A COOPERATIVE POLE RESEARCH PROGRAM

CONSERVING ENERGY BY SAFE AND ENVIRONMENTALLY ACCEPTABLE PRACTICES IN MAINTAINING AND PROCURING TRANSMISSION POLES FOR LONG SERVICE

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by

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ABSTRACT

Improved Fumigants

After 14 years, chloropicrin, Vapam and Vorlex continue to effectively control internal decay of pressure-treated Douglas-fir transmission poles, but 6 years after application of methylisothiocyanate (MIT) some poles are becoming reinfested by decay fungi although MIT residues remain high in these poles. The closed-tube bioassay, developed through our research, is an effective method for detecting fumigant persistance, and future studies will aim at determining the actual fumigant concentrations detected in wood by this bioassay.

A study of MIT movement through Douglas-fir pole sections following treatment with gelatin encapsulated MIT was completed and results indicate that addition of small quantities of water along with the capsules will give excellent fumigant release and movement into the wood. Decay fungi were virtually eliminated from in service transmission poles 21 months after treatment with gelatin encapsulated MIT near the groundline. In poles treated up to 12 feet above the groundline with encapsulated MIT and chloropicrin, no decay fungi could be isolated 1 year after treatment. Both fumigants were well distributed through the poles and appear to have moved laterally from the treatment holes.

One of the goals of our research has been eventual fumigant application to poles at the treatment plant shortly after conventional preservative treatments. This would provide predrilled holes for later fumigant retreatment and would effectively protect the entire

pole cross section. While the most economical application method would involve incorporating the fumigant treatment holes into the conventional predrilling process, it would also result in preservative treated fumigant holes. Consequently we have initiated studies to determine the influence of creosote and pentachlorophenol on fumigant movement into treated wood. Preliminary results indicate that creosote and P-9 penta base oil slow movement of MIT into wood but do not prevent the build up of fungitoxic concentrations in the wood.

The new, pelletized MIT formulation has been evaluated in our laboratory assay for wood fumigants. The results indicate that pelletized MIT is as effective as pure MIT on an active ingredient basis. Since pelletized MIT has many similar application and safety advantages as encapsulated MIT, we intend to further evaluate pellets in poles in service.

Cedar Sapwood Decay Control

The effectiveness of seventeen chemicals (3 oil-borne, 14 water-borne) for controlling above-ground decay of cedar sapwood was evaluated using a modified soil block test and an Aspergillus bioassay. Pentachlorophenol (10%) in diesel oil, currently used for protecting cedar poles, was markedly superior to all other chemicals evaluated probably because of the increased penetrability of the oil, since penta in water at the same strength did not perform as well. Three other formulations, copper-8-quinolinolate (oil), pentachlorophenol (2% in water), and 3-iodo propynyl butyl carbamate (2% in water), exhibited some residual effectiveness; however, more time is necessary to determine if these chemicals will remain effective. An additional five chemicals will be evaluated this coming spring.

The persistence of chloropicrin 5 years after treatment in western redcedar was also evaluated using open tube bioassays, close-tube bioassays and gas chromatographic determinations. The open tube bioassay indicated that chloropicrin still effectively limited growth of the assay fungus, P. placenta. Similarly, closed tube bioassays indicated strong inhibition in the pole interior and lower inhibitions near the surface. Extraction/gas chromatographic procedures detected chloropicrin in all cores examined with the highest concentrations towards the pole interior. Chloropicrin concentration did not correlate with closed tube results, suggesting that these tests are measuring different fumigant properties. The results indicate that chloropicrin should be an effective treatment for preventing cedar-butt rot and may provide some protection to pole sapwood.

Bolt Holes

Control poles for the bolt hole protection study were again sampled and insufficient decay was found in these poles to warrant evaluation of the various decay prevention treatments. We will re-evaluate the control poles this summer.

Detecting decay and estimating residual strength in poles

An infrared spectrophotometric method of analyzing warm water extracts of decayed and non-decay wood was evaluated with a number of brown and white rot fungi. Brown rot was highly correlated with absorption peaks produced at wavelength 1720^{-1}cm. Work is now underway to identify this peak to determine if less involved detection methods might be employed.

Fluorescent labeled lectins, which have high specificity for selected carbohydrates, were also evaluated as potential fungal indicators. Of the lectins tested, wheat germ agglutinin appears the most promising since it strongly reacted with chitin in the fungal cell wall, making decay hyphae visible at very early stages of decay.

Evaluation of Douglas-fir beams air-seasoned for 1 or 2 years using Pilodyn pin penetration, longitudinal compression, radial compression, bending and culturing indicated that, while there is a well established fungal flora in the wood, this flora has not yet affected strength. These tests will be performed on the 3 year air-seasoned beams this coming year. Of the strength tests employed, longitudinal compression appears promising for estimating pole bending strength and we intend to further evaluate this method.

As a second phase of this evaluation, the effect of moisture content on Pilodyn pin penetration was examined. This information is necessary since pin penetration varies with moisture content and must be corrected to compare values from different poles. Pin penetration increased with increasing moisture content up to fiber saturation and stabilized above this point. The moisture content at 0.5 inches was highly correlated with pin penetration, and this depth might be a convenient standard measuring point.

In a new phase of the project, preliminary acoustic testing was begun using small beams from poles at varying stages of decay. These beams were sonically evaluated and then loaded to failure in three point bending tests. Sonic evaluation was highly correlated with MOR; however, much more testing will be necessary before such an apparatus can be applied to posts or poles.

Initiation of decay in Douglas-fir poles prior to pressure treatment

The ability of basidiomycetes isolated from air-seasoning poles to reduce wood strength was evaluated in rapid tests for toughness by impact bending and changes in the breaking radius of Douglas-fir test wafers. Although some fungi behaved differently in the two tests, the test correlations were relatively high (r^2 = 0.78S). Of 26 basidiomycetous species evaluated, Poria placenta, P. carbonica, P. xantha and Crustoderma dryinum most rapidly decayed Douglas-fir heartwood, but at least one isolate of most of the other species tested significantly reduced toughness. While the wood decaying ability of each fungus is important, the frequency of isolation also must be considered when determining the overall importance of a species.

To determine the influence of wood temperature and moisture content on establishment of P. carbonica in Douglas-fir heartwood, a method was developed for direct observation of germinating spores on wood. In this test, chlamydospores and basidiospores failed to germinate or colonize wood at moisture content below fiber saturation suggesting that free water is necessary for infection. Chlamydospores germinated most readily and colonized wood at 22°C, while germination was significantly lower and the fungus failed to become established in wood at 5 or 35°C. Similar temperature responses were obtained with basidiospores although these spores failed to germinate at 5 and 35°C. Nevertheless, basidiospores may remain viable and retain the potential to establish colonies once conditions become more favorable.

Exposure of sterilized pole sections at four Pacific Northwest air-seasoning sites for successive 3-month periods showed a significant increase in basidiomycete isolation frequency for the period Nov. '81-Jan.'82. Furthermore, the frequency increased from the northern to the southern most site. Detailed study of the site weather patterns strongly suggests that increased basidiomycetous infection can be related to number of days with measurable rain fall and temperatures conducive to fungal growth. During the other periods studied, temperature or precipitation conditions were unfavorable for infection and pole section moisture contents fell below fiber saturation. This in turn limited spore germination and fungal colonization of the wood.

About 30 different basidiomycetous species have been identified from isolates cultured from sterilized pole sections exposed at the four sites. In general, the species were the same as those isolated form air-seasoning poles although there were some significant differences between the species obtained from the different sites. The frequency of P. placenta mono- and dikaryons was particularly high with monokaryons more abundant at three of the four locations. Individual species exhibited distinct colonization patterns from different pole zones. For example, P. placenta was isolated most frequently from heartwood exposed at the pole ends while Peniophora spp. and Haemotostereum sanguinolentum were recovered most frequently from the upper surfaces of the pole sections.

Preventing infection of poles by decay fungi during air-seasoning

Pole sections treated with ammonium bifluoride (NH_4HF_2) or gelatin encapsulated MIT and chloropicrin were extensively sampled after air seasoning to determine the influence of these chemicals on wood colonization by decay fungi. Preliminary results indicate that after 2 years NH_4HF_2 and the fumigants significantly reduced basidiomycetous colonization of sterile wood.

Surface Decay

Poles treated with Vapam 14 years ago were extensively cored, the cores were cultured and the resulting fungi were identified to evaluate the fungal flora of fumigant treated wood. A well developed fungal flora was identified that differed from that found in non-fumigant treated wood. These fungi will be further evaluated to determine their role in fumigant effectiveness.

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Pole Supplier

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*OSMOSE

*NOR-AM Chemical Co.

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

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OBJECTIVE I

DEVELOP SAFE AND ENVIRONMENTALLY ACCEPTABLE FUMIGANT TREATMENTS TO CONTROL INTERNAL DECAY OF DOUGLAS-FIR POLES AT AND ABOVE THE GROUNDLINE

PREVIOUS ONGOING AND RELATED RESEARCH ON WOOD IN SERVICE

The evaluation of fumigants (Table 1) placed in decaying pressure-treated Douglas-fir transmission poles in 1969 through 1977 is being continued. Results of this ongoing work and related research on Douglas-fir piles is presented as background information for the development of improved fumigant treatments for the future.

Douglas-fir poles treated in 1969 with chloropicrin, Vapam or Vorlex. Forty internally decaying pressure-treated poles (18 to 24 m long) located on the Santiam-Toledo line near Corvallis, Oregon, were randomly assigned to five test groups. No fumigants were applied to the control group, while poles in the other groups were treated with 1 liter of chloropicrin, Vapam or Vorlex distributed among four holes near the groundline and three holes 1 m above the groundline. The 2-cm diameter holes were plugged with treated dowels. A laminated paper-polyethylene film wrap applied to poles after treatment deterioriated within 1 to 2 years. One group of Vapam-treated poles and the controls were not wrapped.

Treatment effectiveness was evaluated annually by removing three cores equally spaced around each pole. Starting near the widest check, cores were removed -0.3, 0, 0.6, and 1.2 m from the groundline and cultured for the presence of decay fungi. Additional cores were removed from three equally spaced locations 0, 1.2, 1.8, and 2.4, m above the groundline to determine residual fumigant distribution using the closed-tube bioassay.

TABLE 1

VOLATILE CHEMICALS TESTED FOR THEIR ABILITY TO CONTROL DECAY FUNGI IN WOOD

COMMON DESIGNATION	SOURCE AND TRADE NAME	ACTIVE INGREDIENT
Allyl alcohol	Eastman Kodak Co. EK-518	allyl alcohol
Chloropicrin	Dow Chemical Co.	Trichloronitromethane
MIT	NOR-AM Agricultural Products Degussa Corp.	methylisothiocyanate
Vapam	Stauffer Chemical Co.	32% sodium N-methyl dithiocarbamate
Vorlex	NOR-AM Agricultural Products	20% methylisothiocyanate 80% chlorinated C_3 hydrocarbons

Fourteen years after application, chloropicrin and Vorlex remain the most effective fumigants for controlling decay fungi (Table 2, and Fig. 1). Decay fungi have been cultured from three of the eight chloropicrin treated poles, two of eight Vorlex treated poles, and 14 of the 16 Vapam treated poles. Over the last 2 years, the total fungal population has sharply increased in all poles (Fig. 1A), and we are studying the effect of these "non-decay" fungi in more detail (Objective VI).

Chloropicrin vapors have remained most persistant of the three fumigants at various depths from the surface and as high as 2.4 m (8 feet) above the groundline (Table 3). A marked decrease in inhibition level, as measured by increased growth of the assay fungus in the closed-tube bioassay occurred within 5 to 7 years for Vapam, 10 to 11 years for Vorlex, and 12 to 13 years for chloropicrin (Table 4). This marked decrease in vapor concentration coincides with a fungal buildup in the Vapam-and Vorlex-treated poles.

There are also signs that inhibition levels are declining within chloropicrin treated poles. This is especially interesting since the first detectable decline is occurring at the ground level suggesting that the chemical is moving up and down away from this zone and out of the wood.

The closed-tube bioassay may be a useful guide for fumigant retreatment of poles, but additional studies are needed to correlate the actual fumigant levels in the wood with the closed-tube bioassay results. Based on our results to date, retreating cycles of 10 years with Vapam and at least 15 years with the more persistent chloropicrin and Vorlex appear reasonable.

TABLE 2

EFFECTIVENESS OF FUMIGANTS IN
DOUGLAS-FIR POLES TREATED IN 1969

	NUMBER OF POLES WITH DECAY FUNGI[1]				
		VAPAM		VORLEX	CHLOROPICRIN
YEAR	UNTREATED	WRAPPED	UNWRAPPED	WRAPPED	WRAPPED
1968	8	8	8	8	8
1969			POLES TREATED WITH FUMIGANT		
1970	8	4	4	0	1
1971	8	1	1	0	0
1972	8	0	1	0	0
1973	8	0	0	0	0
1974	7	4^{7}	4^{7}	0^{7}	1^{6}
1975	7	1	0	0	0
1976	5	2	3	1	0
1977	5	2	1	0	0
1978	5	3	2	0	0
1979	5	3	2	0	1
1980	5	1	3	2	0
1981	3	2	2^{6}	1	0
1982	2	2	2	1	0
1983	2	2	2	1	0

[1]All poles contained decay fungi before the fumigants were applied. The superscripts denote the number of poles remaining in test; the missing poles were inadvertently removed from service.

Figure 1. Populations of decay fungi and all fungi isolated from internally decaying pressure-treated Douglas-fir poles treated with Vapam, Vorlex or chloropicrin. Each value is the average of 12 cores removed annually from various heights above and below groundline.

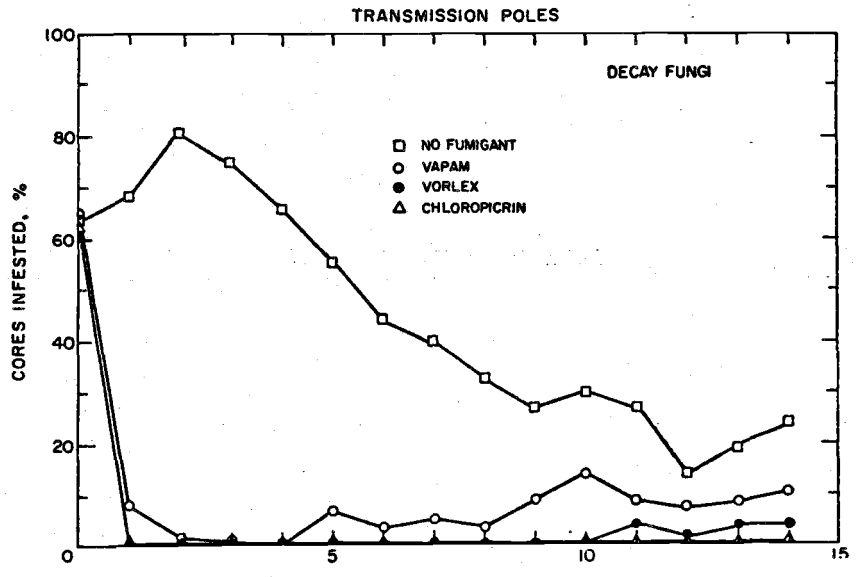

TABLE 3

RESIDUAL FUMIGANT VAPORS IN PRESSURE-TREATED DOUGLAS-FIR POLES 14 YEARS AFTER FUMIGANT APPLICATION

METERS ABOVE GROUND	SEGMENT LOCATION FROM SURFACE (cm)	GROWTH OF THE ASSAY FUNGUS AS A % OF THE CONTROL[1]			
		NO FUMIGANT	VAPAM	VORLEX	CHLOROPICRIN
2.4	0-2.5	83	59	55	14
	5.1-7.6	72	90	79	0
	12.5-15	62	90	86	0
1.8	0-2.5	62	45	38	0
	5.1-7.6	100	83	69	0
	12.5-15	93	83	72	7
1.2	0-2.5	79	59	52	3
	5.1-7.6	72	79	66	24
	12.5-15	97	72	59	21
0	0-2.5	52	66	41	38
	5.1-7.6	100	86	69	79
	12.5-15	83	110	48	48
CONTROL	(NO WOOD)	29[2]			

1 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.

2 Average growth in 22 tubes.

TABLE 4

RESIDUAL FUMIGANT VAPORS IN DOUGLAS-FIR TRANSMISSION POLES AT SELECTED POINTS AFTER APPLICATION OF CHLOROPICRIN, VAPAM, OR VORLEX.[1]

METERS ABOVE GROUND	GROWTH OF THE ASSAY FUNGUS (AS A % OF THE CONTROL) IN THE PRESENCE OF WOOD FROM POLES AT VARIOUS TIMES (YEARS) AFTER FUMIGANT TREATMENT[2]															
	Control (no fumigant)				Vapam				Vorlex				Chloropicrin			
	10	12	13	14	5	7	13	14	10	11	13	14	10	12	13	14
2.4	91	88	96	72	53	100	84	79	48	57	68	72	4	32	36	3
1.8	96	96	100	86	60	78	80	69	35	57	68	59	0	12	28	3
1.2	96	80	80	83	60	78	80	69	39	57	64	59	4	8	40	17
0	100	96	100	79	60	100	88	86	52	48	72	52	17	28	60	55

1 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.

2 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.

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

In 1977, Methylisothiocyanate (MIT) and allyl alcohol, which effectively controlled decay fungi in laboratory fumigant tests, were compared with Vorlex in poles in service. For this test, internally decaying Douglas-fir poles pressure-treated with pentachlorophenol in heavy oil were evaluated for decay by removing three cores from equally spaced locations around the poles at -0.3, 0, 0.6, and 1.2 m from the groundline and culturing the cores for the presence of decay fungi. Because of the prevalence of decay fungi at 1.2 m, cores also were removed 1.8 and 2.4 m above the groundline for culturing.

TABLE 5

EFFECTIVENESS OF FUMIGANTS
IN DOUGLAS-FIR POLES
TREATED IN 1977

	NUMBER OF POLES WITH DECAY FUNGI[1]				
		ALLYL		METHYLISOTHIOCYANATE	
YEAR	UNTREATED	ALCOHOL	VORLEX	20%[2]	100%
1977	9	9	7	9	8
1978	9	9	3	6	2
1979	9	9	4	4	0
1980	9	9	3	3	0
1981	5^5	6^6	0^4	1^5	0^5
1982	5	6	0	1	1
1983	5	6	0	3	2

[1]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 inadvertantly treated with Vapam by a commercial applicator.

[2]In diesel oil.

Selected poles were randomly assigned to groups for treatment with 1 pint of MIT, Vorlex or Allyl alcohol equally distributed between four holes in each pole. MIT was melted and poured into the holes; however, not all of the chemical could be applied because it solidified too rapidly in the wood. We estimate that the amount of MIT applied may be as low as 0.5 pint per pole. The poles were evaluated annually by removing three cores from equally spaced locations around each pole at five levels and culturing these cores to detect the presence of decay fungi. Additional cores were examined for residual fumigant vapor using the closed-tube bioassay with Poria placenta as the test fungus. Three years after fumigant treatment, three to four poles per group were deleted from the test when they were inadvertently treated with Vapam by a commercial applicator.

