce results similar to those found for wood treated with waterborne CCA preservatives. While field treatment might use 20 g MIT/treatment hole, this dosage was reduced in an attempt to compensate for the lack of longitudinal diffusion in this simplified model. The model was continually updated over a series of 2 hr time increments keeping track of the MIT vapor concentration in each discrete region of the pole, the MIT remaining in the treatment hole, and the amount of MIT lost from the wood.

RESULTS: The model was used to evaluate MIT movement through the Douglas-fir cross section over a period of 252 days under a variety of moisture and wood treatment conditions. The results indicated that both factors influenced the predicted behavior of MIT in the wood.

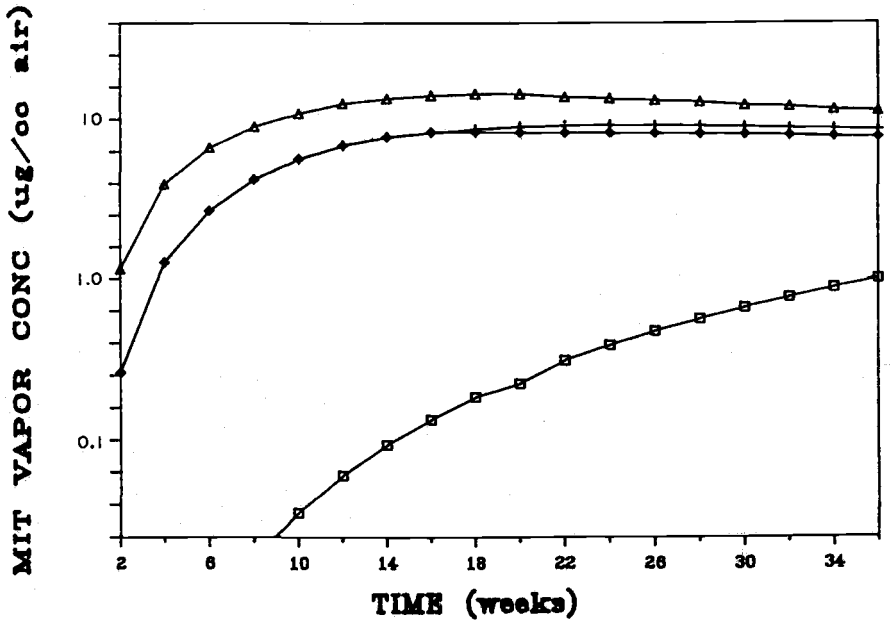
Effects of Wood Moisture Content: Evaluation of MIT movement after 252 days at 14, 22, and 40% MC indicated that movement was lowest at 14% MC and differed little between the 22 and 40% MC (Figure I-6). The decreased distribution at the lower moisture content apparently reflected the stronger sorption of MIT by the dry wood. These results have been confirmed by laboratory trials. In addition to the final differences in MIT gradients within the cross-section, the rate of MIT movement through a given grid location also varied with wood moisture content.

Figure I-6. Predicted methylisothiocyanate (MIT) vapor concentration contours (1.0 and 0.05 ug MIT/cc air) in pole sections 252 days after treatment under conditions of (A) 14% MC heartwood/P-9 Type A oil-treated sapwood shell, (B) 40% MC heartwood/oil-treated shell, (C) 22% MC heartwood/oil-treated shell, and (D) 22% MC heartwood/ untreated shell.



MIT rapidly moved through the wood to zones adjacent to the treating hole in wood at 22 or 40 percent moisture content, but took 9 weeks to reach detectable levels at the same location in wood at 14 percent moisture content, and never reached levels comparable to those found at higher moisture contents during the 252 test period (Figure I-7). In contrast to the minimal difference in MIT movement between 22 and 40 percent moisture content after 252 days, MIT content rose more rapidly at the higher moisture content. The difference in MIT levels between the 22 and 40 percent moisture contents gradually decreased, but remained detectable after 252 days. MIT movement to sites further away from the application point was also affected by moisture content (Figure I-8). As expected, MIT was not detected until some time after

Figure I-7. Predicted methylisothiocyanate (MIT) vapor concentrations in region 20 (see Fig. 3) in poles at 40% MC heartwood with a P-9 Type A oil-treated shell (△), 22% MC heartwood and with either an oil-treated (+) or an untreated (◆) shell, or at 14% MC with an oil-treated shell (□).



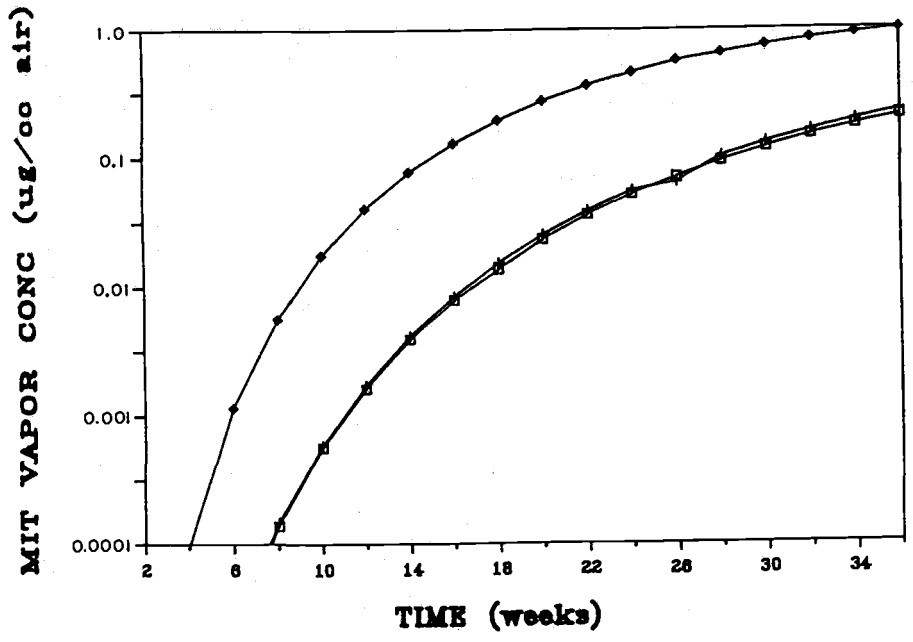


Figure I-8. Predicted Methylisothiocyanate (MIT) vapor concentrations in region 58 (see Fig. 3) in poles at 40% MC heartwood with a P-9 Type A oil-treated shell (◆), or 22% MC heartwood and with either an oil-treated (□) or an untreated (+).

detection at the location nearer the treatment hole. The chemical was first detected in the 40 percent moisture content after 4 weeks and was detected in the 22 percent treatment after 8 weeks. While the levels of MIT in the 40 percent treatments were nearly 50 times greater after 8 weeks, these differences declined to a ten-fold difference after 36 weeks. The results indicate that MIT will readily move through wood at higher moisture contents and remain at concentrations which have been reported to control active basidiomycetes. MIT was not found at detectable levels in a site farthest from the treatment hole in the 14 percent moisture content treatment over the test period. While this suggests that MIT treatment of dry wood would be ineffective, fungal decay will not occur at these low moisture levels. Furthermore, the large quantities of MIT sorbed by dry wood remain available to subsequently migrate through the wood and control decay fungi as moisture content increases.

As expected, increased moisture content resulted in more rapid depletion of MIT from the original treatment hole (Table I-24); however, complete depletion occurred most rapidly from the 22 percent moisture content treatment. This may reflect the higher sorption capacity of the 22 percent MC wood compared to the 40 percent MC sample. The treatment hole for the 14 percent moisture content wood still contained chemical after 252 days of simulation.

The results indicate that moisture content has a profound influence on the rate of MIT migration; however, the long residual periods that the fumigant remains in the wood may modify these differences. In addition, seasonal moisture content variations may affect migration rate. These parameters need to be further investigated.

Effects of Preservative Treatment: In addition to the effect of moisture content on movement of MIT through Douglas-fir heartwood, the outer shell also appears to have some influence on MIT distribution. This effect was most noticeable within the sapwood zone. For example, the presence of P9-Type A oil restricted movement of MIT through the sapwood at 22 percent MC (Figure I-6). Conversely, the MIT concentration was highest in the sapwood near the heartwood-sapwood interface. The predictions suggest that the oil sorbs MIT more effectively than untreated wood. As a result, the MIT levels in the heartwood near the heart-sap interface were quite low, while the levels in the adjacent sapwood were much higher. This difference had little effect on the time required for all of the initial dosage to leave the treatment hole, in spite of a much lower rate of MIT loss from the oil-treated shell (Table -24). This differential effect might, however, eventually result in long term performance differences, but further trials of the model are required to verify this hypothesis. The presence of MIT in the oil may also bolster preservative effectiveness in poles experiencing depletion.

While MIT levels varied with treatment in the sapwood, the treatments had little effect on MIT levels within the heartwood over the time period studied (Figures I-7, I-8). The lack of effect on the heartwood indicates that conditions in the shell will have less effect on conditions within the heartwood.

CONCLUSIONS: The results of the preliminary model indicate that MIT movement is affected to varying degrees by moisture content and the presence of an oil-treated shell. Further studies are planned using a three dimensional model to account for longitudinal diffusion through the wood. In addition, longer time periods must be explored to more fully describe fumigant effectiveness.

TABLE I-24

PREDICTED INFLUENCE OF HEARTWOOD MOISTURE CONTENT (MC) AND P-9 TYPE A OIL TREATMENT OF SAPWOOD ON CUMULATIVE METHYLISOTHIO-CYANATE (MIT) LOSS FROM THE SURFACE OF POLES AND MOVEMENT OF MIT OUT OF THE TREATMENT HOLE. BASED ON THE MATHEMATICAL MODEL SIMULATING A 252 DAY PERIOD.

Wood Moisture Content & Chemical Treatment	Fumigant Loss from Surface[a]	Time Until Residual Fumigant is Exhausted[b]
	(mg MIT)	(days)
40% MC Heartwood & Oil-treated Shell	1.9	94
40% MC Heartwood & Untreated Shell	51.4	95
22% MC Heartwood & Oil-treated Shell	1.4	75
22% MC Heartwood & Untreated Shell	36.0	73
14% MC Heartwood & Oil-treated Shell	0.5	252+

[a] Initial treatment involved application of 200 mg of MIT in the treatment hole.

[b] Residual fumigant refers to fumigant remaining in the treatment hole. When exhausted, wood around the treatment hole will desorb MIT.

Ultimately, the results will be used to identify the most effective treatment dosages, application patterns, and retreatment cycles for chemicals containing MIT as a fungitoxic component.

Emission of MIT, Cs_2 and COS from Vapam or MIT-treated Douglas-fir Heartwood

At present, most fumigant-treated wood is not subject to frequent human contact, but the use of fumigants to protect external beams in buildings is becoming increasingly common. Previous studies indicate that fumigants can migrate up to 3.6 m from the point of application, which suggests that fumigants applied to external beams could escape from wood inside the building and thus might pose a health hazard.

In this study, Douglas-fir heartwood blocks were treated with Vapam, the most widely used commercial fumigant, or methylisothiocyanate (MIT), a decomposition product of Vapam and an active ingredient of Vorlex. Emissions of MIT, carbon disulfide (CS_2), and carbonyl sulfide (COS) were measured over a period of 20 months.

Eight Douglas-fir heartwood blocks, measuring 9 by 14 by 20 cm, were end-sealed to retard transverse migration of fumigant from the wood, and then conditioned to a uniform moisture content. In each of four blocks, two holes, 15 cm deep and 1.5 cm in diameter, were drilled near the center of the 9- by 14-cm face and filled with 40 ml of Vapam. One hole was drilled in each of the other four blocks and filled with 20 ml of MIT. The holes were plugged with tight-fitting rubber dowels and sealed with several layers of epoxy.

The treated blocks were placed in eight 13.7-L polyurethane tanks that were sealed with teflon tape and epoxy. Humidified, filtered air was passed through the tanks at flow rates ranging from 120 to 780 ml/minute. A rubber septum on the top of each tank allowed air samples to be withdrawn without opening the tank. Samples were injected into a gas chromatograph equipped detect MIT, CS_2, or COS.

Although we tried to maintain uniform rates of air flow to each tank, slight changes in rate resulted from inspecting blocks in some of the tanks. However, this did not appear to affect the rate of emission of the volatile sulfur compounds. Results for MIT, CS_2, and COS were calculated on the basis of mg/day and mg/day/m^2 of wood surface.

MIT emissions: In two of the tanks containing blocks treated with Vapam, we found MIT in air samples taken within 24 hours of treatment (Figure I-9). These initial emissions may have been due to small drops spilled near the surface of the hole during application because no further MIT was detected for almost 100 days. Emission levels then ranged from 0.10 to 0.20 mg/day for the

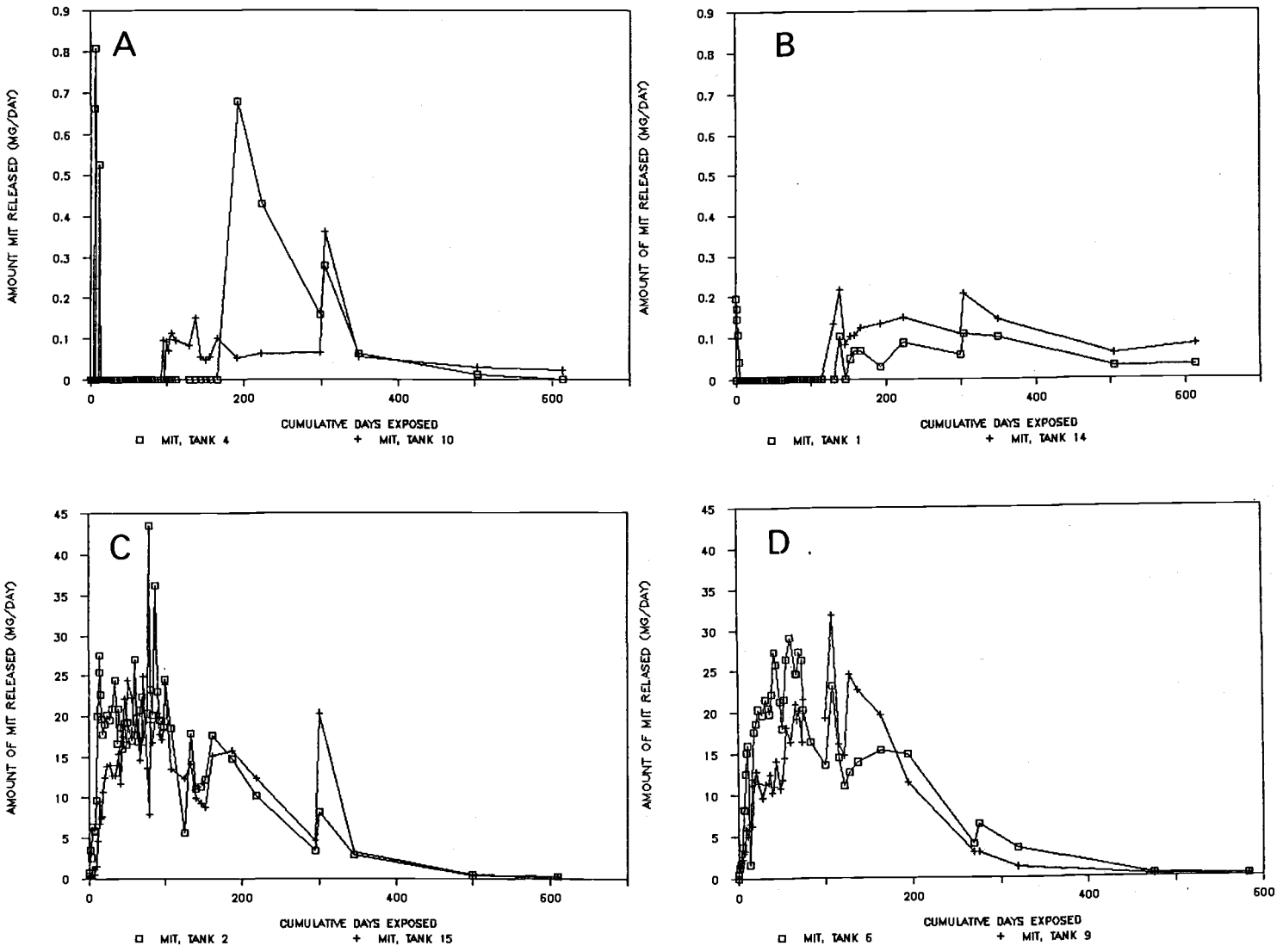


Figure I-9. Emission rate of MIT from blocks of Douglas-fir heartwood treated with Vapam (a, b) or MIT (c, d). Each line represents results from one tank.

first 12 months, but began decreasing during the second year of the test. This relatively slow rate of MIT emission was not unexpected because Vapam must decompose to produce MIT, which is strongly sorbed to wood. Previous studies

suggest that although the theoretical yield of MIT is 40 percent of the active ingredient, the actual conversion rate is far less efficient and sometimes approaches only 40 percent of the theoretical level. The slow conversion of Vapam to MIT within an environment which has strong affinity for the decomposition product helps explain the low emission levels.

While MIT emissions from Vapam-treated wood remained relatively low, those from the wood treated with pure MIT rose rapidly to detectable levels and remained at least ten times as high as those from Vapam-treated wood (Figure I-9 c,d), probably because the MIT did not need to be converted before diffusing through the wood. If Vapam converts to MIT at only 40 percent of the theoretical yield, the original dosage (40 ml) represents an effective dosage of 2 ml of MIT. The tenfold difference in MIT emission rates may reflect this difference. In addition, levels of MIT emissions from the MIT-treated wood began to decline after only 6-10 months, several months earlier than emissions from the Vapam-treated wood. Results from the MIT tanks would be comparable to high dosages of Vorlex, a commercial formulation containing 20 percent MIT in chlorinated C_3 hydrocarbons.

Carbon disulfide emissions: In contrast to the pattern for MIT emissions, CS_2 was detected soon after treatment with Vapam and continued to be present after 20 months, although levels appeared to gradually decline after one year. (Figure I-10). These relatively high levels of CS_2 indicate that large amounts of Vapam are being converted to products with lower fungal toxicity than MIT. CS_2 emissions were also detected early in tanks with the MIT treatment (Figure I-10), where emission levels were 4 to 20 times higher than in those with the Vapam treatment. This suggests that MIT is considerably modified as it passes through wood. Similar reactions have been reported when MIT contacts water, but in our study the moisture content of the wood was not high enough for free water to be present. It is unclear why the CS_2 levels

are so high in air samples associated with MIT-treated blocks, where strong wood interactions should bind large amounts of MIT, making it unavailable for chemical reactions.

