ABSTRACT

Improved Fumigants

After 13 years, chloropicrin, methylisothiocyanate (MIT), Vapam, and Vorlex continue to effectively control internal decay of pressure-treated Douglas-fir transmission poles. The estimated retreating schedules for application of these fumigants to treated wood may be as long as 10 years for Vapam and 15 years for the others. The close-tube bioassay, developed during this research, has proven to be an effective method for determining the persistence of these fumigants in wood and should help in determining when fumigant-treated poles should be retreated.

The use of gelatin to encapsulate MIT for wood treatment was ideal because the capsules did not react with MIT, were MIT impermeable when dry, permitting prolonged storage without significant fumigant loss, and readily released MIT when moistened in the wood.

Although release of encapsulated MIT in the wood was enhanced by small amounts of water, excess moisture appeared to hinder MIT diffusion into wood. Assays of Vapam treated wood show that the amount of MIT released by breakdown of Vapam is significantly lower than the expected theoretical yield from this fumigant. Encapsulated MIT reduced the decay fungus population in poles in service more effectively than applications of Vapam.

The effectiveness of a fumigant in controlling decay may be expressed as the product of the fumigant concentration (C) and the time (T) the decay fungus is exposed to the fumigant before it succumbs. A higher value indicates a less effective treatment. In wood, the CT value obtained for MIT was two times greater at 20% wood moisture content (MC) than at 40 and 75% MC. Although MIT was least effective at 20% MC, there was more MIT

bound to the wood than at the higher moisture levels. This suggests that the MIT bound to the wood structure may be less effective against decay fungi than the MIT in the air and water in the wood. Although the effectiveness of MIT varied with the wood MC, it was nevertheless still very fungitoxic over a broad range of moisture levels.

In chloropicrin treated wood, inhibition of invasion by decay fungi was indicated by the lysis and vacuolation of the fungal hyphae in the wood. Chloropicrin appears to hydrogen bond to wood and may form covalent bonds with phenolic wood extractives and lignin, possibly increasing the persistence of the treatment.

[illegible] have been added to the previously selected [illegible] cedar pole sections at an O.S.U. test site as potential substitutes for the pentachlorophenol in oil treatment currently used. The effectiveness of all treatments will be evaluated later this year using the Aspergillus bioassay and a modified soil block test. The most effective treatments then will be tested on poles in service.

Bolt-hole protection

Later this year cores will be removed from the control bolt holes to evaluate the extent of natural fungal colonization. If a sufficient level of colonization has occurred, the effectiveness of the various chemical treatments in preventing decay in field-drilled bolt holes in Douglas-fir poles will be evaluated.

Detecting decay and estimating residual strength in poles

A serological technique for rapid detection of decay fungi was found to cross react with non-decay fungi and thus lacked the necessary specificity

for identifying decay fungi in wood. Additional work is needed to purify the preparations to render them more specific to decay fungi.

Measurements of modulus of rupture (MOR), modulus of elasticity (MOE), work to maximum load, specific gravity, radial compression strength (RCS), and Pilodyn pin penetration of sound appearing wood containing decay fungi were not significantly different from the corresponding values for wood from which no decay fungi were isolated. However, tests of poles with more advanced decay did show significant reductions in wood strength properties. Specific gravity alone was not a good predictor of bending strength of wood from decayed poles, but the use of both specific gravity and RCS tests significantly improved the ability to predict the bending strength of these wood samples.

Decay of Douglas-fir poles prior to pressure treatment

The continued study of the fungal infestation of poles during air seasoning has demonstrated that there is a significant buildup of Poria carbonica, the major pole decay fungus, with time. In general, as air seasoning time increased, decay fungi infested more poles and occupied more wood within each pole. Sampling of freshly cut poles in the forest this past year showed that some contained potential decay fungi prior to reaching the pole yard. Frequent isolation of decay fungus monokaryons throughout the air seasoning period suggests that spores of these fungi were infesting the poles at a relatively constant rate. The ability of the basidiomycetes isolated from these poles to reduce wood strength will be evaluated in rapid tests for toughness by impact breaking and changes in the breaking radius of Douglas-fir test sticks.

The germination of basidiospores of P. carbonica was studied on culture medium and laboratory techniques are being developed to follow germination on a wood surface under varying environmental conditions to further illucidate their role in the infestation of seasoning wood.

Exposure of sterilized pole sections at four Pacific Northwest air-seasoning sites for successive 3-month periods has been continued. The dramatic increase in infection during Nov.-Jan. '81 at all locations except Arlington WA, did not reoccur in that same time period during 1982. There was, however, a continuing low level of infection at all sites during the year with a slight peak of infection in May-June '82 in Arlington WA. The results of these tests are currently being computer analyzed to more effectively study the patterns of fungal invasion of wood as influenced by environmental factors.

COOPERATORS

Electrical Utilities

*Bonneville Power Adm.

*Empire State Electric Energy Research Corp.

Idaho Power Co.

New York State Electric and Gas Corp.

*Portland General Electric Co.

*Western Wood Preservers Institute

J. H. Baxter & Co.

Koppers Co., Inc.

McFarland-Cascade Co.

Niedermeyer-Martin Co.

Pole Supplier

Crown Zellerbach Corp.

*U.S.D.A. Forest Service, Forest Products Laboratory

*OSMOSE

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*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 research 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 pressure-treated poles from 18 to 24 m long with internal decay and located in a pole line near Corvallis, Oregon, were randomly assigned to five test groups. No fumigants were applied to one control group. 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.

To evaluate effectiveness of the treatments, three cores equally spaced around each pole starting near the widest check were removed at -0.3, 0, 0.6, and 1.2 m from the groundline and cultured for decay fungi. Three additional cores were removed at 0, 1.2, 1.8, and 2.4, m above the groundline to determine distribution of residual fumigant by the closed-tube bioassay.

TABLE 1

CHEMICALS TESTED FOR FUMIGANT ACTION AGAINST 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	96% methylisothiocyanate
Vapam	Stauffer Chemical Co.	32% sodium N-methyl dithiocarbamate
Vorlex	NOR-AM Agricultural Products	20% methylisothiocyanate 80% chlorinated C_3 hydrocarbons

Thirteen years after application, chloropicrin and Vorlex continue to be the most effective fumigants for controlling decay fungi (Table 2, and Figure 1). During the 13 years decay fungi have been cultured from three of the eight poles treated with chloropicrin, two of the eight poles treated with Vorlex, and 14 of the 16 poles treated with Vapam.

Chloropicrin vapors have been the 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 vapor concentrations, as measured by the 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). The marked decrease in vapor concentrations coincides with fungal buildup in Vapam-and Vorlex-treated poles. The closed-tube bioassay may prove to be a guide for retreatment of poles.

A retreating cycle of 10 years with Vapam and 15 or more years with the more persistent chloropicrin and Vorlex appears reasonable.

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

Methylisothiocyanate (MIT) and allyl alcohol, were effective in controlling decay fungi in our laboratory test for fumigants, and were compared with Vorlex in poles in service. For the comparisons, internally decaying poles pressure-treated with pentachlorophenol in heavy oil were selected by removing three cores equally spaced around the poles at -0.3, 0, 0.6, and 1.2 m from the groundline and culturing the cores for decay fungi. Because of the prevalence of decay fungi at 1.2 m, cores also were removed at 1.8 and 2.4 m for culturing.

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

[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.

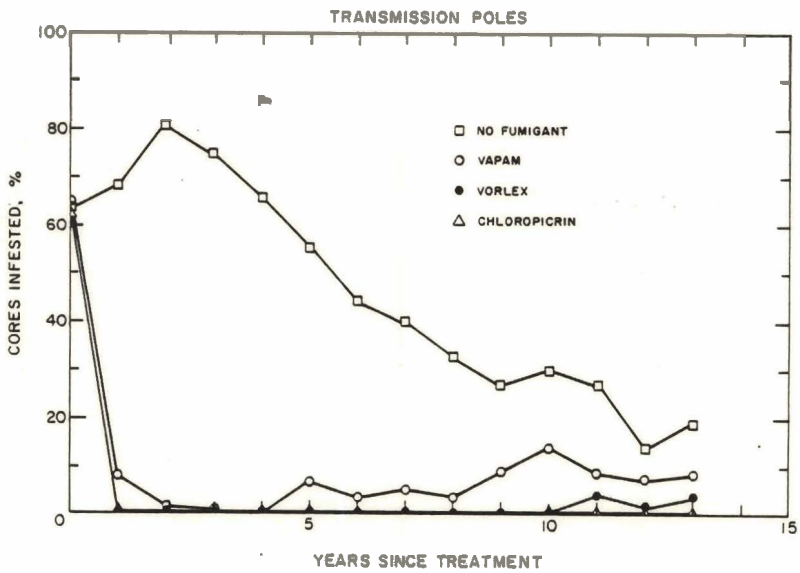

Figure 1. Changes in the population of decay fungi in internally decaying pressure-treated Douglas-fir poles treated with fumigants. Each value is based on 12 cores removed each year times the number of poles in test (Table 1). Decreasing fungal population in untreated poles reflects the decreasing amount of undecayed wood from which decay fungi can be cultured as well as the small number of poles in test.

TABLE 3

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

METERS ABOVE GROUND	SEGMENT LOCATION FROM SURFACE (cm)	AVERAGE GROWTH OF ASSAY FUNGUS, (mm)[1] NO FUMIGANT	VAPAM	VORLEX	CHLOROPICRIN
2.4	0-2.5	20	12	16	9
	5.1-7.6	24	16	15	2
	12.5-15	18	21	17	7
1.8	0-2.5	15	11	14	7
	5.1-7.6	19	19	17	3
	12.5-15	27	20	13	4
1.2	0-2.5	18	13	12	10
	5.1-7.6	20	20	9	1
	12.5-15	--	18	16	9
0	0-2.5	14	19	14	10
	5.1-7.6	15	15	12	13
	12.5-15	27	22	18	15
CONTROL	(NO WOOD)	25[2]			

[1]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 poles with no fumigant or to tubes with no wood indicates the presence of fungitoxic vapors. The lower the number the higher the concentration of vapors in the closed-tube bioassay.

[2]Average growth in 11 tubes.