While Vorlex continues to suppress reinfestation by decay fungi 6 years after application (Table 5), there are an increasing number of poles treated with the MIT formulations from which decay fungi can be cultured, although the percentage of infested cores remains low (Fig. 2). Furthermore, vapors from Vorlex and 20% MIT residues in the wood were significantly less effective in inhibiting growth of P. placenta in the closed-tube bioassay test than they had been in previous years (Table 6). While this suggests the fungitoxic vapors are decreasing in the wood, infestation by decay fungi remains low.

The 100% MIT treatments produced significantly higher residue levels in the wood than those found in Vorlex treated wood (Table 6), but decay fungi nevertheless have been isolated from the former. The reduced MIT effectiveness may reflect our inability to deliver uniform MIT dosages to the poles as well as the lower overall fumigant dosages applied. These factors may have combined to create areas in the poles where little or no MIT moved thus permitting the growth and survival of decay fungi.

Douglas-fir marine piles treated with fumigants. Creosoted Douglas-fir piles with sloping, unprotected tops in a 90 m long bulkhead at Florence, OR, were inspected after 4 years' service by culturing cores from the piles. All were found to be decaying internally below the sound appearing tops. In 1974 the tops were cut off flat, 0.5 liters (1 pt) of Vapam, Vorlex or chloropicrin were distributed among four holes within 1 m of the top, and coaltar cement-fiberglass mesh caps were applied to keep the piles dry and contain the fumigant.

Within 1 year, fumigants virtually eliminated decay fungi from the piles (Fig. 3). While chloropicrin and Vorlex have continued to control

TABLE 6

RESIDUAL FUMIGANT VAPORS IN
DOUGLAS-FIR POLES 6 YEARS AFTER APPLICATION

METERS ABOVE GROUND	SEGMENT LOCATION FROM SURFACE (cm)	GROWTH OF ASSAY FUNGUS AS A % OF THE CONTROL				
		NO FUMIGANT	ALLYL ALCOHOL	VORLEX	METHYLISOTHIOCYANATE 20%[2]	METHYLISOTHIOCYANATE 100%
2.4	0-2.5	76	79	76	60	29
	5.1-7.6	76	64	79	74	21
	12.5-15	69	86	76	50	43
1.8	0.2.5	76	83	57	50	19
	5.1-7.6	88	76	81	69	10
	12.5-15	79	83	60	69	12
1.2	0.2.5	76	83	38	67	17
	5.1-7.6	86	86	33	86	17
	12.5-15	74	88	38	86	10
0.6	0.2.5	71	76	33	79	2
	5.1-7.6	71	79	36	67	17
	12.5-15	79	79	50	86	12
CONTROL	(NO WOOD)	42[3]				

[1] 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.

[2] In diesel oil.

[3] Average growth in 10 tubes.

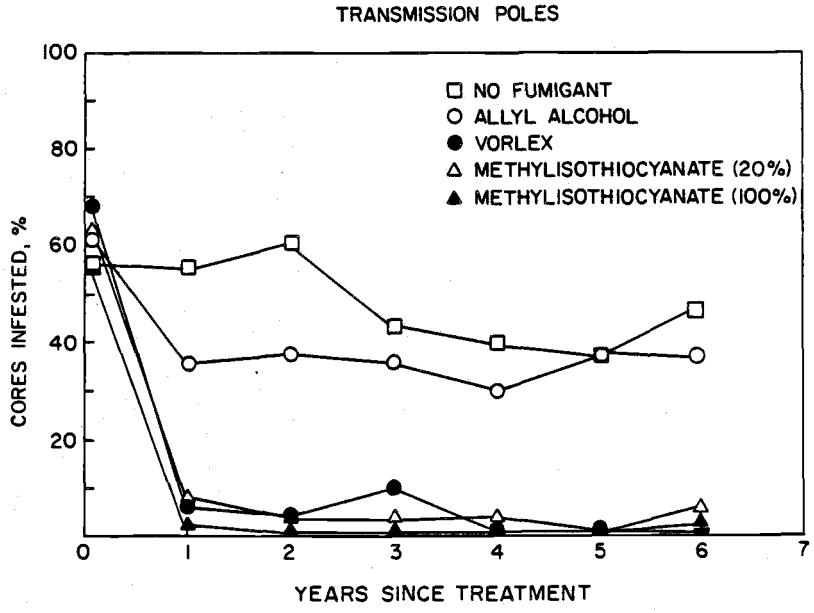

Figure 2. Changes in the population of decay fungi in internally decaying pressure-treated Douglas-fir poles treated with fumigants Each value is based on 15 cores removed at -0.3 to 2.4 m from the groundline from the poles listed in Table 5.

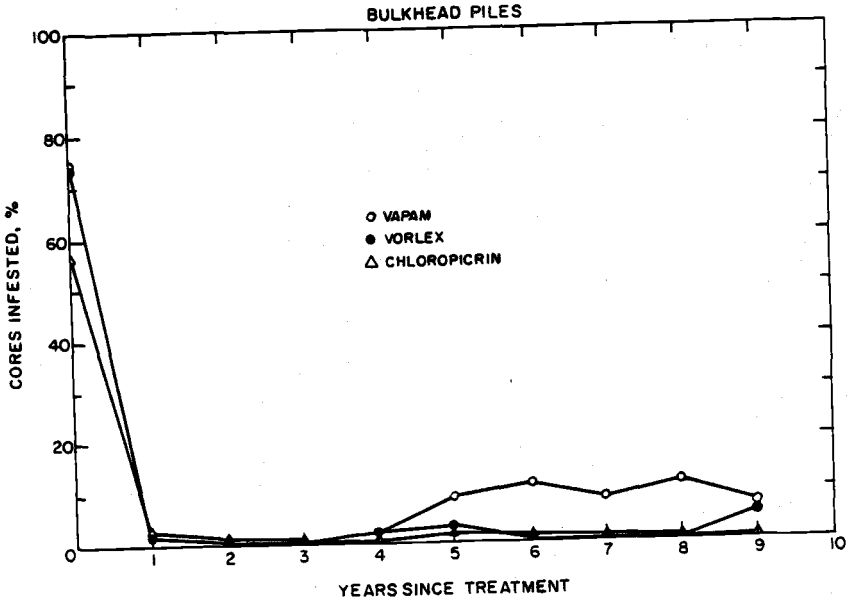

Figure 3. Change in population of decay fungi isolated from creosoted Douglas-fir piles treated with fumigants. Each value represents cultural results of 60 cores from 12 piles.

reinfestation by decay fungi for 9 years, the population of decay fungi has been gradually increasing in Vapam-treated piles since the 4th year. Fungitoxic vapors, especially of chloropicrin and Vorlex, are still present in the wood from 0.3 to 1.8 m below the pile tops.

Conclusions on the use of fumigants on wood in service

- Chloropicrin, methyisothiocyanate, Vapam and Vorlex effectively control internal decay of pressure-treated transmission poles and piles.
- Estimated retreating schedules with these fumigants are: Vapam - 10 years; chloropicrin and Vorlex - 15 years or longer.
- The closed-tube bioassay is an effective method for determining the persistence of fumigants in wood and merits further research as a guide for determining when fumigant-treated poles and piles should be retreated.

A. PREPARATION AND EVALUATION OF ENCAPSULATED METHYLISOTHIOCYANATE

Methylisothiocyanate treatments of Douglas-fir pole sections.

Fifteen Douglas-fir pole sections were used to compare the movement of MIT vapor through wood treated with gelatin encapsulated MIT, non-encapsulated MIT, and Vapam. In addition, the amount of water needed for effective release of MIT from the capsules was investigated. Details of the experimental design and the preliminary results obtained 35 weeks after treatment were described earlier ('83 Ann. Rept., pages 18-22). Following is the final summary of this experiment after monitoring the pole sections for 53 weeks.

Treatment of Douglas-fir pole sections with encapsulated and non-encapsulated MIT resulted in high fumigant concentrations moving through the wood 0.3 and 0.6 m above the treatment holes (Fig. 4). Conversely, pole sections treated with Vapam had MIT concentrations at the lower limit of gas liquid chromatography (GLC) resolution 0.3 m above the treatment holes, and MIT was never detected at the 0.6 m locations during the 1 year sampling period. In MIT treated pole sections, fumigant vapors were rapidly detected in sampling holes 0.3 m above the treatment holes, but 14 to 30 weeks were required for the chemical to reach 0.6 m, and movement to 1.2 m was only detected in one pole after 1 year.

MIT vapor concentrations detected 0.3 and 0.6 m above treatment holes were generally higher in gelatin-encapsulated MIT treated pole sections than when nonencapsulated MIT was used (Fig. 4). However, statistical comparisons of the cumulative MIT dose (MIT concentration x time) 0.3 m above the treatment holes indicated that only pole sections treated with gelatin-encapsulated MIT and 15 ml of water had significantly higher fumigant doses moving through the wood (Table 7). This difference was not significantly higher than other treatments until 44 weeks after treatment, and probably resulted from the large variations in MIT concentrations detected between replicates, especially shortly after treatment, when fumigant vapors were often detected at sampling holes more rapidly in some pole sections than in others.

Treatment holes were opened 1 year after fumigant application to examine the capsules. The outer capsules in each hole, which were broken and empty, were probably pierced by the plugs used to seal the treatment holes.

Figure 4. Average methylisothiocyanate (MIT) vapor concentrations over time monitored in Douglas-fir pole sections 0.3 m (A) and 0.6 m (B) above the treatment holes. Treatments were either 80-88 ml of Vapam •----•, 45 ml of non-encapsulated MIT •____•, or 45 ml of gelatin encapsulated MIT with either 15 ml •____•, 25 ml o--o, or 40 ml ∇---∇, of water added to the treatment holes along with the capsules to aid fumigant release.

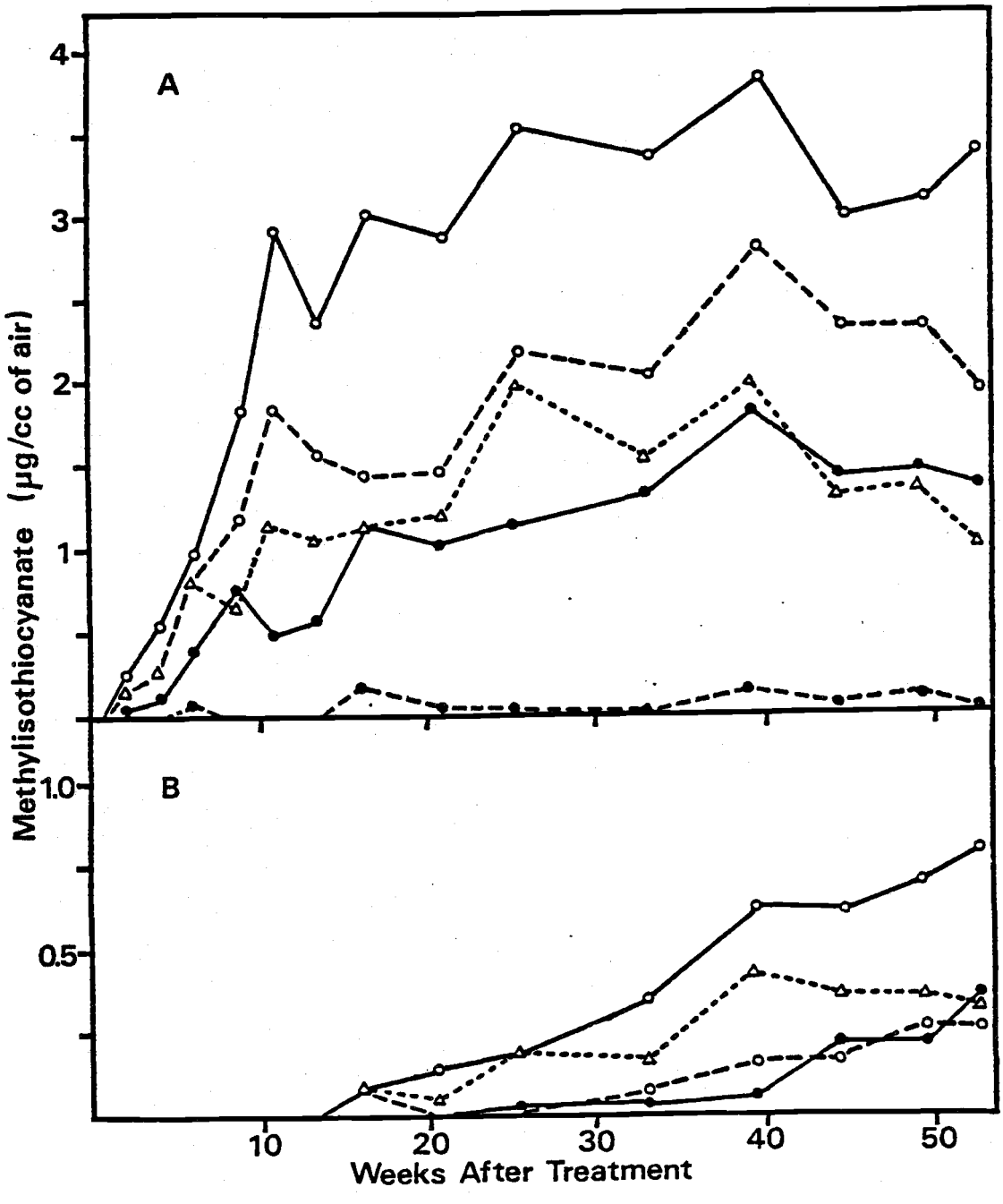

TABLE 7

STATISTICAL COMPARISON OF CUMULATIVE METHYLISOTHIOCYANATE (MIT) CONCENTRATIONS MOVING THROUGH DOUGLAS-FIR POLE SECTIONS[1].

TIME PERIOD (WEEKS)	NON-ENCAPSULATED MIT	ENCAPSULATED MIT TREATMENTS WITH VARIOUS AMOUNTS OF WATER ADDED		
		40 ML WATER	25 ML WATER	15 ML WATER
	$\bar{Y}_1$	$\bar{Y}_2$	$\bar{Y}_3$	$\bar{Y}_4$
0-10	3.92	6.20	8.66	13.60
0-20	12.38	17.56	23.56	40.13
0-32	25.66	35.88	45.18	77.75
0-44	43.06	53.51	70.79	114.00
0-53	56.48	65.01	91.66	143.47

[1] Fumigant movement through pole sections was determined 0.3 m above the treatment sites and was expressed as the cumulative MIT concentration (weeks x µg MIT/ ml Air). Statistical comparisons at the specified time periods were made using the Student-Newman-Keuls test ($\alpha = 0.05$, df = 8). Groups of underlined means are not statistically different.

While the inner capsules appeared intact in all treatments, only one pole section receiving 25 ml of water and 2 pole sections receiving 15 ml of water with the MIT capsules contained any crystalline MIT.

Production of significantly higher MIT vapor concentrations in the wood from encapsulated MIT treatments with 15 ml of water was unexpected, particularly since some of these capsules had not released all of their fumigant. Although the larger quantities of water (25 and 40 ml) gave more complete fumigant release from the capsules, it also hindered fumigant vapor movement through the pole sections.

These results indicate that the addition of a small quantity of water along with the gelatin capsules will give excellent fumigant release and movement through Douglas-fir pole sections.

Methylisothiocyanate movement through preservative treated wood.

One of the goals of our research has been eventual fumigant application to poles at the treatment plant as a part of the normal preservation process. Fumigant application at the plant would treat wood that has the highest residual strength and is most able to retain the chemical for the longest time. This process would also provide predrilled holes for later fumigant re-treatment, and would effectively protect the entire cross section of the pole.

Reason would suggest that fumigants would perform better and last longer in sound wood, giving the user the maximum wood performance for a longer time period. Fumigant treatment could be performed as a part of the standard predrilling pattern, with the fumigants applied shortly after conventional preservative treatment.

The following outlines some preliminary investigations to determine if MIT vapors could effectively penetrate preservative treated wood.

Twelve Douglas-fir heartwood blocks (1 x 1.5 x 7 inches) were each drilled with treatment and vapor sampling holes, separated by 3 inches of wood. The treatment holes were either filled with Shell P-9 penta base oil and place under vacuum for 4 hours to saturate the wood surrounding the holes, or left as unoiled controls. Both oil treated

and control blocks were subsequently treated with either 3.3 ml of non-encapsulated MIT, or with an equivalent amount of gelatin encapsulated MIT with 2 ml of water added to aid fumigant release. Gas-liquid chromatography was used to monitor MIT vapors moving through oil and non-oil treated blocks. Similar experiments were conducted using larger blocks (5 inches between treatment and sampling holes) that had been treated in a conventional creosote treatment cycle.

Although MIT vapors were detected in sampling holes from both preservative treated and control blocks, concentrations were generally much higher in the control blocks. However, after 9 days, blocks treated with P-9 oil and encapsulated MIT had higher fumigant concentrations than control blocks. Capsules removed from the preservative treated blocks and weighed, indicated that twice as much MIT was lost from capsules placed in treated wood than in control blocks. The oil and creosote treated wood apparently retained water around the capsules allowing for quicker MIT release.

The lower fumigant concentrations detected in preservative treated blocks where more MIT was released from capsules may be an experimental artifact. While control blocks often had small checks that could form direct passages for fumigant movement from treatment to sampling holes, these checks would be plugged by heavy oils in the preservative treated blocks. It was also observed that gelatin capsules were easily removed from oil preservative treated holes, but often fused to the wood in untreated holes. This ease of capsule removed should make pole retreatment using the same treatment holes easier when the holes are drilled prior to conventional preservative treatment.

Future studies will be conducted to better determine if predrilling for fumigation, before preservative treating will allow for effective fumigant movement through the poles.

B. EVALUATION OF NEW FUMIGANTS IN THE LABORATORY

A pelletized MIT preparation from the Degussa Corp. was evaluated in our standard laboratory assay for wood fumigants. Freshly cut Douglas-fir heartwood test blocks (2.5 x 2.5 x 10 cm. long) were autoclaved to sterilize the wood and coated on the sides with paraffin wax. The block ends were inoculated with Poria carbonica and the blocks were incubated 1 month to permit the fungus to grow into the wood. Then a 12 mm diameter 22 mm deep hole was drilled at the block midlength and a serum cap was fitted tightly into the hole. Before inserting the serum cap, MIT pellets were placed in the hole. Several blocks also received water which was injected through the serum cap. The treated blocks were then incubated for 1 week.

To determine fumigant effectiveness, two transverse cuts were made at 5 mm intervals from the ends of each block. Four 5 mm cubes cut from the interior of each interior cross section were incubated on nutrient agar to determine the viability of Poria as a measure of fumigant effectiveness.