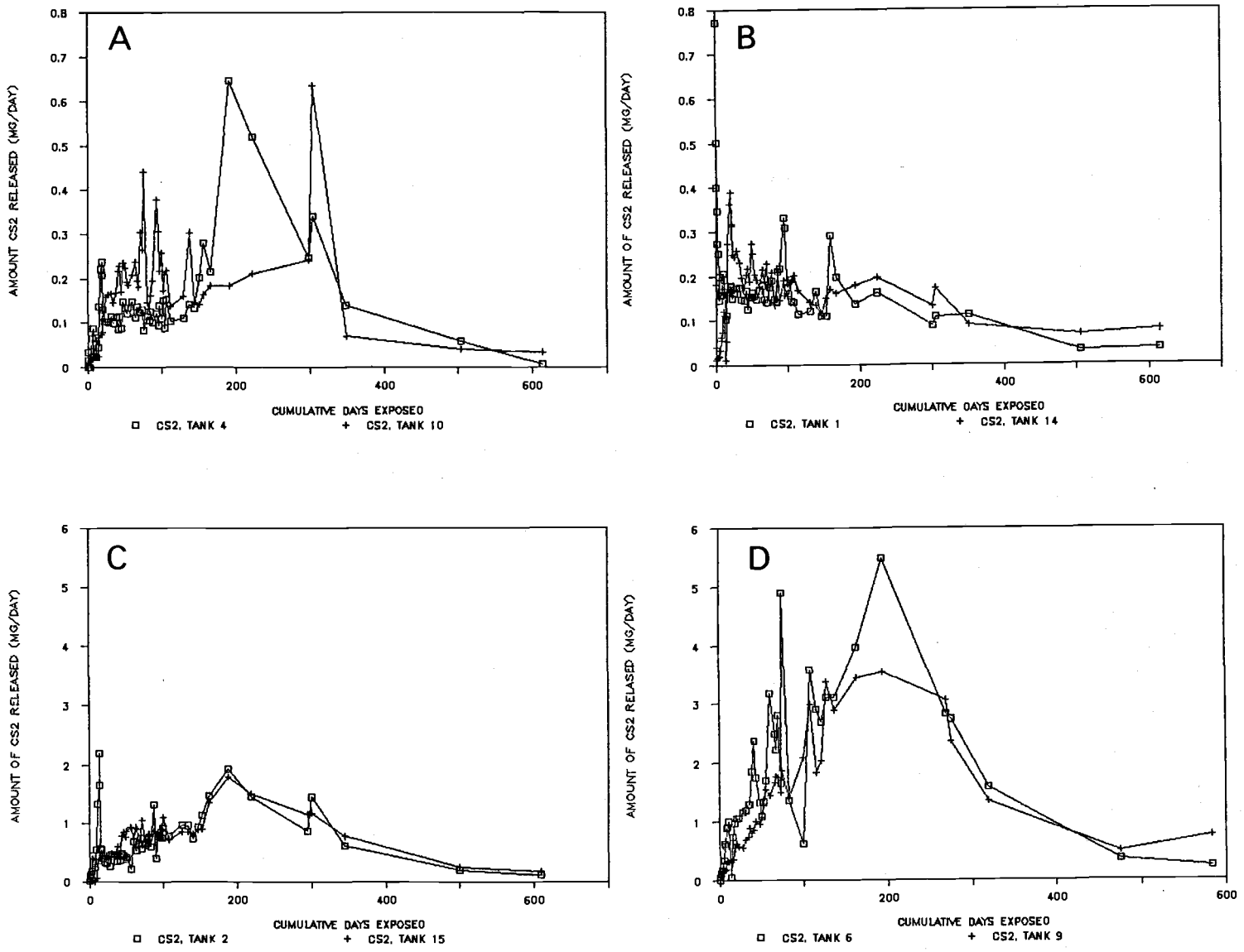


Figure I-10. Emission rate of CS_2 from blocks of Douglas-fir heartwood treated with Vapam (a, b) or MIT (c, d). Each line represents results from one tank.

Carbonyl sulfide emissions: Emissions of COS were similar to those for MIT (Figure I-11). Air samples from the Vapam tanks exhibited little evidence of COS in the first 75 days, after which levels gradually rose and then declined to very low levels after 320 days (Figure I-11). COS was found early in samples from MIT tanks, ultimately reaching levels 3 to 50 times higher than those from Vapam tanks, but also gradually declining after about one year (Figure I-11 c,d).

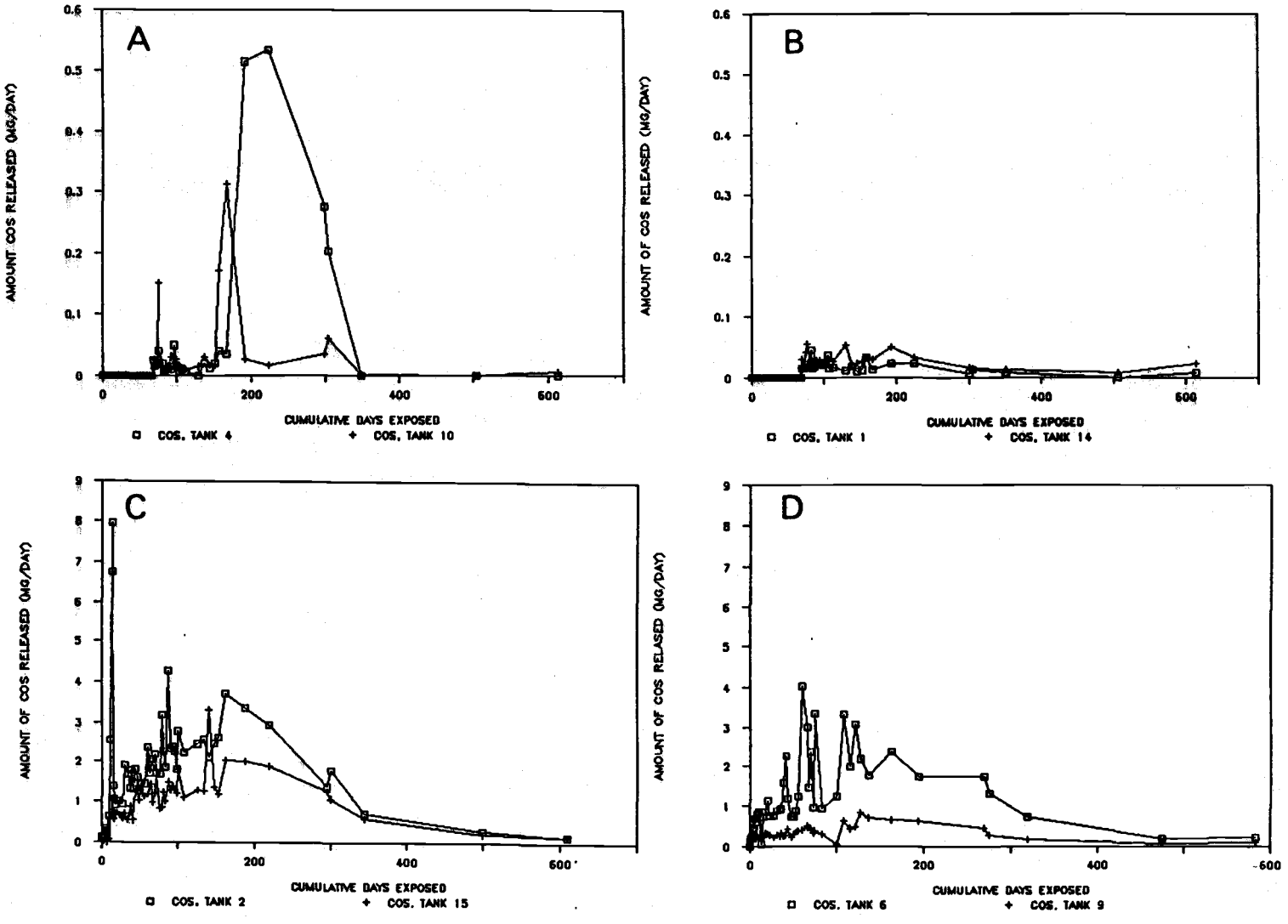


Figure I-11. Emission rate of COS from blocks of Douglas-fir heartwood treated with Vapam (a, b) or MIT (c, d). Each line represents results from one tank.

Some of the wide variation in COS levels may be due to the difficulty of obtaining accurate measurements, but it is apparent that MIT- and Vapam-treated wood emitted considerably different levels of this compound. COS, like CS_2, is less fungitoxic than MIT and the conversion of MIT to either of these compounds may alter its long-term effectiveness. Conversely, these two compounds may act synergistically to enhance the activity of MIT in wood. This enhancement would be difficult to demonstrate, but is suggested by the relatively low conversion efficiency of Vapam to MIT.

Emission effects: MIT has a disagreeable odor, detectable even at low levels, and is a potent skin irritant. High levels of this compound would therefore be unacceptable in inhabited buildings. A recent review, reported that long-term exposure to high levels of CS_2 (>10 ppm) is associated with cardiovascular disease. The effects of COS are not documented, but CS_2 is metabolized to COS in the body, and so its toxicological effects may be similar.

Our results clearly demonstrated that volatile chemicals were emitted from wood treated with Vapam or MIT, although the significance of the levels we found remains unclear. Odors, which were only detected shortly after treatment, probably resulted from small quantities of chemical spilled on the wood surface during application. CS_2 was emitted from the Vapam-treated blocks at a rate of 0.1 to 0.3 mg/day (0.008 to 0.023 ppm), declining to 0.1 mg/day (0.008 ppm) after 320 days. The emission rate from the MIT-treated blocks was 1 to 5 mg/day (0.056 to 0.279 ppm), declining to 0.1 to 0.75 mg/day (0.042 to 0.084 ppm). Although the level of CS_2 in one of the MIT-treated tanks could reach the 10-ppm level in an environment when air exchange was low, emission rates in the remaining tanks were clearly below that level.

It is difficult to extrapolate emission rates for small blocks with a high surface to volume ratio to rates for large beams in buildings, but our results do indicate that caution should be exercised before applying fumigants to wood in inhabited buildings. The area of application should be far enough outside the building to prevent excessive amounts of chemical from migrating inside. Another approach might be to use lower dosages of the fumigant. Although efficiency of fungal control would then be reduced and the wood might need to be treated again, the risk of chemical exposure should override these concerns. In large structures, such as storage buildings or factories where the rate of air exchange is high, fumigation of external wood beams does not appear to pose a hazard; however, treatment of wood in continually inhabited buildings which are tightly sealed (weatherized) should not be attempted.

Effect of voids on fumigant movement and effectiveness in Douglas-fir poles

Last year, we reported on the installation of a series of Douglas-fir pole sections containing large voids (7.5 cm in diameter by 7.5 to 15 cm long). These poles were treated with chloropicrin or Vapam at locations above the void and were to be sampled at six month intervals to determine the effects of the void on fumigant effectiveness ('87 Ann. Rept., pg. 32-33).

Fumigant movement was assessed by placing dowels infested with a test fungus, Poria carbonica, into holes drilled at selected heights above and below the void. The dowels were removed at six month intervals and cultured to determine if the fungus survived the chemical exposure. In addition, a series of increment cores were removed from three equidistant locations around the poles, 0.3 and 0.9 meters above and below the void. The outer 2.5 cm and the inner 12.5-15.0 cm segments inside of the treated shell of these cores were evaluated for residual fungitoxic vapors using the closed tube bioassay. A second series of cores were extracted in the appropriate solvent (ethyl

acetate for Vapam or hexane for chloropicrin) and analyzed using the gas chromatograph.

The survival data indicates that P. carbonica was killed in virtually all of the dowels (Table I-25). The low survival rate reflects drying during exposure, not the movement of chemical. The results indicate that this procedure is less useful for evaluating chemical movement under field conditions.

Closed tube bioassays indicate that fungitoxic levels of Vapam or chloropicrin are present in virtually all of the pole sections (Table I-26). While inhibition of P. placenta was not complete in the chloropicrin treatments, the presence of a void did not appear to adversely affect the movement of chemical through the central core of the pole. The results with the Vapam treatments were less clear, but previous tests indicate that bioassays are less useful for evaluating the performance of this chemical. In general, the degree of inhibition was lower in the outer core segments. While previous tests have also shown that the fumigant first migrates into the central core of wood, the void should have prevented or severely limited this migration. Chemical analyses are now underway to better quantify the relationships between dosage and the presence of voids.

TABLE I-25

MOVEMENT OF CHLOROPICRIN OR VAPAM THROUGH DOUGLAS-FIR WITH AND WITHOUT VOIDS AS MEASURED BY SURVIVAL OF PORIA CARBONICA IN HARDWOOD DOWELS PLACED IN HOLES DRILLED AT SELECTED LOCATIONS ABOVE AND BELOW THE TREATMENT HOLE.

Treatment	Dosage (ml)	Void	Sample Site[a] (m)	Fungal Survival[b] (%)
Vapam	80	+	-0.9	0^{67}
			-0.3	0^{11}
			+0.3	0^{11}
			+0.9	0^{89}
				0^{44}
Vapam	80	-	-0.9	0^{22}
			-0.3	0^{o}
			+0.3	0^{11}
			+0.9	0^{44}
				3^{20}
Vapam	160	+	-0.9	0^{67}
			-0.3	0^{o}
			+0.3	0^{17}
			+0.9	17^{29}
				4^{29}
Vapam	160	-	-0.9	0^{44}
			-0.3	11^{11}
			+0.3	0^{11}
			+0.9	0^{33}
				3^{25}
Chloropicrin	80	+	-0.9	0^{11}
			-0.3	0^{11}
			+0.3	0^{o}
			+0.9	0^{55}
				0^{19}
Chloropicrin	80	-	-0.9	0^{11}
			-0.3	0^{o}
			+0.3	0^{o}
			+0.9	0^{78}
				0^{33}
Chloropicrin	160	+	-0.9	0^{o}
			-0.3	0^{o}
			+0.3	0^{o}
			+0.9	0^{o}
				0^{o}
Chloropicrin	160	-	-0.9	0^{11}
			-0.3	0^{o}
			+0.3	0^{o}
			+0.9	0^{11}
				0^{6}
Control (No chemical)		-	-0.9	0^{17}
			-0.3	1^{17}
			+0.3	0^{o}
			+0.9	0^{o}
				4^{8}

[a] Sampled sites were located at the indicated distances above and below the treatment hole.

[b] Values represent survival of test fungus while superscript denotes isolation of microfungi. Values represent 9 isolations per treatment per pole site, except the control and void containing Vapam 160 ml treatment.

TABLE I-26

RESIDUAL FUNGITOXIC VAPORS IN DOUGLAS-FIR POLES CONTAINING VOIDS FOLLOWING TREATMENT WITH CHLOROPICRIN OR VAPAM AS MEASURED USING A CLOSED TUBE BIOASSAY.

Treatment	Dosage (ml)	Void	Average growth of assayed fungus as % of control[a]							
			-0.9 m		-0.3 m		+0.3 m		+0.9 m	
			outer	inner	outer	inner	outer	inner	outer	inner
Chloropicrin	80	+	25	0	6	0	0	0	37	44
	80	-	31	0	0	0	0	0	18	0
	160	+	0	12	0	0	0	0	56	18
	160	-	43	6	18	0	0	0	6	6
Vapam	80	+	44	43	27	14	33	0	57	25
	80	-	60	33	37	31	29	7	56	21
	160	+	75	75	25	0	62	0	68	31
	160	-	37	36	36	7	32	0	64	19
Controls (none)[b]	(No Wood) 16 mm									

[a] Increment cores were removed from selected heights above and below the treatment hole. The outer 2.5 cm and the inner 12.5 to 15 cm segments were used in a closed tube bioassay with Poria placenta as the test fungus.

[b] Represents the average of nine tubes.

OBJECTIVE II

IDENTIFY ENVIRONMENTALLY ACCEPTABLE PRESERVATIVES FOR PROTECTING WESTERN REDCEDAR SAPWOOD AND FIELD-DRILLED BOLT HOLES

A. FIELD EVALUATION OF CHEMICALS ON CEDAR TEST POLES

In 1981, chemicals which had previously performed well in our laboratory decay tests were applied to a series of eight foot (2.4 m) long western redcedar pole stubs. Each chemical was diluted to its recommended concentration and flooded along the length of one third of the circumference of each of 6 poles. Two sides of each pole were treated with test chemicals while the third served as the untreated control. In 1983, the effectiveness of the chemicals was assayed by removing increment cores for testing using the Aspergillus bioassay and a modified soil block method ('84 Ann. Rept., pg. 26-34).

The chemicals included in this test were ammonium bifluoride, copper-8-quinolinolate, 3-iodopropynyl butyl carbamate and 3 pentachlorophenol formulations. In general, the initial results clearly demonstrated the efficacy of the currently used 10 percent pentachlorophenol in oil treatment. The remaining treatments provided some protection to the outer surface and further testing was suggested.

This past summer the same poles were resampled by removing increment cores for the Aspergillus bioassay and 0.375 inch diameter plugs for decay testing. The methods were the same as those previously described. The results of the Aspergillus bioassays will be reported here, while the decay tests are continuing.

In the Aspergillus bioassays, the increment cores were placed on potato dextrose agar in petri dishes which had been seeded with spores of the test fungus, Aspergillus niger. This fungus typically produces black pigmented

spores on the agar surface. The presence of certain wood preservatives prevents the pigmentation, resulting in a zone of effect (ZOE) around wood containing this chemical. This zone of effect can be directly correlated to the amount of chemical present in the wood.

The plates were incubated for 7 days at room temperature and the ZOE around each core was measured along the core length. The results indicate (Table II-1) that only the penta treatments and the oilborne copper-8-quinolinolate treatments exhibited any efficacy seven years after application.

TABLE II-1

AVERAGE ASPERGILLUS NIGER ZONE OF EFFECT (MM) FROM INCREMENT CORES REMOVED FROM POLES SPRAYED WITH SELECTED DECAY CONTROL CHEMICALS SEVEN YEARS PRIOR TO SAMPLING.

CHEMICAL	CONCENTRATION (% active)	CARRIER	ZONE OF EFFECT (mm)[a] 0-0.6 cm	0.6-1.2 cm
Ammonium bifluoride	20.0	water	0 (0)	0 (0)
Copper-8-quinolinolate	0.12[b]	oil	2 (2)	1 (1)
Copper-8-quinolinolate	0.9[b]	water	0 (0)	0 (0)
3-iodopropynyl butyl carbamate	2.0	water	0 (2)	0 (0)
Pentachlorophenol	10.0	oil	10 (11)	7 (8)
Pentachlorophenol	10.0	water	6 (6)	0 (3)
Pentachlorophenol	2.5	water	1 (2)	0 (0)

[a] Each figure represents average of 18 values. Figure in parentheses represents results for same poles after 2 years.

[b] As percent copper.

The remaining chemicals produced no zone of effect (ZOE) suggesting that no chemical was available for migration into the agar for the A. niger bioassay. The lack of a ZOE suggests that there is no chemical present to prevent fungal colonization; however, decay tests will be performed to confirm these results.

In addition to the pole sections treated in 1981, an additional set of cedar pole stubs were treated in 1985 with zinc naphthenate (MGARD W552), or 2

copper naphthenate formulations (MGARD S520 or S522) by flooding solutions containing 2 percent (as copper or zinc metal) active ingredient on one third sections of otherwise untreated western redcedar sapwood. Samples removed from the treated pole sections for A. niger bioassay three years after treatment indicate that little or no ZOE's were produced by cores from copper napthenate treated poles, while small ZOE's were evident in the zinc naphthenate treated wood (Table II-2). This lack of effect is not surprising since previous tests indicate that copper naphthenate treated blocks produced little or no ZOE, even immediately after treatment ('86 Ann, Rept., pg. 48-57).

While Zinc naphthenate treated blocks did produce measurable ZOE's, this waterborne compound may be more susceptable to leaching. In spite of this prospect, small ZOE's were noted at both sampling depths in the Zinc naphthenate treated sections. These ZOE's suggest that inhibitory levels of chemical (to spores or individual hyphae) may still be present in the wood. The effectiveness of these 3 chemicals will be further assessed using a modified soil block test.

TABLE II-2

AVERAGE ASPERGILLUS NIGER ZONE OF EFFECT (MM) FROM INCREMENT CORES REMOVED FROM POLES SPRAYED WITH SELECTED DECAY CONTROL CHEMICALS THREE YEARS PRIOR TO SAMPLING.

			ZONE OF EFFECT (mm)[a]	
CHEMICAL	SOURCE	CARRIER	0-0.6 cm	0.6-1.2 cm
Copper naphthenate (a)	MGARD S520 Mooney Chem. Co	Oil	0.4	0.0
Copper naphthenate (b)	MGARD S522	Oil	0.0	0.0
Zinc naphthenate	MGARD W552	Water	1.8	0.2

[a] Values represent the average of 5 pole sections per treatment. Increment core samples were divided into outer (0 to 0.6 cm) and inner (0.6 to 1.2 cm) zones, which were used in the A. niger bioassay.

B. LABORATORY EVALUATION OF NEW CHEMICALS AS REPLACEMENTS FOR PENTACHLOROPHENOL IN WESTERN REDCEDAR SAPWOOD

Over the past three years we have evaluated nearly 35 new formulations in our accelerated laboratory trials. These trials have identified a number of promising alternatives which are currently being tested under field conditions. Because so many promising chemicals are already in test, no new formulations were evaluated this past year; however, additional formulations which appear promising will be included as they become available.

C. ACCELERATED FIELD TESTING OF POTENTIAL PENTACHLOROPHENOL REPLACEMENTS FOR WESTERN REDCEDAR SAPWOOD DECAY CONTROL

Although a number of chemicals have been applied to western redcedar pole stubs at our Peavy Arboretum test site, it came to our attention that some poles had been treated with other preservatives prior to use in our test, negating our results. To overcome this problem without repeating the test on full sized material, a series of small blocks (6 by 6 by 4 inches) were cut from weathered western redcedar poles removed from service. Each section contained one 6 by 6 inch sapwood face. All of the remaining surfaces were sealed and the sapwood face was treated with one of the test chemicals. After drying, the blocks were exposed on a test fence outside the laboratory where they were subject to daily watering in the summer months to accelerate leaching and stimulate fungal attack.