TABLE 4

RESIDUAL FUMIGANT VAPORS IN DOUGLAS-FIR TRANSMISSION POLES AT VARIOUS YEARS AFTER APPLICATION OF FUMIGANTS

METERS ABOVE GROUND	AVERAGE GROWTH OF ASSAY FUNGUS, (mm) FOR YEARS SHOWN[1]											
	NO FUMIGANT			VAPAM			VORLEX			CHLOROPICRIN		
	10	12	13	5	7	13	10	11	13	10	12	13
2.4	21	22	24	8	20	21	11	12	17	1	8	9
1.8	22	24	27	9	14	20	8	12	17	0	3	7
1.2	22	20	20	9	14	20	9	12	16	1	2	10
0	24	24	27	9	20	22	12	10	18	4	7	15

[1] Reduced growth denotes presence of fungitoxic fumigant vapors.

The poles were randomly assigned to groups for treatment with 1 pint of fumigant which was distributed between four holes. MIT was melted for pouring into the holes but not all of the chemical could be applied because it solidified too rapidly in the wood. We estimate that the amounts of MIT per pole may be as little as 1/2 pint. Annually thereafter three cores equally spaced around each pole were removed at each of five levels and the cores were cultured to detect decay fungi. Additional cores were tested for residual fumigant vapor by the closed-tube bioassay. During 1980, three or four poles per test group were deleted from the test because they were inadvertently treated with Vapam by a commercial applicator.

Five years after application of the fumigant, the MIT formulations including Vorlex, were controlling decay fungi but allyl alcohol was ineffective (Table 5, Figure 2). MIT was distributed most uniformly through the poles and produced the most persistent fungitoxic vapors (Table 6).

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

[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. Superscript denotes poles remaining in test since 1981. Others were inadvertantly treated with Vapam by a commercial applicator.

[2]In diesel oil.

Summer vs. winter treatment of Douglas-fir poles with fumigants. Forty-eight poles from 21 to 26 m long pressure-treated in 1960 and containing internal decay at various distances from the groundline (Table 7) were selected for this test. Vapam, Vorlex and chloropicrin were applied during August and December of 1973 at 0.15, 1, 2, and 3 m above the groundline depending on the height of the decay. One-half liter of fumigant was poured into three 2-cm diameter holes at 0.15 m; 0.33 liter was applied at other heights. The holes were plugged with treated dowels. Less chemical was used in the winter than in the summer because water in the treatment holes interfered with application of the fumigants. The holes had been

TABLE 6

RESIDUAL FUMIGANT VAPORS IN
DOUGLAS-FIR POLES 5 YEARS AFTER APPLICATION

METERS ABOVE GROUND	SEGMENT LOCATION FROM SURFACE (cm)	AVERAGE GROWTH OF ASSAY FUNGUS,[1] (mm) NO FUMIGANT	ALLYL ALCOHOL	VORLEX	METHYLISOTHIOCYANATE 20%[2]	METHYLISOTHIOCYANATE 100%
2.4	0-2.5	22	19	17	20	12
	5.1-7.6	19	20	15	17	7
	12.5-15	22	23	15	20	8
1.8	0-2.5	19	20	14	15	11
	5.1-7.6	20	18	11	13	2
	12.5-15	25	22	13	15	4
1.2	0-2.5	16	18	7	12	5
	5.1-7.6	17	18	6	7	0
	12.5-15	21	18	8	13	6
0	0-2.5	19	18	7	11	2
	5.1-7.6	18	17	5	10	0
	12.5-15	22	19	6	9	3
CONTROL	(NO WOOD)	27[3]				

[1]A core was removed at each height from four to six poles (Table 5). 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 poles with no fumigant or no wood indicates that fungitoxic vapors are present.

[2]In diesel oil

[3]Average growth in 11 tubes

drilled in the summer and covered with tape but during the heavy autumn rains about one half of the holes filled with water which had to be siphoned out before the fumigants could be applied.

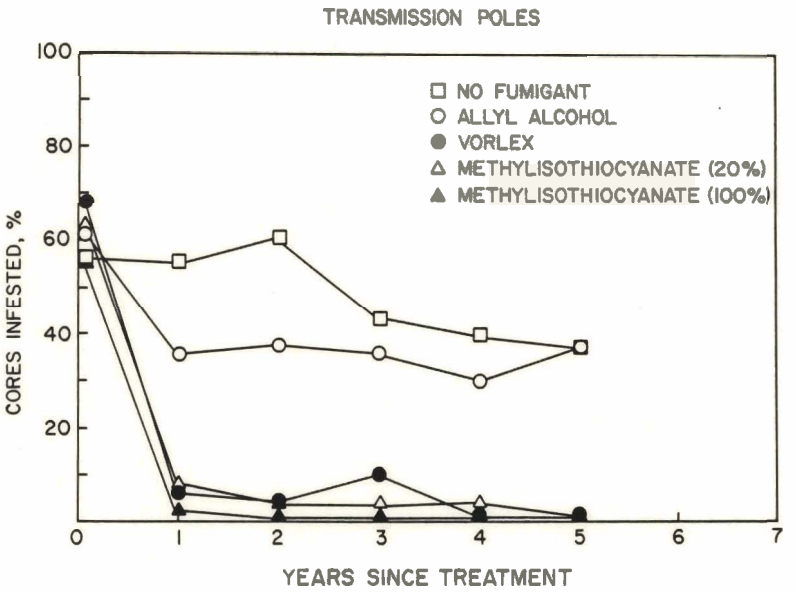

Figure 2. Changes in the population of decay fungi in internally decaying pressure-treated Douglas-fir poles treated with fumigants. Each value is based on 15 cores removed at -0.3 to 2.4 m from groundline from the poles listed in Table 5.

Nine years after application, all three fumigants continue to control decay fungi regardless of time of application (Table 8).

Douglas-fir poles treated with different quantities of fumigant. Forty poles from 18 to 23 m long pressure-treated in 1965 and containing internal decay near the groundline were treated in 1973 by placing various quantities of Vapam, Vorlex and chloropicrin in six 2-cm diameter holes (three 0.15 m and three 1 m above the groundline). The holes were plugged with treated dowels.

Nine years after treatment, as little as 0.25 liters (1/2 pt) of Vorlex and 0.125 liters (1/4 pt) of chloropicrin continued to control decay fungi (Table 9). Residual fungitoxic concentrations of chloropicrin and, to a lesser extent, Vorlex were present in the poles as high as 2.4 m (8 ft) above the groundline (Table 10).

TABLE 7

FREQUENCY OF DECAY AT VARIOUS HEIGHTS
IN 44 DOUGLAS-FIR POLES INSTALLED IN 1960
AND INSPECTED IN 1973

METERS FROM GROUNDLINE	POLES WITH DECAY. (%)[1]		
	NONE	EARLY	ADVANCED
3.7	89	11	0
2.4	57	43	2
1.8	43	57	16
1.2	25	75	34
0.6	11	89	39
0	2	98	61
-0.3	0	98	52

[1]Advanced decay was based on visual inspection of three cores equally spaced around the pole at each height. Early decay was based on out-growth of decay fungi from cores incubated on malt agar.

TABLE 8

EFFECT OF TIME OF APPLICATION OF FUMIGANTS
ON POPULATION OF DECAY FUNGI IN DOUGLAS-FIR POLES

TIME OF APPLICATION AND FUMIGANT	CORES WITH DECAY FUNGI (%)[1]					
	1973[2]	1974	1975	1977	1979	1982
AUGUST, 1973						
VAPAM	64	0	1	0	3	7
VORLEX	65	0	1	0	0	4
CHLOROPICRIN	62	0	0	0	1	0
DECEMBER, 1973						
VAPAM	60	3	2	1	0	2
VORLEX	61	0	1	0	0	0
CHLOROPICRIN	56	0	0	0	0	0

[1]Each value is based on culturing 150 cores in 1973, 30 cores in 1974, and 130 cores thereafter from eight poles.

[2]Prior to treatment with fumigants.

TABLE 9

EFFECT OF QUANTITY OF FUMIGANT ON POPULATION
OF DECAY FUNGI IN DOUGLAS-FIR POLES

FUMIGANT	QUANTITY OF FUMIGANT		CORES WITH DECAY FUNGI,(%)[1]					
	LITERS PER POLE	GRAMS OF ACTIVE CHEMICAL	1973[2]	1974	1975	1977	1979	1982
VAPAM	0.5	248[3]	52	0	0	0	2	8
VORLEX	0.5	115	51	0	2	1	3	0
	0.25	57	42	0	1	0	1	4
CHLOROPICRIN	0.25	410	38	0	0	2	4	0
	0.125	205	44	0	1	0	1	1

[1]Each value is based on culturing 116 cores in 1973, 20 cores in 1974, and 97 cores thereafter from eight poles.

[2]Prior to treatment with fumigant.

[3]As the dihydrate.

TABLE 10

RESIDUAL FUMIGANT VAPORS IN PRESSURE-TREATED DOUGLAS-FIR POLES NINE YEARS AFTER APPLICATIONS OF VARYING QUANTITIES OF FUMIGANT

METERS ABOVE GROUND	LOCATION FROM SURFACE (cm)	AVERAGE GROWTH OF ASSAY FUNGUS (mm) FOR QUANTITIES OF FUMIGANT SHOWN (liters)[1] VAPAM 0.5	VORLEX 0.5	VORLEX 0.25	CHLOROPICRIN 0.25	CHLOROPICRIN 0.125
2.4	0-2.5	22	14	20	10	14
	5-7.5	23	13	19	11	9
	12.5-15	24	14	17	10	11
1.8	0-2.5	23	16	19	7	14
	5-7.5	24	24	16	6	3
	12.5-15	23	11	16	5	0
0.6	0-2.5	21	13	14	0	3
	5-7.5	20	12	14	0	3
	12.6-15	21	14	16	2	3
CONTROL (NO WOOD)		28				

[1]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 poles with no fumigant or to tubes with no wood indicates the presence of fungitoxic vapors.

Douglas-fir marine piles treated with fumigants. Creosoted Douglas-fir piles with sloped and 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 tops which appeared sound. 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.

The fumigants virtually eliminated the decay fungi from the piles within 1 year (Figure 3). Chloropicrin and Vorlex have controlled reinfestation by decay fungi for 8 years, but 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. It merits further research as a guide for determining when fumigant-treated poles and piles should be retreated.

A. PREPARATION AND EVALUATION OF ENCAPSULATED METHYLISOTHIOCYANATE IN LABORATORY WOOD-BLOCK TESTS.

An ideal fumigant encapsulating material should be inert and not interfere with the activity of the fumigant, be impermeable to the fumigant prior to application for safe storage and handling, and be easily made permeable to the fumigant for release from the capsule during treatment.