The results indicated that pelletized MIT was as effective in this assay (Table 8) as pure MIT in previous tests. However, unlike gelatin encapsulated MIT, water added at treatment time tended to reduce effectiveness of the pelletized formulation. Since the pelletized preparation has most of the same application and safety advantages as encapsulated MIT, we intend to further evaluate pellets in pole sections and poles in service.

TABLE 8

FUNGITOXICITY OF PELLETIZED METHYLISOTHIOCYANATE (MIT) TO PORIA CARBONICA IN WOOD

MIT CONC. MG/BLOCK[1]	AMOUNT OF WATER ADDED (ML)	PERCENT INHIBITION OF PORIA IN WOOD BLOCKS[2]
195.5	none	100
97.5	none	81
48.5	none	31
24.5	none	6
196.2	0.5	100
97.5	0.5	66
48.5	0.5	9
24.2	0.5	6

1 Test blocks were freshly cut Douglas-fir heartwood measuring 2.5 x 2.5 x 10 cm long.

2 Each value is based on recovery of Poria from 32 wood cubes cut from four blocks

C. EVALUATION OF THE MOST PROMISING FUMIGANTS IN POLES

New York field test with encapsulated MIT

Twenty four chromated copper arsenate (CCA)-treated Douglas-fir poles placed in service near Hamburg, New York in 1972 with a high incidence of decay fungi were used to compare the effectiveness of gelatin encapsulated MIT with a standard Vapam treatment. In October 1981, groups of six poles were treated with 473 ml of encapsulated MIT plus 1 liter of water, 950 ml of encapsulated MIT plus 900 ml of

water, or 950 ml of Vapam or were left untreated as controls. The water was added with encapsulated MIT treatments to aid in fumigant release from the capsules. Experimental details were previously described ('82 Ann. Rept., pages 21-11) and sampling procedures and results obtained 9 months after treatment have been discussed ('83 Ann. Rept., pages 31-33).

In July, 1983 (21 months after treatment) the poles were resampled to determine the effectiveness of the fumigant treatments. Decay fungi were virtually eliminated in the MIT-treated poles, and were infrequently isolated from those treated with Vapam (Table 9). Reduced growth of the assay fungus used in the closed-tube bioassay was observed in all fumigant treatments, indicating the presence of residual fumigant vapors in the poles (Table 10). While encapsulated MIT treated poles had high levels of fungitoxic vapors at all sampling sites, Vapam treated poles had high levels of fungitoxic vapors only deep in the wood near the groundline.

The gelatin-encapsulated MIT treatments (475 and 950 ml) were equally effective in eliminating decay fungi from these poles and in producing high concentrations of residual fungitoxic vapors to prevent reinfection.

During the inspections, plugs were removed from a number of the treatment holes that received the encapsulated MIT, to assess capsule condition. While many capsules had not completely released their fumigant after 9 months and contained crystalline MIT ('83 Ann. Rept., pg. 33), by 21 months, all capsules examined were empty. This demonstrates that under field conditions, gelatin capsules will effectively release their MIT for movement into wood to control decay fungi.

TABLE 9

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

SAMPLING DATE	METERS ABOVE GROUNDLINE	NUMBER OF CORES WITH DECAY FUNGI[1]			
		NO FUMIGANT	VAPAM 950 ML	ENCAPSULATED MIT[2] 475 ML	950 ML
June 1981	0	15	11	14	14
	0.6	11	13	11	10
Oct. 1981		Poles treated with fumigants			
July 1982	0	17	4	4	1
	0.6	12	3	0	1
	1.2	4	1	1	1
July 1983	0	8	1	0	0
	0.6	11	2	0	1
	1.2	6	0	0	0

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

2 About 1 liter 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 the capsules for the 950 ml treatments.

Treatment of through-bored Douglas-fir poles with gelatin encapsulated MIT or chloropicrin

A field test comparing the effectiveness of gelatin encapsulated MIT and chloropicrin was initiated in Bonneville Power Administration poles (Dorena-tap line) near Cottage Grove OR. Details of the experimental design were presented earlier ('83 Ann. Rept., pages 33-34). Decay fungi were detected in the poles up to 12 feet above the groundline, indicating that, while through-boring had effectively prevented decay at the groundline, it did not affect the entry of decay fungi above this zone.

TABLE 10

RESIDUAL FUMIGANT VAPORS IN DOUGLAS-FIR POLES 21 MONTHS AFTER APPLICATION OF ENCAPSULATED METHYLISOTHIOCYANATE (MIT) OR VAPAM[1]

METERS ABOVE GROUND	SEGMENT LOCATION INSIDE THE TREATED SHELL (CM)	AVERAGE GROWTH OF THE ASSAY FUNGUS[2] (mm)			
		NO FUMIGANT	VAPAM 950 ML	ENCAPSULATED MIT 475 ML	ENCAPSULATED MIT 950 ML
0	0-2.5	24	21	0	0
	12.5-15	20	5	0	0
0.6	0-2.5	25	21	0	2
	12.5-15	24	20	0	4
1.2	0-2.5	31	26	9	4
	12.5-15	29	20	0	0
Control (no wood)		35			

1 Poles were 52-60 cm diameter at breast height, treated with CCA and placed in service near Hamburg, New York, in 1972.

2 The average growth of Poria placenta in the closed-tube bioassay was determined after 8 days using cores from six replicate poles from each fumigant treatment.

Since these poles could not be safely treated above the groundline by conventional remedial treatments, it was decided to evaluate gelatin encapsulated fumigants which permit handling of the volatile chemicals above the groundline with minimal risk of spillage.

About 1 year after fumigant treatment, the poles were reinspected by removing increment cores from two sites 90° on either side of the treatment holes at each height. Core segments from the outer zone (0-1 inch) inside the treated shell, and the inner heartwood zone (5-6 inches)

were used in closed-tube bioassays to monitor radial and transverse fumigant movement. The remainder of the core was cultured for the presence of decay fungi.

Chloropicrin and MIT were well distributed throughout the poles (Table 11) and appear to have moved laterally from the treatment holes. Fumigant odors were detectable in all cores examined but both MIT and chloropicrin were less concentrated in the outer parts of the cores. In no case were decay fungi isolated from the portions of the cores cultured on nutrient medium.

These results suggest that fumigant encapsulation will permit treatment of previously difficult to treat above-ground decay in a safe and environmentally sound manner.

Treatment of Douglas-fir poles with encapsulated MIT.

The application of encapsulated fumigants by line personnel for controlling internal decay of Douglas-fir was evaluated on 17 poles in which small decay pockets had been detected. The selected poles were in Portland General Electric Co.'s Salem-Gresham line and were examined by removing three increment cores from equally spaced locations around each pole at -1, 0, 2, 4 and 6 feet from the groundline.

The cores were visually examined for evidence of advanced decay and cultured for the presence of decay fungi. Advanced decay was identified in 67% of the cores while decay fungi were cultured from 20% of the cores. The poles were divided into three equal treatment groups based on the cultural results. The remaining two poles were used to replace those deemed unfit for treatment. At each of five

TABLE 11

RESIDUAL FUMIGANT VAPORS IN DOUGLAS-FIR POLES AFTER APPLICATION OF ENCAPSULATED METHYLISOTHIOCYANATE (MIT) OR CHLOROPICRIN

POLE NO.	FUMIGANT AND AMOUNT PER POLE	HEIGHT ABOVE GROUNDLINE (FEET)	GROWTH OF ASSAY FUNGUS AS A % OF THE CONTROL[1] — CORE LOCATION (QUADRANTS) Q1 CORE OUTER	Q1 SEGMENT INNER	Q2 CORE OUTER	Q2 SEGMENT INNER	Q3 CORE OUTER	Q3 SEGMENT INNER	Q4 CORE OUTER	Q4 SEGMENT INNER
3/2 B	MIT	17			0	0			59	31
	(372 ml)	14			0	0			0	0
		12	0	0			0	0		
		10			0	0			0	0
		8	0	0			0	0		
		6			0	0			0	0
		4	0	0			0	-[2]		
		2	0	0			0	0		
3/2 A	MIT	14			77	72			90	0
	(310 ml)	11			0	0			51	0
		9	0	0			0	-		
		7			0	0			0	0
		5	0	0			0	0		
		3	77	0					0	0
4/6 A	MIT	17	0	0			0	0		
	(372 ml)	14	66	0			0	0		
		12			0	0			0	0
		10			0	0			0	0
		8	0	0			68	0		
		6	0	0			0	0		
		4			0	0			53	0
		2					0	0		
4/6 B	Chloropicrin	13			0	0			0	0
	(310 ml)	10			0	0			0	0
		8	50	0			0	0		
		6			0	0			0	0
		4	0	0			0	0		
		2			0	0				
5/4 B	Chloropicrin	9			58	66			66	92
	(177.5ml)	6			47	0			0	0
		4	0				0	0		
		2	0				0	0		
5/5 A	Chloropicrin	11			79	71			89	82
	(248 ml)	8			87	0			0	0
		6	0	0			0	0		
		4	0	0			0	0		
		2			0	0			79	0

[1] The values represent growth of the assay fungus (Poria placenta) in the closed tube assay expressed as a percent of the growth obtained in the control tubes (38 mm) which contained no wood. Cores from the treated poles were divided into 1 inch segments from the outer (0-1 inch) and inner (5-6 inches) zones of each core. from poles 4/6A, 4/6B, 5/4B and 5/5A were obtained 12.5 months after treatment while those from poles 3/2A and 3/2B were obtained 15.5 months after treatment. The horizontal bars indicate the location of the fumigant treatment holes.

[2] No sample collected due to advanced decay.

sites per pole, four gelatin capsules containing a total of 88 ml of MIT were placed into a 17 inch long, 7/8 inch diameter hole drilled downward at a 45° angle. The holes were drilled in a spiral pattern at 3 foot intervals from the groundline to 15 feet. As the holes were drilled, wood shavings were collected for additional culturing to determine fungal distribution at locations above the groundline. Culturing the shavings indicated extensive colonization of the wood by decay fungi (primarily P. carbonica) up to 15 feet above the groundline (Table 12). Since this was the highest point sampled it is not unlikely that decay extended well above this height in some poles.

TABLE 12

LOCATION OF DECAY FUNGI ISOLATED FROM DOUGLAS-FIR POLES PRIOR TO TREATMENT WITH GELATIN ENCAPSULATED MIT

POLE NO.	MIT[1] TREATMENT	PRESENCE OF DECAY FUNGI IN SHAVINGS FROM TREATMENT HOLES AT VARIOUS DISTANCES (FT) ABOVE THE GROUNDLINE[1]					
		0	3	6	9	12	15
2674	dry	X	X	X	X	X	X
3274	dry	X	X	X			
5796	dry		X	X	X		
5830	dry	X	X	X	X		
7491	dry	X	X				
1975	moist	X	X	X	X	X	
3265	moist	X	X				
5785	moist	X	X	X	X	X	X
5823	moist		X	X	X	X	X
7494	moist		X	X	X	X	
2701	wet	X	X	X	X	X	
2769	wet	X	X				
2796	wet		X	X	X		
3273	wet	X	X	X	X		
5828	wet	X	X	X	X	X	
7490	wet		X	X	X	X	

1 Four capsules, each containing approximately 22 ml of MIT, were placed in 7/8 inch holes drilled to a depth of about 17 inches at each treatment site. Then either 70 ml of water (wet), 40 ml of water (moist), or no water (dry) was added to each treating hole.

2 Wood shavings, collected as the fumigant treatment holes were drilled, were cultured on malt extract agar and observed for the presence of decay fungi.

After adding the capsules, 70 ml of water (wet), 40 ml of water (moist), or no water (dry) were added and the holes were plugged with treated dowels. By this method, we hope to determine the most effective moisture level to release the fumigant from the gelatin capsules.

The use of gelatin encapsulated MIT should provide a method for above-ground treatment that drastically reduces the risks associated with currently used fumigants. Presently used liquid treatments are hazardous above the groundline since treating holes that cross checks in the wood provide perfect avenues for the chemical to leak out, endangering those working near the pole and contaminating the environment. This problem was clearly demonstrated while treating this particular line. At several points, water added to the poles intersected a check and ran out the other side. Had liquid fumigants been used, a serious accident might have occurred; however, with the solid chemicals this problem was avoided.

The effectiveness of the chemicals applied to these poles will be evaluated on an annual basis by removing increment cores for culturing and by closed-tube bioassays to detect the presence of fungitoxic vapors in the wood.

OBJECTIVE II

DEVELOP ENVIRONMENTALLY ACCEPTABLE PRESERVATIVE TREATMENTS FOR SAFELY CONTROLLING ABOVE-GROUND SAPWOOD DECAY OF CEDAR POLES.

A. DECAY RESISTANCE OF SAPWOOD FROM POLES 2 YEARS AFTER SPRAYING WITH CANDIDATE CHEMICALS.

Seventeen chemicals (three oil-borne, 14 water-borne) were evaluated in the laboratory for control of sapwood decay in western redcedar while resisting depletion by weathering. The test was biased toward waterborne chemicals because water is the preferred carrier to replace the oil currently used with pentachlorophenol. Ten chemicals imparted marked decay resistance to small blocks in a laboratory test even after severe "weathering" for 4 weeks. The presence of eleven chemicals could be detected by the Aspergillus (mold) bioassay which was described earlier ('82 Ann. Rept., pages 25-30 and '83 Ann. Rept., pages 37-38). Decay tests with five of the chemicals were presented last year ('83 Ann. Rept., pages 37-38).

In October 1981 seven chemicals were field tested by spraying weathered cedar pole stubs in Peavy Arboretum, and five more chemicals were applied in July 1983. Since that time, the stubs have been automatically sprinkled through the dry summer months to increase the decay hazard.

Generally, two chemicals were applied to each stub, one third of the circumference being allotted to each. The remaining third was left as an unsprayed control. The treatment areas were oriented N, SE, and SW, and each chemical was assigned to these sectors in rotation. When sprayed, the sapwood was approximately air dry, noticeably checked, and had a moisture content of 14%.

Data and conclusions presented here are based on soil-block tests of sapwood plugs removed from pole stubs sprayed in 1981. The findings provide preliminary information on the protection afforded by the chemicals applied to typical weathered poles with generally firm sapwood. Final conclusions about the merits of the respective chemicals will depend on further pole evaluations.

Sampling

The treatments were evaluated 2 years after spraying using a modified soil-block test and an Aspergillus bioassay. One half inch diameter sapwood plugs were cut from the upper and lower positions of each pole face using a power drill and evaluated by soil block tests. Increment cores 5mm in diameter were taken from three heights (upper, middle and lower) for the Aspergillus bioassay.

Decay tests

The soil block tests were performed in 2 oz wide mouth bottles using 1/8 inch thick circular wood specimens cut from the plug samples and according to the standard ASTM Soil-Block method D 1413 for accelerated preservative testing. Specimen decay was measured by weight loss caused by the fungus Poria placenta, and degree of decay control was determined by subtracting the weight loss of the non-sprayed control from that of the corresponding sprayed wood.

To develop a more meaningful measure of chemical effectiveness, soil block weight losses were converted to average decay suppression (i.e. % suppression = 100 - % weight loss) (Table 13). These values are positive expressions of decay control and reflect differences between sprayed wood and control wood weight losses where 0% suppression

TABLE 13

AVERAGE PERCENT DECAY SUPPRESSION OF 3/8-INCH DIAMETER DISCS REMOVED FROM WESTERN REDCEDAR POLE STUBS 2 YEARS AFTER SPRAYING WITH VARIOUS DECAY CONTROL CHEMICALS AS EVALUATED USING A MODIFIED SOIL BLOCK TEST.

SPRAY CHEMICAL		POLES	MEAN DECAY SUPPRESSION (%)[1] SAMPLE DEPTH			
			0-1/8 inch	1/8-1/4	1/4-3/8	3/8-1/2
A	Pentachlorophenol, 10% in diesel oil	1,2,3 10,11,12	100 (98)	100 (100	100 (100)	100 (88)
C	Copper 8-quinolinolate, (0.121% Cu) in diesel oil	1,2,3 13,14,15	100 (39)	50 (30)	33 (8)	50 (29)
E	3-iodo-propynyl-butyl carbamate, 2% in water	4,5,6 10,11,12	83 (24)	50 (21)	50 (16)	50 (21)
H	Copper 8-quinolinolate, 0.9% + 1% diesel oil in water	4,5,6 16,17,18	67 (14)	50 (3)	67 (7)	33 (3)
I	Pentachlorophenol (D) 10% in water	14,19,21 22,22,23	100 (91)	83 (53)	50 (10)	33 (3)
J	Pentachlorophenol (R) 2% in water	7,8,9 16,17,18 21,23	87 (34)	62 (20)	43 (13)	43 (9)
M	Ammonium bifluoride 20% in water	7,8,9 13,14,15 19	57 (17)	43 (0)	57 (10)	42 (4)

[1] Average decay suppression represents the weight loss for each treatment subtracted from the control weight loss (100). The figure in parenthesis represents the percentage of poles with decay suppression values greater than 10%.

equals the control weight loss. Within this same table, treatments showing 10% or greater decay suppression are also identified to indicate the relative decay control level.

From the results it is apparent that even the least effective chemical, ammonium bifluoride (M) exhibited some decay control at the innermost point sampled, (3/8-1/2 inch). The two most effective chemicals at this depth were oil-borne pentachlorophenol (A) and copper 8-quinolinolate (C). This effect can be largely attributed to the greater penetrability of oils.

To facilitate chemical comparison, decay suppression and preservative penetration depths were combined into single values (Table 14) reflecting simple and weighted percent decay suppressions at each of the four depths. The simple average assumes that protection at all depths is equally important, while the weighted average places less emphasis on protection at greater depths and stresses the capacity of chemicals to withstand surface leaching. Although the averaging method affected relative decay-suppression values it did not affect the order of chemical effectiveness.

Based on these results the chemicals can be placed in order of decreasing residual effectiveness as follows:

1- (A) Pentachlorophenol, 10% in diesel oil

2- (I) Pentachlorophenol, 10% in water

3- (C) Copper 8-quinolinolate 0.121% Cu in diesel oil

(J) Pentachlorophenol, 2% in water

(E) 3-iodo-propynyl-butyl-carbamate, 2% in water

4- (H) Copper 8-quinolinolate, 0.9% + 0.1% diesel oil in water

(M) Ammonium bifluoride, 20% in water

TABLE 14

SUMMARY APPRAISALS OF SHELL ROT CONTROL CHEMICALS
AT ALL POLE DEPTHS

	MEAN DECAY SUPPRESSION			
	POLES WITH > 10% DECAY SUPPRESSION		AVERAGE DECAY SUPPRESSION	
CHEMICAL SPRAY[1]	SIMPLE[2] MEAN %	WEIGHTED[3] MEAN %	SIMPLE[2] MEAN %	WEIGHTED[3] MEAN %
A	100	100	97	98
I	66	78	39	55
C	58	67	26	29
J	59	66	19	23
E	58	63	20	21
H	54	59	8	9
M	50	51	8	9

1 A - Pentachlorophenol, 10% in diesel oil
C - Copper 8-quinolinolate, (0.121% Cu) in diesel oil
E - 3-iodo-propynyl-butyl carbamate, 2% in water
H - Copper 8-quinolinolate, 0.9% + 1% diesel oil in water
I - Pentachlorophenol (D) 10% in water
J - Pentachlorophenol (R) 2% in water
M - Ammonium bifluoride 20% in water

2 Reflects the average of the values in Table 2 for the four depths sampled per pole.

3 Reflects the weighted averages of the Table 2 values, obtained by multiplying weight losses at 0-1/8, 1/8-1/4, 1/4-3/8, 3/8-1/2 inches, by 4, 3, 2, and 1, respectively.