The exposed faces of these blocks were sampled by removing increment cores from the exposed sapwood face of each block. These cores were then tested using the Aspergillus bioassay to detect the presence of residual chemicals. The results (Table II-3) indicate that 22 of the 32 treatments produced measurable zones of effect when wood from the outer zone (0 to 0.6 cm) was sampled, while 19 treatments produced measurable ZOE's in the inner

TABLE II-3

RESIDUAL FUNGICIDAL PROTECTION IN INCREMENT CORES REMOVED FROM THE SAPWOOD ZONE OF WESTERN REDCEDAR POLE SECTIONS TREATED WITH SELECTED DECAY CONTROL AGENTS AS MEASURED USING AN ASPERGILLUS NIGER BIOASSAY.

CHEMICAL	Source	CARRIER	CONCENTRATION	Average Zone of Effect (mm) 0-0.6 cm	0.6-1.2 cm
Azaconazole	Janssen Pharm.	Water	0.30	0	0
			0.15	0	0
ACAR 86013		Water	1.0	0	0
86032		Water	1.0	0	0
Copper 8 quinolinolate	Chapman Chem. Co.	oil	0.12 (Cu)	5	0
Copper 8 quinolinolate	Nuodex	Water	0.3 (Cu)	4	0
Copper naphthenate	Tenino Wood Pres.	oil	2.0 (Cu)	0	0
CWP 44	Chapman Chem Co.	Water	10.0	0	0
Diiodomethyl-paratolyl sulfone	Akzo Chemie	oil	1.0	18	12
Dodecyl dimethyl ammonium salt	Nuodex	oil	8.0	1	2
		Water	8.0	0	0
3-iodo 2-propynyl butyl carbamate (IPBC)	Troy	Water	2.0	0	0
	Beecham	oil	0.5	14	4
Isothiazolone	Rohm and Haas	oil	1.0	12	11
Methylene bisthiocyanate (MBT) plus Thiocyanomethylthio benzothiazole (TCMTB)	Buckman Laboratories	Water	4.0	7	1
			2.0	5	1
TCMTB	Buckman Laboratories		4.0	10	5
			2.0	8	1
Trimethylcocammonium chloride (TMCAC)	Akzo Chemie	Water	5.0	0	0
Zinc naphthenate (a)	Mooney Chemical	Water	4.0	11	7
			2.0	7	3
Zinc naphthenate (b)	Mooney Chemical	Water	4.0	0	0
Pentachlorophenol	Chapman Chem. Co.	oil	10.0	17	12
Tributyltinoxide		oil	5.0	19	15
IPBC/Busperse 47 (B-47)	Troy/Buckman	oil	1.0/5.0	1	4
Isothiazolne/B-47	Rohm and Haas/Buckman	oil	1.0/5.0	11	10
TMCAC/I-PBC	Akzo Chemie/Troy	oil	4.0/2.5	2	0
TCMTB/B-47	Buckman	Water	4.0/5.0	11	3
			2.0/2.5	10	2
(MBT/TCMTB)/B-47	Buckman	Water	4.0/5.0	10	5
			2.0/2.5	9	4
Isothiazolone/TMCAC	Rohm and Haas Akzo Chemie	oil	3.5/6.0	9	7
Control	-	-	-	0	0

sapwood zone (0.6 to 1.2 cm). Since these blocks were exposed to normal u.v. light and accelerated leaching conditions, the presence of detectable levels of chemical suggest that these chemicals will remain in the wood for long

periods under less severe conditions. Of the chemicals tested, diiodomethylparatolyl sulfone (Amical 48), IPBC in oil, Isothiazolone, TCMTB, MBT/TCMTB, Tributyl tin oxide and zinc naphthenate (a) all produced ZOE's which approached those found with 10 percent pentachlorophenol. While some other compounds such as Azaconazole, several quaternary ammonium compounds and copper naphthenate, which have performed well in previous decay tests, failed to produce measurable ZOE's, these chemicals have strong interactions with the wood and do not perform well in the A. niger bioassay. More elaborate decay resistance tests will be performed next year.

At the present, a number of promising cedar sapwood decay control agents are under study, but further tests are required to confirm this performance.

D. EVALUATE TREATMENTS FOR PREVENTING BOLT HOLE ASSOCIATED DECAY.

The experimental field trials to evaluate the ability of initial treatments with Polybor, ammonium bifluoride, Patox washers, Boracol 40 or 10 percent pentachlorophenol in oil to prevent decay initiation in field drilled bolt holes in Douglas-fir poles is now in its sixth year. The poles have been exposed at the Peavy Arboretum test site and have been watered on a daily basis during the dry summer months to accelerate decay. The poles have been sampled on an annual basis by removing increment cores from sites directly beneath the gain plate or above the washer on the opposite site of each bolt hole. These cores were cultured for the presence of decay fungi, which served as a measure of chemical effectiveness.

The results indicate that colonization levels in all of the poles remain uniformly low, in spite of the accelerated decay conditions (Table II-4). While there are some minor differences between the treatments, only the Patox washers, 10 % Penta, and the controls contained viable decay fungi after 6

TABLE II-4

COLONIZATION OF FIELD DRILLED BOLT HOLES IN DOUGLAS-FIR POLES BY DECAY FUNGI AFTER FIVE OR SIX YEARS OF EXPOSURE.

TREATMENT	YEARS OF EXPOSURE	POLES COLONIZED (%)	CORES WITH DECAY FUNGI (%)[a] LOWER SITE	UPPER SITE	ALL SITES
Ammonium bifluoride	5	25	0	6	3
	6	0	0	0	0
Patox washers	5	100	16	6	11
	6	50	6	3	5
Boracol 40	5	25	0	6	3
	6	0	0	0	0
Penta (10%)	5	50	9	3	6
	6	25	3	0	2
Polybor	5	100	6	25	16
	6	0	0	0	0
Control	5	63	2	19	10
	6	50	1	5	3

a Each treatment was tested on 4 poles, except the control, in which 8 poles were sampled. A total of 32 cores were removed from each treatment group, except controls where 64 cores were tested.

years exposure. These results differ from last years sample, suggesting a high degree of sampling variation. This variation reflects the small number of cores removed from each site, which is necessitated by the need to retain the integrity of the pole for further testing. As additional samples are removed, general trends in the test results should become more evident.

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

While field tests on full-size poles provide the most meaningful data, the bolt hole tests previously established at Peavy Arboretum have been remarkably slow in developing useful results. Since a number of additional compounds which might prove useful for preventing bolt hole decay have been identified since the initial test was established in 1981, we sought a simpler, more rapid method for assessing chemicals.

The method developed for this purpose uses Douglas-fir heartwood blocks (4 inches (10 cm) square) which were dipped in 1.0 percent chromated copper arsenate to produce a thin, preservative treated shell. After storage for one month to permit chemical fixation, a 0.94 cm (0.375 inch) diameter hole was drilled completely through the radial face. One end of the hole was plugged with a tight-fitting rubber stopper and 2 ml of the test chemical was flooded into the hole. The open end of the hole was plugged and the block was agitated for several minutes to evenly distribute the chemical throughout the hole. After soaking for 15 minutes, the stoppers were removed and grooved, galvanized bolts were inserted in the holes. The groove was made lengthwise along the bolt to encourage entry of moisture during the weathering phase of the test. A total of 14 chemicals were used to treat blocks in this test, and each chemical was applied to 6 blocks (Table II-5). An additional set of 6 blocks was left untreated to serve as a control.

Two blocks from each chemical treatment were set aside and the remaining test blocks were then placed in a weatherometer which exposed the samples to continuously alternating periods of wetting (8 hours) and drying (16 hours) for periods of 2 or 4 months. At each time point, two blocks from each treatment group were removed and stored at constant temperature and humidity conditions.

At the end of the weathering period, the ability of remedially applied chemicals to prevent fungal invasion of the field-drilled holes will be assessed by placing each block in an open plastic bag and autoclaving for 20 minutes 100^{o} C. The bags will then be sealed and 1 ml of a suspension containing hyphae of Poria placenta will be injected into the block through the grooved slot in the bolt hole. The blocks will then be incubated for 2 months at 28^{o} C. At the end of the test period, the blocks will be removed

Table II-5
CHEMICALS EVALUATED AS POTENTIAL REMEDIAL BOLT HOLE DECAY CONTROL TREATMENTS IN AN ACCELERATED LABORATORY DECAY TEST.

TRADE NAME	CHEMICAL	DILUENT	CONCENTRATION
Amical-48	diiodomethyl-paratolyl sulfone	oil	1.0
Arquad C-50	3-trimethyl-coc-ammonium chloride	water	5.0
Busan 1009	methylene bis(thio cyanate) (MBT)/ 2 (thiocyanomethylthio) benzothiazole (TCMTB)	water	4.0
Busan 1030	TCMTB	water	4.0
Rodewood SC-503	Azaconazole	water	0.3
Copper 8	Copper 8 quinolinolate	water	1.0[a]
Copper naphthenate	Copper naphthenate	oil	4.0[a]
Polyphase	3-iodo 2-propynyl butyl carbamate (IPBC)	water	2.0
Woodlife	IPBC	oil	0.5
Isothiazolone		oil	1.0
N-100-WD	Dodecyl dimethyl ammonium salt of naph-thenic acid	water	4.0
Pentachlorophenol	same	oil	10.0
M-GARD 553	Zinc naphthenate	water	4.0[a]
Koppers NP-1	IPBC/quaternary ammonium compound	water	1.0

a Chemical active ingredient based upon metal content.

and sampled by removing small wood plugs from locations above and below the bolt hole. These plugs will be cultured for the presence of decay fungi. The remainder of the block will be oven-dried at 54^{o} C and reweighed to determine fungal associated weight loss. The weight lost by removal of the sample plugs will be corrected.

The combination of fungal survival and wood weight loss should provide a meaningful measure of the ability of each test chemical to prevent fungal colonization of field-drilled bolt holes.

F. ABOVE GROUND FUMIGANT TREATMENT WITH GELATIN ENCAPSULATED OR PELLETIZED MIT.

While initial treatment of field-drilled bolt holes represents the simplest method for protecting these zones, the personnel responsible for treating these holes often have little responsibility for the ultimate performance of the pole. Thus, the likelihood that the chemical will be applied when the hole is drilled is quite low. One method for overcoming this problem would be to fumigant treat the zone around the field-drilled bolt hole.

In 1985, a series of Douglas-fir poles on which a distribution line had been underbuilt were treated with gelatin encapsulated or pelletized MIT. Poles received either 45 or 90 ml of gelatin encapsulated MIT or 60 or 120 grams of pelletized MIT. These treatments were applied to holes drilled 0.6 m below the field drilled bolt holes for the underbuilt line.

The poles have been sampled on an annual basis by removing increment cores from sites below the field drilled bolt hole for culturing and closed tube bioassays. Last year ('87 Ann. Rept., pg 87-89), a number of poles were found to contain decay fungi 1.2 meters below the treatment holes; however, the most recent sampling indicates that decay fungi have been eliminated (Table II-6). In addition, the levels of non-decay fungi at these sites has also declined. Closed-tube bioassays of wood samples from the same zones indicate that fungitoxic levels are present in all treatments (Table II-7).

TABLE II-6
FUNGAL POPULATION NEAR BOLT HOLE ATTACHMENTS IN DOUGLAS-FIR POLES TREATED WITH ENCAPSULATED OR PELLETIZED MIT

		CORES WITH DECAY/NON-DECAY FUNGI (%)[a]			
TREATMENT	DOSAGE	1984	1985	1986	1987
MIT Capsules	45 ml	33/33	0/70	11/100	0/11
MIT Capsules	90 ml	0/50	0/67	17/100	0/0
MIT Pellets	60 gm	50/50	0/50	17/100	0/8
MIT Pellets	120 gm	0/20	0/46	0/100	0/17

[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.

These results indicate that the pelletized and gelatin encapsulated MIT have both become well-distributed throughout the pole section and chemical levels should be sufficient to prevent colonization of the untreated wood exposed in the field-drilled bolt hole. Further evaluations of these poles will continue to determine if chemical performance mirrors that found closer to the groundline.

TABLE II-7
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*[a]					
		OUTER ZONE			INNER ZONE		
TREATMENT (dosage)	REPLICATES	1985	1986	1987	1985	1986	1987
MIT Capsules (45 ml)	6	70	79	12	35	57	4
MIT Capsules (90 ml)	2	40	37	5	30	0	0
MIT Pellets (60 g)	5	42	38	16	25	30	6
MIT Pellets (120 g)	2	28	17	17	40	0	18
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.

OBJECTIVE III

DETECT EARLY DECAY IN WOOD AND ESTIMATE RESIDUAL STRENGTH OF POLES IN SERVICE

A. USE OF FLUORESCENT-COUPLED LECTINS TO DETECT FUNGI AT EARLY STAGES OF DECAY

As previously reported ('87 Ann. Rept., pg. 90), fluorescent-coupled lectins have shown some applicability to the detection of incipient decay. This past year, a comparison of fluorescent-coupled lectins with convectional chemical stains was completed using Poria placenta, Coriolus versicolor, and Chaetomium globosum on Douglas-fir heartwood and Ponderosa pine sapwood. These fungi produce brown, white, and soft rot, respectively. The colonization characteristics of each fungus were followed over a 12-week period using an agar block test. Following fungal exposure, the test blocks were sectioned on the radial, tangential, and transverse faces. These sections were stained with safranin-O followed by picro aniline blue or reacted with fluorescent-coupled wheat germ agglutinin (WGA), a lectin with high specificity for fungal chitin. The sections were then mounted and examined with the microscope using the appropriate filters.

While conventional stains reacted with many of the hyphae, the lectin more uniformly reacted with fungal hyphae at the early stages of decay. In general, hyphae colonization was correlated with weight loss, except for C. globosum, which caused little or no weight loss over the test period. Further evaluations of micrographs from this study are under way and will be discussed in next year's report.

B. ESTIMATING STRENGTH OF DAMAGED WESTERN REDCEDAR UTILITY POLES.

It is generally difficult to accurately assess internal pole damage resulting from impact loads, especially when there is no evidence of damage to

the pole surface. This difficulty was recently demonstrated when an automobile collided with a western redcedar transmission pole, damaging the cross-arm but producing only minor surface damage at point of impact. A visual inspection indicated that the pole was safe for climbing; however, the structure failed at groundline while two linemen were repairing the cross-arm. Fortunately, there was no serious injury. The purpose of this study was to determine the cause of pole failure to prevent recurrence of this dangerous situation.

Visual pole inspection: Inspection of the pole at the break suggested that the car impact caused extensive internal wood damage, leading to pole failure when the weight of the lineman loaded the structure. The break at groundline was brash on the impact side of the pole, where stress at time of impact and resulting wood damage would have been greatest. Many growth ring separations and radial fractures were present in this zone. This damage extended at least five feet above the break on the impact side of the pole. In addition to internal damage, there was an eight-inch-deep, centrally located heart-rot pocket fifteen inches below groundline and a deep seasoning check centered through the impact area. Wood adjacent to the rot pocket as well as to the seasoning check appeared sound.

Culturing for decay: Wood samples were collected from the decay pocket, along the seasoning check centered through the impact area, and near the pith in the break zone in order to determine if active decay fungi were present. The samples were placed on malt agar media and fungi which grew from samples were identified. None of the fungi cultured from the pole sections (Table III-1) were white- or brown-rot fungi and the fungi isolated do not have the ability to produce the heart-rot pocket found in the pole. The isolations

TABLE III-1

IDENTITY OF FUNGI ISOLATED FROM FAILED WESTERN REDCEDAR POLE

	Radial distance from decay pocket, in.		Distance above groundline, ft.		
Fungal Species	1	3	0	2	3
Cladosporium, sp.					X
Penicillium, sp.			X	X	
Scytalidium, sp.	X	X			
Trichoderma, sp.	X	X	X		
no growth					X
unknown C			X		

suggest that the decay pocket originated in the standing tree and had not significantly increased in size while the pole was in service.

Mechanical tests: Bending strength and specific gravity were determined for 1- by 1- by 16-inch long beams cut from intact wood adjacent to the break zone (Figure III-1). Strength measurements fell within the 95% confidence interval of published values for sound western redcedar beams (Table III-2), indicating that wood adjacent to the break zone was not decayed or inherently weak prior to the accident. The mechanical properties of these beams were similar to those of beams cut from 11 used cedar transmission poles which had previously been full-length tested for bending strength and determined to have adequate strength for re-use.

The results indicate that the wood from the pole retained sufficient strength to fall within the range of western redcedar. Thus, pole failure resulted from the internal wood damage, caused by the auto impact. The internal void below ground probably originated in the standing tree and had little influence on mechanical strength.

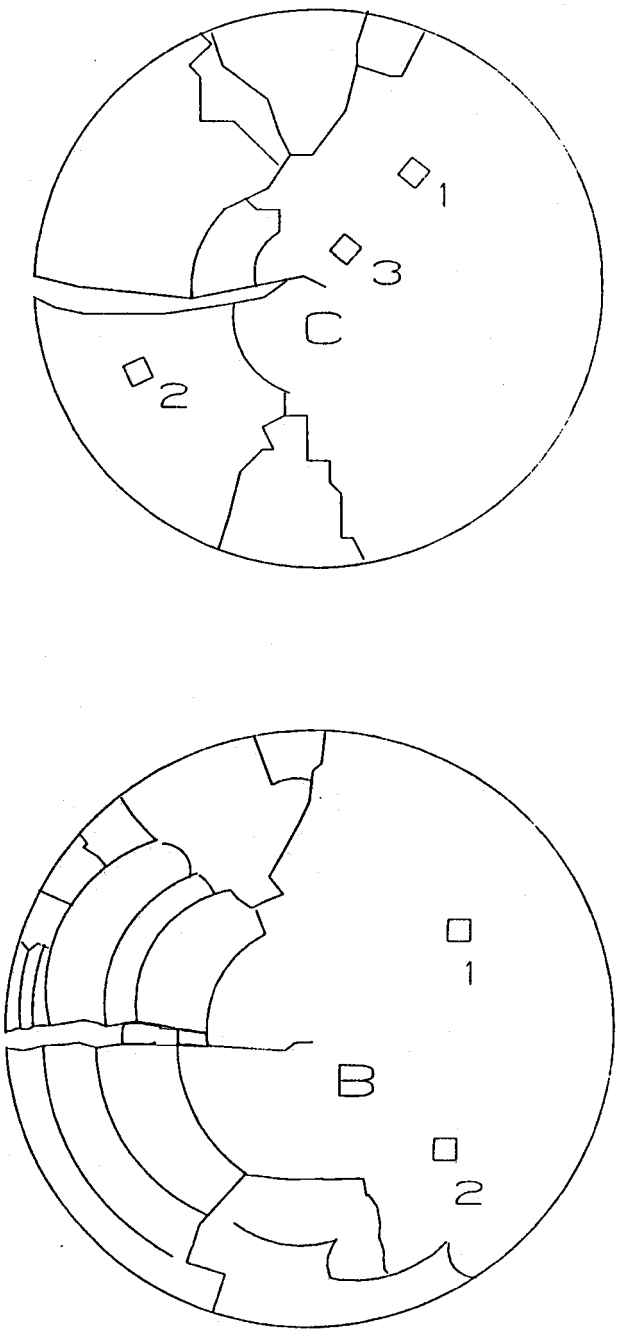


Figure III-1. Pole cross sections B (at groundline) and C (3-feet above groundline) showing pattern for cutting 1- by 1- by 16-inch long beams for strength testing.

TABLE III-2

STRENGTH AND SPECIFIC GRAVITY OF BEAMS FROM A FAILED WESTERN REDCEDAR POLE AND FROM PREVIOUS WESTERN REDCEDAR BEAM TESTS

SAMPLE NUMBER	MOR (psi)	MOE (psi)	Specific Gravity[a]
BEAMS FROM FAILED WESTERN REDCEDAR POLE.[b]			
B-1	4,433	646,171	0.32
B-2	5,043	659,735	0.32
C-1	5,525	747,403	0.32
C-2	4,940	736,511	0.31
C-3	5,093	609,517	0.31
Average	5,007	679,868	0.32
PUBLISHED VALUES FOR SOUND WESTERN REDCEDAR BEAMS (1)[c]			
Mean	5,184	939,000	0.31
Std. Dev.	761	223	0.027
95% Interval	3,692-6,676	502,000-1,376,000	0.26 -0.36
BEAMS FROM 11 USED WESTERN REDCEDAR POLES (4).[d]			
Pole			
1	5,513	1,094,000	0.36
2	5,480	1,119,000	0.34
3	4,864	956,000	0.33
4	4,905	1,022,000	0.32
5	5,006	935,000	0.34
6	5,462	996,000	0.37
7	4,407	657,000	0.32
8	5,072	1,129,000	0.32
9	4,285	826,000	0.30
10	5,150	916,000	0.34
11	5,721	1,224,000	0.37
Average	5,079	988,000	0.34

[a] Based on green volume and oven-dried wood weight.