Last year we reported on studies evaluating the use of gelatin for encapsulating MIT and chloropicrin for control of decay fungi in wood. These studies demonstrated that MIT could be sealed in gelatin capsules

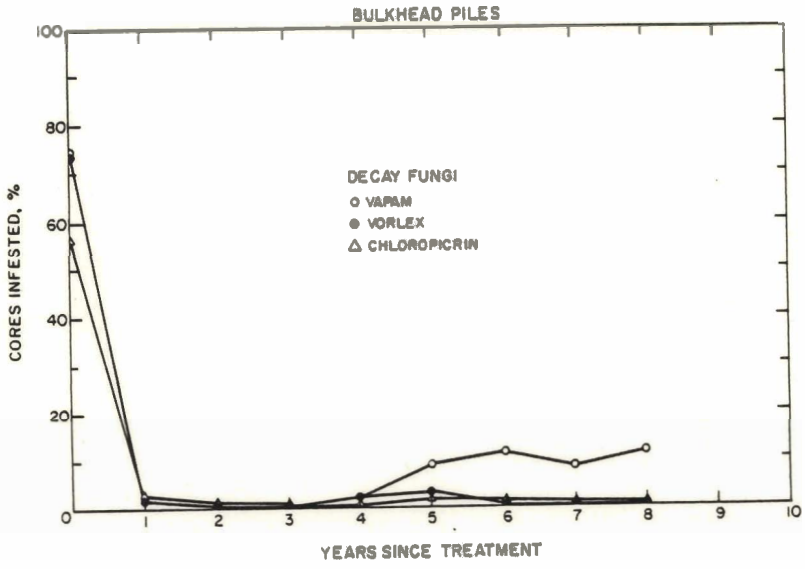

Figure 3. Change in population of decay fungi in creosoted Douglas-fir piles treated with fumigants. Each value in the figure is from 60 cores from twelve piles.

with only slight vapor loss for up to 181 days, that MIT and chloropicrin can be released from capsules when placed in wood, and that encapsulated fumigant treatments are just as effective as non-encapsulated treatments in our standard wood block tests. We have continued to study and evaluate encapsulated MIT in the laboratory and have extended the evaluation to field trials.

Inertness of gelatin to methylisothiocyanate.

Two studies demonstrated that gelatin would not significantly interfere with the effectiveness of MIT when used to encapsulate the fumigant. In the first study, the ability of gelatin to bind and thereby reduce the availability of MIT in encapsulated fumigations was studied. Small quantitites of MIT (20 µl) were placed in glass stoppered flasks along with a comparatively large quantity of gelatin (200 mg), a small vial containing 1.5 ml of water serving as a vapor trap, and 0.2 g of Douglas-fir heartwood sawdust at 8.5% moisture content (MC). One-half of the gelatin in the flasks was kept dry, and the other half was moistened with 0.2 ml of water to allow gelatin in both states the opportunity to bind MIT. Indentical flasks were prepared lacking only the gelatin. The sealed flasks were stored at 20-22°C for 24 hrs to allow the MIT to partition between the gelatin, wood, and the vapor-trap water. The vapor-trap water was then extracted with ethyl acetate and the MIT concentrations were determined by gas-liquid chromatography (GLC) methods.

The concentration of MIT in the vapor-trap water in flasks containing gelatin was only slightly lower than that in identical flasks lacking gelatin (4.4-4.5 versus 4.7-4.9 mg MIT/ml water) even though the amount of gelatin was 10 times that of MIT. This demonstrates that an insignificant amount of MIT will bind to gelatin and therefore become unavailable for movement into wood for control of decay fungi.

In the second study, the influence of gelatin on the breakdown of MIT was studied. Technical grade MIT that had been encapsulated in a 1.0 ml gelatin capsule for over 8 months was heated, the MIT was removed, and 25 µl was transferred and dissolved in 5.0 ml of distilled water. An identical solution was prepared from technical grade MIT that had been stored in glass over the same time period. A bioassay was conducted to compare the fungitoxicity of the two MIT solutions to Poria carbonica in infested Douglas-fir heartwood. After 48 hours exposure to the MIT solutions, samples of the treated wood were ground and suspended in nutrient medium to determine the viability of the Poria in the wood.

The recovery of P. carbonica propagules was similar in both treatments (Table 11) demonstrating that storage of MIT in gelatin capsules for over 8 months does not significantly alter the fungitoxicity of the fumigant to P. carbonica.

TABLE 11

INFLUENCE OF METHYLISOTHIOCYANATE (MIT) STORAGE IN GELATIN CAPSULES ON MIT's FUNGITOXICITY TO PORIA CARBONICA

MIT STORAGE CONDITION	NUMBER OF P. CARBONICA COLONIES RECOVERED FROM INFESTED DOUGLAS-FIR HEARTWOOD SECTIONS[1] EXPOSED FOR 48 HR TO VARYING QUANTITIES OF MIT (mg/CHAMBER)			
	2.6	1.5	1.0	0.51
Gelatin encapsulated[2]	0	3	26	110
Glass bottle	0	3	20	94

[1]Four wood sections (12mm X 7 mm X 120µm) cut from an infested Douglas-fir heartwood block were randomly selected for each treatment, fumigated, and the surviving P. carbonica propagules determined by dilution plating.

[2]MIT had been stored in a gelatin capsule for over 8 months prior to use.

Encapsulation of MIT in gelatin. MIT was encapsulated into standard two-piece hard gelatin capsules. Prior to filling the capsules, a small injection hole was made in the center of each capsule top, and the capsules were cleaned with acetone to remove surface oils that might hinder sealing. The capsule halves were sealed together by coating the overlapping portions with a thick, hot gelatin solution (Knox Unflavored Gelatin) and sliding the halves together. After the capsules dried, the joint was recoated with gelatin. Technical grade MIT (95% active ingredient) was warmed to 40-50°C, pipetted into each capsule, and then allowed to cool and solidify. Capsule tops were recleaned with acetone and the injection holes were sealed with solidified gelatin disks glued into place with a hot gelatin solution. After drying, the injection holes were recoated twice with gelatin to insure complete sealing.

MIT loss from gelatin capsules during storage.

Slight leakage of MIT from gelatin capsules during an 181 day storage was reported last year. The capsules have now been maintained under dry storage conditions for over 1 year without significant loss of MIT (Table 12). Capsule weights fluctuated slightly throughout the 389 day storage period probably due to moisture uptake or loss by the gelatin capsule material depending on the air moisture content. After the 389 days of storage, capsule weight losses averaged only 0.15% of the initial MIT content of each capsule. This demonstrates that encapsulation of MIT in gelatin capsules and storage under dry conditions should allow prolonged storage of the fumigant without serious loss of MIT.

TABLE 12

WEIGHT CHANGES OVER TIME OF GELATIN CAPSULES CONTAINING METHYLISOTHIOCYANATE (MIT) AND STORED IN A LABORATORY FUME HOOD

TIME (DAYS)	WEIGHT OF FOUR MIT CAPSULES (GRAMS)[1]			
	1	2	3	4
0[2]	20.212	20.377	20.115	20.541
7	20.221	20.383	20.129	30.551
31	20.191	20.349	20.104	20.521
181	20.151	20.301	20.062	20.473
389	20.189	20.344	20.101	20.516

[1]Empty gelatin capsules weighed about 3.1g.

[2]Initial capsule weights (zero time) were recorded 2 days after filling the capsules to allow them to thoroughly dry and equilibrate after sealing.

Methylisothiocyanate treatments of Douglas-fir pole sections

Wood pole sections were used to compare the concentration and movement of MIT vapor through wood treated with gelatin encapsulated MIT, non-encapsulated MIT, and Vapam. In addition, the amount of water required for adequate release of MIT from capsule treatments was investigated. Fifteen Douglas-fir pole sections (2.6 meter by 25-33 cm diameter) were end-painted with "lumber seal" to retard end penetration by preservatives and the pole sections were pressure treated with pentachlorophenol in heavy oil[1]. A single treatment hole (2.1 cm diameter of 24 cm deep) was drilled at a 30° angle downward at 0.75 meter from the butt end of each pole section. Three vapor sampling holes (1.1 cm diameter by 16.5 cm deep) were drilled perpendicular to the surface of each pole at 0.3, 0.6, and 1.2 meters directly

[1]Pole sections were treated and donated by McCormick & Baxter Creosoting Co.

above the treatment holes. The two more distant vapor sampling holes were slightly offset to opposite sides of the first sampling hole to minimize interference of the closer sampling holes on the diffusion of MIT to the more distant sampling holes. The sampling holes were sealed with rubber serum caps glued in place with a silicone sealant. All holes were positioned to avoid major checks, and spiral grain was taken into account during vertical alignment of the sampling holes.

The pole sections were treated with one of five different fumigant treatments: 80-88 ml of Vapam, 45 ml of non-encapsulated molten MIT, or 45 ml of gelatin encapsulated MIT with either 40, 25, or 15 ml of water added to each treatment hole along with capsules to aid fumigant release. The 80-88 ml of Vapam used in treatments was the amount required to completely fill each treatment hole. The maximum amount of encapsulated MIT that could easily be placed in similar treatment holes was 45 ml, distributed between two 1.9 cm diameter by 9.5 cm long gelatin capsules, and the greatest quantity of water that could be added along with the capsules to each treatment hole was 40 ml. Non-encapsulated MIT treatments also used only 45 ml of fumigant per treatment hole to enable direct comparison with encapsulated treatments. All treatment holes were sealed with 5 to 6 cm long paraffin wax-coated hardwood plugs 2.2 cm in diameter.

The pole sections were treated on 26 August 1982 and were then stored vertically in two rows outside in Corvallis, OR. MIT vapor concentrations in the poles were monitored for over 35 weeks by periodically removing 4.5 ml vapor samples from the sampling holes and analyzing the samples for MIT content by GLC. The air temperature during sampling varied from 1-24°C.

MIT was first detected in sampling holes 0.3 meter from the treatment holes after 9 to 18 days (Figure 4), and in sampling holes 0.6 meter from

treatment holes 100 to 180 days after treatment. Vapam treated poles had low levels of MIT vapor at 0.3 meter from the treatment holes throughout the monitoring period. The MIT peaks produced following Vapam treatment were often at the lower limit of GLC resolution and sometimes could not be quantified. Vapam is 32.7% sodium N-methyl dithiocarbamate and the amount of Vapam added to each pole could theoretically yield the amount of MIT in about 18 ml of the technical grade MIT. But the recovery of MIT vapor at 0.3 meter above treatment holes in the pole sections treated with 80-88 ml of Vapam was generally less than 1/15 of that recovered from poles treated with 45 ml of MIT.