Pole spray (A), presently used by Bonneville Power Administration, was clearly superior to the others. This effectiveness can be attributed to both the strength of the penta solution (10%) and the oil carrier. The advantage of the oil as a carrier is clearly shown by the decreased effectiveness of penta in water at the

same strength (I). This effect was not unexpected since oil solutions were outstanding for penetrating capacity in earlier laboratory trials.

Although there was no noteworthy difference between the decay resistance provided by chemicals C, J and E, the degree of protection was relatively low. The oil-borne copper-8 (C), while known to be less potent than penta was probably comparable to the 2% penta (J) because of the oil carrier. The performance of 3-iodo-propynyl-butyl-carbamate (E) was disappointing in view of its reported effectiveness as a new water-borne fungicide.

Waterborne Copper 8 (H) and ammonium bifluoride (M) proved to be distinctly inferior, although the poor performance of the copper-8 (H) may reflect the low copper content in this formulation. The highly soluble ammonium bifluoride (M) apparently could not withstand leaching from the pole surface or did not penetrate deeply into the wood.

In earlier decay tests, laboratory "weathered" wood treated with chemicals (E), (H), (I), or (J) showed higher weathering resistance than was apparent on pole specimens. Wood treated with these chemicals also showed comparatively high laboratory decay resistance, while wood treated with (C) was moderately resistant and that treated with (M) was comparatively nonresistant. These results suggest that laboratory procedures, while valuable for identifying potential chemicals, should not be depended upon to provide all the answers.

Aspergillus Bioassay

In the Aspergillus tests, the outer 0-0.25 and 0.25-0.5 inch segments from increment cores removed from the test poles at three heights were laid onto potato dextrose agar plates previously seeded with a dilute suspension of Aspergillus niger spores. These plates were incubated for 7 days at room temperature, after which the resulting zone of inhibition due to chemical diffusion from the core to the culture medium was measured.

The Aspergillus tests (Table 15) again indicated that 10% pentachlorophenol in diesel oil was the most effective chemical tested, producing the largest inhibition zone and deepest wood penetration. The other chemicals tested all produced variable inhibitions that ranged from 0 to 50% of that produced by the oil borne penta.

These results were disappointing, since several of the chemicals had performed well in laboratory experiments using small wood wafers; however, the 10% waterborne penta, the copper-8 in oil and the 3-iodo-propynyl-butyl-carbamate did confer some level of sapwood protection. While the level was lower than that produced by oil borne penta, it may still be sufficient to protect the poles for a sufficient time period.

Among the water-borne chemicals reported examined, (I), (J), and (E) appear most deserving of further attention with (E) being most desirable because of its low reported mammalian toxicity. While Copper-8 (H) also might be acceptable from a hazard standpoint, the concentration would have to be increased above the 0.9% used in these investigations to be effective. Combining Copper-8 with an oil component also warrants further investigation.

TABLE 15

AVERAGE ASPERGILLUS BIOASSAY ZONE OF EFFECT OF INCREMENT CORES FROM CEDAR POLES 2 YEARS AFTER SPRAYING WITH SAPWOOD DECAY CONTROL CHEMICALS AND END WAFERS WEATHERED 4 WEEKS AFTER TREATMENT WITH THE SAME CHEMICALS.

	CORE BIOASSAYS[1]				WAFER BIOASSAYS	
	ZONE OF EFFECT (MM) AT TWO SAPWOOD DEPTHS (IN)[2]				ASPERGILLUS BIOASSAYS	DECAY RESISTANCE TESTS[3]
CHEMICAL SPRAY	0-0.25		0.25-0.50		MAX. DEPTH OF RESIDUAL PRESERVATIVE (MM)	DECAY RESISTANCE OF OUTER 4 MM OF WAFER
A - 10% penta in diesel oil	6-14	(11)	5-13	(8)	11-15	VR
copper 8 quinolinolate Cu .121% in diesel oil	1-3	(2)	0-2	(1)	0-4	MR
E-2% (3-iodo propynylbutyl carbamate) in water	0-8	(2)	0-0	(0)	11-15	VR
H-0.9% Cu-8-0.1 oil in water	0-0	(0)	0-0	(0)	0-4	VR
I-10% Penta in water	2-10	(6)	0-5	(3)	5-9	VR
J-5% Penta in water	0-3	(2)	0-0	(0)	5-9	VR
M-20% Ammonium bifluoride in water	0-0	(0)	0-0	(0)	0-4	MR

1 Each chemical was evaluated at 18 locations on six poles, except chemicals M and H which were tested at 21 locations on seven poles and I which was on 4 poles and 18 locations.

2 Values represent the range of zones of effect (three values per pole) while figures in parenthesis represent means of all values.

3 "Soil-block" tests produced weight losses from 1 to 40 % classified as: 0 - 10% = Very Resistant (VR); 11-24% = Resistant (R); 25-44% = Moderately Resistant (MR); and 45 + % = Non Resistant (NR).

The additional chemicals being evaluated on test poles will be appraised in July 1985, 2 years after their application. These chemicals are: (F) diethyl dialkyl ammonium chloride (10% in water); (Q) 3-trimethyl cocammonium chloride (5% in water); (P) copper naphthenate (2% in water); (Q) fluor chrome arsenic phenol (5% in water); and (S) ammoniacal copper arsenate (3% in water). In laboratory decay tests with weathered wood, blocks treated with (F) and (Q) were very decay resistant; while those treated with (P) and (S) were classified as resistant. These chemicals may prove more effective as potential penta replacements than those evaluated this past year.

B. PROTECTION OF WESTERN REDCEDAR SAPWOOD BY APPLICATION OF FUMIGANTS.

Although no new experiments have been established under this phase of the project, we recently re-evaluated fumigant persistence in cedar pole sections 5 years after addition of 0.25 or 0.5 liters of chloropicrin. The poles were maintained in a protected area within the Forest Research Lab and were sampled using closed tube and open tube bioassays to evaluate fumigants effectiveness. The closed tube bioassay was performed using the same procedures as those employed for evaluating fumigants in Douglas-fir, while the open tube tests were performed by attaching 165 x 18 mm(OD) glass tubes containing agar slants inoculated with P. placenta to perforated screw caps epoxied to holes at 1 foot height increments away form the treatment zone. These holes had been drilled into the poles shortly after fumigant treatment and were plugged with rubber stoppers after 2 years. The open tubes were attached to the poles for 7 days, and the resulting fungal growth

measured. Tubes in which the fungus failed to grow were subcultured onto fresh medium to determine if this inhibition was fungistatic or fungicidal.

In addition to the two bioassays, increment cores were taken from sites adjacent to the closed tube locations, extracted in hexane, and analyzed using a gas chromatograph (GC) equipped with a Ni^{63} electron capture detector. Three core zones corresponding to the outer, middle and inner zones (0 -1.5, 6.25 - 8.75, and 12.5 - 15.0 cm) tested by the closed tube method were analyzed. By measuring the peak heights produced by the GC, it was possible to quantify the amount of chloropicrin in a given wood volume (Fig. 5) and compare them with the closed tube test results.

These tests (Figs. 5 & 6 and Table 16) indicated that chloropicrin was present in all core sections, at concentrations ranging from 2 - 53,000$\mu g/cm^3$ of wood. While this variation was high, it was reduced when only the middle and inner core segments were examined. The presence of measurable chloropicrin near the wood surface was particularly encouraging, although the pole sections were not exposed to the elements (rain, sun, etc.) where weathering could rapidly deplete surface concentrations. We intend to evaluate effectiveness of chloropicrin and MIT for protecting the surface of cedar pole sections at Peavy Arboretum.

Attempts to correlate chloropicrin concentration determined gas chromatographically, with results of the closed tube bioassay proved futile. The inability to directly compare the tests may be due to the use of cores from closely spaced but separate wood sections where

Figure 5. Gas chromatographic analysis: a hexane sample showing no peak eluted 3 to 4 minutes after injection; a control-sample extract from non-fumigant-treated wood showing a possible cedar extractive peak but no chloropicrin; and an extract from fumigant-treated wood showing a possible cedar extractive peak and a chloropicrin peak.

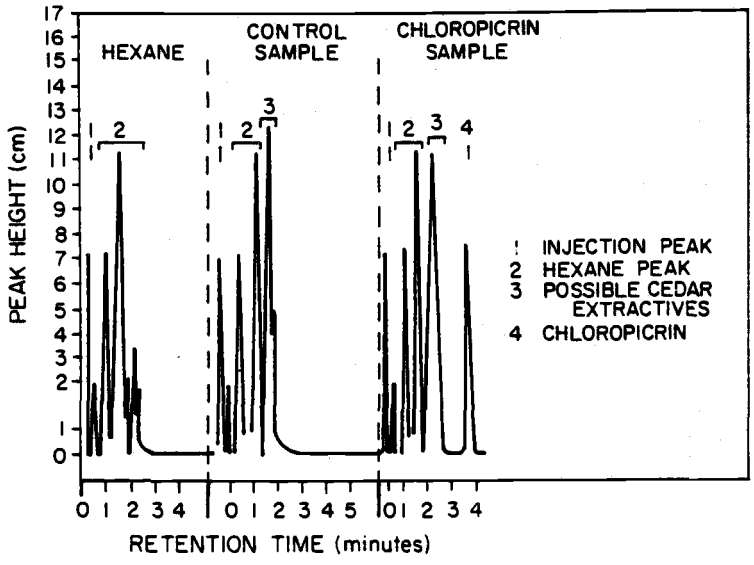

Figure 6. Chloropicrin concentrations detected by means of gas chromatographic techniques on core segments removed from four cedar pole sections 5 years after chloropicrin treatment: A) sites directly above or below fumigant treatment holes; B) sites between treatment holes.

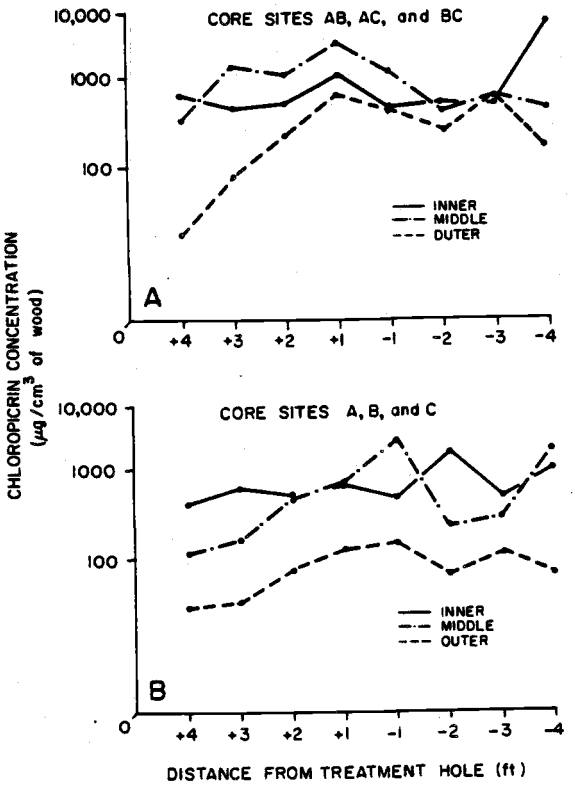

TABLE 16

CHLOROPICRIN CONCENTRATION AT SAMPLING SITES OF CEDAR STUBS FIVE YEARS AFTER ADDITION OF CHLOROPICRIN AS MEASURED USING A VARIAN 3700 GAS CHROMATOGRAPH EQUIPPED WITH 63 NI ELECTRON CAPTURE DEVICE.[1]

		MEAN CHLOROPICRIN CONCENTRATION ($\mu g/cm^3$ OF WOOD)		
POLE[2] NO.	CORE SEGMENT	SITES[3] AB/AC/BC	SITES[3] A, B, C,	ALL SITES COMBINED
1+2	0-2.5	75	50	63
	6.75-8.25	721	356	538
	12.5-15.0	375	400	387
3+4	0-2.5	494	127	308
	6.75-8.25	1660	1398	1530
	12.5-15.0	2427	1090	1744
ALL POLES	0-2.5	282	89	185
	6.75-8.25	1191	877	1034
	12.5-15.0	1379	752	1066

1 Cores were removed from the test poles and extracted with hexane for 48 hours. A 4 µl sample of the extract was examined using a Varian 3700 gas chromatograph.

2 Poles 1+2 originally received 0.25 liters of fumigant while poles 3+4 received 0.5 liters of chemical.

3 Sites A, B, C were equally spaced around the pole at a given height and were offset 60° from the treatment hole, while sites AB, BC, AC were similarly spaced but placed directly in line with the treatment holes.

natural wood variation may have created an uneven chloropicrin distribution. The lack of comparison suggests that the tests may be measuring different fumigant properties. While chemical extraction and gas chromatographic analysis measure the total chloropicrin present

in the wood (95% efficient), the closed tube bioassay estimates the available fumigant that is capable of diffusing out of the wood and into the culture medium.

An additional factor affecting the closed tube tests was fungal inhibition by toxic heartwood extractives. While heartwood compounds that inhibit P. placenta are readily detected using gas chromotography, they do not interfere with chloropicrin analysis. However, their presence in the closed tube test could produce inhibition of the test fungus leading to confounded results.

We intend to evaluate the correlation between fumigant concentration and closed tube bioassay results under more controlled conditions using small cedar and Douglas-fir test blocks. This information will produce a useful curve relating fumigant concentration to closed tube bioassay results and aid in determining when fumigant retreatment should be made.

OBJECTIVE III

PREVENT DECAY INITIATION IN FIELD-DRILLED BOLT HOLES IN DOUGLAS-FIR POLES

An experimental field trial was initiated in 1981 to evaluate various chemical treatments to prevent decay in field-drilled bolt holes in Douglas-fir poles ('82 Ann. Rept., pages 31-33). During the summers of 1982 and 1983, cores were removed from sites near bolt holes in four control poles and the cores were cultured to determine if the incidence of decay fungi in the unprotected bolt holes was high enough to warrant similar assessment of poles with treated bolt holes. Cores were removed from sites directly beneath the gain plate and above the washer on the opposite side on each of the eight bolt holes per pole.

In 1982, decay fungi were cultured from three cores above the bolt holes in two poles. Thus the incidence of decay fungi in 1982 was too low to warrant evaluation of the treated poles at that time. Similarly, cores removed during 1983 had a low incidence of decay fungi, and sampling of the test treatments was again delayed.

We will resample the control poles this summer in hopes that decay has begun.

OBJECTIVE IV

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

A. DETECTING INCIPIENT DECAY BY ANALYSIS OF WARM WATER EXTRACTS USING INFRARED SPECTROSCOPY.

Warm water extracts from small samples of non-decayed and decayed beams were used to evaluate infrared (IR) spectrophotometry analysis as a method for detecting early decay and predicting residual strength of the decayed wood.

Douglas-fir heartwood samples were decayed by six representative brown and white rot fungi. Brown rot fungi were associated with weight losses in small wafers after 10 days incubation, whereas, white rot fungi did not cause measurable wafer weight loss until 42 days of incubation. The small, end-matched beams were decayed to a series of weight losses up to 5%.

Non-decayed and decayed end-matched beams were tested in static bending and modulus of rupture (MOR) from which the modulus of elasticity (MOE) was calculated. The mean MOR and MOE values for brown and white rotted beams were significantly less than the mean values for non-decayed beams. Correlation coefficients as high as 0.62 were obtained from simple linear regression analyses of percent strength loss versus weight loss in brown rotted beams, while the correlations were much lower for white rotted beams.

Comparisons between IR spectra of non-decayed and decayed wood extracts identified an absorption peak at a wavenumber of 1720 cm^{-1} in

the spectra of decayed sample extracts from beams with no measurable weight loss. Peak ratios (PR) and full peak ratios (FPR), developed to measure the extent of decay, both increased as decay progressed. Correlation coefficients as high as 0.72 and 0.70 were obtained from simple linear regression analyses between these ratios and MOR loss in brown rotted beams. Relationships involving MOE loss and white rot strength values were again lower.

These results suggest that IR analysis of warm water extracts may be a valuable laboratory means for identifying very early decay (incipient) by brown rot fungi. Further work is underway to identify the peak to determine if a less involved technique could be used to detect it.

B. DETECTING DECAY FUNGI USING FLUORESCENT LABELED LECTINS.

Detecting decay fungi in wood before measurable weight loss occurs is of great importance in preliminary inspection programs since substantial decrease in strength properties can occur before weight loss is apparent. While much effort has been directed towards using chemicals to detect decay associated changes or make hyphae more visible in the wood, most chemicals have limited usefulness due to wood and fungal variability. We recently evaluated the use of fluorescent-labeled lectins as possible fungal indicators. These plant derived chemicals have high specific affinities for various carbohydrates. When coupled with a fluorescent compound, the site where the lectin attaches in the wood can be identified using a fluorescent microscope equipped with the proper filters. We evaluated seven lectins with

specificities for various carbohydrates present in fungal hyphae or the wood cell wall. Of these lectins, wheat germ agglutinin proved to be the most useful. This lectin has affinity for n-acetylglucosamine, which is the primary component of chitin, a common polymer of the fungal cell wall. Wheat germ agglutinin coupled to fluorescein markedly improved the visualization of decay hyphae within the wood. This improvement was most noticeable in the early stages of decay, when hyphae were extremely difficult to detect using a conventional Safranin O-picroaniline blue staining technique. The lectin indicated that a large number of hyphae were present in the wood at a point when no measurable weight loss had occurred.

These evaluations were done on laboratory decayed blocks. This coming year we hope to evaluate these chemicals on increment cores as a possible prescreening technique for decay fungi. This process would reduce the amount of culturing required in a large scale evaluation and direct the effort towards cores containing decay fungi.

C. ESTIMATING STRENGTH OF POLES

Residual strength of Douglas-fir poles during air-seasoning

The effect of fungal colonization on strength properties was investigated using compression, bending, and Pilodyn tests on wood from Douglas-fir pole sections after 2 years of air-seasoning and comparing them with strength tests on similar sections after 1 year of air-seasoning as well as those reported in the literature for Douglas-fir.

The objectives of this phase of our study were:

. . .to determine the impact of decay fungi in air-seasoning poles ('83 Ann. Report, pages 49-54) on wood strength;

. . .to evaluate non-destructive tests for detecting early decay and estimating wood strength.