[b] 1.0 by 1.0 by 16 in. long beams; tested for static bending strength according to ASTM procedure D-143: Secondary methods.

[c] ASTM standard D-2555 - 81, establishing clear wood strength values; p.516.

[d] Values based upon 1.0 by 1.0 by 16 in. long beams; six beams per pole.

C. EFFECT OF FUNGAL COLONY SIZE ON STRENGTH OF DOUGLAS-FIR POLES

Over the past 6 years, we have developed a wealth of information on the sequence, location, and identity of fungi colonizing Douglas-fir poles during air-seasoning. Strength measurements of beams cut from poles containing decay fungi have shown no significant strength losses after two years of

air-seasoning. These results differ from standard laboratory decay tests in which strength losses can be detected shortly after exposure to decay fungi. Differences in results may reflect the fact that standard tests expose large surfaces of sound wood to mature, dense, fungal populations while air-seasoning wood is more likely to be colonized by single fungal spores or hyphal fragments. To better understand the effects of Basidiomycete colonization on wood strength in relation to air-seasoning, a decay test was needed which more closely represented natural fungal colonization.

A series of 1.25 by 1.25 by 20 cm long (0.5 by 0.5 by 8 in.) Douglas-fir sapwood or heartwood beams were cut from a fresh, debarked log. A 2 mm diameter hole was drilled radially into each beam at the mid-point, the beams were water-soaked, sealed in plastic bags, and the wood was sterilized by steaming for 25 minutes at 100°C. After cooling, the beams were inoculated by injecting a drop of a hyphal fragment/spore suspension of the test fungus through the plastic bag and into the hole. The hole in the bag produced by the needle was then sealed and the beams were incubated at 28°C. The fungi chosen for these tests were Poria carbonica, Poria placenta, Peniophora spp., and Haematostereum sanguinolentum. The former two species were tested on heartwood, while the latter species were tested on sapwood. The species chosen represented the four most commonly isolated fungi from air-seasoning Douglas-fir poles. At present, results with P. carbonica and Peniophora spp. have been completed, while tests with H. sanguinolentum and P. placenta are now underway.

At selected time points, eight beams inoculated with each test fungus were removed and tested for residual strength and degree of colonization. Four beams were tested to failure in bending and the results were used to determine modulus of rupture (MOR), modulus of elasticity (MOE), and work to

maximum load (WORK). Since bending strength is most affected by changes near the beam mid-point, the degree of fungal colonization was measured in the center 7.5 cm (3 in.) of each tested beam by cutting a series of 16 cross sections. These sections were cut into 4 equal sized cubes which were plated on potato dextrose or malt agar and observed for growth of the test fungus. Initially, we presumed that fungal colonization would be slow and that strength would be inversely proportional to colony size; however, fungal colonies extended throughout the sample area within one or two months for the P. carbonica or Peniophora spp. inoculated beams, respectively, while there was no measurable strength loss.

In addition to the bending strength tests, a second set of four beams was tested for changes in longitudinal compression strength (LCS). Four beams and a non-fungal-exposed control beam were cut into a series of 13 one quarter inch cubes. A 120 u thick section was cut from the cross section of 5 cubes: one from the beam center, one from each beam end, and one from sites halfway between the center and beam end. These sections were macerated in sterile distilled water and mixed with molten agar, which was poured into petri dishes and allowed to cool. The plates were observed for the presence of fungal colonies, which were counted to determine the density of fungal colonization in the beams. The remaining eight cubes were then tested for LCS on an Instron Universal Testing Machine at a head speed of 0.2 cm/ minute as described previously ('86 Annl. Rept., pg 79-81).

One problem which has been encountered in the completed tests has been competition from thermo-tolerant Penicillium sp. Although the beams were steamed for 25 minutes, thermo-tolerant fungal species were found in certain beam sets. Higher temperatures (121°C) might have eliminated these fungi; however, these temperatures would also alter wood strength and change wood

properties relative to fungal colonization. These changes might appreciably alter the relationship between the degree of fungal colonization and wood strength. Conversely, the presence of competing microflora in the wood, while posing a dilemma for analyses, more closely approximates the natural colonization process.

The competition from Penicillium sp. and some bacteria is reflected in the isolation of these organisms from beams over a 13-month period (Table III-3). In general, the 7.5 cm sample zone in the Douglas-fir heartwood beams was rapidly colonized by P. carbonica, and was more slowly colonized by the

TABLE III-3

FUNGAL COLONIZATION OF DOUGLAS-FIR BEAMS AT MONTHLY INTERVALS FOLLOWING INOCULATION WITH PORIA CARBONICA OR PENIOPHORA SPP. AS MEASURED BY CULTURING THICK SECTIONS.

	FUNGAL COLONIZATION (%)[a]							
	PORIA CARBONICA INOCULATED BEAMS				PENIOPHORA SPP. INOCULATED BEAMS			
INCUBATION PERIOD (MONTHS)	DECAY FUNGUS	CONTAMINANTS		WOOD MC(%)	DECAY FUNGUS	CONTAMINANTS		WOOD MC(%)
		PENICILLIUM	BACTERIA			PENICILLIUM	BACTERIA	
1	95	8	7	78	87	1	0	111
2	89	22	58	93	99	23	0	109
3	98	63	11	77	-	-	-	-
4	100	9	0.4	77	44	57	0	80
5	100	13	7	76	19	90	27	66
6	100	55	0.5	89	-	-	-	-
7	100	36	3	100	52	81	25	60
8	-	-	-	-	41	86	8	56
9	99	62	0	80	0.4	100	1.2	09
10	100	68	15	89	-	-	-	-
11	-	-	-	-	50	79	0.4	18
12	100	10	0	91	-	-	-	-
13	100	41	0	-	-	-	-	-

[a] Average percent colonization of sixty-four 0.25-in. cubes, cut after bending-strength test, from a 3-in.-long section at beam mid-span. Four beams per time point.

contaminants. Peniophora spp. rapidly colonized the wood, then declined in frequency, while the contaminants increased in frequency. In addition, moisture content (MC) of the beams varied with incubation time in the sapwood, while MC of the heartwood beams remained relative stable. The MC decline in sapwood beams may represent increased physiologic activity in the more readily

attacked material or variations in humidity conditions within individual incubations.

While both species were able to colonize the beams within 2 months after inoculation, only P. carbonica was capable of significantly reducing bending MOR, while MOE and WORK were unaffected by the 13-month exposure to this test fungus (Table III-4). This fungus is one of the two species most commonly isolated from air-seasoning Douglas-fir poles; however, its effect on wood strength, even under optimal conditions (28°C, ideal moisture conditions) suggests that is initial effects on wood strength are minimal. At later stages, as the fungus becomes more thoroughly established, it is likely that this situation would change. The results seem to corroborate previous reports that the effects of air-seasoning on wood strength properties are minimal for the first two years of air-seasoning, in spite of high levels of fungal colonization.

While colony size measurements indicated that there was little change in P. carbonica infected beams over the 13-month incubation period, colony density measurements indicated a more dynamic system (Table III-5). As expected, colony counts were highest at the beam center and declined away from this zone; however, colony density also declined in the beam center after 10 months, suggesting that available nutrients in this zone had been exhausted. In general, colony density away from the beam center remained relatively low throughout the course of the study. Penicillium species were once again found in the beams, but their incidence varied widely. The colony density measurements would very probably seriously overstate the importance of Penicillium species, since they are normally abundant sporulaters. The random Penicillium colony patterns suggest that these species did not markedly alter colonization of the beam by P. carbonica.

TABLE III-4

MECHANICAL PROPERTIES OF DOUGLAS-FIR SAPWOOD OR HEARTWOOD BEAMS INFECTED WITH PORIA CARBONICA OR PENIOPHORA SPP., AS MEASURED AT MONTHLY INTERVALS AND COMPARED USING 95 PERCENT TUKEY HSD INTERVALS.[a]

	FUNGUS TESTED			
	PORIA CARBONICA		PENIOPHORA SPP.	
	MULTIPLE RANGE ANALYSIS FOR MODULUS OF RUPTURE (MOR)			
INCUBATION PERIOD (MONTHS)	REPLICATES	MOR (PSI)	REPLICATES	MOR (PSI)
1	4	7545.2500 *	4	7419.0000 *
2	4	6363.0000 **	4	6447.0000 *
3	4	7101.5000 **	-	-
4	4	6321.0000 **	4	6720.0000 *
5	4	5984.7500 **	4	6917.0000 *
6	4	6027.0000 **	-	-
7	4	7486.2500 *	4	7035.0000 *
8	-	-	3	6328.0000 *
9	4	6008.0000 **	-	-
10	4	5097.0000 *	-	-
12	4	5880.0000 **	-	-
13	5	6335.4000 **	-	-
	MULTIPLE RANGE ANALYSIS FOR MODULUS OF ELASTICITY (MOE)			
INCUBATION PERIOD (MONTHS)	REPLICATES	MOE (PSI X 1000)	REPLICATES	MOE (PSI X 1000)
1	4	1468.7500 *	4	1472.0000 *
2	4	1337.0000 *	4	1367.5000 *
3	4	1521.5000 *	-	-
4	4	1495.5000 *	4	1490.2500 *
5	4	1319.5000 *	4	1477.5000 *
6	4	1308.0000 *	-	-
7	4	1284.2500 *	4	1579.5000 *
8	-	-	3	1560.6667 *
9	4	1170.7500 *	-	-
10	4	1165.0000 *	-	-
12	4	1187.2500 *	-	-
13	5	1291.0000 *	-	-
	MULTIPLE RANGE ANALYSIS FOR WORK TO MAXIMUM LOAD			
INCUBATION PERIOD (MONTHS)	REPLICATES	WORK (IN-LBS)	REPLICATES	WORK (IN-LBS)
1	4	15.512500 *	4	29.490000 *
2	4	10.485000 *	3	19.792500 *
3	4	5.857500 *	-	-
4	4	6.527500 *	4	25.802500 *
5	4	13.102500 *	4	13.927500 *
6	4	6.877500 *	-	-
7	4	14.280000 *	4	14.357500 *
8	-	-	3	13.116667 *
9	4	13.605000 *	-	-
10	4	9.012500 *	-	-
12	4	10.617500 *	-	-

[a] Numbers with asterisks in the same columns are not significantly different. Location with (-) indicate no sample taken.

TABLE III-5

FUNGAL COLONY DENSITY IN DOUGLAS-FIR HEARTWOOD BEAMS INOCULATED WITH PORIA CARBONICA AS MEASURED BY COLONY COUNTS OF MACERATED WOOD ON NUTRIENT MEDIA.[a]

INCUBATION PERIOD (MONTHS)	BEAM MOISTURE CONTENT (%)	COLONY COUNT				
		BEAM LEFT END	TWO IN. FROM LEFT END	BEAM MID-SPAN	TWO IN. FROM RIGHT END	BEAM RIGHT END
		Poria carbonica				
2	106	0	0	0	0	0
3	90	1	1	3	1	0.2
4	83	0	1	1	0	0
5	77	16	82	476	15	44
6	83	16	13	529	87	65
8	72	10	5	502	5	10
9	26	5	12	119	6	14
10	49	25	19	324	14	19
11	22	2	1	1	2	2
13	122	33	34	43	17	43
		Penicillium (inoculated beams)				
2	106	4	0	0	0	0
3	90	1	5	0	25	13
4	83	15	18	4	5	9
5	77	0	33	0	12	0
6	83	91	90	288	75	94
8	72	18	1	70	56	16
9	26	15	64	1	14	34
10	49	0	1	1	1	1
11	22	2	0.2	0	6	0
13	122	31	103	113	127	368
		Bacteria (inoculated beams)				
2	106	12	13	19	3	16
3	90	152	152	45	105	1
4	83	8	10	38	68	31
5	77	0	1	0	13	0.2
6	83	2	3	2	2	1
8	72	9	6	16	6	9
9	26	3	10	17	1	8
10	49	12	3	3	3	11
11	22	4	20	2	0	9
13	122	0	0	0.2	0.2	0
		Penicillium (control beam)				
2	96	0	0	0	0	0
3	105	0	0	0	0	0
4	97	60	40	100	35	100
5	68	0	0	1	0	1
6	68	67	105	55	65	100
8	74	49	1	2	95	0
9	57	0	0	0	0	0
10	17	2	0	0	0	0
11	35	0	2	0	2	0
13	-	-	-	-	-	-
		Bacteria (control beam)				
2	96	0	2	0	1	0
3	105	1	8	241	8	0
4	97	0	0	0	0	0
5	68	1	0	0	0	2
6	68	0	0	0	0	0
8	74	1	1	3	2	3
9	57	0	0	2	0	0
10	17	4	9	0	10	0
11	35	1	1	0	2	5
13	-	-	-	-	-	-

[a] Average number of colonies per 0.02 cm^3 of wood at each time point.

The decline in colony density detected in the P. carbonica infected beams coincides with a decline in LCS 9 months after inoculation (Table III-6). Although the LCS values varied with continued incubation, the levels remained significantly different from those found in untreated control sections. This suggests that complete utilization of the wood by the test fungus had occurred at this point.

TABLE III-6

LONGITUDINAL COMPRESSION STRENGTH (LCS) OF DOUGLAS-FIR SAPWOOD OR HEARTWOOD BEAMS INFECTED WITH PORIA CARBONICA OR PENIOPHORA SPP. AS MEASURED AT MONTHLY INTERVALS FOLLOWING INOCULATION.

	TEST FUNGUS			
	PORIA CARBONICA		PENIOPHORA SPP.	
INCUBATION PERIOD (MONTHS)	REPLICATES	LCS (KG)	REPLICATES	LCS (KG)
0	8	416.71875 *	7	412.75000 *
1	-	-	6	394.85417 *
2	4	410.21875 **	6	380.62500 *
3	4	426.96875 *	-	
4	4	405.56250 **	4	404.78125 *
5	4	391.40625 ***	-	-
6	4	399.87500 **	4	385.87500 *
7	-	-	-	-
8	4	358.84375 ****	4	375.12500 *
9	3	293.33333 *	4	377.96875 *
10	4	334.93750 ***	-	-
11	3	316.75000 **	-	-
12	-	-	2	380.43750 *
13	4	304.75000 *	-	-

[a] Values represent averages. Numbers with asterisks in the same columns are not significantly different by Tukey HSD at the 95 percentile.

Beams inoculated with Peniophora spp. did not appear to experience the same relatively high colony densities found with P. carbonica inoculated beams (Table III-7). Colony densities at the beam center were low, while those midway between the center and beam end were occasionally highest. The variable colonization levels were complicated by an increased presence of Penicillium species over the course of incubation. This presence appears to have inhibited colonization by the test fungus. In the natural system, Peniophora spp. appears infrequently in test poles, although it is the third most commonly isolated fungal species from this environment. In general, it

TABLE III-7

FUNGAL COLONY DENSITY IN DOUGLAS-FIR SAPWOOD BEAMS INOCULATED WITH PENIOPHORA SPP. AS MEASURED BY COLONY COUNTS OF MACERATED WOOD ON NUTRIENT MEDIA.

INCUBATION PERIOD (MONTHS)	BEAM MOISTURE CONTENT (%)	COLONY COUNTS[a] BEAM LEFT END	TWO IN. FROM LEFT END	BEAM MID-SPAN	TWO IN. FROM RIGHT END	BEAM RIGHT END
		Peniophora spp.				
1	110	0	8	13	15	0
2	108	24	18	34	33	37
4	90	31	45	0	92	32
6	75	11	7	11	8	7
8	67	0	0	0	0	0
9	65	24	29	16	21	35
12	40	0	0	0	0	0
		Penicillium (inoculated beams)				
1	110	0	0.2	4	0	1
2	108	133+	1	16	4	6
4	90	60	36	88	116	84
6	75	110	0.2	54	43	48
8	67	21	29	118	96	87
9	65	778+	790+	658+	768+	688+
12	40	380+	324+	568+	378+	560+
		Bacteria (inoculated beams)				
1	110	0	500+	0.3	83	1
2	108	-	-	-	-	-
4	90	134	131	4	63	125
6	75	342	148	56	153	231
8	67	1	0	0.2	0	0.2
9	65	31	5	52	0	5
12	40	0	2	0	0	1
		Penicillium (control beam)				
1	110	0	0	0	0	0
2	106	-	-	-	-	-
4	105	250+	250+	250+	250+	250+
6	85	4	60	45	126	4
8	114	9	1	28	79	57
9	114	400+	500+	1000+	250+	500+
12	77	250+	250+	250+	250+	250+
		Bacteria (control beam)				
1	110	0	0	0	0	0
2	106	-	-	-	-	-
4	105	0	0	0	0	0
6	85	240	240	18	20	400
8	114	0	0	0	0	0
9	114	0	0	0	0	0
12	77	0	276	0	7	361

[a] Average number of colonies per 0.02 cm^3 of wood at each time point. Values followed by a plus indicated colony counts greater than reported, but not quantifiable because colonies coalesced before measurement.

is isolated at high frequency from one pole and completely absent from others at a given site. This variable frequency suggests that microbial competition, as occurred in this test, may play a major role in colonization by this fungus. The results of this test will be repeated to more accurately determine the effects of this fungus in the absence of microbial contamination.

LCS measurements of sections from the Peniophora spp. exposed beams also indicated that the fungus caused no significant effect over the incubation period (Table III-6). While previous reports indicate that Peniophora spp. have a minimal effect on bending properties, the presence of Penicillium sp. in our beams makes it difficult to accurately determine the effect of the former fungus on properties of Douglas-fir sapwood.

These tests will continue in an effort to better delineate the influence of these fungi on properties of air-seasoning Douglas-fir poles. At present, the results suggest that colonization from dilute suspensions of spores or hyphal fragments is a slow process, with minimal effect on the wood for relatively long periods, even under optimal conditions. As such, the effects on air-seasoning Douglas-fir poles exposed under less than optimal conditions in the field should be less significant. Nevertheless, the fungi colonizing the wood during air-seasoning must be eliminated at some point prior to installation in service to prevent long-term decay problems.

OBJECTIVE IV

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

A. DECAY DEVELOPMENT STUDY

Of the more than 30 fungal species isolated from the air-seasoning Douglas-fir pole sections over a 3 year period (1981 Annual Report, pg. 44-45) most appeared only sporadically. Unless our isolation procedures are faulty, these fungi probably represent chance infestations by fungi not normally found in air-seasoning Douglas-fir.

For our purposes, we will only consider those fungi which appear 10 or more times in a given year. A total of 11 fungal species were isolated at this frequency rate for any given year (Tables IV, 1-5). The characteristics of each isolate in relation to each of the four air-seasoning sites will be discussed individually.

Coriolus versicolor is a commonly isolated white rotter that attacks both soft- and hardwood in service. In this study, it was only sporadically isolated, primarily from the outer one and two inch segments at the two northern sites. The incidence of this fungus increased after two years, but it was still primarily isolated from the outer two inches. The incidence and habitat of C. versicolor was little changed after three years of seasoning, suggesting that this fungus was, at least initially, confining its attack to the sapwood zone. Coriolus versicolor has been isolated from Douglas-fir heartwood in oil-treated utility poles, but our results indicate that its primary habitat in untreated poles is the sapwood. Fungi in these locations should be eliminated by the preservative treatment process.

Epicoccum nigrum is not a basidiomycete; however, its initial appearance is so similar to the basidiomycetes that we have maintained records of the

TABLE IV-1

FREQUENCY OF SELECTED BASIDIOMYCETES AND Epicoccum nigra AT ONE INCH INTERVALS IN DOUGLAS-FIR POLE SECTIONS AIR-SEASONED FOR ONE, TWO OR THREE YEARS AT SCAPPOOSE, OR AS MEASURED BY REMOVING INCREMENT CORES FOR CULTURING.