One possible explanation for low MIT recovery from Vapam treated poles is that the conversion of sodium N-methyldithiocarbamate to MIT in Douglas-fir heartwood occurs at less than 100% efficiency. To test this, 0.2 g of Douglas-fir heartwood sawdust (9.5% MC) and a small open glass vial containing 7.5 ml of chromatographic grade ethyl acetate were placed in each of four 250 ml glass stoppered Erlenmeyer flasks. The flasks were then treated by pipeting either 400 µl of Vapam, or 86 µl of purified MIT (the amount of MIT expected from 400 µl Vapam) into the flasks which were then sealed. After 10 hr, the ethyl acetate was spilled from vials, and allowed to extract the contents of the flasks for 1.5 hours, after which the MIT content was determined by GLC. The MIT concentrations in Vapam treated chambers were only 39-42% of the concentration detected in MIT treated chambers, indicating about 40% conversion of Vapam to MIT. The poor conversion of Vapam to MIT observed in wood may be a result of the acidic pH of wood and/or the low moisture content of the wood. It also is possible that Vapam breaks down to other fungitoxic materials in wood besides MIT, but these materials were not detected by our GLC methods.

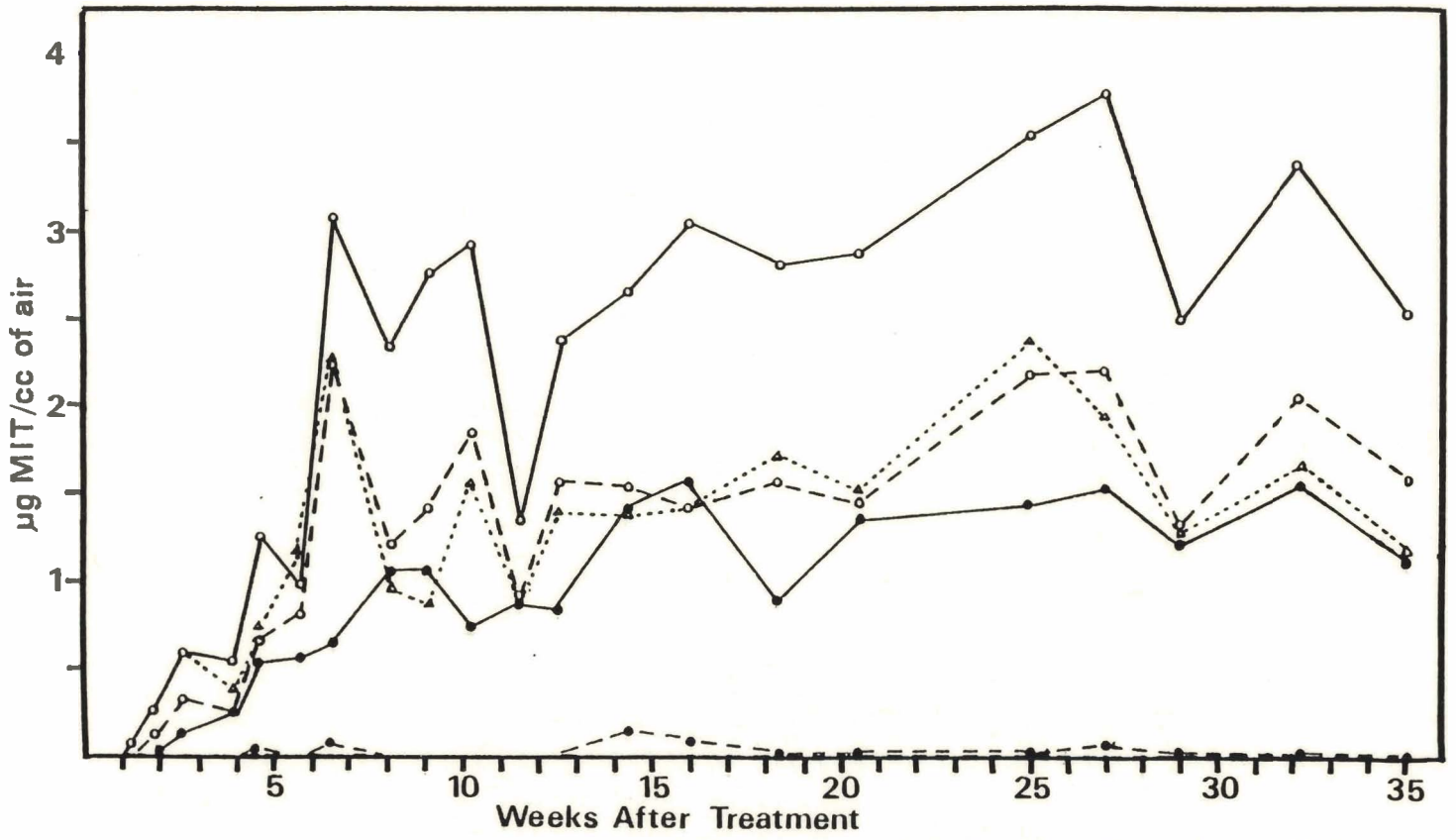

Figure 4. Average MIT vapor concentrations over time monitored in Douglas-fir pole sections 0.3 meter above the treatment sites. Treatments involved either 80-88 ml Vapam ●--●, 45 ml of non-encapsulated MIT ●—●, and 45 ml of gelatin encapsulated MIT with either 15 ml of water o—o, 25 ml of water o--o, or 40 ml of water Δ··Δ. Water was added to the treatment holes along with the capsules to aid fumigant release.

Vapam is effective in controlling decay fungi in utility poles, but it has shown less residual effectiveness than Vorlex (20% MIT) with a virtual absence of fungitoxic vapors in wood poles 10 years after treatment. Even though smaller quantities of encapsulated MIT were used than Vapam (45 ml vs 80-88 ml), the resulting MIT concentrations in the wood were much higher in MIT treatments. This is an important consideration for treatment of wood products serving a structural function, where size and number of treatment holes that can safely be drilled into the products is limited, and the maximum amount of active ingredient for greatest control and residual effectiveness is desired.

MIT vapor concentrations 0.3 meter from the treatment holes were highest in poles treated with gelatin encapsulated MIT and the lowest quantity of water, i.e. 15 ml per pole (Figure 4). The encapsulated treatments with larger quantities of water produced MIT vapor concentrations that were slightly higher than those in non-encapsulated treatments, but only about 0.5-0.75 the concentrations detected in encapsulated treatments with only 15 ml of water added per pole. The larger quantities of water added with the gelatin encapsulated MIT may have hindered the movement of fumigant vapor through the wood. This experiment was run over the wet winter months (Sept.-April) and it is not yet known whether the smaller quantity of water used would have been sufficient for MIT release during the warmer and drier summer months.

B. EVALUATION OF NEW FUMIGANTS IN THE LABORATORY

No new fumigants were evaluated in the laboratory during the past year. The volatile fungicides identified for consideration as wood fumigants all had undesirably high mammalian toxicity.

C. INFLUENCE OF ENVIRONMENTAL FACTORS ON EFFECTIVENESS AND PERSISTENCE OF FUMIGANTS.

To obtain as better understanding of the fungitoxicity of MIT to decay fungi in wood, and the influence of environmental factors on the effectiveness of this fumigant, fungitoxicity curves were generated for P. carbonica grown in Douglas-fir heartwood and then treated at different moisture contents. Results of these studies should be useful in defining the effective range of fumigant movement through poles, the length of the residual effectiveness, and limitations that environmental conditions may impose on fumigant effectiveness.

Influence of wood moisture content on the fungitoxicity of MIT

Dosage-response relationships describing the response of P. carbonica in Douglas-fir heartwood to MIT vapors was studied at three different wood moisture contents. Small Douglas-fir heartwood blocks were infested with P. carbonica for 8 weeks and then the blocks were adjusted to about 20%, 40%, or 75% MC. The blocks ranged in moisture content, i.e. 17-22%, 36-43% and 66-80% MC respectively, but will be referred to by their average values. The blocks were fumigated at different MIT vapor concentrations and time periods in a continuous flow fumigation apparatus and the effectiveness of the treatments was determined by comparing prefumigation and post-fumigation population levels of P. carbonica in each fumigated block. Methodology details were presented in the 1981 Ann. Rept., pages 12-15, and the 1982 Ann. Rept., pages 17-21.

The dosage-response curves (Figure 5) for P. carbonica in wood at the three moisture levels were used to generate concentration-time (CT) curves