Small beams were cut from 24 pole sections air seasoned for 2 years and examined by the same methods used for the 1-year air-seasoned beams previously tested ('83 Ann. Report, pages 40-41). In addition to the bending and radial compression strength (RCS) tests previously used, longitudinal compression strength (LCS) tests were made on 0.5 inch diameter, 1 inch long plugs radially cut near one end of each beam after static bending tests were completed. These plugs were water soaked to insure moisture contents above 30% and LCS was measured using an Instron Universal Testing Machine equipped with a specially-made compression jig, (Fig. 7). The opposite end of each beam was tested using 6-Joule and an 18-Joule Pilodyns equipped with various diameter pins.

Following mechanical testing, wood was removed near the mid-span area and cultured on nutrient medium for the presence of fungi. Decay fungi were isolated from 10 of the 136 beams tested, representing five of the 24 pole sections examined. Areas of discolored wood that might indicate early (incipient) decay were observed in four of the five pole sections when the beams were cut; however, beam strength did not differ from the strength of beams without decay fungi (Table 17). These results suggest that the decay was at a very early stage or that the fungi isolated were not actively attacking the wood.

Figure 7. Front (A) and side (B) views of longitudinal compression strength test (LCS) apparatus.

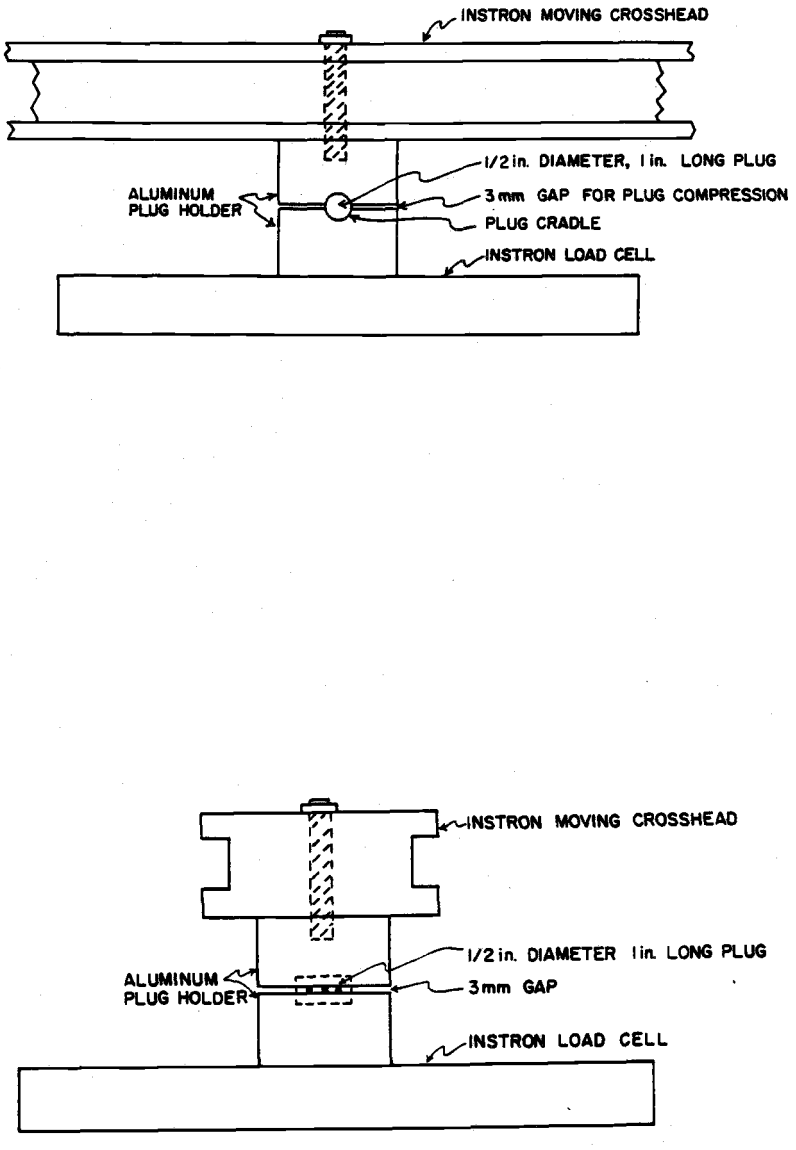

TABLE 17

COMPARISON OF MECHANICAL PROPERTIES OF BEAMS CUT FROM COAST DOUGLAS-FIR POLE SECTIONS

SAMPLES COMPARED	STATIC BENDING TESTS			NON-DESTRUCTIVE TESTS		
	SPECIFIC GRAVITY (GREEN)	MODULUS OF RUPTURE (GREEN)	MODULUS OF ELASTICITY (GREEN)	WORK TO MAXIMUM LOAD (GREEN)	PILODYN[1] PENETRATION (12% MC)	RCS[2] (GREEN)	LCS[3] (GREEN)
		psi	x1000	lb/cu.in	mm	psi	lb
One-year Air-seasoned:	.45[4]	7163	1539	8.7	17.7	369	
	(.04)	(980)	(220)	(2.8)	(3.1)	(77)	
VS	143	143	142	142	137	138	
Two-year Air-seasoned	.44[N.S.][5]	6994[N.S.]	1467[N.S.]	7.6**[5]	19.6**	340**	1022
	(.03)	(772)	(206)	(2.1)	(2.7)	(63)	(50)
	134	134	131	127	128	102	94
Two-year Air-seasoned, No decay fungi:	.44	7001	1467	7.6	19.6	341	1023
	(.03)	(781)	(207)	(2.1)	(2.8)	(64)	(51)
VS	124	124	122	119	118	97	89
Two-year Air-seasoned, Decay fungi present:	.45[N.S.]	6905[N.S.]	1474[N.S.]	7.0[N.S.]	19.5[N.S.]	315[N.S.]	1008[N.S.]
	(.03)	(664)	(211)	(1.3)	(1.5)	(43)	(42)
	10	10	9	8	10	5	5
	COAST DOUGLAS-FIR, PUBLISHED VALUES[6]						
	.45	7665	1560	7.6			
		(1317)	(315)				

[1] 1.8 mkp model using 3mm diameter pin, 70 mm long.

[2] Radial compression strength of 0.5 in diameter plugs, 0.75 in long.

[3] Longitudinal compression strength of 0.5 in diameter plugs, 1.0 in long.

[4] In each set of numbers the first value is the mean, the value in parentheses is the standard deviation and the value beneath is the sample size.

[5] N.S. No significant difference (0.95% confidence level) or **Significant difference (0.99% confidence level).

[6] From ASTM D2555-78. Establishing clear wood strength values. Work value from the Wood Handbook.

Comparisons between 1 and 2-year air-seasoned beams (Table 17) indicated that MOE, work, Pilodyn pin penetration, and RCS were significantly reduced; however, all values were within the range of reported strength values for clear coast Douglas-fir beams. These results suggest that while there is a well developed fungal flora associated with this wood ('83 Ann. Rept., pages 50-54), the colonization has not yet affected important strength properties.

There has been growing interest in developing non-destructive test methods for estimating the bending properties of wood poles and timber. Cown and Hutchison[1], for example, destructively tested full-length Pinus radiata poles by cantilever loading and found a strong relationship between Pilodyn pin penetration of the outer 20% of the radius of the pole at groundline and pole strength ($r = -0.79$) or stiffness ($r = -0.69$). Wilson[2] also found a relationship ($r = -0.50$) between Pilodyn readings and static bending strength of ponderosa pine utility poles. Chudnaff et al.[3] used the Pilodyn and sonic stress-wave measurements to estimate strength of mine timbers. In our study, the Pilodyn was a good predictor of beam strength ($r = -0.64$) and stiffness ($r = -0.35$) with the best strength estimates obtained by testing wet wood ($\geq$ 30% MC) and using a Pilodyn-pin combination producing an average wood penetration approximately 3/4 of the depth of the specimen tested (Table 18).

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[1] Cown, D. J. and J. D. Hutchison. 1983. Wood density as an indicator of the bending properties of Pinus radiata poles. New Zealand Jour. of For. Sci. 13(1):87-99.

[2] Wilson, J. B. 1981. Pole inspection using the Pilodyn. Paper 1665. For. Res. Lab., Oregon State Univ., Corvallis, OR.

[3] Chudnoff, M., W. E. Eslyn, and D. B. McKeever. 1984. Decay in mine timbers. Part III. Species-independent stress grading. For. Prod. Jour., Vol. 34(3):43-50.

TABLE 18

RELATIONSHIP BETWEEN NON-DESTRUCTIVE TEST VALUES AND MECHANICAL PROPERTIES OF DOUGLAS-FIR BEAMS

PIN DIAMETER (MM)	WOOD MOISTURE CONTENT	AVERAGE STRENGTH VALUE	COEFF. OF VARIATION(%)	CORRELATION COEFFICIENTS[1] SG[2]	MOR[3]	MOE[4]	WORK[5]
		LONGITUDINAL COMPRESSION STRENGTH[6]					
	>30%	1023 lbs	5	.78	.74	.48	.22
		6 - JOULE PILODYN PENETRATION					
3.0	>30%	10.5 mm	16	-.46	-.41	-.25	-.27
2.5		14.0 mm	15	-.34	-.39	-.16	-.08
2.0		20.0 mm	12	-.63	-.64	-.35	-.28
3.0	12%	6.7 mm	20	-.24	-.26	-.13	-.23
2.5		9.3 mm	16	-.35	-.26	-.16	-.25
2.0		13.6 mm	14	-.45	-.39	-.25	-.25
		18 - JOULE PILODYN PENETRATION					
3.0	12%	19.6 mm	14	-.50	-.41	-.10	-.25

1 A correlation coefficient of 1.0 or -1.0 means that there is a perfect correlation between two variables. Radially oriented test plugs 0.5 inches in diameter and 1 inch long were cut from one end of each beam. Beams were 1 x 1 x 14 inches long.

2 SG = specific gravity.

3 MOR = modulus of rupture.

4 MOE = modulus of elasticity.

5 WORK = work to maximum load

6 Tested by compression of 0.5 inch diameter 1 inch long plugs cut redially from 1 x 1 x 16-inch beams on an Instron Universal Testing Machine.

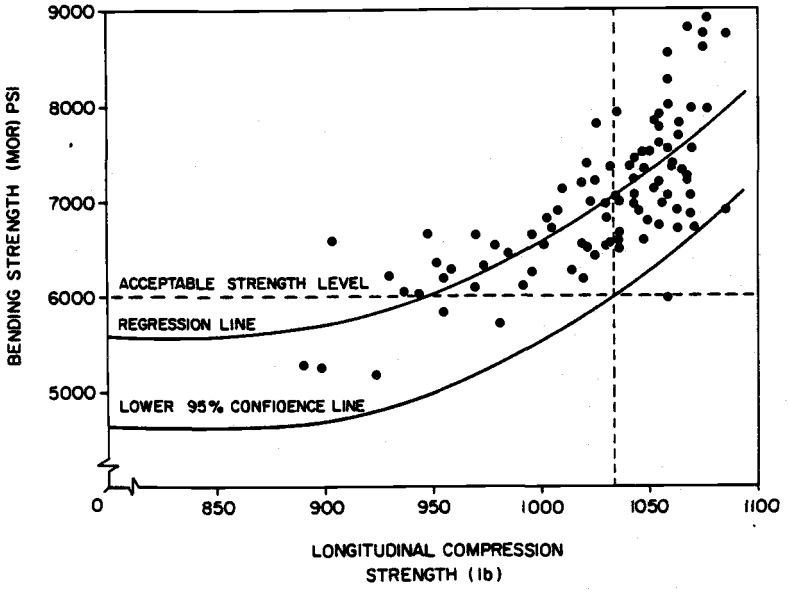
Longitudinal compression strength (LCS) tests of plugs removed from each beam were the best predictor of beam strength ($r = 0.74$) and stiffness ($r = 0.48$). The relationship between bending strength of small beams (MOR) and longitudinal compression strength (LCS) [Fig. 8] indicates that LCS measurements could be useful for selecting high-strength wood material. In this example, 6000 pounds/square inch was chosen as the lowest acceptable bending strength value. The figure illustrates that at an LCS of 1030 lbs. or greater, bending-strength would generally exceed the acceptable value.

These results suggest that unexpected transmission pole failures could be reduced by using non-destructive tests to select high strength poles (or trees) for use in lines subject to heavy load from snow and ice or sudden impact stresses from wind. The strong relationships between Pilodyn readings, LCS or sonic stress-waves and wood strength indicate that a study relating non-destructive tests with the bending properties of full-length poles would be beneficial.

Conclusions are:

- Although some pole sections air-seasoned for 2 years were infected by decay fungi, the wood strength was not significantly affected.
- Decay in the 2-year air-seasoned pole sections is at too early a stage to be indicated by RCS, PCS or Pilodyn penetration values.
- Pilodyn pin penetration and parallel compression strength both provided good estimates of Douglas-fir bending strength.

Figure 8. A procedure for using longitudinal compression strength values to select wood with acceptable bending strength (MOR) (based on a schematic sort presented by Chudnoff, et al[3]).



Pilodyn pin penetration vs. moisture content of Douglas-fir.

Since wood moisture contents below 30% (fiber saturation point) affect a number of wood strength properties, we found it necessary to adjust Pilodyn readings for moisture content differences before comparing pin penetrations from individual poles or groups of poles. Moisture gradients were often present in the outer pole radius and average moisture content was estimated using a resistance type moisture meter with insulated pins driven to a predetermined depth from the wood surface. Although strength properties generally do not vary in wood above the fiber saturation point, Pilodyn readings are reported to be sensitive to moisture changes above this level. While in-service pole moisture contents often exceed 30%, electrical resistance meters have a very poor correlation with these moisture levels, therefore, correcting Pilodyn readings for moisture content differences above fiber saturation poses a problem. The objectives of this study were to determine the relationship between Pilodyn pin penetration and wood moisture content of Douglas-fir at various moisture levels and to establish a standard sampling depth to provide the best estimate of average wood moisture content for Pilodyn pin penetration corrections.

To accomplish these goals, 106 blocks (2 inches square) were cut from three freshly-peeled Douglas-fir pole sections (specific gravity 0.40 to 0.50). These blocks were conditioned to moisture contents ranging from 6 to 180% (oven-dry wood weight basis) and each block was tested using 6-Joule and 18-Joule Pilodyns. The average wood moisture content to the depth of the Pilodyn pin penetration and moisture content

0.5 inches from the wood surface were determined by weighing and oven-drying small increments of wood surrounding the Pilodyn pin path. Regression analyses were made to describe the relationship between Pilodyn pin penetration and average wood moisture content from 6 to 30% and to investigate the relationship between pin penetration and moisture contents above 30%. In addition, the average moisture content in the test zone was compared to the moisture content 0.5 inches from the wood surface.

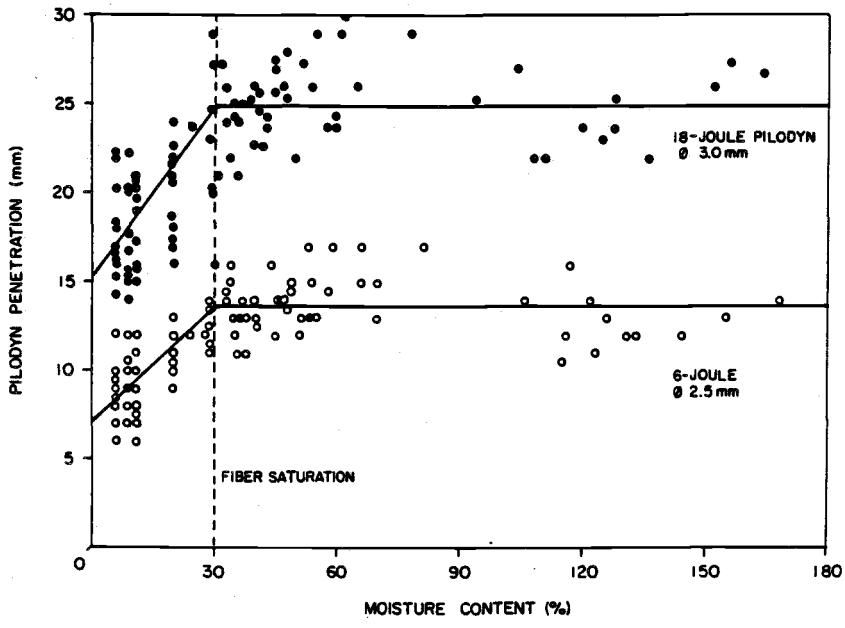
Using the 6-Joule Pilodyn, pin penetration increased about 1 mm per 4.5% increase in moisture content at moisture levels up to 30%, while pin penetration increased about 1 mm for every 3.0% moisture content increase using the 18-Joule Pilodyn (Fig. 9). Interestingly, pin penetration did not vary with moisture contents above fiber saturation.

A high correlation was found between average wood moisture content and moisture content at 0.5-inch depth from the wood surface ($r = 0.99$). These results suggest that the Pilodyn could be used for pole inspections by correcting pin penetration using a resistance-type moisture meter with insulated pins to measure moisture content 0.5 inches from the surface. The meter would detect moisture variations and its inability to accurately measure higher moisture contents (>30%) would be immaterial since Pilodyn pin penetration is unaffected by these moisture levels.

Acoustic testing of poles

Although a number of acoustic testing devices are available for use by the utility industry for inspecting wood poles, none have proven satisfactory in assessing pole quality nor can they reliable predict

Figure 9. Pilodyn pin penetration (mm) of 2 inch square Douglas-fir heartwood blocks at selected moisture contents.



pole breaking strength. However, the potential exists for using recently developed signal analysis techiques to study pole acoustic properties for predicting breaking strength. To evaluate this technique, we have begun by establishing basic acoustic properties of wood, an integral step to the successful development of a field-practical acoustic testing device.

From a materials science viewpoint, a wood utility pole is a complex material with many naturally occurring characteristics, such as grain direction, knots, shake, growth rings and sapwood that contribute to pole performance. Because of the difficulty of studying such a complex material, our initial efforts have been directed at clear, straight grain sections from decayed poles.

Eighteen Douglas-fir beams (1 x 1 x 16 inches long) at varying stages of decay, were acoustically tested and then loaded to failure in three-point bending to measure MOR. Correlations were made then between MOR and the acoustic characteristics of the beam.

The acoustic properties of the beams were evaluated by applying a known accoustic wave pattern and measuring pattern modifications caused by beam characteristics. The difference between acoustic wave patterns of the weakest and the strongest beams tested were clearly evident (Fig. 10). These wave patterns can be likened to finger prints and can be used to identify the material characteristics of the beam.

A method was devised to analyze the wave pattern and the resulting values were correlated with MOR (Fig. 11). The high correlation between MOR and acoustic analysis value suggest that acoustic analysis

would be an ideal nondestructive MOR predictor. However, since only a limited number of beams were tested, more specimen tests are needed to confirm the initial results. In addition, testing additional beams will further refine acoustic analysis to more acurately predict MOR.