	ISOLATION FREQUENCY (%) BY INCH OF CORE																	
	ONE YEAR						TWO YEARS						THREE YEARS					
FUNGAL SPECIES	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
C. versicolor	0.5	0.2	-	-	-	-	3.1	3.1	1.0	0.2	0.2	-	3.2	2.3	0.4	-	-	-
E. nigra	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
G. saepiarum	1.2	1.4	-	-	-	-	6.3	2.8	0.7	0.5	0.2	-	10.4	4.9	1.1	0.2	-	0.2
H. sanguinolentum	1.1	1.1	0.3	0.2	0.2	-	6.0	5.5	1.0	0.5	0.2	-	4.4	2.7	1.5	-	0.4	-
Peniophora spp.	3.1	1.1	0.2	-	-	0.2	5.1	1.0	0.8	0.2	0.2	-	3.8	1.1	1.9	2.8	2.8	3.4
Phanerochaete sordida	0.2	-	-	-	-	-	0.5	0.3	-	-	-	0.3	-	-	-	-	-	-
P. placenta	0.9	0.6	1.1	0.8	0.9	0.5	-	0.2	1.0	2.0	1.5	0.3	1.5	0.9	2.8	4.0	5.1	6.3
P. placenta (monokaryon)	0.8	0.3	0.3	0.9	0.6	0.3	-	0.7	1.7	2.2	2.8	2.0	0.2	0.2	0.2	0.2	0.6	1.1
P. carbonica	0.3	1.1	1.9	1.9	2.7	1.6	1.7	4.0	5.0	7.5	10.4	9.6	5.3	18.0	21.8	25.8	26.6	21.3
S. brinkmanii	-	-	-	-	-	0.2	1.5	1.2	0.3	-	-	-	3.2	2.7	1.3	-	0.2	-
S. hirsutum	0.6	0.2	-	-	-	-	.3	0.3	-	-	-	-	1.1	1.9	1.1	0.2	0.2	-
Unidentified Basidiomycete	1.6	0.3	-	-	0.3	-	4.6	1.7	0.7	0.7	1.0	0.7	15.0	8.7	4.2	2.8	1.9	0.8
Unidentified Basidiomycete without clamps	0.8	0.2	0.2	0.2	0.2	-	1.0	0.5	0.2	-	-	-	2.7	2.1	1.1	0.6	0.9	1.1

TABLE IV-2

FREQUENCY OF SELECTED BASIDIOMYCETES AND Epicoccum nigra AT ONE INCH INTERVALS IN DOUGLAS-FIR POLE SECTIONS AIR-SEASONED FOR ONE, TWO OR THREE YEARS AT ARLINGTON, WA AS MEASURED BY REMOVING INCREMENT CORES FOR CULTURING.

	ISOLATION FREQUENCY (%) BY INCH OF CORE																	
	ONE YEAR						TWO YEARS						THREE YEARS					
FUNGAL SPECIES	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
C. versicolor	0.2	-	-	-	0.2	0.2	0.3	-	-	-	-	-	0.2	-	-	-	-	-
E. nigra	1.2	-	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
G. saepiarum	1.0	0.2	0.4	0.2	-	-	0.9	-	-	-	-	-	4.1	3.9	-	-	-	-
H. sanguinolentum	11.1	3.3	0.2	0.2	-	-	15.8	10.0	0.6	0.3	0.6	0.3	12.4	10.2	0.9	-	-	-
Peniophora spp.	1.2	0.4	-	-	-	-	2.6	-	-	-	0.3	-	4.4	1.5	0.2	0.2	0.4	0.2
Phanerochaete sordida	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P. placenta	-	-	0.2	0.2	-	-	1.1	1.4	0.9	1.4	1.4	1.1	0.4	1.3	3.1	3.7	2.8	2.4
P. placenta (monokaryon)	0.4	-	-	-	0.6	0.6	1.4	1.4	1.1	1.7	1.7	1.1	-	0.4	0.7	0.7	0.4	-
P. carbonica	0.6	-	1.2	1.0	2.1	2.3	1.1	6.3	6.0	7.4	12.0	11.7	2.2	10.0	20.5	29.8	32.5	26.6
S. brinkmanii	0.4	-	-	-	-	-	0.9	0.6	0.3	-	0.3	-	0.9	0.9	-	-	-	-
S. hirsutum	0.2	-	0.2	-	-	-	0.3	-	-	-	-	-	2.2	1.5	-	-	-	-
Unidentified Basidiomycete	0.4	-	0.2	-	0.2	-	1.4	0.6	0.6	-	0.9	0.3	9.2	5.4	1.7	1.7	0.7	0.7
Unidentified Basidiomycete without clamps	1.2	0.6	0.2	0.6	-	-	1.7	0.6	0.6	0.6	0.6	0.6	8.5	4.6	1.5	2.0	1.3	1.7

TABLE IV-3

FREQUENCY OF SELECTED BASIDIOMYCETES AND Epicoccum Nigra AT ONE INCH INTERVALS IN DOUGLAS-FIR POLE SECTIONS AIR-SEASONED FOR ONE, TWO OR THREE YEARS AT OROVILLE, CA AS MEASURED BY REMOVING INCREMENT CORES FOR CULTURING.

	ISOLATION FREQUENCY (%) BY INCH OF CORE																	
	ONE YEAR						TWO YEARS						THREE YEARS					
FUNGAL SPECIES	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
C. versicolor	-	-	-	-	-	-	-	-	-	-	-	-	0.4	0.2	-	-	-	-
E. nigra	1.5	-	0.8	0.6	-	-	0.5	-	0.2	-	-	-	0.4	-	-	-	-	-
G. saepiarum	-	-	-	-	-	-	-	0.2	-	-	-	-	0.2	-	-	-	-	-
H. sanguinolentum	-	-	-	-	-	-	-	0.5	0.2	0.2	-	-	-	-	-	-	-	-
Peniophora spp.	0.8	0.6	0.4	0.6	0.4	0.4	11.5	6.6	3.2	2.0	1.2	1.0	14.5	4.8	0.4	0.4	0.2	0.2
Phanerochaete sordida	-	0.2	-	-	-	0.2	0.2	-	-	-	-	0.2	-	-	-	-	-	-
P. placenta	0.6	0.9	1.1	1.3	0.8	0.6	0.5	0.5	1.7	2.5	0.7	0.7	0.2	-	-	-	-	-
P. placenta (monokaryon)	0.2	-	-	-	0.4	-	0.2	0.5	0.5	1.2	0.5	0.5	-	-	-	-	-	0.2
P. carbonica	0.2	0.4	-	0.2	0.2	0.2	0.7	0.7	0.7	0.7	0.2	-	-	-	-	-	0.2	0.2
S. brinkmanii	-	-	-	-	-	-	0.2	0.2	0.2	-	0.2	-	0.2	-	-	-	-	-
S. hirsutum	-	-	-	-	-	-	2.0	2.5	2.2	0.5	-	0.2	1.0	1.1	0.2	0.2	-	-
Unidentified Basidiomycete	4.5	3.4	3.4	1.7	0.6	-	5.4	3.4	1.7	1.0	1.0	0.7	16.8	3.3	0.6	0.2	0.6	-
Unidentified Basidiomycete without clamps	1.3	1.5	0.6	0.4	0.9	0.9	2.2	1.2	1.2	1.0	0.2	0.5	3.3	1.0	0.4	0.2	0.2	0.2

TABLE IV-4

FREQUENCY OF SELECTED BASIDIOMYCETES AND Epicoccum nigra AT ONE INCH INTERVALS IN DOUGLAS-FIR POLE SECTIONS AIR-SEASONED FOR ONE, TWO OR THREE YEARS AT EUGENE, OR AS MEASURED BY REMOVING INCREMENT CORES FOR CULTURING.

	ISOLATION FREQUENCY (%) BY INCH OF CORE																	
	ONE YEAR						TWO YEARS						THREE YEARS					
FUNGAL SPECIES	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
C. versicolor	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2	-
E. nigra	0.3	-	0.2	-	-	0.2	0.9	-	-	-	-	-	0.2	0.2	0.2	0.2	-	0.2
G. saepiarum	1.9	0.3	0.2	-	-	-	0.7	0.9	-	0.2	-	-	4.0	2.1	0.6	0.4	0.2	-
H. sanguinolentum	0.2	-	0.2	-	0.2	-	0.9	0.5	0.2	-	-	-	0.6	-	-	-	-	-
Peniophora spp.	2.6	0.2	0.2	-	0.2	0.2	11.5	1.4	-	0.2	-	0.2	5.0	0.6	0.6	-	0.2	0.4
Phanerochaete sordida	0.2	-	-	-	-	-	0.9	0.5	-	-	-	0.2	-	-	-	-	-	-
P. placenta	3.6	3.3	5.6	5.6	6.6	5.9	1.6	2.1	4.2	6.6	7.0	5.6	6.5	6.5	10.0	11.1	10.9	10.0
P. placenta (monokaryon)	1.7	0.5	1.6	0.7	1.6	1.2	-	0.2	0.7	1.2	1.9	1.6	0.6	0.4	0.8	0.6	1.5	1.3
P. carbonica	2.4	3.6	3.5	2.3	4.7	5.7	0.9	2.3	4.9	8.0	12.0	8.5	8.8	17.6	22.4	25.5	23.4	16.1
S. brinkmanii	-	0.2	-	-	0.2	0.2	0.9	.5	-	-	0.2	0.7	1.5	0.6	0.2	-	-	-
S. hirsutum	0.3	0.7	0.3	-	0.2	0.3	1.6	1.4	0.7	-	0.2	-	2.1	1.5	0.8	0.6	0.2	-
Unidentified Basidiomycete	0.7	0.3	0.2	0.3	0.9	0.7	4.5	1.2	0.5	-	-	-	8.0	3.8	1.5	2.1	2.3	1.5
Unidentified Basidiomycete without clamps	1.7	1.4	1.4	0.9	1.0	1.0	-	-	-	-	-	0.2	1.9	1.0	1.0	1.0	0.6	0.8

TABLE IV-5
FREQUENCY OF SELECTED BASIDIOMYCETES AND Epicoccum nigra AT ONE INCH INTERVALS IN DOUGLAS-FIR POLE SECTIONS AIR-SEASONED FOR ONE, TWO OR THREE YEARS AT ALL YARDS COMBINED AS MEASURED BY REMOVING INCREMENT CORES FOR CULTURING.

	ISOLATION FREQUENCY (%) BY INCH OF CORE[a]																	
	ONE YEAR						TWO YEARS						THREE YEARS					
FUNGAL SPECIES	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
C. versicolor	0.2	-	-	-	-	-	1.1	1.1	0.3	0.1	0.1	-	1.0	0.6	0.1	-	-	-
E. nigra	0.8	-	0.3	0.1	-	-	0.4	-	0.1	-	-	-	0.1	-	-	-	-	-
G. saepiarum	1.1	0.5	0.1	-	-	-	2.5	1.2	0.2	0.2	0.1	-	4.7	2.7	0.4	0.1	-	-
H. sanguinolentum	2.8	1.0	0.2	0.1	0.1	-	5.3	4.0	0.6	0.3	0.2	0.1	4.1	3.0	0.6	-	0.1	-
Peniophora spp.	2.0	0.6	0.2	0.1	0.1	0.2	7.6	2.2	1.0	0.6	0.4	0.3	7.0	2.0	0.8	0.9	0.9	1.1
Phanerochaete sordida	0.1	-	-	-	-	-	0.4	0.2	-	-	-	0.2	-	-	-	-	-	-
P. placenta	1.3	1.3	2.1	2.0	2.1	1.8	0.7	1.0	1.9	3.1	2.6	1.8	2.2	2.2	4.0	4.7	4.8	4.7
P. placenta (monokaryon)	0.8	0.2	0.5	0.4	0.8	0.5	0.3	0.7	1.1	1.6	1.8	1.4	0.2	0.2	0.4	0.3	0.6	0.7
P. carbonica	0.9	1.3	1.7	1.4	2.5	2.5	1.2	3.3	4.2	6.0	8.8	7.6	4.1	11.5	16.1	20.0	20.3	15.7
S. brinkmanii	0.1	-	-	-	-	0.1	1.0	0.7	0.2	-	0.2	0.2	1.5	1.0	0.4	-	-	-
S. hirsutum	0.3	0.2	0.1	-	-	0.1	1.0	1.0	0.7	0.1	0.1	0.1	1.6	1.5	0.5	0.2	0.1	-
Unidentified Basidiomycete	1.8	1.0	0.9	0.5	0.5	0.2	4.1	1.7	0.8	0.4	0.7	0.4	12.4	5.3	2.0	1.7	1.4	0.7
Unidentified Basidiomycete without clamps	1.3	0.9	0.6	0.5	0.5	0.5	1.2	0.6	0.4	0.3	0.2	0.3	3.9	2.1	1.0	0.9	0.7	0.9

[a] Isolation frequency represents the number of infested core segments divided by the number of cores sampled multiplied by 100.

incidence of this fungus. This fungus was a relatively common colonizer of poles air-seasoned for one year, with the majority of isolations from the outer inch. This fungus was also isolated from the three, four and six inch samples at Oroville, CA and Eugene, OR but the reasons for colonization at this depth in the wood remain unclear. The incidence of E. nigra declined after one year, with the majority of isolations occurring at the Eugene site. Epicoccum nigra is an imperfect stage of a fungus which is capable of causing minor soft rot attack under ideal conditions. It is unlikely that this fungus causes noticeable wood degradation in the poles. More likely, it is utilizing the free sugars in the ray cells present near the wood surface and the decline in incidence may reflect depletion of this energy source. This fungus may serve as an indicator of the switch from rapidly growing molds to fungi which have a greater influence on the wood structure.

Gloeophyllum saepiarum is a brown rot fungus which attacks conifers and hardwoods. After one year, this fungus was isolated from the outer one to two inches of poles at all sites but Oroville. After two years, the fungus was

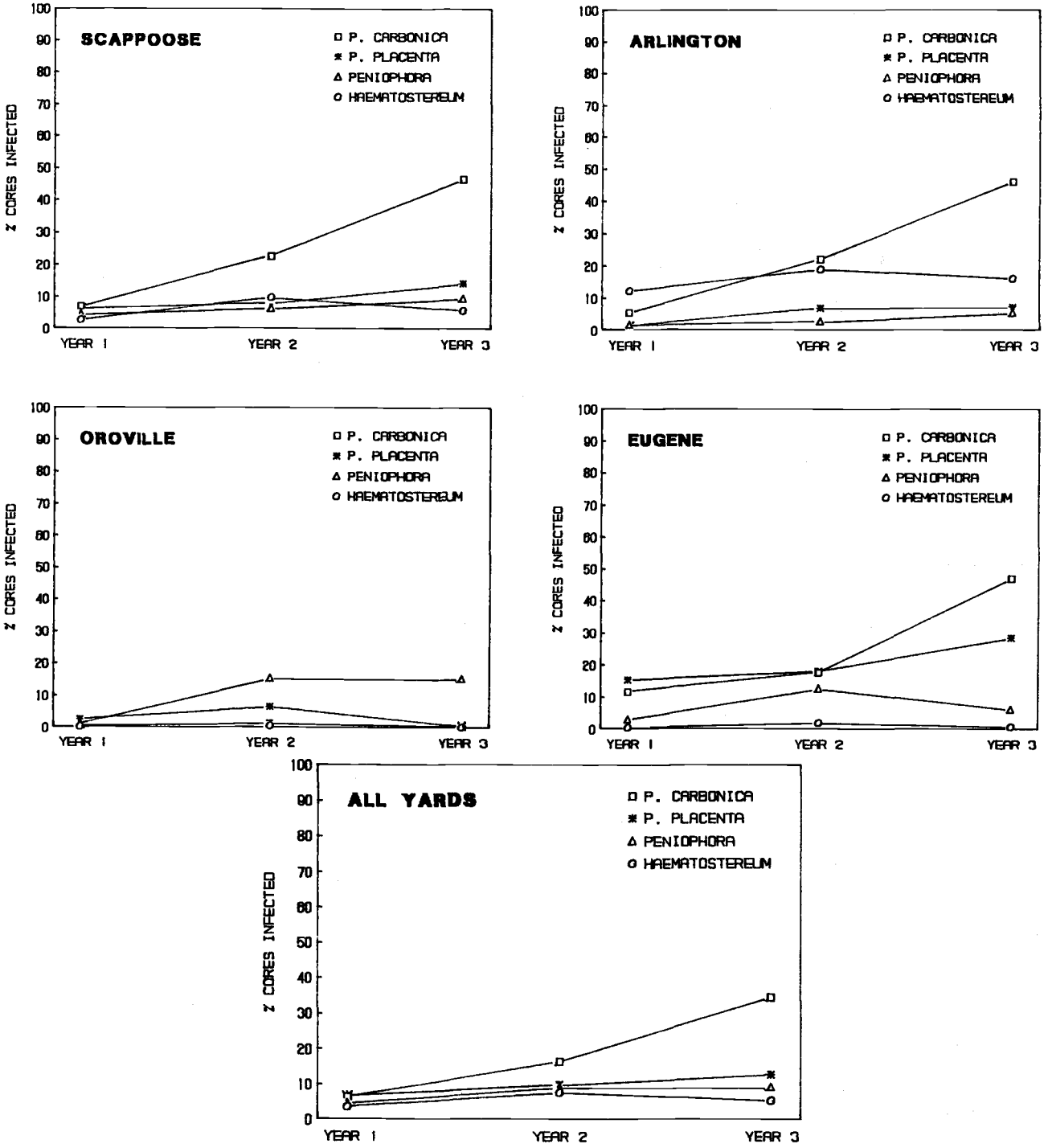


Figure IV-1. Incidence of Poria placenta, Poria carbonica, Peniophora spp. and Haematostereum sanguinolentum at: (A) Scappoose, OR; (B) Arlington, WA; (C) Oroville, CA; or (D) Eugene, OR; (E) all four sites combined.

about two times as abundant and was still prevalent on the outer two zones, but was also isolated from inner sites of poles exposed at Scappoose. This fungus was only isolated from one core at Oroville. The incidence of G. saepiarum nearly doubled between two and three years, with the majority of isolations (151/165) occurring in the outer two inches. These results indicate that this fungus is acting primarily in the sapwood zone where it will be especially sensitive to chemicals during the pressure treating process.

Haematostereum sanguinolentum is a white rotter typically found on conifers and hardwoods. In Douglas-fir pole sections, this fungus was one of the four most commonly isolated species. After one year, this fungus was most frequently isolated from the outer two inches of the poles, although it was sporadically present at all depths. The Arlington and Scappoose sites contained the highest levels of this fungus, while Eugene experienced little incidence and the fungus was absent from Oroville, CA. These patterns suggest that H. sanguinolentum requires moist conditions for colonization, since the highest colonization levels occurred at the wettest seasoning site. The incidence of H. sanguinolentum increased 56 percent between the first and second years of air-seasoning. Once again, the fungus was most prevalent in the outer two inches, particularly at the Arlington and Scappoose sites. The fungus was isolated with a slightly greater frequency at Eugene and was isolated from only one pole section exposed at Oroville. After three years, the levels of H. sanguinolentum were stable and the patterns of isolation remained similar. In general, colonization by this fungus was confined to the outer three inches of the pole section (approximating the sapwood). Preliminary tests indicate that this fungus does not have a significant impact on wood strength. The combination of minimal strength effects, and location

in the sapwood where presence of chemical preservative, and the application of high temperature during treatment should eliminate the fungus, suggest that the presence of H. sanguinolentum in air-seasoning Douglas-fir poles should not pose a problem. However, its potential role as a wood conditioner for other fungi should not be overlooked.

Another fungal group among the four most common isolates, Peniophora spp. was also frequently isolated from the outer sections of the wood. This fungal group was primarily isolated from the outer inch, except at Oroville, where it was isolated from all depths from a single pole section. The incidence of this fungus tripled between one and two years, with the most frequent isolations occurring in the outer two inches of the pole. Peniophora spp. were most prevalent at Oroville and the frequency of isolations declined at more northern sites. This decline may reflect depletion of readily accessible nutrients, changes in wood moisture content, or variations in temperature which favored colonization by other fungi. The incidence of Peniophora spp. stabilized after three years; however, the distribution of this fungal group was altered somewhat. In general, isolations were most frequent in the outer two inches, but isolations were made from all sampling depths at the Scappoose site. While one pole section at this site was heavily colonized, 80 percent of the poles contained this group. The more thorough colonization by Peniophora spp. in the heartwood conflicts with previous reports that this fungal group is typically found in the sapwood. The role of this group in Douglas-fir pole sections remains unclear. While this fungal group is prevalent, its high frequency in the sapwood and its apparent minimal effect on wood strength suggest that it should not pose a threat to poles in service.