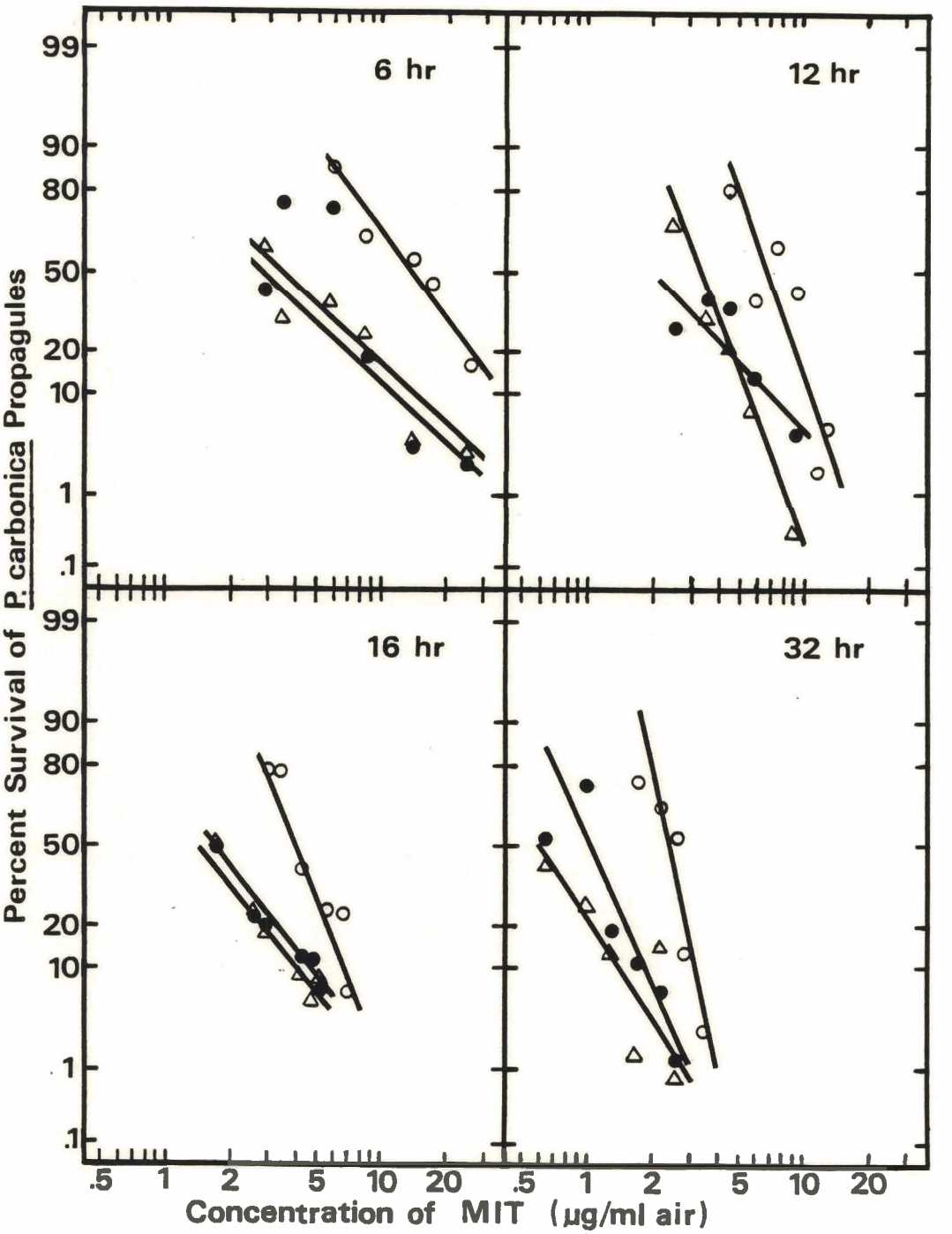

Figure 5. Influence of the wood moisture content on the fungitoxicity of MIT to P. carbonica growing in Douglas-fir heartwood blocks. Infested wood blocks were at either 17-22% MC o, 36-43% MC •, or 66-80% MC Δ (oven dry weight basis), and were exposed to constant concentrations of MIT vapors for 6, 12, 16, or 32 hr periods. Each data point is the average survival from four fumigated blocks.

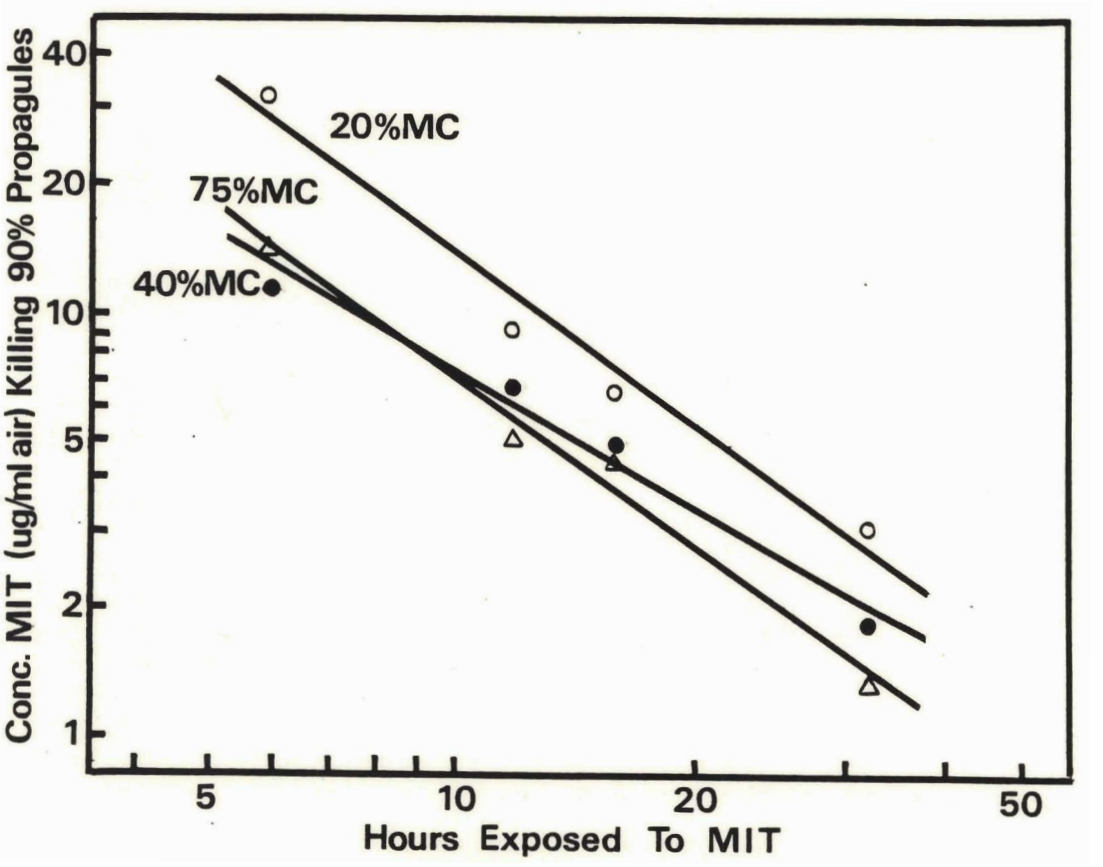

Figure 6. Relationship between MIT concentrations and exposure times required to kill 90% of the Poria carbonica propagules in Douglas-fir heartwood blocks at various wood moisture contents:
o = 17-22% MC, ● = 36-43% MC, and Δ = 66-80% MC.

that describe the product of fumigant concentrations and exposure times necessary for MIT to kill 90% of the P. carbonica propagules in wood at the three different wood moisture contents (Figure 6).

The effectiveness of MIT was influenced by the moisture content of the wood. For example, P. carbonica in wood at 20% MC required a 1.4 to 2.2 fold higher CT product for 90% kill than in wood at 40% MC, and about a two fold higher CT product than in wood at 75% MC. The CT curves in wood at 40% and 75% MC intersected, with higher CT products necessary to control P. carbonica in wood at 40% MC than in wood at 75% MC, except during short exposures (less than about 8 hr) where the reverse relationship was found.

The greater resistance of P. carbonica to MIT in wood blocks at 20% MC, than in the wetter blocks, is probably due to the fungus being metabolically less active in the drier wood. The fiber-saturation point of Douglas-fir heartwood is about 28% MC, and fungi in wood below this moisture content do not actively grow and significantly decay wood. On the other hand, the wood blocks at 40% and 75% MC are above the fiber-saturation point of Douglas-fir heartwood and fungi in these blocks should be actively growing.

Theoretically, the fumigant dose or CT product required for a given level of fungal control should remain constant except during extremely short exposure periods or for very low fumigant concentrations. However, with MIT fumigations of P. carbonica in wood at the different wood moisture contents, a lower CT product was required for 90% kill during long exposures than during short exposures (Table 13). This was particularly evident

in wood at 20% and 75% MC where an almost two-fold higher CT product was required during the 6 hr fumigant exposures than during the 32 hr exposures.

The observation that P. carbonica is more susceptible to MIT during long exposures than during short exposures may be important in defining residual effectiveness in large wood poles where low fumigant concentrations can be detected for many years after the initial treatment, and in determining the rate and effective range of fumigant movement through wood. Results for longer fumigant exposure periods are needed to determine the limit of increasing MIT toxicity with increasing length of fumigant exposure, and the minimum MIT concentration that will eradicate P. carbonica from wood.

TABLE 13

CONCENTRATIONS X EXPOSURE TIMES (CT) NECESSARY FOR 90% KILL OF PORIA CARBONICA PROPAGULES IN DOUGLAS-FIR HEARTWOOD BLOCKS AT THREE DIFFERENT WOOD MOISTURE CONTENTS.

HOURS EXPOSURE	CT VALUES[1] (µg MIT X HR/cc AIR) FOR 90% KILL OF P. CARBONICA IN WOOD AT VARIOUS MOISTURE CONTENTS		
	17-22% MC	36-43% MC	66-80% MC
6 hr	179	80	88
14 hr	126	73	65
32 hr	91	67	46

[1] The CT values were obtained from the regression lines in Figure 5.

The *P. carbonica* infested Douglas-fir heartwood blocks used in these toxicity studies were monitored for MIT sorption after each fumigation by measuring the amount of MIT extractable with ethyl acetate. This included MIT bound to the wood structure, as well as MIT in the air and dissolved in the water within the wood. The greatest quantity of MIT was sorbed by wood at 20% MC, the least by wood at 40% MC, and an intermediate amount by wood at 75% MC (Figure 7).

Most of the MIT sorbed by these blocks was bound in some way to the wood structure. For example, wood at 75% MC and exposed to 2 µg MIT/ml air for 32 hours sorbed a total of about 1000 µg of MIT/g OD weight wood (Figure 7). Based on the published ratio of MIT in water to MIT in air at 21°C (150:1), there should be about 0.3 mg MIT dissolved per ml water in these blocks. Douglas-fir heartwood at 75% MC contains about 1 cc air and 0.5 ml free water (water above fiber-saturation point) per g OD weight. Therefore, of the 1000 µg MIT/g OD weight, only about 150 µg MIT should be dissolved in water, and about 2 µg MIT in the air within the wood. The rest of the MIT (848 µg/g OD weight wood) must be bound in some way to the wood structure. The amount of MIT bound to wood at 20% MC is higher (Figure 7), even though there is no free water in the wood. This suggests that essentially all the MIT must be bound to the wood structure at this moisture content.

The higher sorption of MIT by wood at 75% MC than by wood at 40% MC is probably due to the MIT dissolved in the larger quantity of water present in the 75% MC wood. The greater sorption of MIT by the dry wood (20% MC), in comparison to wood at higher moisture contents suggests that water may interfere with the ability of MIT to bind to the wood structure.