Further tests are underway to examine whether our acoustic analysis method predicts the strength of larger wood specimens. We have already acoustically tested 150 pieces of three grades of Douglas-fir of lumber measuring 1.5 x 3.5 x 144 inches. The results of the analysis will be evaluated following the completion of bending tests on these specimens.

Figure 10. Typical acoustic emission patterns from strongest (sound) and weakest (decayed) wood beams. Note sharp loss in signal from decayed wood.

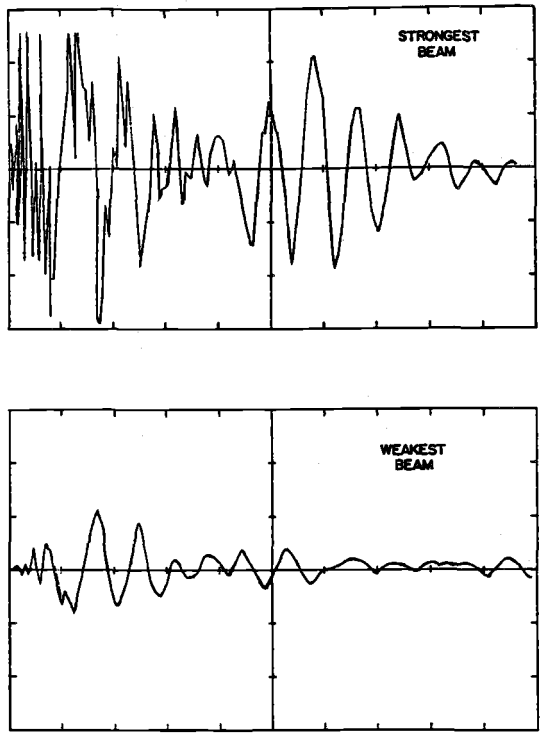
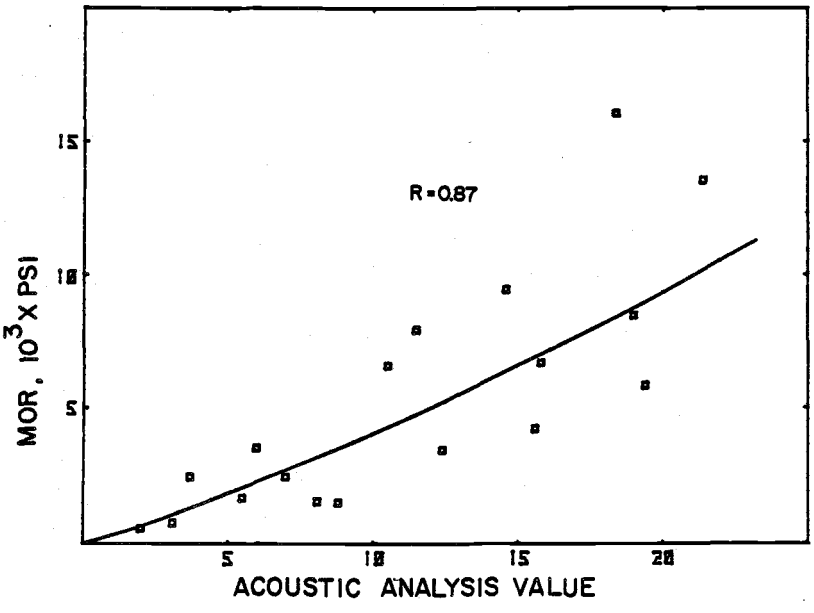


Figure 11. Comparison of acoustic emission signal analysis and bending strength (MOR) for small clear Douglas-fir beams.



OBJECTIVE V

CONSERVE ENERGY BY PROCURING DOUGLAS-FIR POLES THAT HAVE BEEN SEASONED BY THE MOST EFFICIENT METHODS AND THAT ARE AND WILL REMAIN FREE OF VIABLE DECAY IN SERVICE

A. DETERMINE THE INCIDENCE AND SPECIES OF DECAY FUNGI IN FRESHLY CUT POLES AND IN POLES STORED IN WIDELY SCATTERED AIR-SEASONING YARDS ONE, TWO OR MORE YEARS.

Studies under this objective were initiated in 1981, when air-seasoning poles in 11 pole yards in the Pacific Northwest were sampled. Fourteen 6-inch long cores were removed from sites along the length of each pole and the cores were brought to the laboratory where they were flamed and plated on malt agar medium. Resulting fungal cultures were examined microscopically to detect the presence of basidiomycetes, the major wood decay organisms. The basidiomycetes and fungi suspected of being basidiomycetes were isolated in pure culture for identification and tested for their ability to decay wood.

In 1982, poles from seven additional yards and freshly cut poles from six different locations distributed through the geographic range of Douglas-fir pole production were sampled. During this past year no additional poles were sampled, but some fungi among the unknowns were identified. In our next annual report, the summary presented last year ('83 Ann. Rpt., pages 49-54) for this phase of our study will be updated to include all identified basidiomycetes.

B. WOOD DECAY POTENTIAL OF FUNGI FROM AIR-SEASONING POLES

The toughness tests described here were developed through previously described experiments to rapidly assess the decay potential of fungi isolated from air-seasoning poles (see '82 and '83 Ann. Repts.). For these tests, petri plates containing malt extract-agar medium were

prepared and four glass supports were placed on the medium surface. The plates were inoculated with the test fungus, and incubated 7 days before placing four autoclaved 0.042 x 0.240 x 2 inch Douglas-fir heartwood wafers on the glass supports. The test fungi rapidly grew over the wood wafers which were at moisture contents above 50%. Experimental controls were prepared by incubating wood wafers over uninoculated culture medium.

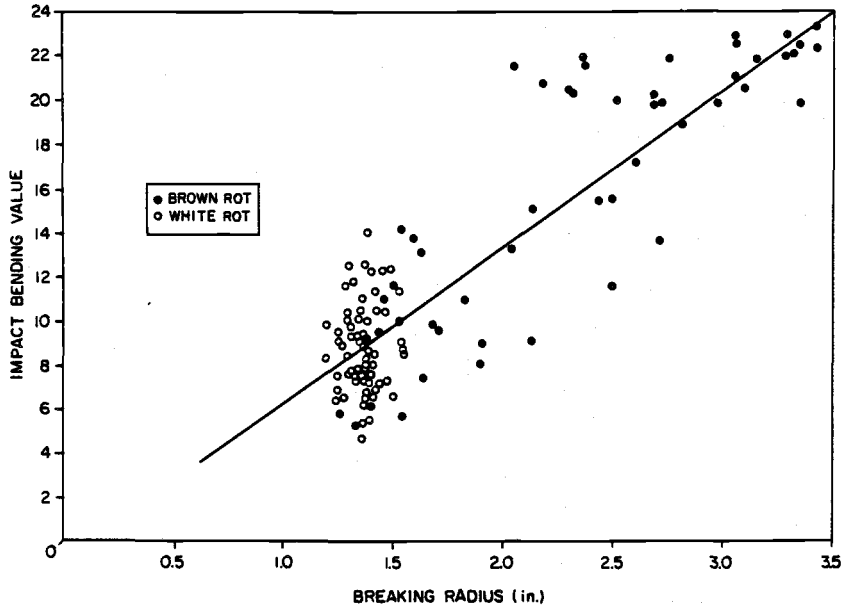
After 4 weeks incubation, the wood was tested for toughness in two assays. In one test, 16 wafers infested with each fungus were oven-dried then bent around a series of wooden mandrels of decreasing diameter to failure. The radius of the mandrel on which the sticks broke (breaking radius) was then used as an estimate of wood toughness.

In a second test, 12 sticks per fungal isolate were wet tested for inpact bending strength on a pendulum device in which the pendulum arm strikes the wood section at the nadir of its arc. The height attained by the arm after breaking the wafer indicates the energy absorbed by the wood and this can be converted to toughness.

The average toughness values for each of 135 fungal isolates from air-seasoning poles using the first batch of wood wafers demonstrated that white-rot fungi caused less strength loss in both tests than brown-rot fungi (Fig. 12). However, since most white rots decay wood at a slower initial rate than brown rots, these differences may be due to the relatively short incubation period used in our tests.

A significant difference in the initial toughness of the undecayed wood in two batches of wafers used in these tests prevented direct comparisons between tests using different wood batches.

Figure 12. Comparison of impact bending and breaking radius tests for determining toughness loss of Douglas-fir heartwood wafers exposed to 117 isolates of ten representative basidiomycetous fungi cultured from air seasoning poles.



White-rot fungi generally produced relatively similar breaking radius values, but exhibited a broad range of values for the impact bending test (Fig.12). Nevertheless, the correlation between the two tests was relatively high ($r^2 = 0.78$).

Fourteen fungal species were evaluated in the two toughness tests using the first batch of wood wafers (Table 19), and 12 species were evaluated with the second batch of wafers (Table 20). In these tests, Poria placenta, P. carbonica, P. xantha, and Crustoderma dryinum most rapidly decayed Douglas-fir heartwood, however, at least one isolate of most of the other species tested significanly reduced toughness. This indicates that most basidiomycetes isolated from Douglas-fir poles are capable of causing some wood damage. While the wood decaying ability of each fungus is important; however, the frequency of isolation should also be considered when determining the overall importance of a species.

The need to evaluate the decay potential of several isolates of the same fungus was evident in six species that had isolates that differed significantly from each other in at least one of the toughness tests (Table 19 & 20).

C. DETERMINE THE ABILITY OF VARIOUS FUNGAL STRUCTURES TO INITIATE DECAY AND DETERMINE HOW AND WHEN POLES IN SERVICE ARE INFECTED WITH DECAY FUNGI.

P. carbonica is the major decay fungus in Douglas-fir poles in the Pacific Northwest, but relatively little is known about its means of spread and infection in poles. Although infection can occur through direct contact with soil-borne hyphae, air-dissemination by the fungus is also involved. In earlier studies ('82 Ann. Rept.,

TABLE 19

TOUGHNESS REDUCTIONS AS MEASURED BY BREAKING RADIUS AND IMPACT BENDING TESTS OF DOUGLAS-FIR HEARTWOOD EXPOSED TO SELECTED BASIDIOMYCETES ISOLATED FROM AIR-SEASONING POLES

FUNGAL SPECIES	BREAKING RADIUS TEST			IMPACT BENDING TEST		
	NO. OF ISOLATES TESTED[1]	NO. OF ISOLATES SIGNIFICANTLY HIGHER THAN CONTROL[2]	AVERAGE BREAKING RADIUS (IN)	NO. OF ISOLATES TESTED[1]	NO. OF ISOLATES SIGNIFICANTLY HIGHER THAN CONTROL[2]	AVERAGE IMPACT BENDING VALUES
Poria placenta	10*	10	3.03	10*	10	20.25
P. placenta monokaryon	10*	10	2.87	10*	10	21.71
Crustoderma dryinum	7*	7	2.59	7*	6	18.87
Poria carbonica	8*	8	2.19	9*	6	11.89
P. carbonica monokaryon	8*	8	1.73	8*	7	12.91
Coriolus versicolor	7	6	1.35	7	2	8.91
C. versicolor monokaryon	9	8	1.41	9	5	10.73
Haematostereum sanguinolentum	8	6	1.42	7	1	8.95
Gloeophyllum saepiarium	9*	8	1.51	9*	1	7.63
Phanerochaete sordida	9	6	1.38	9	2	8.52
Phlebia "A"	14	12	1.38	14	0	7.35
Peniophora spp.	17	14	1.37	17	2	8.28
Stereum hirsutum	10*	3	1.32	10	3	9.93
Epicoccum nigrum[3]	10	4	1.34	10	1	8.65
Control	--	--	1.18	--	--	7.40

[1] An asterisk denotes statistically significant differences between the test results with different isolates of the same fungal species.

[2] t-test ($\alpha = 0.05$).

[3] Not a basidiomycete.

TABLE 20

TOUGHNESS REDUCTIONS AS MEASURED BY BREAKING RADIUS AND IMPACT BENDING TESTS OF DOUGLAS-FIR HEARTWOOD EXPOSED TO SELECTED BASIDIOMYCETES ISOLATED FROM AIR-SEASONING POLES

FUNGAL SPECIES	BREAKING RADIUS TEST			IMPACT BENDING TEST		
	NO. OF ISOLATES TESTED[1]	NO. OF ISOLATES SIGNIFICANTLY HIGHER THAN CONTROL[2]	AVERAGE BREAKING RADIUS (IN)	NO. OF ISOLATES TESTED[1]	NO. OF ISOLATES SIGNIFICANTLY HIGHER THAN CONTROL[2]	AVERAGE IMPACT BENDING VALUES
Poria xantha	6*	6	2.48	6*	6	17.31
P. xantha monokaryon	5*	5	2.82	5*	5	20.85
Poria cinerascens	5	1	1.20	5	0	2.71
P. cinerascens monokaryon	6	6	1.29	6	2	4.81
Phlebia albida	1	0	1.21	1	0	2.87
P. albida monokaryon	1	1	1.33	1	0	4.05
Phlebia gigantea	3	3	1.29	3	0	3.64
Phlebia radiata	4	2	1.33	4	0	4.14
P. radiata monokaryon	6	1	1.18	6	0	2.71
Heterobasidion annosum	6	4	1.25	6	0	1.58
Sistotrema brinkmanii	6	3	1.23	6	0	4.07
Schizophyllum commune	6	2	1.22	6	0	4.32
Control	--	--	1.125	--	--	3.93

[1] An asterisk denotes statistically significant differences between the test results with different isolates of the same fungal species.

[2] t-test ($\alpha = 0.05$).

pages 40-41) we demonstrated that single, asexual spores (i.e. chlamydospores) were capable of establishing infections under near optimum conditions. Additionally, sexual spores (i.e. basidiospores) are important dissemination units for many decay fungi and isolation of monokaryons from our infection studies indicate that these spores play a similar role for P. carbonica. A method for obtaining spores in culture was developed and the environmental conditions favoring basidiospore germination were studied as predictive indicators of high-risk decay periods.

During this past year we continued to develop the methodology for studying the influence of wood temperature and moisture content on establishment of P. carbonica in Douglas-fir heartwood from basidiospore inoculum.

A method for studying spore germination on wood.

A method was developed for direct observation of germinating spores on wood, whereby thin Douglas-fir heartwood sections (8mm x 8 mm x 60 µm) were cut with a sliding microtome and placed between two glass slides to hold them flat. The slides containing the wood sections were placed in petri plates and autoclaved to sterilize the wood. The sections were removed from the slides, placed on sterile filter paper in petri plates, and inoculated with 25 µl of a spore suspension. Excess water was wicked through the sections by the filter paper, leaving the spores deposited on the wood sections. A second section was then placed on top, forming a "spore sandwich" with the spores between the two sections. The "spore sandwiches" were removed from the petri plates and placed between the halves of a

Douglas-fir block (2 by 1 by 1 cm), which was secured by rubber bands. The blocks were then placed in the desired temperature or humidity chamber for incubation.

Following the incubation period, the "spore sandwiches" were removed from between the blocks, and the wood sections were peeled apart. Each section was carefully placed, inner side up, on top of a small drop of stain (0.05 % trypan blue in lactophenol) that colored the spores without washing them from the sections. Microscopic examination of both sections allowed an equal chance for each spore to be counted as germinated. Spores were counted as germinated when the germ tube length exceeded the spore diameter.

A second set of blocks containing inoculated wood sections were incubated for 1 month, after which aseptic isolations were made 1 mm in from the split face on each block to determine colonization success of by the decay fungus. Wood chips were removed from the split face, plated on nutrient medium, and observed for fungal growth 1 month later.

Effect of wood moisture content on spore germination and colony establishment in wood.

Although decay fungi are known to require wood at or above the fiber saturation point to cause significant decay, the influence of wood moisture content on spore germination has yet to be critically studied.

The thin wood sections used in the spore sandwich were unsatisfactory for investigating the influence of wood moisture content on spore

germination because it was impossible to adjust and maintain the sections at a desired moisture content. However, the blocks enclosing the sections provided a volume of wood large enough to accurately achieve desired moisture levels, to which the sections rapidly equilibrated after insertion.

Wood blocks for studying the influence of moisture content on spore germination were oven dried, split with a razor blade, and banded together with the "spore sandwich" inside. Blocks below, at, and above fiber saturation were placed on glass supports in sterile, sealed jars over either a salt solution or distilled water to maintain the desired moisture content levels. The blocks were weighed before insertion of the "spore sandwich" and again after removal of the sections to obtain an average wood moisture content during the germination period.

Chlamydospores and basidiospores failed to germinate or colonize the Douglas-fir blocks at wood moisture contents below fiber saturation. However, the spores germinated and were able to establish colonies in wetter wood (Table 21). There were no significant differences between the germination rates of basidiospores and chlamydospores in blocks at and above fiber saturation. The higher moisture content of the fiber saturation blocks used for the basidiospore germination experiment was due to condensation on the blocks caused by a faulty temperature control. In an additional experiment with blocks at around 24% and 30% moisture content, chlamydospores also failed to germinate on wood below fiber saturation. These results suggest that free water is necessary for spore germination and establishment of a decay fungus colony.

TABLE 21

EFFECT OF WOOD MOISTURE CONTENT ON *PORIA CARBONICA* SPORE GERMINATION AND COLONY ESTABLISHMENT IN DOUGLAS-FIR HEARTWOOD BLOCKS.[1]

WOOD MOISTURE CONTENT[2] (%)		PERCENT GERMINATION[3]	PERCENT COLONIZATION[4]
Chlamydospores			
16.6	(15.4-17.5)	0	0
29.2	(25.2-34.7)	70.6	100
60.1	(38.2-81.3)	90.4	100
Basidiospores			
15.3	(14.8-16.0)	0	0
35.2	(30.8-39.0)	91.6	100
82.8	(71.0-99.0)	90.1	100

1 Data represents three replicate tests of 18 blocks each.

2 Average percent wood moisture content with the range in parenthesis.

3 Percent germination for the two higher moisture contents are not significantly different (Student's t-test, $p=0.02$).

4 Percent colonization is based on the number of successful isolations of *P. carbonica* from blocks incubated for 1 month.

Influence of temperature on spore germination and colony establishment in wood

The "spore sandwich" methodology was also used to study the influence of temperature on spore germination and colony establishment in wood. In this case, water saturated blocks (with the "spore sandwich" inserted) were suspended in cheesecloth bags over distilled water in

tightly stoppered 250 ml flasks. After incubating the flasks at different temperatures for several days, the blocks were weighed after removing the wood sections to determine moisture content, and the number of germinated spores per section was determined. Isolations were made from the blocks after incubating for 1 month to determine if fungal colonization had occurred. Since previous experiments showed frequency of spore germination to be independent of wood moisture content above fiber saturation, the blocks were adjusted and maintained at or above this moisture level.

While some fungal spores germinated between 0 and 10°C, the optimum temperature for germination was generally between 15 and 44°C. The influence of temperature on spore germination by wood decaying basidiomycetes is poorly understood, with most previous studies using malt extract agar as a substrate, the frequency of spore germination could be significantly different from that on wood.