Phanerochaete sordida is a white rotter which was infrequently isolated from all sites, but Arlington, after one year. There appeared to be no trend

to the isolation. After two years, the incidence of this fungus increased four fold, but still remained at low levels. The majority of isolations were made in the outer two inches and no isolates were made from Arlington. The incidence of this fungus declined dramatically after three years, suggesting that it is a minor component of the Douglas-fir fungal flora.

One of the two most abundant basidiomycetes in the heartwood zone was Poria placenta and its monokaryon. The relatively high frequency of monokaryons indicates that basidiospores represented an important component of infestation by this fungus. Poria placenta was the second most frequently isolated fungus after one year (most frequent if both mono- and di-karyons are combined). This fungus was most abundant at Eugene, followed by Scappoose and Oroville, but was virtually absent at Arlington. While the incidence of the monokaryon was lower, it generally followed the distribution of the dikaryon. This fungus was isolated from all depths of the pole sections, but was found most frequently at three to five inches from the wood surface. The nature of the high incidence of P. placenta at Eugene is unclear, but the abundance of forest products industry around this site may provide ample debris for the growth and sporulation of this fungus.

After 2 years, the incidence of P. placenta increased by slightly more than 20 percent. Once again the fungus was isolated from all core depths and was most prevalent at Eugene. In addition, the incidence of monokaryons was high, suggesting that conditions for colonization were still adequate. While colonization increased by nearly 50 percent between two and three years, the frequency of monokaryons declined, suggesting that conditions in the wood were less conducive to germination and growth of P. placenta basidiospores. Alternative explanations for the low incidence of monokaryons might include the possibility that dikaryons formed from germ tubes or the increased degree

of colonization enhanced the likelihood that mating types would come in contact. Conversely, the increased incidence of dikaryons suggests that existing colonies were expanding into previously unoccupied wood. Poria placenta was nearly absent from Oroville (1 isolation). The infrequent isolation of this fungus after one and two years, and its virtual absence after three years at Oroville is perplexing. It is possible that the exceptional dryness and high temperatures at this site created unfavorable conditions for continued growth of P. placenta. The presence of P. placenta at all depths in pole sections at the remaining sites is cause for concern. This fungus is one of the most commonly isolated species from Douglas-fir poles in service. The presence of this fungus at high levels during air-seasoning provides ample opportunity for survival through an inadequate treatment cycle and continued growth in the treated product. Careful adherence to required heating times represents the most effective method for insuring that this situation does not occur.

The remaining species among the four most commonly isolated, Poria carbonica, was the most frequently isolated species after one year. Once again, this fungus was most abundant at Eugene, followed by Scappoose and Arlington. The fungus was infrequently isolated from Oroville. Like P. placenta, this fungus was isolated from all depths sampled, although levels in the inner five- and six-inch zones were slightly higher. In addition to P. carbonica dikaryons, a number of monokaryons were isolated; however, the frequency of these isolates remained low. This low frequency may reflect a naturally high rate of conversion to the dikarotic state or may suggest that other structures, such as hyphal fragments play a more important role in colonization.

After two years of air-seasoning, the incidence of P. carbonica more than doubled. Once again the incidence was lowest in Oroville, but was nearly equal at the three remaining sites. Distribution within individual pole sections was highest within the inner three inches. After three years, the incidence of this fungus again more than doubled; however, P. carbonica was virtually absent from Oroville, where moisture conditions were less conducive to fungal colonization. At the remaining sites, fungal distribution was similar to that found after two years, with highest incidence in the heartwood zone. It was not possible in our study to determine if increased isolations represented new infestations or expansion of existing colonies. It is interesting to note that P. carbonica, typically a heartwood colonizer of preservative-treated Douglas-fir in service, was quite abundant in the sapwood.

Sistotrema brinkmanii causes a white rot of conifers and hardwoods. In our tests, it was infrequently isolated from various locations on poles from all but the Oroville site after one year. After two years, the incidence of this fungus increased ten fold, with all but one isolation being made in the outer three inches of the poles. The increased levels were most noticeable at Scappoose. The incidence of this fungus stabilized after three years, with distributions that were similar to those found after two years, suggesting that S. brinkmanii has occupied all of the available niches. Portions of the wood remain uncolonized, but other factors such as moisture content or the presence of microfungi may be limiting further colonization by this fungus.

The final fungus, Stereum hirsutum, causes a white rot in conifers and hardwoods. In this study, it was isolated at low levels from all but the Oroville site after one year, with the highest levels occurring at Eugene. At Eugene, the fungus was isolated up to six inches from the wood surface. The

incidence of this fungus doubled after two years, but the fungus was most abundant at Oroville, where it was present at depths up to four inches. In general, this fungus was most prevalent in the outer two inches. The higher levels of S. hirsutum at Oroville suggest that rapid drying may favor this fungus; however, conditions did not allow for further expansion of colonies or renewed infestations as shown by the decreased levels of this fungus at Oroville after three years. The incidence of the fungus did increase at the three remaining sites. In general, the presence of S. hirsutum in the outer three inches should result in its elimination during the treatment process, provided some heating (steaming or heating in oil) is included in the cycle.

As we have discussed previously, the air-seasoning study clearly illustrated that all air-seasoning sites are not created equal (Table IV-6). This is particularly true at Oroville, where the low humidity, elevated temperatures, and dry summers combine to reduce the likelihood that infestation will occur. While the percentage of cores infested with basidiomycetes increased at the four sites over the first two years, the incidence after three years declined dramatically at Oroville, while increasing dramatically at the remaining sites. The exception to this trend was the outer inch of poles at Oroville, where infestation levels approached those at the other sites. These higher levels may reflect slight changes in conditions due to rainfall or temperature moderations which permitted renewed colonization. Further comparisons are planned between isolation patterns and climatological data collected near each site. The distribution of fungal species at the four sites varied widely. This was particularly true at Eugene and Oroville. At the former site, P. carbonica and P. placenta dominated the

TABLE IV-6

FREQUENCY OF BASIDIOMYCETES ISOLATED FROM DOUGLAS-FIR POLE SECTIONS EXPOSED AT FOUR PACIFIC NORTHWEST SITES FOR ONE, TWO OR THREE YEARS AS DETERMINED BY CULTURING INCREMENT CORES REMOVED FROM EACH SECTION.

	CORES CONTAINING BASIDIOMYCETES (%)[a]							
	DEPTH (INCHES)							
SITE	1	2	3	4	5	6	7	CORES SAMPLED
				YEAR ONE				
Scappoose	13	7	4	4	5	3	1	641
Arlington	19	5	3	3	4	3	1	486
Oroville	9	7	6	5	3	2	2	530
Eugene	16	11	13	10	16	16	9	576
Total	14	8	7	5	7	6	3	2233
				YEAR TWO				
Scappoose	31	22	13	14	17	13	1	604
Arlington	29	21	10	12	18	15	0	349
Oroville	24	17	12	9	4	4	0	408
Eugene	25	12	12	16	22	18	2	426
Total	28	18	12	13	15	13	1	1787
				YEAR THREE				
Scappoose	51	46	38	37	39	34	0	527
Arlington	45	40	29	38	38	32	0	459
Oroville	37	10	2	1	1	1	0	523
Eugene	41	35	39	42	40	31	1	522
Total	43	33	27	29	29	24	0	2031

[a] % cores containing basidiomycetes represents the number of infected cores divided by number of cores sampled from that site multiplied by 100.

isolations. As mentioned, the proximity to other forest industries where sanitation may be lax could explain the relatively high incidence of these two species. The higher incidence, coupled with the fact that these two fungi are extremely important decayers of Douglas-fir in service, places added importance on the need to sterilize the wood during treatment.

At Oroville, the incidence of both P. carbonica and P. placenta are remarkably low. It is likely that temperature and humidity conditions do not favor colonization or continued growth by these fungi. Conversely, there are increasing numbers of Basidiomycetes at these sites which can not be identified using conventional keys. Further studies are underway to identify these isolates, but their presence highlights the dramatic difference in fungal flora between Oroville and the remaining sites. These differences are also illustrated by the incidence of Peniophora spp. and H. sanguinolentum. The latter fungus became increasingly prevalent in the outer two inches of pole sections at the two most northern sites, but was absent from Oroville. Conversely, Peniophora spp. was present at all sites, but at Oroville, this fungus was largely confined to the outer two inches and was present at the highest levels in the outer inch. While the presence of this fungus should pose few problems in service, the distribution highlights the ecological differences between these sites.

One factor which remains to be explored is the delineation between increased isolations due to new infestations and expansion of existing colonies. The presence of monokaryons can provide some measure of these differences; however, monokaryons are short lived or absent in many species. To overcome this limitation, three dimensional comparisons of existing data are planned to evaluate the fungi isolated from adjacent zones on individual cores and cores removed from adjacent sites. This analysis should provide some measure of rate of spread of existing colonies vs. additional infestations.

B. ABILITY OF POLYBORATES TO PREVENT COLONIZATION OF DOUGLAS-FIR POLES BY BASIDIOMYCETES DURING AIR-SEASONING.

Despite the lack of significant effects on mechanical properties by decay fungi colonizing Douglas-fir poles during the first 2 years of air-seasoning, it is readily apparent that preventing colonization will limit the possibility

of fungi surviving the treating process to cause decay in service. In a previous test, ammonium biofluoride (20 percent) was flooded on pole sections shortly after peeling and prior to exposure at Oroville, CA; Eugene, OR; Arlington, WA; or Scappoose, OR; for one, two or three years. At each time point, selected poles were removed and extensively sampled for the presence of decay fungi. Ammonium bifluoride delayed colonization for up to two years in northern sites and was remarkably effective at the California site. While these results were promising, many treaters expressed concern about the possibility of fluoride leaching from the wood into the seasoning yard. To eliminate this possibility, we evaluated polyborates as potential air-seasoning treatments. Borates have exceptionally low mammalian toxicity. In addition, boron is an essential micronutrient, although it is toxic to plants at higher dosages.

The feasibility of one borate, sodium octaborate tetrahydrate (Timbor), was evaluated by spraying freshly treated pole sections with a 10 percent [Boric Acid Equivalent (BAE)] solution of Timbor. Pole sections (2.4 cm) were obtained from area cooperators and sampled by removing increment cores every 15 cm around the pole circumference 0.3 m in from each end of the pole. The cores were cultured to determine the initial incidence of decay fungi. The outer 0.3 m on each end of the pole was removed and one end of each pole was sealed with an elastomeric paint to retard moisture movement and simulate a continuous wood pole. Separate sets of sprayed poles were subsequently resprayed at 6 month intervals to provide renewed protection to the wood surface as checking patterns developed (Table IV-7). An additional set of poles was dipped for 3 minutes in a 20 percent BAE solution of the same compound. The poles were then exposed at our Peavy Arboretum test site. Additional sets of dipped or untreated pole sections were exposed at the

Oroville, CA site. Previous tests indicated that the degree of colonization at the 3 northern test sites did not vary greatly, while the conditions at the Oroville site were less conducive to fungal colonization. For this reason, the southern site was retained for this study. At annual intervals, five poles from each treatment group from each site were returned to the laboratory and extensively sampled using increment borers. The resulting increment cores were cultured for the presence of decay fungi, which were identified to species. The study is now in its second year.

TABLE IV-7

SCHEDULE FOR TREATMENT OF DOUGLAS-FIR POLE SECTIONS WITH SODIUM OCTABORATE TETRAHYDRATE (TIMBOR).

	MONTHS OF AIR-SEASONING[b]						
TREATMENT[a]	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 (TIMBOR)	X	-	SAMPLE	-	SAMPLE	-	SAMPLE
DIP (THIOBOR)	X	-	-	-	-	-	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] Where "X" denotes treatment and "-" denotes no treatment. Five poles per treatment were removed at each sampling date.

The cultural results indicate that initial levels of colonization in the untreated pole sections ranged from 0 to 15.63 percent of the cores (Table IV-8). It was not possible to segregate poles into separate treatment groups based upon isolation frequency, since culturing took 1 month and the borate

had to be applied shortly after peeling to be most effective. As a result, the initial incidence of decay fungi varied widely in the treatment groups.

TABLE IV-8

BASIDIOMYCETE COLONIZATION OF DOUGLAS-FIR POLE SECTIONS TREATED WITH SODIUM OCTABORATE TETRAHYDRATE BY VARIOUS SCHEDULES AND SAMPLED BEFORE AND ONE YEAR AFTER TREATMENT.[a]

	PERCENTAGE OF CORES CONTAINING EACH FUNGUS													
	OROVILLE, CA				CORVALLIS, OR									
	DIPPED		UNTREATED		DIPPED		SPRAY 0		SPRAY 0/6 MO		SPRAY 6 MO		UNTREATED	
FUNGAL SPECIES	0	1yr	0	1yr	0	1yr	0	1yr	0	1yr	0	1yr	0	1yr
Unidentified w/clamps	0.00	0.74	0.00	0.25	0.00	1.61	4.69	4.05	5.63	4.84	0.00	4.06	1.79	8.11
Unidentified without clamp	9.23	3.92	3.64	2.70	0.00	8.49	10.94	4.28	14.08	6.18	20.00	5.49	10.71	9.09
Coriolus versicolor	-	-	-	-	0.00	0.00	-	-	-	1.08	-	0.48	0.00	0.49
Haematostereum sanguinolentum	-	-	-	-	-	-	-	-	1.41	2.15	5.45	0.72	0.00	0.49
Heterobasidion annosum	0.00	0.25	0.00	0.00	-	-	-	-	-	-	-	-	-	-
Peniophora spp.	-	-	-	-	0.00	0.46	0.00	2.25	-	3.49	-	3.10	0.00	3.19
Poria carbonica	-	-	-	-	-	-	0.00	1.13	-	0.27	-	0.24	1.79	0.25
Poria placenta	0.00	0.00	0.00	0.50	-	-	-	0.23	-	-	-	-	0.00	0.49
Schizophyllum commune	0.00	0.00	1.82	4.90	-	-	-	-	-	-	-	-	0.00	0.25
Sistotrema brinkmanii	0.00	0.25	0.00	0.50	0.00	0.23	-	0.45	1.41	-	-	0.48	0.00	0.49
Stereum hirsutum	-	-	-	-	-	-	-	0.68	0.00	0.81	-	0.24	0.00	0.49
Total Basidiomycetes	9.23	5.16	5.46	8.85	0.00	8.03	15.63	13.06	22.54	18.82	9.09	14.55	12.50	23.34
Total cores	65	408	55	408	60	436	64	444	71	372	55	419	56	407

[a] For key to spray and dip schedules consult Table IV-7.

One year after treatment, samples removed from pole sections exposed at Oroville, CA generally had the lowest incidence of decay fungi, both in the treated and untreated samples. Dip treated poles experienced a decline in the incidence of fungi, while the untreated control experienced a sixty percent rise in fungal colonization. The majority of the isolations in the untreated controls were Schizophyllum commune, a sapwood colonizer which is not believed

to cause substantial wood strength loss. Poria placenta was only isolated from two cores in the untreated pole sections, while P. carbonica was absent from the sampled poles. These two fungi are normally among the most common colonizers of Douglas-fir poles, but are less common at the Oroville site.

Poles exposed at the Corvallis site were generally colonized to a greater degree one year after treatment, although the initial spray and the initial spray followed by a second spray at six months both experienced lower levels of colonization at that time (Table IV-8). The dip treated pole sections experienced a large increase in colonization; however, the initial sampling, which revealed no fungi were present, may have overlooked existing infestations. Despite the degree of increase compared to the initial sample, the levels of colonization at one year were lowest in the dip treated pole sections. The lower incidence of fungi in this treatment is not surprising since dip treatments are the recommended method for applying borates to green lumber. The least effective treatment was the borate spray applied six months after air-seasoning began, which experienced a 77 percent increase in fungal colonization after one year. Borates diffuse most effectively through green wood and the initial period of air-seasoning may have limited the degree of diffusion. In addition, the six month delay permitted invasion by fungi which could grow beyond the depth of any subsequent borate penetration. The results indicate that treatment immediately after peeling provides the most effective barrier to fungal invasion. The effectiveness of regular retreatment with borates remains unknown and will become more evident as the two and three year air-seasoning samples are taken.

C. INTERNAL WOOD TEMPERATURE IN DOUGLAS-FIR POLES DURING PRESERVATIVE TREATMENT.

Last year, we described a series of studies to determine the temperatures achieved in Douglas-fir poles during treatment with oil-borne pentachlorophenol or waterborne ammoniacal copper arsenate (ACA) ('87 Ann. Rept., pg. 105-111). These studies indicated that oilborne treatments which included a long Boulton-seasoning cycle resulted in thorough sterilization, while a six hour steaming period at the start of the ACA treatment cycle resulted in temperatures sufficient for sterilization in poles less than 16 inches (40 cm) in diameter. The allowable steaming period was recently raised to 8 eight hours for Coastal Douglas-fir poles and we are still actively seeking charges which use this steam period. A single test of the eight hour steam period produced somewhat anomalous results and the data from these tests are currently being reanalyzed.

The results from previous tests have been examined more closely and several figures which were mislabeled in last year's report are included in their corrected versions (Figures IV, 2-4). In addition, the data from these tests is currently being evaluated by a cooperating chemical engineer, with the goal of developing more accurate heating curves. Preliminary examination reveals that the currently used curves are overly optimistic with regard to the rate of heating. Further studies are underway to more precisely define heating rates.

An examination of heating curves from the completed runs with ACA indicate that poles up to 30 cm in diameter achieve temperatures above 150 F (65.5 C) for at least 2 hours, while 50 cm diameter poles fail to reach this temperature (Table IV-9). This data suggests that larger poles should be heated for longer periods to achieve sterilization. Confounding this result,

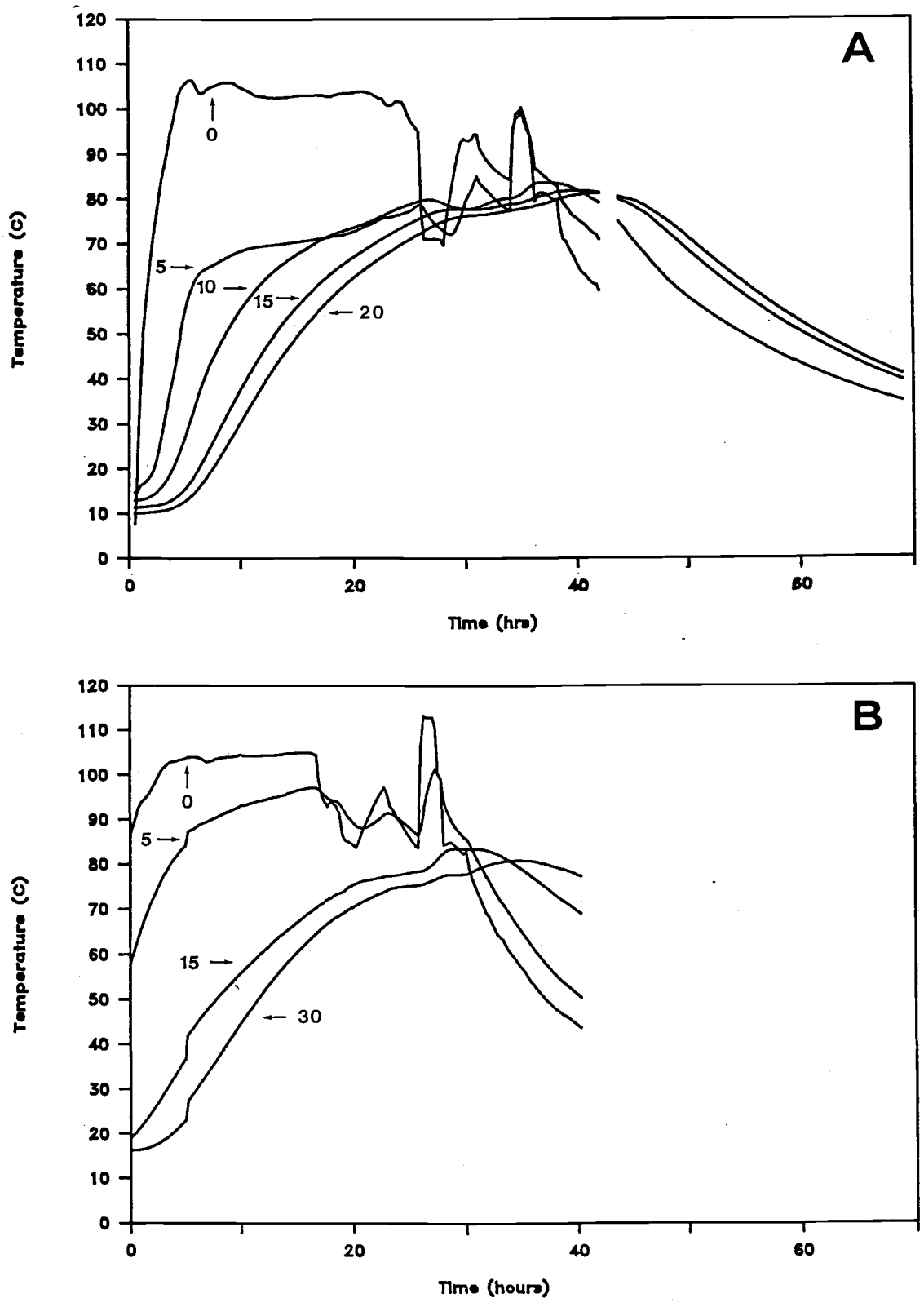


Figure IV-2. Internal temperatures in Douglas-fir poles during pressure treatment with oilborne pentachlorophenol embedded to specified depths in each pole section.