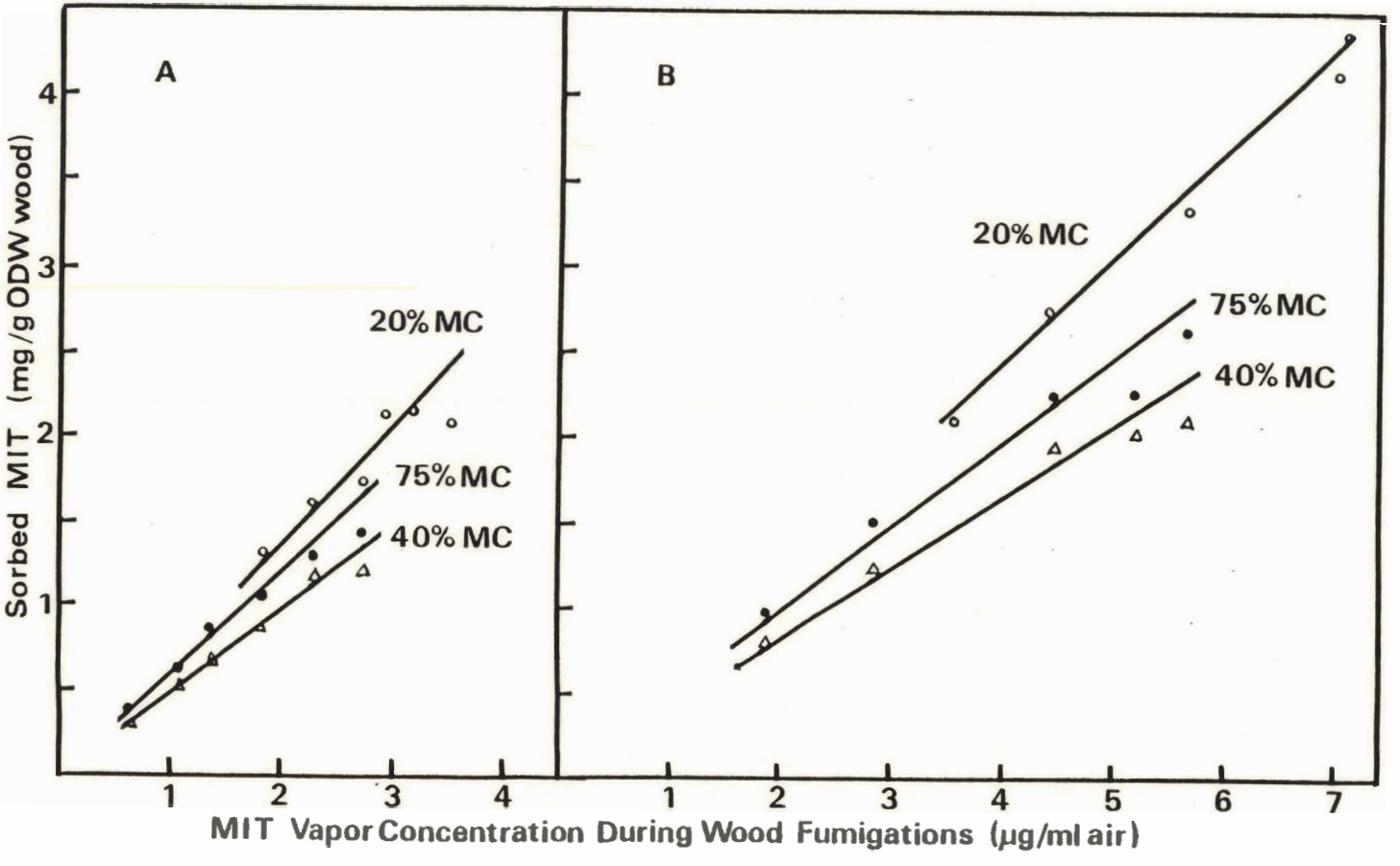

Figure 7. Influence of wood moisture content on MIT sorption by Poria carbonica infested Douglas-fir heartwood blocks after exposures for: A) 32 hr, and B) 16 hr, to air containing various concentrations of MIT vapors. Moisture contents of the infested blocks (oven-dry weight basis) ranged from 17-22% (20% MC), 36-43% (40% MC), and 66-80% (75% MC). Each point is the average sorption of four blocks fumigated together.

The fact that infested wood with the highest total fumigant sorption (20% MC wood) also has the highest survival of the decay fungus is contrary to what might be expected. However, this suggests that the MIT bound to the wood structure is probably less effective against the decay fungus than the MIT in the air and water surrounding the fungus. Furthermore, determination of the total MIT content of wood without knowledge of wood moisture content will be a poor predictor of expected control.

Although there were differences in the effectiveness of MIT in woods of varying moisture content, MIT was still very fungitoxic at all three wood moisture contents tested. The increased effectiveness in wet wood should be beneficial during fumigation of large poles where fumigant penetration into wet areas of the wood may be hindered compared to penetration into drier wood. Furthermore, effectiveness in wet areas of wood is desirable because this is where active decay and wood degradation are most likely to occur.

D. EVALUATION OF THE MOST PROMISING FUMIGANTS IN POLES

New York field test with encapsulated MIT

Twenty four Douglas-fir poles treated with CCA and placed in service near Hamburg, New York in 1972, were infested with decay fungi and were used to compare the effectiveness of gelatin encapsulated MIT with a standard Vapam treatment. In October 1981 groups of six poles were either treated with 475 ml encapsulated MIT plus 1 liter of water, 950 ml encapsulated MIT plus 900 ml of water, 950 ml of Vapam per pole, or were left untreated as controls. Water was added with encapsulated MIT treatments to aid in fumigant release from the capsules. Details of treatments were described in the 1982 Ann. Rept., pages 21-22.

In July, 1982, these poles were sampled to determine the effectiveness of the fumigant treatments. A single core off set around the pole by 120° was removed at 0, 0.6, and 1.2 meter above the groundline from each pole, and the presence of fungitoxic vapors from these cores was determined by New York State Electric and Gas Corp. personnel using the closed tube bioassay. Reduced growth of the assay fungus, indicating the presence of fungitoxic vapors in the wood, was observed in all pole treatments (Table 14). Fungitoxic vapors were particularly strong in wood 12.5-15 cm inside the CCA treated shell, while wood nearer the outside of the pole (0-2.5 cm

TABLE 14

RESIDUAL FUMIGANT VAPORS IN DOUGLAS-FIR POLES[1]
NINE MONTHS AFTER APPLICATION OF ENCAPSULATED MIT OR VAPAM

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	950 ml
0	0-2.5	31	30	27	17
	12.5-15	36	10	1	3
0.6	0-2.5	37	24	16	30
	12.5-15	36	4	9	4
1.2	0-2.5	34	31	28	20
	12.5-15	32	26	6	7
Control (No wood)		33			

[1]Poles were 52-60 cm DBH, treated with CCA and placed in service near Hamburg, NY 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.

from the treated shell) had much lower concentrations and vapors could not be detected in wood nearest the outside of some poles. In line with previous experience, this test indicated that poles treated with encapsulated MIT had higher levels of fungitoxic vapors than wood from poles treated with Vapam.

These poles were also sampled for the presence of decay fungi. Three cores equally spaced around each pole at 0, 0.6, and 1.2 meters above the groundline were removed in July 1982, and were cultured on nutrient medium. The fumigant treatments greatly reduced the number of cores containing decay fungi (Table 15). The most effective treatment was the 950 ml of encapsulated MIT, followed by the 475 ml of encapsulated MIT. Vapam was slightly less effective at this first sampling date.

TABLE 15

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

SAMPLING DATE	METERS ABOVE GROUNDLINE	NUMBER OF CORES WITH DECAY FUNGI[1]			
		NO FUMIGANT	VAPAM	ENCAPSULATED MIT[2]	
			950 ml	475 ml	950 ml
June 1981	0	14	10	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	3	1	1	1

[1]A total of 18 cores were removed from six poles at each position on the 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 with the capsules for the 950 ml treatments.

The plugs were removed from some of the holes that received the encapsulated MIT, and the condition of the capsules was observed. Most capsules were about one half full of MIT crystals, the gelatin was soft and rubbery, and the capsules and treatment holes smelled strongly of MIT. This suggests that the capsules were still releasing MIT for movement into the wood.

This first evaluation of fumigant effectiveness was only 9 months after treatment which is a relatively short time period for fumigation of large wood poles. The cold winter temperatures during the treatment period may have slowed fumigant diffusion through the wood. These poles have been resampled in June of 1983 and this should give a more definitive comparison of the effectiveness of encapsulated MIT and Vapam treatments.

Oregon field test of encapsulated fumigants in poles above the groundline

A field test comparing the effectiveness of MIT and chloropicrin applied in gelatin capsules was initiated in Bonneville Power Administration poles (Dorena tap line) near Cottage Grove, OR. In June 1982 cores were removed from 16 poles for culturing to detect decay fungi. Subsequently six infected poles with decay fungi well above the groundline were selected to evaluate the ease of applying encapsulated fumigants above the groundline. Three to six holes (0.75" diameter x 16" deep) at 2 to 14 feet above the groundline were drilled in the poles (Table 16) and generally two 4 inch capsules and one 2.5 inch capsule containing the fumigants were placed in each hole. A small quantity of water was added to all treatment holes before sealing with treated wooden dowels. The poles will be sampled late this summer to determine the decay-fungus population as an estimate of fumigant effectiveness.

TABLE 16

EXPERIMENTAL DESIGN FOR THE EVALUATION OF ENCAPSULATED MIT AND CHLOROPICRIN IN DOUGLAS-FIR TRANSMISSION POLES IN SERVICE

POLE NO.	NUMBER OF CORES WITH DECAY FUNGI[1]	FUMIGANT	FUMIGANT PER POLE (ml)	LOCATION OF TREATMENT HOLES (ft ABOVE GROUND)
3/2-A	1/4	MIT	310	3, 5, 7, 9, 11
3/2-B	2/7	MIT	372	4, 6, 8, 10, 12, 14
4/6-A	4/9	MIT	372	4, 6, 8, 10, 12, 14
4/6-B	3/4	Chloropicrin	310	2, 4, 6, 8, 10
5/4-B	2/3	Chloropicrin	177.5	2, 4, 6
5/5-A	4/7	Chloropicrin	248	2, 4, 6, 8

[1]Number of cores with decay fungi over the total number of cores removed from the poles.

E. MICRODISTRIBUTION AND RETENTION OF CHLOROPICRIN IN SOUND AND DECAYED WOOD

Retention of chloropicrin in wood, chloropicrin breakdown products in wood, and the effects of chloropicrin treatment on invading decay fungi were explored and the following conclusions were reached:

• Chloropicrin treated wood does not swell, suggesting that the monomolecular layer of chloropicrin, which may hydrogen bond to wood, does not have sufficient bulking effect to overcome the forces binding the lignin and cellulose constituents of the wood cell walls. Evidence that chloropicrin

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[1]Goodell, Barry S. 1983. Microdistribution and Retention of Chloropicrin in Douglas-fir Heartwood. Ph.D. Thesis, Oregon State University.

will hydrogen bond to wood is suggested by the lower retention of chlorinated material in wood with greater amounts of decay. Both hydrogen bonding and van der Waal's forces play a significant role in the retention and slow release of chloropicrin from wood.