Poria carbonica chlamydospores germinated most readily and were able to colonize Douglas-fir heartwood blocks at 22°C (Table 22). Germination frequencies at 5, 30, and 35°C were significantly lower than that at 22°C (Student's t-test, $p=0.05$). After incubating 3 days, the germ tubes of spores held at 22 and 33°C were between 100 and 1000 µm in length. Spore germination at 5 and 35°C was significantly lower than at 22°C, and germ tubes produced by these spores ranged from 10 and 100 µm in length, and were usually less than 50 µm.

The chlamydospores maintained at the two extreme temperatures were unable to establish colonies 1 mm into the blocks (Table 22). The germinating spores maintained at 35°C were probably killed by the prolonged high temperature, while the lower temperature probably limited

TABLE 22

EFFECT OF WOOD MOISTURE CONTENT ON PORIA CARBONICA SPORE GERMINATION AND COLONY ESTABLISHMENT IN DOUGLAS-FIR HEARTWOOD BLOCKS.[1]

TEMP. (C)	WOOD MOISTURE CONTENT[2] (%)		GERMINATION[3] (%)	COLONIZATION[4] (%)
Chlamydospores				
5	105.7	(95.4-137.1)	20	0
22	111.7	(73.4-150.9)	90	100
30	88.6	(71-113)	86	100
35	115.6	(94.2-157.3)	41	0
Basidiospore				
5	93.2	(63.9-117.2)	0	0
22	92.7	(67.3-115.2)	95	100
30	93.5	(79.9-106.5)	33	100
35	91.4	(71.9-111.6)	0	0

1 Data represents three replicate tests of 18 blocks each.

2 Average percent moisture content with the range in parenthesis.

3 Percent germination is significantly different for all temperatures (Student's t-test, p=0.05).

4 Percent colonization is based on the number of successful isolations of P. carbonica from blocks incubated for 1 month.

germination and colonization by slowing fungal metabolism. Spores at the lower temperature were probably not killed, and would have resumed growth had the temperature been raised.

The temperature range for germination of basidiospores of Poria carbonica was more restricted than that found for chlamydospores (Table 4). Basidiospores failed to germinate at 5 and 35°C, although some spore swelling was observed at 35°C. Germination was significantly lower at 30°C than at 22°C (Student's t-test, p=0.05), but colonies were established in the wood at both temperatures. Many of the ungerminated spores at 30°C were swollen after 3 days, suggesting they would germinate later.

Discussion of laboratory studies of Poria carbonica and their relationship to pole infection by decay fungi.

Poria carbonica is one of the major decayers of Douglas-fir poles in service and has been isolated from poles in air seasoning yards prior to pressure treatment. This decay fungus produces both chlamydospores and basidiospores that are capable of wind dispersal to establish colonies in wood.

Soil particles containing hyphal cells and chlamydospores, might be important short range dispersal propagules. P. carbonica could grow from colonized wood debris into the surrounding soil where, during dry conditions, soil particles similar to the ones used in our study could become air borne by wind or yard machinery. With sufficient moisture and favorable temperatures, a single clamydospore containing soil particle could land on a pole and start a new colony of P. carbonica in the pole. Whether this does, in fact, occur is unknown, however, the results of our tests indicate that it can occur.

Basidiospores are generally thought of as dispersal spores for many decay fungi. The isolation of P. carbonica monokaryons from air seasoning poles indicates that basidiospores are also acting as

dispersal spores for this decay fungus. Basidiospores which are small and can be wind borne for long distances are important as long range as well as short range dispersal spores.

Both chlamydospores and basidiospores require wood at or above fiber saturation to successfully colonize Douglas-fir heartwood, suggesting that poles are susceptible to colonization by P. carbonica as long as their moisture content exceeds this value. Moisture contents exceeding fiber saturation commonly occur in the soil/pole contact zones and checks where rainwater may be trapped.

Temperature is also an important environmental factor that must be within a favorable range for colonization of wood by decay fungi. However, non-germinated spores at low temperatures may still be viable, retaining the potential to establish colonies when conditions become more favorable. Temperatures between 5°C and 30°C appear favorable for colony establishment by P. carbonica chlamydospores and basidiospores in wood. However, temperatures between 5 and 22°C need to be tested to establish the minimum and optimum colonization temperatures.

A combination of favorable temperatures and sufficient water in the wood are necessary for successful colonization of wood by P. carbonica. While temperature would seldom be limiting in the Pacific Northwest's mild maritime climate, optimum moisture levels are more likely to occur during the winter months. Thus the potential for colonization by decay fungi would be highest during this period.

Our investigations of temperature and humidity influences on P. carbonica spore germination tested only the extremes. More carefully

controlled and graduated experiments are needed to define the optimums. However, these results suggest that temperature and moisture are very important in defining favorable periods for colonization by decay fungi.

The methodology used during these investigations have both strong points and weaknesses. The "spore sandwich" methodology placed spores in an environment that was surrounded by wood that restricted airflow and inhibited wetting or drying. This buffered environment could be quite similar to the surroundings spores encounter in the bottom of a check or crack in a pole, where successful colonization probably takes place. Exposed surfaces would be subject to greater temperature and moisture fluctuations and would be less likely to have conditions conducive to spore germination. While in a pole that is generally above fiber saturation, the surface is probably below fiber saturation during much of the year. Spores landing on this surface are less likely to be successful than those which fall into seasoning checks or cracks. Thus, the "spore sandwich" is measuring conditons where colonization is most likely to occur.

Infection Study

To study environment influences on how and when air seasoning poles become infected with decay fungi, sterilized pole sections were exposed horizontally and vertically for 3 month intervals at four locations in the Pacific Northwest. The sections were sampled after exposure and the resulting fungi cultured and identified. Details of the experimental design were presented earlier ('81 Ann. Rept., pages 42-44), and infection results over a 2 year period were summarized last year ('83 Ann. Rept., page 63).

During this past year we have continued our efforts to identify the basidiomycetes isolated, and, through computer analysis, study the correlation between the weather at the four sites and the pole infection results.

In our infection study, the isolation frequency of basidiomycetes was generally lower in the summer than in the winter months. A significant increase occurred in the period from November, 1981 to January, 1982 at three of the four sites, but this increase was not repeated the following year. During this interval, the frequency of decay fungi isolated increased from north to south. The northern most location, Arlington, WA, showed no increase during the time period from November, 1981 to January, 1982, but had a significant increase during May through July 1982.

Weather data for this study was obtained from the nearest U.S. Climatological Service weather stations. Data from Seattle, WA (urban site) was used for Arlington, WA. Arlington is about 45 miles north of Seattle, 20 miles east of the Puget sound, and experiences the same maritime climate as Seattle. Data from the Portland airport which is about 30 miles from the Scappoose, OR, site was used. The data for Eugene, OR was collected at the airport, which is about 4 miles from the study site, and data from Red Bluff, CA (60 miles from the study site in Oroville) was used since both are located in the Sacramento Valley, and experience similar weather patterns.

Effects of precipitation. Moisture is an important factor in spore release and germination. The number of days with measurable precipitation at each plot location was significantly higher during the

period from November 1981 to January 1982 than during any other 3 month period (Table 23). This increase in days with precipitation was probably responsible for a portion of the higher frequency of decay fungi isolated from pole sections exposed during this period. Increased precipitation could have resulted in higher initial fungal inoculum levels, an increase in the percentage of propagules which successfully colonized the wood, or an increase in the growth rate of the decay fungi in the wood.

TABLE 23

NUMBER OF DAYS WITH DETECTABLE PRECIPITATION AT FOUR LOCATIONS IN THE PACIFIC NORTHWEST

WEATHER STATION LOCATION[1]	NUMBER OF DAYS WITH DETECTABLE PRECIPITATION DURING 3 MONTH INTERVALS						
Begin	5/81	8/81	11/81	2/82	5/82	8/82	11/82
End	7/81	11/81	1/82	4/82	7/82	11/82	1/83
Seattle, WA	49	39	72	54	39	46	53
Portland, OR	46	32	74	64	26	44	54
Eugene, OR	--	39	71	50	30	40	57
Red Bluff, CA	11	14	52	35	9	22	52

[1] Weather data was from the U.S. Climatological Service weather station closest to each infection study plot.

Effects of temperature. While increased wood moisture levels helped to increase the isolation frequency of basidiomycetes from the northern to the southern-most plots during the period from November 1981 to January 1982, the increase might also have resulted from an increased number of days with temperatures conducive to fungal growth (Table 24). During this period, the number of days with temperatures

TABLE 24

NUMBER OF DAYS WITH AN AVERAGE DAILY TEMPERATURE EQUAL TO OR GREATER THAN 10°C AT FOUR LOCATIONS IN THE PACIFIC NORTHWEST

WEATHER STATION LOCATION[1]	NUMBER OF DAYS WITH AN AVERAGE TEMPERATURE ABOVE 10°C DURING 3 MONTH INTERVALS						
Begin	5/81	8/81	11/81	2/82	5/82	8/82	11/82
End	7/81	11/81	1/82	4/82	7/82	11/82	1/83
Seattle, WA	93	94	32	60	92	94	24
Portland, OR	92	96	47	93	73	90	36
Eugene, OR	—	87	35	78	99	76	17
Red Bluff, CA	92	93	81	85	99	87	69

[1] Weather data was from the U.S. Climatological Service weather station closest to each infection study plot.

above 10°C was lowest in Seattle and highest in Red Bluff. The lack of any increase in isolation frequency of basidiomycetes from pole sections exposed in Arlington was probably due to cold temperatures. Eugene had fewer warm days than Portland during this period, yet the isolation frequency of basidiomycetes was higher from sections exposed in Eugene than from those exposed in Scappoose. This may have resulted from a higher local inoculum level in Eugene. The study site was located in an area near several log storage yards where the large volume of wood and debris could have harbored sporophores that increased the local spore density.

Effect of temperature and precipitation on moisture content of the pole sections. As discussed previously, germination and colony establishment by basidiospores requires wood above fiber saturation.

Generally accepted values for fiber saturation in Douglas-fir heartwood range from about 26 to 32% moisture content (based on oven dry weight). Since temperature and precipitation interact to affect the moisture content of wood (e.g. high temperatures increase the drying rate and more precipitation is required to keep wood above fiber saturation, while, less precipitation is required to reach and maintain fiber saturation at low temperatures), it is likely that temperature and precipitation interactions were responsible for the increased isolation frequency of basidiomycetes during the period from November 1981 to January 1982. Pole section moisture contents were well above fiber saturation at all locations during this period (Table 25). During the other periods studied, however, either temperature or precipitation was unfavorable for infection and the moisture content of the pole sections fell below fiber saturation, thus limiting spore germination and fungal colonization of the wood.

Species of decay fungi isolated from sterilized pole sections. About 30 different species of decay fungi have been identified from the isolates cultured from sterilized pole sections placed at all four plot locations (Tables 26-29). With the exception of the period from November 1981 to January 1982, the isolation frequency of basidiomycetes was low, but nevertheless colonization occurred throughout the year at all four locations. The basidiomycetes isolated differed between locations. This variation was probably due to differences in climate, pole sources, and local inoculum sources.

TABLE 25

MOISTURE CONTENT OF STERILIZED POLE SECTIONS EXPOSED FOR THREE MONTH INTERVALS AT FOUR LOCATIONS IN THE PACIFIC NORTHWEST

EXPOSURE SITE	WOOD MOISTURE CONTENT (% DRY WT.) 2 INCHES FROM THE SURFACE OF POLE SECTIONS EXPOSED FOR 3 MONTH INTERVALS						
Begin	5/81	8/81	11/81	2/82	5/82	8/82	11/82
End	7/81[1]	11/81	1/82	4/82	7/82	11/82	1/83
Arlington, WA	15	28	42	20	16	17	27
Scappoose, OR	14	25	41	17	19	20	31
Eugene, OR	--[2]	26	39	16	13	15	29
Oroville, CA	8	23	34	10	8	12	21

1 Pole sections used in the first exposure period were not sterilized.

2 Results lost due to contamination of the culture plates by a Neurospora sp.

The frequency of different basidiomycetes isolated from the exposed pole sections summed over all the 3 month periods increased from north to south (Table 30). The frequency of Poria placenta mono and dikaryons was particularly high, with monokaryons more abundant than dikaryons at three of the four locations. This suggests that basidiospores are responsible for a high percentage of the pole colonization by P. placenta, and that basidiospore sources at each location may be relatively homogeneous.

TABLE 26

FREQUENCY OF BASIDIOMYCETES ISOLATED
FROM STERILIZED POLE SECTIONS EXPOSED FOR
THREE MONTH INTERVALS AT ARLINGTON, WA

	NUMBER OF CORES CONTAINING BASIDIOMYCETES ISOLATED FROM POLE SECTIONS AFTER 3 MONTHS EXPOSURE						
FUNGI	BEGIN 5/81 END 7/81[1]	8/81 11/81	11/81 1/82	1/82 4/82	5/82 7/82	8/82 11/82	11/82 1/83
Poria placenta (dikaryon)	1	3	0	0	5	0	0
monokaryon	0	0	2	0	2	2	0
Stereum hirsutum	0	0	2	0	0	0	0
Peniophora spp.	0	2	3	0	0	0	0
Sistotrema brinkmanii	0	0	1	0	0	0	0
Phanerochaete sordida	1	1	0	0	0	4	0
Poria xantha (dikaryon)	0	0	0	0	0	1	0
monokaryon	0	0	0	0	1	0	0
Epicoccum nigrum[2]	0	0	0	0	1	0	0
Coriolus versicolor (monokaryon)	0	0	1	0	0	1	1
Phlebia radiata (dikaryon)	0	1	0	0	0	0	0
monokaryon	1	0	0	0	0	0	0
Phlebia 'A' (monokaryon)	0	0	0	0	0	1	0
Poria carbonica (dikaryon)	0	1	0	0	1	0	0
monokaryon	0	1	0	0	0	0	0
Phlebia gigantea	0	0	0	0	0	1	0
Poria cinerascens (monokaryon)	0	0	0	0	0	0	1
Phlebia albida	0	0	1	0	0	0	0
Unidentified Basidiomycete	4	2	1	2	2	0	0
Unidentified suspect fungi[3]	2	1	4	3	16	1	0
Number of cores with fungi[4]	17	14	44	15	8	4	3
Total cores taken	335	211	283	288	257	350	251
Percent cores with fungi	5.1	6.6	15.3	5.2	3.1	111	1.2

[1] Pole sections in the first exposure period were not sterilized.

[2] Not a basidiomycete.

[3] Suspect fungi are those isolates which have basidiomycetous characteristics but lack clamp connections.

[4] Does not equal the sum of the column as cores may contain more than one fungus.

TABLE 27

FREQUENCY OF BASIDIOMYCETES ISOLATED FROM STERILIZED POLE SECTIONS EXPOSED FOR THREE MONTH INTERVALS AT SCAPPOOSE, OR

	NUMBER OF CORES CONTAINING BASIDIOMYCETES ISOLATED FROM POLE SECTIONS AFTER 3 MONTHS EXPOSURE						
BEGIN	5/81	8/81	11/81	1/82	5/82	8/82	11/82
FUNGI END	7/81[1]	11/81	1/82	4/82	7/82	11/82	1/83
Poria placenta (dikaryon)	0	0	3	2	0	0	0
monokaryon	1	5	8	1	1	1	0
Stereum hirsutum	3	1	1	0	1	0	0
Peniophora spp.		1	18	0	0	0	0
Sistotrema brinkmanii	0	1	1	0	0	0	0
Phanerochaete sordida	0	3	0	0	3	2	0
Haematostereum sanguinolentum	0	0	1	3	0	0	0
Poria xantha (monokaryon)	4	0	4	0	0	0	0
Coriolus versicolor (dikaryon)	0	0	0	1	0	0	0
monokaryon	1	0	0	1	1	0	0
Phlebia radiata (dikaryon)	0	0	1	0	0	0	0
monokaryon	0	0	1	0	0	0	0
Phlebia 'A' (monokaryon)	0	0	1	0	0	0	0
Phlebia gigantea	0	0	0	0	0	0	1
Heterobasidion annosum	0	0	0	1	0	0	1
Poria cinerascens (monokaryon)	0	0	0	1	0	0	1
Unidentified Basidiomycetes	1	1	3	0	0	0	0
Unidentified suspect fungi[2]	7	2	3	6	2	1	0
Number of cores with fungi[3]	17	14	44	15	8	4	3
Total cores taken	335	211	288	288	257	360	261
Percent cores with fungi	5.1	6.6	15.3	5.2	3.1	111	1.2

[1] Pole sections in the first exposure period were not sterilized.

[2] Suspect fungi are those isolates which have basidiomycetous characteristics but lack clamp connections.

[3] Does not equal the sum of the column as cores may contain more than one fungus.