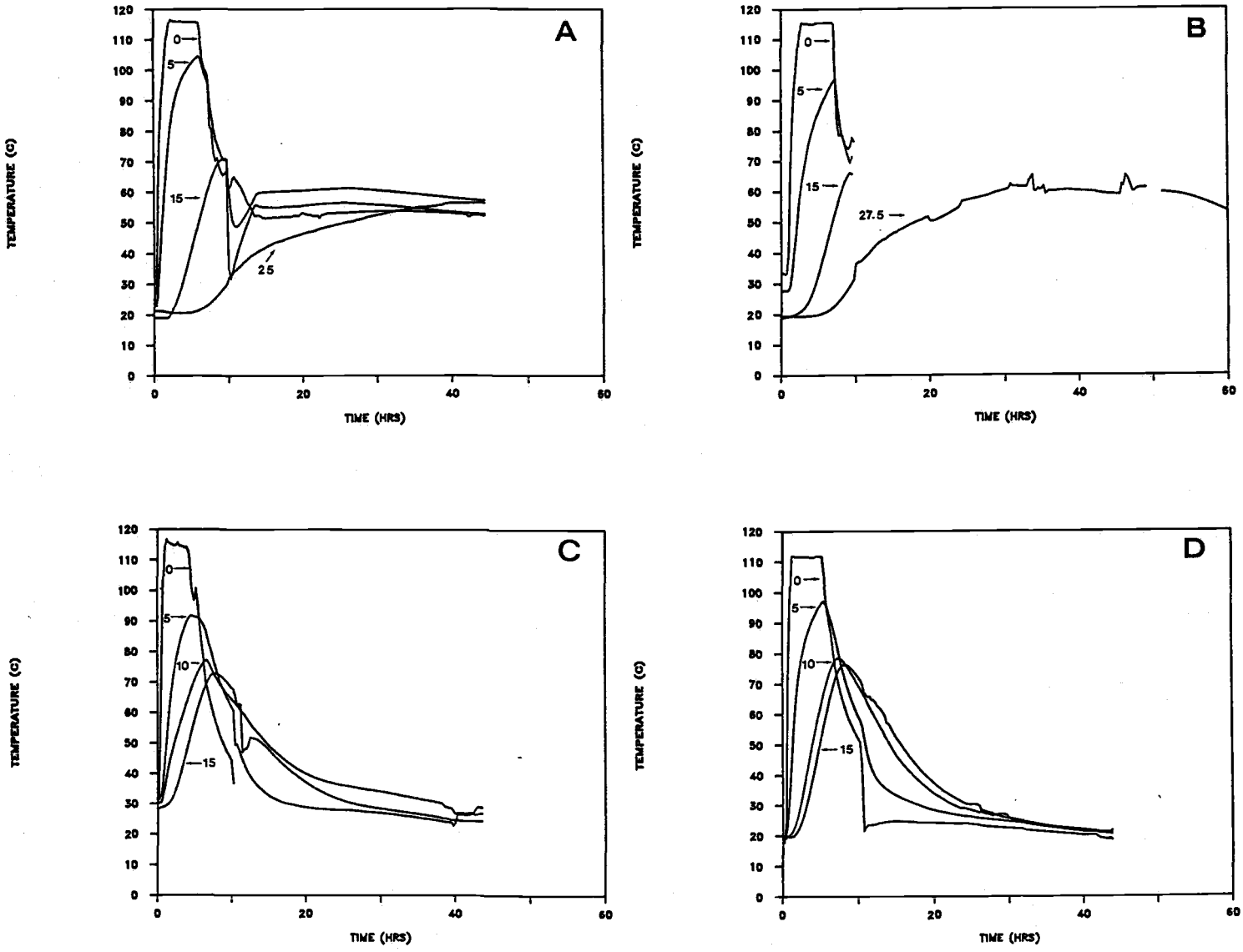


Figure IV-3. Internal temperature in Douglas-fir poles during pressure treatment with unheated ammoniacal copper arsenate (140° F) as measured by thermocouples embedded to the specified depths in each pole section.

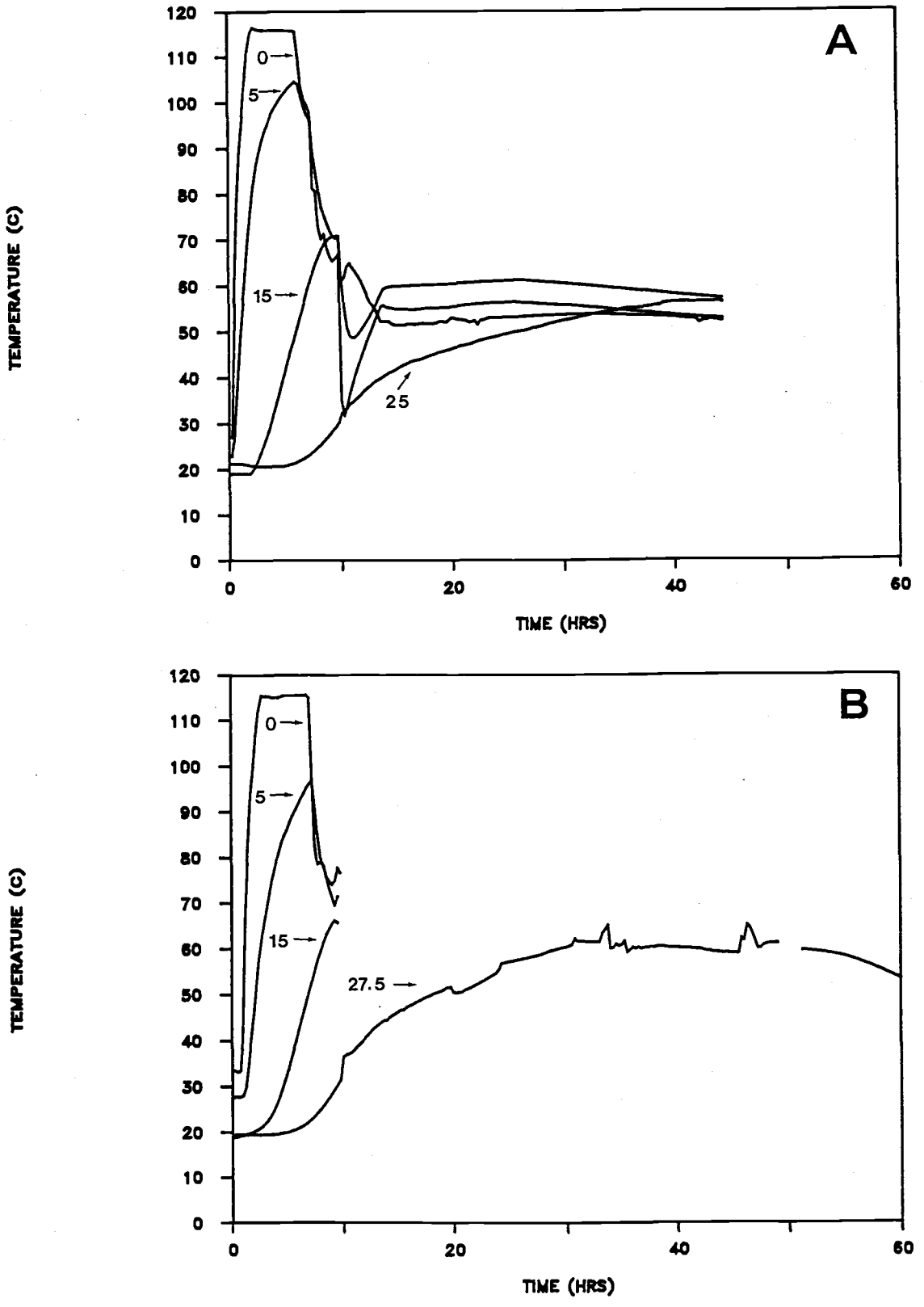


Figure IV-4. Internal temperature in Douglas-fir poles during pressure treatment with ammoniacal copper arsenate (140^{o} F) as measured by thermocouples embedded to the specified depths in each pole section.

however, is the absence of fungal colonization in larger poles which failed to reach the critical temperature for the required period.

Poles treated with pentachlorophenol in oil achieved internal temperatures above 65.5 C for periods exceeding 20 hours, even 30 cm (12 inches) from the surface. These results illustrate the benefits of a long heating cycle to thoroughly sterilize the wood.

TABLE IV-9

AVERAGE PERIOD OF TIME THAT A DOUGLAS-FIR POLE ACHIEVED A DESIRED TEMPERATURE DURING THE TREATMENT WITH PENTACHLOROPHENOL IN P-9 TYPE A OIL OR AMMONIACAL COPPER ARSENATE AS MEASURED BY THERMOCOUPLES EMBEDDED AT THE SPECIFIED DEPTH IN A 2.4 LONG POLE SECTION.[a]

THERMOCOUPLE DEPTH (CM)	TARGET TEMPERATURE (C)	TIME AT TARGET TEMPERATURE (HOURS)	MAXIMUM TEMPERATURE (C)
	Pentachlorophenol		
5	65.5	38	101.4
10	65.5	33	90.1
15	65.5	32	83.6
20	65.5	31	82.0
30	65.5	>20	81.0
	Ammoniacal Copper Arsenate		
5	60.0	9	103.9
	65.5	8	
	71.1	7	
10	60.0	7	77.6
	65.5	5	
	71.1	2.7	
15	60.0	5	72.2
	65.5	3.5	
	71.1	2	
25	57.2	10	62.8
	60.0	2	
	65.5	0	

[a] As measured using copper contantin thermocouple embedded to the specified depth.

temperature. One of the treating facilities in our trials maintained their preservative solutions at 140 F, while the other plant used ambient temperature solution.

One interesting effect which has been noted with the ACA treatments has been the effect of using heated solution on maintenance of internal temperature solutions. Heated solutions did not alter the maximum temperature

achieved, but they did delay the decline in internal temperature (Figure IV-5). As a result, the wood will be maintained at higher temperatures for longer periods, enhancing the sterilization effect. The results would suggest that heated solution, which has other beneficial effects on penetration and retention, should improve the likelihood of internal sterilization during treatment.

Two questions which have been raised about last year's report relate to the accuracy of the thermocouples in comparison to previous studies performed using thermometers inserted into holes drilled in the freshly treated poles and to the degree of longitudinal heat transfer. In the first instance, a comparison of thermocouple readings with those obtained from thermometers inserted in holes drilled in freshly treated poles indicated that the drilling process heated the wood about 4 C. Leaving the hole open for 10 minutes resulted in cooling to the temperature measured by the imbedded thermocouple (Table IV-10). Leaving the thermometer in the hole resulted in only a minor loss of heat and would result in abnormally high temperature readings. These results indicate that great care must be taken when performing measurements on logs removed from the treating cylinder. While thermocouples are tedious to install, they provide high accuracy and, when they fail, produce readings which clearly indicate problems with the system.

In the second instance, there was concern that the end-grain heat transfer through the pole sections would exceed radial transfer to the degree that readings from the embedded thermocouples would be adversely affected by longitudinal heat transfer. To evaluate this parameter, thermocouples were embedded to a depth of 4 inches (10 cm) 0.5, 1.0, 2.0, 3.0 and 5 feet (0.15, 0.3, 0.6, 0.9, and 1.5 m, respectively) from the pole end and the poles were included in a charge treated with heated ACA using an 8 hour steaming period.

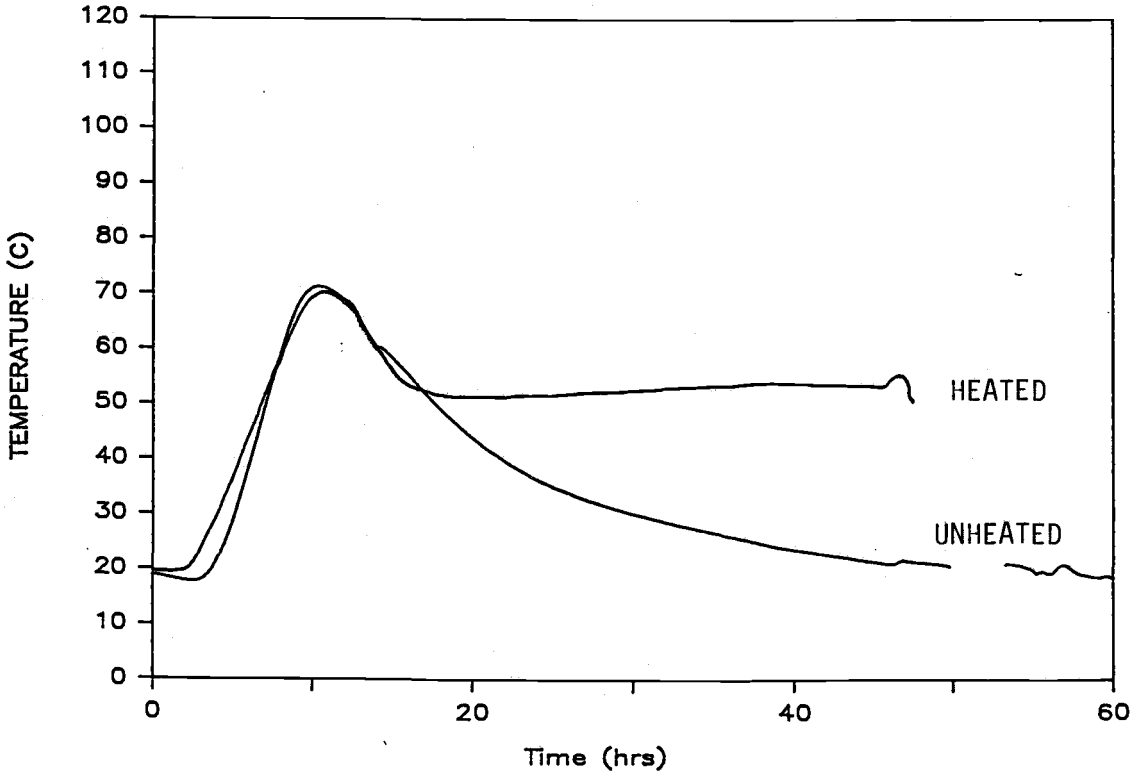


Figure IV-5. Effect of using heated (140 F) Ammoniacal copper arsenate on internal temperature achieved during pressure treatment of Douglas-fir pole sections as measured 4 inches (10 cm) from the surface.

TABLE IV-10

INTERNAL POLE TEMPERATURE FOLLOWING ACA TREATMENT AS MEASURED USING A COPPER CONTANTIN THERMOCOUPLE, THERMOMETER INSERTED IMMEDIATELY AFTER DRILLING SAMPLE HOLE AND LEFT, OR THERMOMETER INSERTED IMMEDIATELY THEN REMOVED AND REINSERTED 10 MINUTES LATER.

	MAX. TEMP. MEASURED (C)	
TREATMENT	0 MINUTES	10 MINUTES
THERMOMETER (left in place)	30	29
THERMOMETER (open)	30	26
THERMOCOUPLE	26.2	26.1

Thermocouple readings from these test poles indicated that only the thermocouples embedded 0.5 and 1 foot from the pole end were affected by longitudinal heat transfer, while the remaining thermocouples remained unaffected (Table IV-11). These results indicate that the previous decision to install thermocouples at least two feet from the pole end limited the potential effects of end-grain heat transfer.

In addition to continued studies of heat transfer with ACA or ACZA treatments, we also plan a brief evaluation of internal heating during treatment using the Cellon process. Preliminary tests indicate that the system currently used for the ACA studies is compatible with butane and the other components of the Cellon system. Several trials are scheduled for later this summer to evaluate the sterilizing capability of this treatment process. At the same time, a series of pole sections will be evaluated for the degree of fungal flora before and after Cellon treatment to determine the effect of treatment conditions on fungal survival.

TABLE IV-11

MAXIMUM TEMPERATURE ACHIEVED AT SELECTED DISTANCES FROM THE POLE END AS DETERMINED BY INSERTING THERMOCOUPLES TO 4 INCHES (10 CM) AND MEASURING TEMPERATURE DURING AN ACA TREATMENT CYCLE.

DISTANCE FROM POLE END (FT)	MAX. TEMP. (C) AT 4 INCHES
0.5	91
1.0	78
2.0	68
3.0	71
5.0	68

D. FUNGAL COLONIZATION OF PRESERVATIVE-TREATED DOUGLAS-FIR POLES DURING STORAGE

Pressure treatment of Douglas-fir poles with oil- or waterborne preservatives produces a sapwood shell that limits fungal colonization and, except when chromated copper arsenate (CCA) is applied at ambient temperature, sterilizes the wood before pole installation. Unfortunately, checks that develop as a pole seasons in service can provide avenues of entry into untreated heartwood and can also retain water, creating ideal conditions for decay.

Although most poles are placed into service shortly after treatment, a certain percentage are stored by utilities for emergency repairs. These poles are generally used within two years; however, in some circumstances, poles are stored for five years or more. Many utilities question whether long-term storage can lead to increased colonization of poles by decay fungi. To answer this question, the following survey was undertaken.

Ninety-five Douglas-fir poles that had been treated with pentachlorophenol in oil (penta), ammoniacal copper arsenate (ACA), or CCA and stored for up to 18 years in New York, Oregon, and Washington were selected for sampling. Increment cores were removed from each pole on either side of the widest

check, located at a height ten percent of the total pole height plus two feet (corresponding to groundline zone when the pole is installed), and at three equidistant points between the first sampling point and the pole top. Some poles were stacked together; because they were less accessible, these poles were cored less intensively. The outer preservative-treated portion of each core was discarded and the remaining portion placed in a labeled drinking straw and returned to the laboratory. The cores were removed from the straws, flamed to eliminate surface contamination, and placed onto 1 percent malt extract agar in petri plates. The plates were observed for 30 days and suspect fungi growing from the cores were examined microscopically for characteristics (clamps, growth on special media) typical of Basidiomycetes, a class of fungi containing many wood decayers.

None of the poles sampled contained evidence of advanced decay, but storage of poles even for only 5 years led to a high incidence of colonization by both decay (2 to 28% of cores) and nondecay (7 to 91% of cores) fungi (Table 12). Although the levels of colonization were far lower than the 90 percent colonization level found in untreated Douglas-fir poles air-seasoned for longer that 1 year, they represent a substantial risk to utilities, which do not want to place poles with active decay fungi into service. However, colonization of poles by decay fungi did not consistently increase with length of storage, indicating that colonization may be influenced by factors such as incomplete sterilization during preservative treatment or storage conditions.

One factor of major importance is the formation of deep checks that penetrate beyond the treated shell, acting as avenues of entry for fungal spores. Other factors are pole storage conditions, such as physical arrangement (whether poles are stacked or unstacked, raised or lying on the ground) and climate, which influences the wetting and drying of poles, hence

TABLE IV-12

FUNGAL COLONIZATION OF DOUGLAS-FIR POLES TREATED WITH THREE PRESERVATIVES AND STORED FOR UP TO 18 YEARS.[a]

PRESERVATIVE TREATMENT AND STORAGE TIME (YR.)[b]	NO. OF POLES	STORAGE LOCATION	POLES COLONIZED		CORES COLONIZED	
			DECAY FUNGI	NONDECAY FUNGI	DECAY FUNGI	NONDECAY FUNGI
			(%)			
Penta						
0	10	Oregon	0	0	0	0
2	12	Oregon	0	58	0	20
5 to 9	21	Oregon	48	81	11	23
	7	New York	29	86	4	13
10 to 14	11	Oregon	18	91	2	53
	6	New York	17	50	6	20
	10	Washington	10	20	3	7
15 to 18	3	Oregon	33	100	21	25
	2	New York	0	100	0	31
ACA						
5 to 9	9	New York	78	100	21	60
CCA						
10 to 14	4	New York	75	100	28	91

[a] Based on culturing of increment cores removed at selected locations on each pole. Decay fungi represent members of the Basidiomycetes, a class of fungi containing many wood decayers.