• A 1-1.5% residue of chlorinated material is present in aerated chloropicrin treated wood. The residue cannot be removed by heating, repeated acetone extraction, or high vacuum treatment suggesting that covalent bonds between chloropicrin and/or its breakdown products and wood may be formed. Thin layer chromatography of acetone-extracted, treated wood also indicates that chlorine containing products covalently bound to wood extractives.

• Indications of covalent bonding between chloropicrin degradation products and phenolic wood extractives and lignin may be observed by mass spectrographic and energy dispersive X-ray analyses. Greater amounts of chlorinated materials are found in phenolic rich sites of treated wood.

• Chloropicrin desorbtion studies and energy dispersive X-ray analysis show that the amount of chlorinated residues retained by treated wood is affected by the amount of chemical applied and the length of contact time with wood. A time dependent effect could be explained by the slow breakdown of chloropicrin to a compound or compounds that react with wood. However, preliminary studies to test the reactivity of chloropicrin degradation products with wood derivatives were inconclusive.

• Light microscopic analysis shows that chloropicrin treatment cannot be expected to fully protect wood from fungal attack under severe decay conditions. Preliminary micromorphological studies of the fungi invading

treated wood show that the treatment does have an inhibitory effect, as evidenced by lysis and vacuolation of the fungal hyphae. It was not determined whether the fungi played an active role in releasing the fumigant from the wood.

OBJECTIVE II

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

The aim of this research is to find waterborne chemicals as replacements for pentachlorophenol in oil to arrest sapwood decay by spraying cedar poles in service. Several decay fungi associated with sapwood rot in western redcedar poles have been identified and laboratory tests were developed to screen 12 potential new fungicides for evaluation in the field. One of the waterborne preservatives exhibited qualities equal to those of pentachlorophenol in oil, and a number of others also appeared very promising. Seven chemicals were incorporated in field trials on pole sections in 1981. (1982 Ann. Rept., pages 25-30).

During this past year, four additional fungicides were tested in the laboratory (Table 17), and although none were outstanding in these tests all but the chromic acid were added to the field trials.

This fall plugs or cores of treated wood will be removed from the pole sections and the presence of fungitoxic residues in the wood will be determined by the Aspergillus bioassay where appropriate and by soil-block tests of decay resistance.

TABLE 17

CHEMICAL EFFECTIVENESS IN PREVENTING NORMAL DEVELOPMENT OF ASPERGILLUS NIGER SPORES AND WEIGHT LOSS OF WOOD BLOCKS EXPOSED TO PORIA PLACENTA

CHEMICAL	ZONES OF EFFECT (mm) IN THE ASPERGILLUS BIOASSAY FROM WAFERS CUT AT DISTANCES SHOWN FROM ENDS OF UNWEATHERED AND WEATHERED WOOD BLOCKS[1]												WEIGHT LOSS BY WAFERS IN WEIGHT LOSS DECAY TEST (%)
	0 mm			5 mm			10 mm			15 mm			
	U	W2	W4	U	W2	W4	U	W2	W4	U	W2	W4	
A	8	7	6	8	6	6	7	5	5	7	5	6	3
P	6	--	0	0	--	0	0	--	0	0	--	0	13
Q	14	--	0	3	--	1	3	--	2	2	--	1	26
R	12	--	0	3	--	0	0	--	0	0	--	0	49
S	15	--	6	13	--	2	10	--	3	5	--	1	19

[1]Sample size was six blocks. U = unweathered, W_2 = weathered 2 weeks, W_4 = weathered weeks.

[2]A = Pentachlorophenol, 10% in diesel oil
P = solubilized copper naphthenate, cunapsol, 2% copper in water, Chapman Chemical Co.
Q = Fluor-chrome-arsenic-phenol, 5% in water
R = Chromic acid, 5% in water
S = Ammoniacal copper arsenate, 3% in water, J. H. Baxter & Co.

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 (1982 Ann. Rept., pages 31-33). During the summer of 1982, cores were removed with an increment borer near bolt holes in four control poles and they were cultured to determine if the incidence of decay fungi in the unprotected bolt holes was high enough to warrant similar assessment of the poles with treated bolt holes. A core was removed directly below the gain plate and above the washer on the opposite side of the pole. Each pole contained eight bolt holes and consequently 16 cores per pole were cultured for decay fungi.

Decay fungi were obtained from three cores above the bolt holes from two different poles. Thus the incidence of decay fungi in 1982 was too low to warrant evaluation of the treated poles at that time. However, cores will be removed from all poles during the summer of 1983.

OBJECTIVE IV

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

A. DETECTING EARLY DECAY IN DOUGLAS-FIR BY A SEROLOGICAL TECHNIQUE.

A serological technique for the detection and identification of decay fungi in culture and in wood was investigated as a method for detecting incipient decay in poles. Two rabbits were injected with aqueous preparations of *Poria placenta* hyphae. Later, the rabbits were bled to obtain serum which might contain antibodies specific against *Poria*.

Initial results indicate that antibody specificity for the decay fungus is marginal. Although the antisera from the rabbits reacted positively with *Poria* cultures, its reaction with *Aspergillus niger* and *Pennicillium expansum*, two nondecay fungi used as controls, was undesirably strong. Additional extensive experimentation would be needed to fully evaluate this technique for detection of early decay in poles.

B. ESTIMATING RESIDUAL STRENGTH OF POLES

Compression, bending, and Pilodyn tests of wood from air seasoned Douglas-fir poles.

Pole sections from our studies on decay development during air seasoning ('81 Ann. Rept., pages 44-45) were used to evaluate strength tests on wood that recently had become infested with decay fungi. The pole sections had been exposed at four sites in the Pacific Northwest. After air-seasoning for 1 year, 24 pole sections (six from each of the exposure sites) were cut to provide six beams 2.54 x 2.54 x 40.6 cm long from each pole section (144 beams in all).

All beams were immersed in water under a vacuum-pressure cycle to bring the wood to a moisture content of at least 30%, and the beams were tested to failure at mid-span by bending. Radial compression strength (RCS) of the wood was tested on 0.5 inch diameter plugs cut radially near one end of each beam. Before testing, the plugs were soaked in water under vacuum to insure a moisture content above 30%. Strength perpendicular to the grain in the radial direction was then measured using an Instron Universal Testing Machine at a head speed of 0.03 cm/min. Following the latter test, the plugs were cultured for decay fungi.

Beams containing only sapwood were tested with a Pilodyn which consists of a spring driven pin and an indicator to measure radial penetration of the pin.

Decay fungi or fungi with decay potential were isolated from 28 of the 144 beams representing 14 of the 24 pole sections (Table 18). The fungi were equally prevalent in the sapwood and heartwood.

Measurements of modulus of rupture (MOR), modulus of elasticity (MOE), work to maximum load, RCS, and Pilodyn pin penetration of the wood containing decay fungi were not significantly different from the corresponding values for wood from which no decay fungi were isolated (Table 19). Although infested with potentially destructive decay fungi, the wood in these pole sections was apparently at too early a stage of decay to show significant strength reduction. Pilodyn and RCS test values for these specimens will be used as the range of values indicative of sound, untreated Douglas-fir (Figure 8).

Some interesting associations between the test values (Table 19) were evident. For example, specific gravity was more highly associated with MOR than with MOE or work to maximum load, while RCS was not associated with specific gravity or bending strength properties of the wood. For sapwood, specific gravity was more highly associated with MOR than Pilodyn penetration. Combining specific gravity and Pilodyn penetration did not improve the association with MOR.

TABLE 18
DECAY FUNGI IN SMALL BEAMS FROM DOUGLAS-FIR POLE SECTIONS AIR-SEASONED FOR ONE YEAR

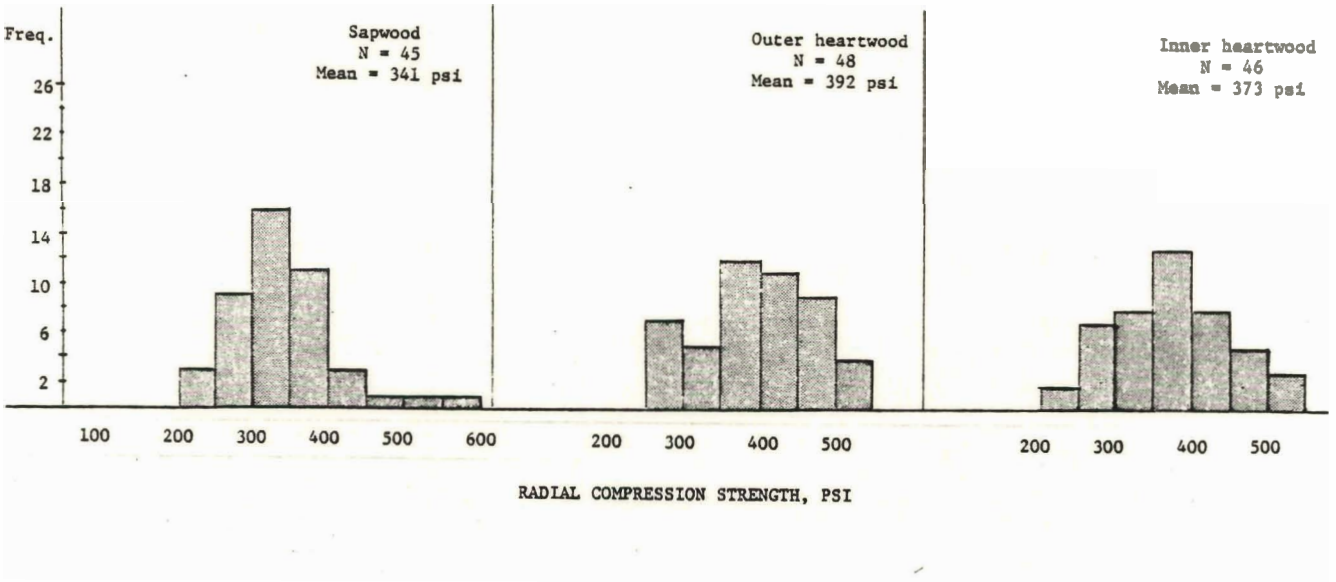
FUNGUS	NUMBER OF BEAMS WITH DECAY FUNGI[1]			TOTAL ISOLATED
	SAPWOOD	OUTER HEARTWOOD	INNER HEARTWOOD	
Coriolus versicolor	1			1
Phanerochaete sordida	2	3	2	7
Poria carbonica		1		1
Poria placenta		3	5	8
Stereum hirsutum	1			1
Unidentified	5	1	4	10
Totals	9	8	11	28

[1] Decay fungi isolated from 144 beams cultured.