TABLE 28

FREQUENCY OF BASIDIOMYCETES ISOLATED FROM STERILIZED POLE SECTIONS EXPOSED FOR THREE MONTH INTERVALS AT EUGENE, OR

	NUMBER OF CORES CONTAINING BASIDIOMYCETES ISOLATED FROM POLE SECTIONS AFTER 3 MONTHS EXPOSURE						
	BEGIN 5/81	8/81	11/81	1/82	5/82	8/82	11/82
FUNGI	END 7/81[1]	11/81	1/82	4/82	7/82	11/82	1/83
Poria placenta (dikaryon)	-	0	5	1	0	0	0
monokaryon	-	0	11	1	0	0	2
Stereum hirsutum	-	0	9	1	0	1	1
Peniophora spp.	-	0	16	0	0	0	0
Sistotrema brinkmanii	-	0	30	0	0	0	0
Haematostereum sanguinolentum	-	0	3	0	0	0	0
Poria xantha (monokaryon)	-	0	0	0	0	1	0
Epicoccum nigrum[2]	-	0	0	2	1	0	0
Coriolus versicolor	-	0	0	0	0	3	0
Unidentified Basidiomycetes	-	11	16	0	0	0	1
Unidentified suspect fungi[3]	-	6	6	1	1	0	1
Number of cores with fungi[4]	-	17	92	6	2	5	5
Total cores taken	-	209	288	280	281	269	293
Percent cores with fungi	-	8.1	32.9	2.1	0.7	1.9	1.7

1 Pole sections in the first exposure period were not sterilized.

2 Not a basidiomycete.

3 Suspect fungi are those isolates which have basidiomycetous characteristics but lack clamp connections.

4 Does not equal the sum of the column as cores may contain more than one fungus.

TABLE 29

FREQUENCY OF BASIDIOMYCETES ISOLATED
FROM STERILIZED POLE SECTIONS EXPOSED FOR
THREE MONTH INTERVALS AT OROVILLE, CA

	NUMBER OF CORES CONTAINING BASIDIOMYCETES ISOLATED FROM POLE SECTIONS AFTER 3 MONTHS EXPOSURE						
BEGIN	5/81	8/81	11/81	2/82	5/82	8/82	11/82
FUNGI END	7/81[1]	11/81	1/82	4/82	7/82	11/82	1/83
Poria placenta (dikaryon)	1	0	12	0	0	0	0
monokaryon	1	0	16	0	0	0	0
Stereum hirsutum	0	1	25	7	0	2	0
Peniophora spp.	0	2	21	1	0	0	0
Sistotrema brinkmanii	0	2	2	0	0	1	0
Phanerochaete sordida	1	0	17	2	0	0	0
Poria xantha	0	0	3	0	0	0	0
Epicoccum nigrum[2]	0	0	1	1	0	0	0
Coriolus versicolor (dikaryon)	1	0	0	1	0	0	0
monokaryon	0	1	0	1	0	0	0
Phlebia radiata (monokaryon)	0	0	1	0	0	1	0
Phlebia 'A' (monokaryon)	0	0	0	0	0	1	0
Poria cinerascens (monokaryon)	0	0	0	0	0	1	0
Fomitopsis cajanderi (monokaryon)	0	1	0	0	0	0	0
Unidentified Basidiomycetes	1	1	7	5	0	0	0
Unidentified suspect fungi[3]	2	3	5	6	4	2	0
Number of cores with fungi[4]	7	11	103	17	4	8	0
Total cores taken	183	222	301	288	265	261	275
Percent cores with fungi	3.8	5.0	34.2	5.9	1.5	3.1	0

1 Pole sections in the first exposure period were not sterilized.

2 Not a basidiomycete.

3 Suspect fungi are those isolates which have basidiomycetous characteristics but lack clamp connections.

4 Does not equal the sum of the column as cores may contain more than one fungus

TABLE 30

FREQUENCY OF BASIDIOMYCETES ISOLATED
FROM STERILIZED POLE SECTIONS EXPOSED FOR
THREE MONTH INTERVALS AT FOUR SITES IN THE PACIFIC NORTHWEST

FUNGI	PERCENT OF THE TOTAL CORES CONTAINING BASIDIOMYCETES ISOLATED FROM POLE SECTIONS EXPOSED AT FOUR LOCATIONS FOR 3 MONTH INTERVALS OVER A 21 MONTH PERIOD.[1]			
	ARL.	SCA.	EUG.	ORO.
Poria placenta (dikaryon)	0.5	0.3	0.4	0.7
monokaryon	0.3	0.9	0.9	0.9
Stereum hirsutum	0.1	0.3	0.7	1.9
Peniophora spp.	0.3	0.7	1.0	1.3
Sistotrema brinkmanii	0.1	0.1	1.9	0.3
Phanerochaete sordida	0.3	0.4	-	1.1
Haematostereum sanguinolentum	-	0.4	0.2	-
Poria xantha (dikaryon)	0.1	-	-	0.2
monokaryon	0.1	0.2	0.1	0.1
Epicoccum nigrum[2]	0.1	-	0.2	0.1
Coriolus versicolor (dikaryon)	-	0.1	0.2	0.1
monokaryon	0.2	0.1	-	-
Phlebia radiata (dikaryon)	0.1	0.1	-	0.1
monokaryon	0.1	0.1	-	0.1
Phlebia 'A' (monokaryon)	0.1	0.1	-	-
Poria carbonica (dikaryon)	0.1	-	-	-
monokaryon	0.1	-	-	-
Phlebia gigantea	0.1	0.1	-	-
Heterobasidion annosum	-	0.1	-	
Poria cinerascens (monokaryon)	0.1	0.1	-	0.1
Fomitopsis cajanderi	-	-	-	0.1
Phlebia albida	0.1	-	-	-
Unidentified Basidiomycetes	0.6	0.1	1.7	0.8
Unidentified suspect fungi[3]	1.5	1.1	0.9	1.2
Number of cores with basidiomycetes	78	105	127	150
Total number of cores	1848	2000	1620	1795
Percent cores with basidiomycetes	4.2	5.3	7.8	8.4

1 ARL. = Arlington, WA; SCA. = Scappose, OR
EUG. = Eugene, OR ; ORO. = Oroville, CA

2 Not a basidiomycete.

3 Suspect fungi are those isolates which have basidiomycetous characteristics but lack clamp connections.

Frequency of decay fungi in sterilized pole sections exposed for six month intervals. Generally, there was an increase in the number of species and in the frequencies of individual species of basidiomycetes isolated from pole sections exposed for 6 months compared to sections exposed for 3 months (Table 31). This was due, in part, to the longer incubation time that allowed more of the colonies in the wood to grow to detectable sizes. For example, Crustoderma dryinum was not isolated from poles sections exposed for 3 months, but was from sections exposed for 6 months. However, Peniophora spp., which were abundant in poles sections exposed for 3 months, decreased in relative frequency in pole sections exposed for 6 months. This pattern is similar to the trends in air seasoning poles and is probably due to depletion of readily available carbohydrates in the sapwood, where Peniophora was usually found.

The isolation frequencies of P. placenta were much higher in pole sections exposed at Scappoose and Eugene than in those exposed at Arlington and Oroville. This variation could be due to higher spore concentrations at Eugene and Scappoose since the number of sporophore containing untreated logs, stored in and around these yards was greater than at Arlington and Oroville.

Colonization of the different pole surfaces. There were no significant differences between the isolation frequencies of basidiomycetes from the different surfaces sampled on the 2 and 4-foot pole sections for all the exposure periods combined (Table 32). However, individual species exhibit distinct distribution patterns reflecting their relative competitiveness in the different pole zones. For example,

TABLE 31

FREQUENCY OF BASIDIOMYCETES ISOLATED
FROM STERILIZED POLE SECTIONS EXPOSED FOR
6 MONTHS AT FOUR LOCATIONS IN THE PACIFIC NORTHWEST

	PERCENT CORES CONTAINING BASIDIOMYCETES ISOLATED FROM POLE SECTIONS EXPOSED FOR TWO 6 MONTH INTERVALS AT FOUR LOCATIONS[1]							
	May - Nov. 1981[2]				Nov. - May 1982			
FUNGAL SPECIES	A	S	E	O	A	S	E	O
Poria placenta (dykaryon)	-	0.8	0.9	-	0.7	26.7	19.3	4.5
monokaryon	0.4	0.8	1.8	-	3.1	13.4	6.8	9.6
Stereum hirsutum	0.4	-	-	0.4	0.7	2.5	3.2	10.1
Peniophora spp.	2.2	-	-	-	1.0	1.1	0.7	2.8
Haematostereum sanguinolentum	6.7	-	-	-	3.1	-	0.4	-
Sistotrema brinkmanii	-	0.4	0.4	-	2.1	-	3.9	-
Crustoderma dryinum	-	-	-	-	0.7	1.1	2.5	-
Poria carbonica (dikaryon)	-	0.8	-	-	-	-	0.4	-
monokaryon	-	1.2	-	-	-	-	-	-
Coriolus versicolor (dikaryon)	-	-	-	-	-	-	0.7	-
monokaryon	-	-	0.4	-	0.3	1.1	-	0.3
Phlebia radiata (dikaryon)	0.9	-	0.4	-	0.3	1.1	-	-
monokaryon	-	-	0.9	-	1.0	-	-	-
Poria xantha (dikaryon)	-	-	-	-	-	2.9	-	-
monokaryon	-	-	-	-	-	0.7	0.4	0.7
Phanerochaete sordida	0.4	0.4	0.4	0.4	0.3	-	-	-
Phlebia 'A' (monokaryon)	-	-	-	-	-	0.3	0.7	-
Unidentified Basidiomycetes	1.3	1.6	1.3	0.4	5.6	14.4	7.8	5.9
Unidentified suspect fungi[3]	0.9	3.6	1.3	1.4	2.8	5.8	2.1	10.4
Percent of cores with fungi	12.0	12.7	7.6	3.2	20.5	59.6	47.5	41.8
Total cores taken	225	244	224	219	288	277	280	287

1 A = Arlington, WA; S = Scappoose, OR
E = Eugene, OR; O = Oroville, CA

2 Poles sections in the first exposure period were not sterilized.

3 Suspect fungi are those isolates which have basidiomycetous characteristics but lack clamp connections.

TABLE 32

FREQUENCY AND DISTRIBUTION OF BASIDIOMYCETES ON STERILIZED POLE SECTIONS EXPOSED FOR 3 MONTH INTERVALS AT FOUR LOCATIONS IN THE PACIFIC NORTHWEST

	PERCENT CORES CONTAINING BASIDIOMYCETES ISOLATED FROM POLE SECTIONS EXPOSED FOR 3 MONTH INTERVALS.				
	TWO FOOT SECTIONS		FOUR FOOT SECTIONS		
FUNGI SPECIES	TOP	MIDDLE	TOP	UPPER	BUTT
Poria placenta (dikaryon)	4.2	1.2	1.9	0.8	1.9
monokaryon	2.1	1.4	2.6	1.8	1.7
Stereum hirsutum	1.4	1.5	1.2	0.8	1.3
Peniophora spp.	0.4	0.9	0.6	3.5	0.5
Sistotrema brinkmanii	0.6	0.7	0.8	0.5	1.1
Phanerochaete sordida	0.7	0.2	0.6	0.4	0.2
Haematostereum sanguinolentum	0.4	0.3	0.6	3.5	0.5
Crustoderma dryinum	0.5	0.1	0	0	0
Poria xantha (dikaryon)	<[2]	0	0.3	0.5	0.2
monokaryon	0.1	0.1	0.4	0.2	0.2
Epiccoccum nigrum[1]	<	0	0.4	0.2	0.3
Coriolus versicolor (dikaryon)	0.1	0.1	0.2	0	0.1
monokaryon	<	0.1	0.3	0.3	0
Phlebia radiata (dikaryon)	0	0.1	0	0.3	0.1
monokaryon	0	0.3	0.2	0.1	0.1
Phlebia 'A' (monokaryon)	<	0.1	0.1	0.1	0.1
Poria carbonica (dikaryon)	<	0.1	0	0.1	0
monokaryon	<	0	0	0	0
Phlebia gigantea	0	0.1	0	0	0
Heterobasidion annosum	0	0.1	0	0	0
Antrodia serialis	0	0.1	0	0	0
Fomitopsis pinicola	0	0	0	0	0.1
Poria cinerascens (dikaryon)	<	0	0	0	0
monokaryon	<	0.1	0.1	0	0
Fomitopsis cajanderi(monokaryon)	0	0	0	0	0.1
Unidentified Basidiomycetes	3.0	0.9	1.8	1.9	1.3
Unidentified suspect fungi[3]	2.2	1.4	2.2	1.2	1.5
Number of cores with fungi[4]	329	179	145	135	117
Total cores taken	2269	1928	1137	1177	1148
Percent cores with fungi	14.5	9.3	12.8	11.5	10.2

1 Not a basidiomycete.

2 "<" = one isolate, which is less than 0.1%

3 Suspect fungi are those isolates which have basidiomycetous characteristics but lack clamp connections.

4 Does not equal the sum of the column as cores may contain more than one fungus.

Poria placenta was isolated more frequently from the exposed heartwood at the ends of the sections than from the upper pole surface. Conversely, Peniophora spp. and Haematostereum sanguinolentum were isolated more frequently from the upper surfaces.

The use of pole sections as "spore traps" to estimate the relative frequencies of decay fungi has both positive and negative aspects. Although frequency of decay fungi isolated may not reflect the actual population of fungal propagules in the study area, the decay fungi isolated are those fungi whose propagules can land, germinate, and establish a colony large enough to be detected. The viability of the propagules, competition between fungi on the pole sections, growth rate of the basidiomycetes, and weather conditions all affect the frequency of isolation. However, the pole sections used in this study accurately detect those fungi that can infect and decay poles in air seasoning yards and thus produces results that are more meaningful than total spore counts would have been.

The variation in isolation frequency of individual basidiomycetes between yards suggests that sanitation measures aimed at reducing the inoculum level by removing wood that may contain decay fungi could reduce pole colonization. Some of the measures to implement this would include: (i) the use of treated stickers and skids, (ii) removal of all wood debris adjacent to air seasoning poles, (iii) avoiding bulk log storage adjacent to the seasoning yard, and (iv) prompt removal of cull poles. These actions are especially critical during the winter months when the conditions are favorable for colonization of wood by decay fungi.

Decay Development Study

This experiment was designed in 1981 ('81 Ann. Rept., pages 44-45) to determine the volume of wood colonized by basidiomycetes during air-seasoning. The pole sections were extensively sampled following exposure so that a three-dimensional estimate of the colonized wood could be obtained. Currently we are sampling pole sections exposed for 3 years. The basidiomycetes isolated from pole sections seasoned for 1 and 2 years have been identified, and the results have been entered into a data base that will be analyzed to provide an estimate of the volume of wood colonized by individual decay fungi, and the pattern of colonization. The computer analyses will be made after entering this year's results into the data base.

D. INVESTIGATE METHODS OF PREVENTING INFECTION OF POLES BY DECAY FUNGI DURING AIR-SEASONING AND FOR ELIMINATING THE DECAY FUNGI PRIOR TO AND DURING PROCESSING.

In 1981, 15 pole sections (6 ft. long) placed horizontally on treated skids at each of the four test sites, were treated by flooding with a 32% solution of ammonium bifluoride (NH_4HF_2). In 1982 and 1983 five pole sections were extensively sampled to determine the influence of NH_4HF_2 on colonization of the air-seasoning wood by basidiomycetes. We are currently completing identification of the decay fungi isolated in '82 and '83, and are sampling an additional set of pole sections exposed for 3 years. Results of this test will be analyzed with the decay development results and presented in detail later. However, a preliminary analysis of the results from poles exposed for 2 years shows that NH_4HF_2 significantly reduced the incidence of basidiomycetes (Table 33).

Because there were some basidiomycetes already present in the pole sections before treatment with NH_4HF_2, another test was set up at the Northwest Forest Genetics Center near Corvallis, OR in which a 20% solution of NH_4HF_2 was drenched on 4 ft. Douglas-fir pole sections that had been heat sterilized. In addition, gelatin encapsulated chloropicrin and methylisothiocyanate were applied to some nonsterile pole sections to determine if the fumigants could protect air seasoning wood from colonization by decay fungi.

Preliminary results from these tests show that after 1 year both NH_4HF_2 and the fumigants significantly reduced basidiomycete colonization of the sterile wood (Table 34). Strong fumigant odors were detected at sampling sites suggesting that these chemicals may produce additional reductions in the decay fungus population with increasing exposure time. Analysis of the basidiomycete species isolated is currently underway to determine if the fungi isolated from the treated wood are the same as those known to initiate decay of in service Douglas-fir poles.

TABLE 33

THE INFLUENCE OF AMMONIUM BIFLUORIDE ON THE FREQUENCY OF DECAY FUNGI IN DOUGLAS-FIR POLE SECTIONS AIR SEASONED FOR 2 YEARS AT FOUR LOCATIONS IN THE PACIFIC NORTHWEST

AIR SEASONING LOCATION	PERCENTAGE OF CORES CONTAINING DECAY FUNGI[1]	
	UNTREATED CONTROL	AMMONIUM BIFLUORIDE TREATED[2]
Arlington, WA	66.4	45.2
Scappoose, OR	71.5	45.6
Eugene, OR	64.3	25.1
Oroville, CA	40.0	12.1

1 Percentages are based on a total of 1845 and 1943 cores from 18 control pole sections and 19 pole sectionsd treated with ammonium bifluoride respectively.

2 Pole sections were flooded with a 20% solution of ammonium bifluoride on the upper surfaces and end grains at the initiation of air seasoning.

TABLE 34

THE FREQUENCY OF DECAY FUNGI ISOLATED FROM DOUGLAS-FIR POLE SECTIONS TREATED WITH FUMIGANTS PRIOR TO AIR SEASONING FOR 1 YEAR IN CORVALLIS, OR

CHEMICAL TREATMENT	TOTAL NO. OF CORES TAKEN	NO. OF CORES WITH DECAY FUNGI	PERCENT OF CORES WITH DECAY FUNGI
Sterilized pole sections			
Ammonium bifluoride[1]	960	46	4.8
Control	936	171	18.3
Nonsterile pole sections [2]			
Chloropicrin	902	113	12.5
Methylisothiocyanate	887	118	13.3
Control	936	432	46.2

1 Pole sections were drenched with 20% solution of ammonium bifluoride.

2 Chloropicrin and methylisothiocyanate were applied (74 ml per 4 ft. pole section) encapsulated in four gelatin capsules placed in two holes per pole section.

VI. DETERMINE THE EXTENT OF AND POTENTIAL FOR EXTERNAL DECAY OF PRESERVATIVE TREATED DOUGLAS-FIR IN GROUND CONTACT

While fumigant treatments have effectively controlled decay fungi for over 14 years, non-decay fungi have colonized the fumigated wood at relatively high levels. Although the role of these fungi in fumigant treated wood is unclear, non-decay fungi have been implicated in preservative detoxification, decay fungus inhibition, soft-rot, and may affect fumigant effectiveness. Since a number of test lines are approaching the point where fumigant retreatment might be necessary, we thought it advisable to determine the role of non-decay fungi in fumigant treatment.

Thus, a limited survey was made of non-decay fungi present in poles fumigated with Vapam in 1969.

Preliminary studies of cores extracted 6 inches to 6 feet above or below the groundline of Douglas-fir utility poles 14 years after fumigant treatment indicated the presence of a diverse fungal flora (Table 35). As expected, the non-decay fungi were more abundant and diverse in the non-fumigated controls; however, the levels in fumigant treated poles were still quite high. Among the fungi isolated were several cellulolytic fungi (Scytalidium and Trichoderma viride) and one genus that is reported to be antagonistic to decay fungi (Scytalidium). The latter fungus might be enhancing fumigant effectiveness by preventing reentry of decay fungi, although more work would be necessary to confirm this effect.

In addition, three species (T. viride, Pennicillium italicum, Oidiodendron sp.) were only isolated from the fumigant treated wood, suggesting that fumigant treatment selectively alters the fungal flora.

TABLE 35

RELATIVE FREQUENCY OF FUNGI ISOLATED FROM VAPAM TREATED AND NONTREATED DOUGLAS-FIR UTILITY POLES [1]

FUNGAL SPECIES	VAPAM WRAPPED[2]	VAPAM UNWRAPPED	VAPAM TOTAL	CONTROL TOTAL
Scytalidium lignicola	1	13	6	35
Scytalidium sp.	0	0	0	12
Penicillium italicum	17	6	11	0
Penicillium sp A	3	4	3	10
Basidiomycetes	8	21	14	43
Trichoderma viride	3	0	2	0
Trichoderma sp A	0	0	0	10
Trichoderma sp B	0	0	0	6
Oidiodendron sp	8	0	4	0
Chalara sp	0	0	0	27

1 Fungi were isolated from cores removed from 6 inches to 6 feet above and below the groundline. Relative frequency = $\frac{\text{number of isolations of a species}}{\text{total isolations attempted}} \times 100$

2 Poles were wrapped after fumigation. Wrap deteriorated after 2 years.