[b] Penta = pentachlorophenol in oil; ACA = ammoniacal copper arsenate; CCA = chromated copper arsenate.

their decay hazard. Because poles were stored for such long periods, it was not possible to accurately assess the storage history of each.

Poles treated with CCA had a high incidence of colonization by decay fungi. This is not surprising because CCA is applied to air-seasoned poles at ambient temperature and does not sterilize the heartwood. However, poles treated with ACA, which is applied at higher temperatures, also had a high incidence of colonization after 8 years. Preliminary results indicate that these high-temperature treatments should eliminate decay fungi that become

established during air seasoning, they cannot combat entry of decay fungi in seasoning checks that open later on.

Although the poles sampled ranged from 55 to 105 feet long in American National Standards Institute (ANSI) classes ranging from 4 to H5, a clear relationship between pole size and fungal colonization could not be established. Larger diameter poles should check to a deeper depth, exposing more untreated heartwood, but the low number of poles in each size class per year of storage may have obscured this trend.

These results indicate that long-term pole storage poses a serious concern for utilities that must retain sufficient stock for emergency pole replacements. To reduce the risk of fungal colonization of poles, utilities could:

1. Adopt a policy of using extra poles for routine change outs on a "first in, first out" rotation, to prevent poles from remaining in storage longer than 2 years;
2. Treat stored poles with fumigants at regular intervals (6 to 8 ft.) along the entire pole length when pole stock cannot be rotated, to eliminate established decay fungi and limit renewed colonization for long periods.

Although fumigation can minimize the potential for colonization, it should not replace a well-managed pole inventory program. Apparently, long-term storage of treated poles increases the risk of fungal attack and the likelihood of early failure should these poles be placed in service. Strict adherence to a pole stock rotation policy is the best way to minimize this risk.

OBJECTIVE V

DETERMINE THE ROLE OF NON-DECAY FUNGI IN INTERNAL AND EXTERNAL DECAY OF PRESERVATIVE-TREATED DOUGLAS-FIR IN GROUND CONTACT

A. INTERACTIONS BETWEEN MICROFUNGI ISOLATED FROM FUMIGANT TREATED DOUGLAS-FIR HEARTWOOD AND Poria carbonica and Poria placenta.

While fumigant treated Douglas-fir heartwood is rapidly colonized by Basidiomycetes when large amounts of inoculum are used under controlled laboratory conditions, the natural rate of recolonization by these fungi is apparently very low. In previous reports, we found that poles treated with fumigants 15 years prior to sampling contained lower populations of microfungi and basidiomycetes than similar untreated control poles ('87 Ann. Rept., pg 118-120). The microfungi isolated included several Scytalidium and Trichoderma spp. Members of these genera have been reported as antagonistic to Basidiomycetes and may restrict recolonization of fumigant-treated wood. In addition, they may be capable of invading wood while fumigant levels remain relatively high. The following tests were performed to investigate these possibilities.

Fumigant Treatment: Three hundred and sixty Douglas-fir heartwood blocks (2.0 by 0.3 by 1.0 cm long) were labeled, oven-dried, and weighed (to the nearest 0.001 g) prior to being conditioned to 20 to 25% moisture content over a water bath. Groups of 90 blocks were selected for treatment with two levels of Vapam or chloropicrin. One ml of either fumigant was placed in a glass jar, the blocks were placed on a screen above the chemical, the jar was sealed, and the blocks were incubated for 24 to 48 hr. At this point, the blocks contained high levels of the fumigants and were aerated under a fume hood to reduce chemical levels to the point where fungal colonization could occur. At random intervals, selected blocks were removed, placed in 5 ml of ethyl acetate if they had been treated with Vapam or of hexane if they had

been treated with chloropicrin, and extracted for 24 hr. The extracts were analyzed for methylisothiocyanate (MIT), the major fungitoxic product of Vapam, or chloropicrin by previously described methods ('87 Ann. Rept., pg. 17-18). The results were quantified according to prepared standards to determine residual chemical content in each block. The selected blocks were stored in Teflon-capped jars once they had aerated to 0.015 or 0.075 mg of MIT per cm^3 of wood or 0.0015 or 0.015 mg of chloropicrin per cm^3 of wood. The storage served the dual purpose of ensuring that the chemical remained in the wood and of equilibrating blocks in the same jar to uniform chemical contents.

Decay Tests: The treated blocks were used in two tests to evaluate the ability of Scytalidium lignicola, S. aurantiacum, Trichoderma viride, or a Penicillium sp. to prevent decay (loss in wood weight) caused by Poria carbonica or Poria placenta. The microfungi had been isolated from Douglas-fir poles previously treated with Vapam, Vorlex (20% MIT in chlorinated C_3 hydrocarbons), or chloropicrin. The blocks were exposed to the fungi in one of four sequences:

a. To the microfungus for 4 weeks and then to the decay fungus for 4 weeks.

b. To the decay fungus for 4 weeks and then to the microfungus for 4 weeks.

c. To the microfungus for 8 weeks.

d. To the decay fungus for 8 weeks.

Details of these exposure sequences in the two decay tests are described below.

Petri dishes containing malt extract agar (2.5%) were inoculated with one of the test fungi and incubated until the fungus covered the agar surface. At that point, sterile glass rods were placed on the agar surface and the test blocks were aseptically placed on the glass rods. The dishes were sealed with

parafilm and incubated for 4 or 8 weeks at 25°C. Seven blocks were tested for each fungus/treatment combination.

At the end of each incubation period, five blocks from each combination were removed, scraped clean of adhering mycelium, reconditioned to 20 to 25% moisture content, and then weighed. Weight lost during fungal exposure was recorded. The remaining two blocks were solvent-extracted and analyzed for residual fumigants by gas chromatography as previously described.

Blocks to be exposed to two fungi were then placed on glass rods over cultures of the second fungus for an additional 4 weeks. At the end of the test period, the blocks were removed, reconditioned, and weighed.

Soil Block Tests: Ten g of soil was added to each of eight hundred seventy-five 112-ml glass bottles. A western hemlock feeder strip (1.0 by 2.0 by 0.3 cm long) was placed on the soil surface, and 3 ml of distilled water was added to bring soil to 60% moisture content. The bottles were capped, autoclaved for 45 minutes at 121°C, cooled overnight, and reautoclaved for 15 minutes at 121°C. After cooling, they were inoculated by placing a 5-mm-diameter plug of agar cut from the edge of an actively growing culture of the test fungus on the edge of the feeder strip. The test blocks were placed on the feeder strip once it was covered by the fungus, and the bottles were incubated for 4 or 8 weeks. At that point, five blocks from each fungus/treatment combination were removed, scraped clean of adhering mycelium, conditioned to a constant moisture content, and weighed. Weight losses were compared with those of control blocks that had not been exposed to the test fungi. Two more blocks from each combination were extracted and analyzed for residual fumigants as described above.

Blocks to be exposed to two fungi were then placed in bottles inoculated with the second fungus and incubated for an additional 4 weeks. At the end of

this period, the blocks were removed and treated as described for the 4-week tests.

Results: The results were subjected to an analysis of variance. Means from each microfungus-treatment combination were separated by Scheffe's procedure; differences are at the a=0.10 level.

Agar Block Tests: As expected, in each fungal combination weight losses were less when a fumigant was present than when it was absent (Table V-1). However, all of the fungi were capable of growing on the blocks, a fact suggesting that the fumigant dosages chosen were appropriate to the tests. The fumigants apparently dissipated from the wood over the course of the study were not detectable after 8 weeks.

Weight losses associated with microfungi without Basidiomycetes ranged from 0.3% to 4.1% and were lower for fumigant-treated blocks than for the controls. Weight losses associated with Basidiomycetes without microfungi or fumigants were somewhat larger, ranging from 7% to 10% for P. carbonica and from 11% to 14% for P. placenta. Although these weight losses were low, they exceeded those associated with microfungi without Basidiomycetes or fumigants.

Although exposure first to a microfungus and then to a Basidiomycete generally resulted in less weight loss than did exposure to the Basidiomycete alone, this effect was significant only when untreated controls exposed to either isolate of T. viride plus P. placenta were compared with those exposed only to P. placenta.

Soil Block Tests: Weight losses associated with both microfungi and Basidiomycetes, alone or in combination, were higher in the soil block tests than in the agar block tests (Table V-2). There were several reasons for this difference. In the soil block tests, the blocks were in direct contact with a feeder strip at a high moisture content--ideal conditions for fungal

colonization and attack. In the agar block tests, the blocks were exposed on glass rods above the media. As a result, the fungus had to grow up into blocks whose moisture levels probably did not increase greatly over the incubation period and were therefore less conducive to fungal attack. Thus, the soil block test apparently simulates wood in ground contact, where decay hazard is high, whereas agar block test simulates wood not in ground contact and therefore under less severe hazard of decay.

Once again, weight losses were less when a fumigant was present than when it was absent. This effect was least noticeable with the lowest Vapam treatment and most noticeable with the highest chloropicrin treatment. Chloropicrin is strongly bound to the cell wall of wood, whereas Vapam decomposes to produce MIT and a number of other products that are present for only a short time. That these two fumigants are associated with differing losses in wood weight apparently reflects their differing affinities for wood or different fungitoxic mechanisms.

As in the agar block tests, exposure first to a microfungus and then to a Basidiomycete generally resulted in less weight loss than did exposure to the Basidiomycete alone. These differences were significant for all P. placenta combinations except that with Penicillium sp. at 0.015 mg of Vapam per cm^3 of wood and those with S. lignicola, S. aurantiacum, and I. viride str. 1 at 0.015 mg of chloropicrin per cm^3. As for the P. carbonica combinations, the only significant difference was among the controls, where exposure first to S. aurantiacum and then to the Basidiomycete resulted in significantly less weight loss than did exposure to the Basidiomycete alone.

The P. carbonica used for these studies was isolated from a decaying Douglas-fir pole in 1978 and has been used as a standard test fungus in the laboratory. This isolate has apparently lost much of its ability to cause

decay. Thus, substituting a more aggressive isolate of this species might alter the test results.

Although the mechanisms by which these microfungi affected losses in wood weight caused by Basidiomycetes could not be explored in this series of tests, these same species or other members of the same genera have been studied previously. Fungal inhibition of other fungi may occur as a result of competition for essential nutrients, the production of antibiotics (water-soluble or volatile), or mycoparasitism.

Scytalidium spp. have been reported to produce scytalidin, an antibiotic released in the presence of certain Basidiomycetes. Scytalidium spp. are common inhabitants of Douglas-fir heartwood, and their use as biocontrol agents for this tree species has been proposed; however, field tests proved the treatment was ineffective.

While any antagonistic effects of I. viride in wood are less well known, the genus Trichoderma has been the subject of considerable research resulting in the development of one commercial biocontrol formulation. Trichoderma spp. have been shown to produce water-soluble antibiotics such as trichodermin and volatile fungal inhibitors, and they can parasitize hyphae of some Basidiomycetes. Prior colonization by I. viride has been shown to inhibit Basidiomycete colonization of hardwood logs, probably by nutrient depletion. Conversely, prior colonization by P. placenta inhibits growth of I. viride. In our studies, it was not possible to distinguish clearly between the effects of I. viride and those of P. placenta; however, exposure first to P. placenta and then to I. viride resulted in slightly lower weight losses than did exposure to P. placenta alone. This pattern suggests that an effect by I. viride on P. placenta was not evident in our system.

Both Trichoderma and Scytalidium spp. have been incorporated into biocontrol formulations. To date, however, these formulations have performed less than satisfactorily, primarily because the biocontrol agents have been unable to colonize the wood thoroughly and protect it. Furthermore, these formulations have not performed well against established infestations of Basidiomycetes.

One approach for overcoming these limitations is applying fumigants to sterilize the wood before applying a biocontrol agent with some tolerance to the fumigant. The biocontrol can be introduced several years after the fumigants because the latter will prevent colonization by delay fungi. The microfungi evaluated in our tests exhibited some tolerance to fumigants as well as some biocontrol capabilities; consequently, they might be candidates for such a chemical/biological control scheme.

TABLE V-1

AVERAGE WEIGHT LOSSES OF DOUGLAS-FIR HEARTWOOD BLOCKS TREATED WITH EITHER OF TWO FUMIGANTS BEFORE BEING EXPOSED TO VARIOUS FUNGAL COMBINATIONS IN AN AGAR BLOCK TEST.

Fungal combination[a]	Wood weight loss (%)[b]				
	After treatment with Vapam at dosage[c] of--		After treatment with chloropicrin at dosage[c] of--		
	0.015	0.075	0.0015	0.015	Control
PE+PC	2.91abcd	1.07a	1.26ab	0.94a	3.36abcd
PC+PE	2.97abcd	2.46abcd	2.51abcd	2.06abcd	5.62abcd
PC	4.72abcd	3.3 abcd	3.10abcd	2.43abcd	8.18abcde
PE+PP	7.25abcde	5.57abcd	3.88abcd	2.84abcd	7.11abcde
PP+PE	7.78abcde	7.22abcde	5.58abcd	3.14abcde	9.25bcde
PP	8.73bcde	5.23abcd	7.17abcde	3.27abcd	14.77e
PE	2.26abcd	1.85abcd	1.62abcd	1.30abc	2.34abcd
SA+PC	1.53ab	1.06ab	0.78ab	0.31a	5.32abcde
PC+SA	1.15ab	1.24ab	1.16ab	0.77ab	6.26bcde
PC	3.21abcd	2.13ab	2.30abc	1.45ab	7.71cdef
SA+PP	1.49ab	1.27ab	1.41ab	0.69ab	8.52def
PP+SA	2.86abcd	2.37abc	1.98abc	1.18ab	9.38ef
PP	5.64abcde	4.05abcde	4.96abcd	1.95abc	12.23f
SA	1.21ab	1.07ab	1.04ab	0.73ab	1.36ab
SL+PC	5.63abcdef	2.09abcd	1.28abcd	1.12abc	6.05abcdef
PC+SL	4.57abcdef	2.74abcdef	2.51abcd	1.24abc	6.63bcdefg
PC	6.22abcdef	4.94abcdef	2.04abcd	1.61abcd	7.02cdefgh
SL+PP	6.20abcdef	4.15abcdef	1.57abcd	1.39abcd	6.94bcdefgh
PP+SL	7.61defgh	6.09abcdef	2.34abcde	2.15abcde	8.61fgh
PP	2.36gh	8.11efgh	8.54abcdef	2.73abcdef	12.92h
SL	4.10abcdef	2.57abcde	0.87ab	0.50a	4.11abcdef
TV1+PC	2.82abcd	2.11abc	1.58abc	1.19ab	6.10cdef
PC+TV1	4.30abcde	3.50abcd	2.46abcd	1.67abc	7.04defg
PC	5.42bcde	3.77abcd	2.59abcd	2.13abc	10.73fg
TV1+PP	5.21bcde	5.21abcd	2.38abc	2.17abc	6.25cdef
PP+TV1	6.00cdef	4.90abcde	3.21abcd	1.80abc	8.92efg
PP	8.89efg	4.92abcde	5.60bcde	2.19abc	11.36g
TV1	2.12abc	1.84abc	2.20abc	0.31a	2.46abcd
TV2+PC	2.23ab	1.99ab	2.15ab	1.53a	3.64abcd
PC+TV2	3.29abc	2.82abc	2.29ab	2.21ab	4.71abc
PC	4.12abc	3.42abc	3.18abc	2.42ab	7.04abcd
TV2+PP	2.62abc	2.49ab	3.38abc	2.28ab	5.79abc
PP+TV2	3.36abc	2.28ab	5.88abc	2.65abc	8.25bcd
PP	7.16abcd	4.88abc	8.93cd	2.53ab	13.38d
TV2	2.07ab	1.64a	1.47a	0.90a	3.12abc

[a] PE = Penicillium sp.; PC = Poria carbonica; PP = P. placenta; SA = Scytalidium aurantiacum; SL = S. lignicola; TV = Trichoderma viride (str. 1 and 2).

[b] Within each group of fungal combinations coupled with a fumigant dosage, means followed by the same letter are not significantly different at P = 0.10 according to Scheffe's test.

[c] Dosages are reported in mg of chloropicrin or MIT (for Vapam) per cm^3 of wood.

TABLE V-2

AVERAGE WEIGHT LOSSES OF DOUGLAS-FIR HEARTWOOD BLOCKS TREATED WITH EITHER OF TWO FUMIGANTS BEFORE BEING EXPOSED TO VARIOUS FUNGAL COMBINATIONS IN A SOIL BLOCK TEST.

Fungal Fungal combination[a]	Wood weight loss (%)[b]				
	After treatment with Vapam at dosage[c] of--		After treatment with chloropicrin at dosage[c] of--		
	0.015	0.075	0.0015	0.015	Control
PE+PC	7.88ab	6.07a	6.73a	5.11a	8.97abc
PC+PE	10.13abc	8.92ab	7.32a	6.47a	12.43abc
PC	12.19abc	10.61abc	9.67ab	6.74a	26.61bcdef
PE+PP	37.30defghi	21.06abcde1	7.63abcd	7.82ab	42.52fghi
PP+PE	44.84fghi	37.86efghi	33.39defgh	29.02cdefg	45.70ghi
PP	52.23hi	45.98hi	41.72fghi	33.64defgh	54.60i
PE	4.95a	4.01a	3.94a	2.6a	5.66a
SA+PC	3.71a	3.01a	3.38a	2.56a	6.08ab
PC+SA	5.27ab	3.82a	4.24ab	3.32a	7.55ab
PC	15.41abcde	5.24ab	8.94ab	5.94ab	35.06g
SA+PP	9.33ab	2.70a	5.54ab	4.97ab	10.73abc
PP+SA	27.74efg	25.48cdefg	19.69bcdef	11.73abcd	34.67fg
PP	36.63g	26.14defg	29.69efg	10.53abc	56.58h
SA	2.62a	2.24a	2.57a	2.03a	2.53a
SL+PC	13.12abcdef	6.67abcde	7.97abcde	5.39abcd	13.24abcdef
PC+SL	12.49abcde	10.45abcdef	9.63abcde	7.24abcde	14.81bcdef
PC	14.61abcdef	11.50abcde	11.40abcde	8.98abcde	21.08bcdef
SL+PP	14.84abcdef	11.08abcde	8.20abcde	6.61abcde	16.03abcdef
PP+SL	25.96defg	24.80defg	25.57efg	21.50cdef	47.50h
PP	43.86gh	32.46fgh	41.84gh	12.48abcde	49.63h
SL	5.38abcd	2.28abc	1.93ab	0.88a	5.21abc
TV1+PC	5.27ab	2.49a	2.65a	2.15a	6.41ab
PC+TV1	5.60ab	3.20a	3.12a	2.58a	7.78ab
PC	8.68abc	5.26ab	4.22a	3.01a	17.99abcd
TV1+PP	12.54abc	4.25a	3.80a	2.50a	15.93abcd
PP+TV1	34.28def	23.15bcde	12.74abc	8.50ab	34.94def
PP	38.98ef	33.64def	26.97cde	12.90abc	47.90f
TV1	12.31a1.	23a	0.77a	0.60a	3.09a
TV2+PC	5.81a	5.20a	4.60a	3.65a	6.32ab
PC+TV2	6.78ab	5.82a	5.35a	4.79a	9.58ab
PC	9.16ab	7.06ab	6.22ab	5.43a	20.88bcde
TV2+PP	8.53ab	5.94a	5.47a	4.91a	13.61abc
PP+TV2	27.22cdef	25.27cdef	16.02bcd	9.75ab	30.30def
PP	35.69f	27.37cdef	29.51def	33.44ef	61.14g
TV2	4.86a	4.32a	3.50a	2.65a	5.73a

[a] PE = *Penicillium* sp.; PC = *Poria carbonica*; PP = *P. placenta*; SA = *Scytalidium aurantiacum*; SL = *S. lignicola*; TV = *Trichoderma viride* (str. 1 and 2).

[b] Within each group of fungal combinations coupled with a fumigant dosage, means followed by the same letter are not significantly different at P = 0.10 according to Scheffe's test.

[c] Dosages are reported in mg of chloropicrin or MIT (for Vapam) per cm^3 of wood.