TABLE 19
MECHANICAL PROPERTIES OF SMALL BEAMS CUT FROM COAST DOUGLAS-FIR POLE SECTIONS AIR-SEASONED FOR ONE YEAR

DESCRIPTION OF MATERIAL	NUMBER OF BEAMS	SPECIFIC GRAVITY (GREEN)	STATIC BENDING STRENGTH			PILODYN[1] PENETRATION (12% MC)	RCS[2] (GREEN)
			MODULUS OF RUPTURE (GREEN)	MODULUS OF ELASTICITY GREEN)	WORK TO MAXIMUM LOAD (GREEN)		
			(psi)	(million psi)	(lb/in^3)	(mm)	(psi)
Sound wood no decay fungi	117	0.44	7100	1.5	8.6	18	368
Sound wood decay fungi present	26	0.45	7448	1.6	9.4	17	371
Coast Douglas-fir (Publ. values)		0.45[3]	7665[3]	1.6[3]	7.6[4]		

[1] 1.8 MKP Model, pin 3 mm diameter 70 mm long. Specimens tested contained only sapwood.
[2] Wood plugs were 0.5 inches in diameter and 0.75 inches long.
[3] From ASTM D2555-78. Establishing clear wood strength values.
[4] Wood Handbook value.



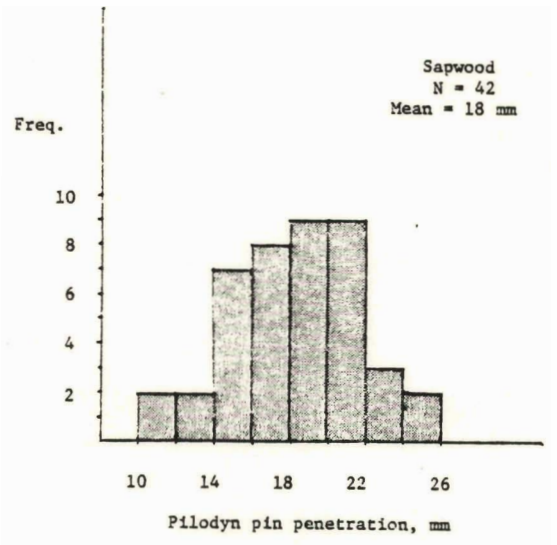


Figure 8. (A) Radial compression strength values, green moisture content and (B) Pilodyn penetration values, 12% moisture content of sound, untreated Douglas-fir.

Compression, bending, and Pilodyn tests of wood from decayed Douglas-fir poles in service.

Matched pairs of beams (2.5 by 2.5 by 35-cm long) were cut from poles with wood that varied from sound appearing to obviously decayed. The beams were stored at 70°C and a relative humidity providing a wood equilibrium moisture content of 12%. One set of beams was tested for bending strength, specific gravity, RCS, and Pilodyn penetration. The data were analyzed for the ability of various tests to predict bending strength. The remaining set of beams will be analyzed using sonic stress wave patterns.

The bending strength values of most of the beams were much lower than the average strength values for coast Douglas-fir (Table 20). Specific gravity (measured near the test break) was less useful for predicting modulus of rupture (MOR) of beams from poles with decay than it was for beams from undecayed poles. This is in agreement with observations that decay causes strength loss more rapidly than specific gravity loss.

Radial compression strength (RCS) values were generally less than 200 psi in the plugs from beams with an MOR (green) below 4949 psi which approximates the lower 5% limit for coast Douglas-fir (Table 20). These results are in agreement with previous findings (Fig 8, A) that the RCS of sound heartwood ranges from 221 to 539 psi. The correlation between RCS and MOR in these beams from decayed poles was poor, but when specific gravity values were considered along with the RCS values the relationship to the MOR values was improved.

The Pilodyn pin penetrated completely through all but one beam with an MOR (green) below 4949, consequently readings above 25 mm indicate low strength wood. These results support the previous finding (Fig. 8, B) that Pilodyn pin penetration ranging between 10 and 25 mm indicates sound Douglas-fir wood.

TABLE 20

MECHANICAL PROPERTIES OF 19 SMALL HEARTWOOD BEAMS CUT FROM DOUGLAS-FIR POLES WITH DECAY

SPECIFIC GRAVITY (green)	STATIC BENDING STRENGTH MOR (12% MC)	MOR (adj. to green MC)	MOE (12% MC)	WORK (12% MC)	PILODYN[1] PENETRATION (12% MC)	RCS (green)
	psi	psi	psi x 1000	lb/cu.in	mm	psi
.38	789	488	199	0.2	–[2]	–[2]
.32	1230	760	509	0.2	+[3]	154
.32	1533	948	798	0.1	+	99
.33	1651	1020	788	0.2	+	180
.34	2139	1322	985	0.2	+	101
.32	2379	1470	770	0.4	+	135
.32	2414	1492	846	0.4	+	148
.38	2731	1688	499	3.0	21.5	191
.41	2778	1717	372	3.5	+	378
.38	2786	1724	667	1.1	+	208
.38	3043	1881	711	1.0	+	121
.34	3478	2150	1068	0.7	+	211
.40	4586	2835	1209	1.1	+	194
.36	5179	3201	1139	1.4	+	196
.42	5461	3376	1288	1.7	+	165
.44	8007	4949	965	24.4	13.5	312
.41	9863	6097	1578	10.4	22.75	255
.49	10410	6435	1827	11.7	24	295
.40	10859	6712	1728	6.9	18.25	326
AVERAGE PROPERTIES OF SOUND DOUGLAS-FIR						
.45[4]	12400[5]		7665[4]	1950[5]	9.9[5]	18[6]	392[6]

1.8 mkp model, pin 3mm diameter 70 mm long.

2 Specimen too decayed for test.

3 +=Pilodyn pin penetrated through specimen.

4 From ASTM D 2555-78. Establishing clear wood strength values.

5 Wood Handbook value.

6 From previous tests of sound Douglas-fir (see Figure 8).

In summary, these results suggest that specific gravity is not a good predictor of bending strength of wood from poles with decay, but considering both specific gravity and RCS tests improves the ability to predict bending strength. RCS and Pilodyn tests merit further study as field methods for identifying poles with low strength wood.

Significance of discolored heartwood in ammoniacal copper arsenate (ACA) treated Douglas-fir poles.

Red discoloration of wood on the inside edge of the treated zone along with the isolation of bacteria and imperfect fungi from the treated zone led one electric utility to believe that there was wood deterioration in poles which had been in storage for 4 years. To assess the condition of these poles, plugs were removed with a half-inch diameter plug cutter from 26 poles and radial compression strength was determined. The RCS values of the sapwood and heartwood from the ACA-treated poles were significantly lower than the corresponding values from untreated Douglas-fir (Table 21). The sapwood value for the ACA-poles was especially low and may indicate reduced residual pole strength. Consequently, we have recommended that bending strength tests should be made on small beams removed from these poles, and Pilodyn readings be taken.

Results of tests to determine ACA penetration and observations of untreated Douglas-fir soaked in ammonia suggest that red-discolored wood is probably heartwood stained by ammonia.

Douglas-fir poles infected with the decay fungus Schizophyllum commune during air-seasoning.

Abundant growth of a black mold and fruiting bodies of Schizophyllum commune appeared on freshly peeled Douglas-fir poles during the wet mild

Oregon winter of 1983. Yard personnel observed that poles with the black mold were slow to dry and were concerned about wood degradation. In April, 1983, a preliminary study was made on a small sample of poles.

TABLE 21

RADIAL COMPRESSION STRENGTH (RCS) OF WOOD FROM ACA-TREATED AND UNTREATED DOUGLAS-FIR POLES[1]

WOOD TESTED	AVERAGE RCS VALUES (psi)	
	ACA-TREATED POLES	UNTREATED POLES
Sapwood	204	341
Heartwood (red discolored)	303	---
Heartwood (untreated)	330	392

[1] From previous tests of sound Douglas-fir (Figure 8, A)

Poles with the black mold had a sapwood moisture content of about 45%, but RCS values for wood from these poles were not significantly different from those for sound, untreated Douglas-fir.

The poles containing Schizophyllum commune had moisture contents between 25 and 32%, and RCS values slightly lower than the average values for sound, untreated Douglas-fir (Table 22). Should this problem reoccur, tests will be made to determine contributing factors and bending strength tests will be performed on samples from the infected poles.

TABLE 22

RADIAL COMPRESSION STRENGTH (RCS) OF
WOOD FROM DOUGLAS-FIR POLES
INFECTED BY SCHIZOPHYLLUM COMMUNE AND SOUND POLES

WOOD TESTED	AVERAGE RCS VALUES (psi)	
	UNTREATED POLES WITH SCHIZOPHYLLUM COMMUNE	SOUND UNTREATED POLES[1]
Sapwood	294	341
Outer Heartwood	336	392
Inner Heartwood	328	373

[1]From previous tests of sound Douglas-fir (see Figure 8, A).

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 the summer and fall of 1981, when air-seasoning poles in 11 pole yards in the Pacific Northwest were sampled. Fourteen 6-inch long cores distributed along the length of each pole were removed and 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 testing. Suspect fungi are isolates with most of the morphological characteristics of basidiomycetes but positive identification is pending. Often these isolates turn out to be monokaryons of decay fungi that lack clamp connections, one microscopic characteristic used to identify basidiomycetes.

Ten air-seasoning yards were sampled in 1982, seven of which were not visited in 1981. Sampling was concentrated on poles seasoned for 1 year and longer and on freshly cut poles which were sampled at six additional locations distributed through the geographic range of Douglas-fir pole production. A total of 21,222 cores from 1540 poles have been taken and processed since the beginning of this study. Identification of most of the isolates from 1981 has been completed and identification of 1982 isolates is currently underway. About 77% of the total number of isolates have been

identified. The large amount of data generated in this study has been prepared for computer analysis. We are now in the final stages of debugging the data base so that reports can be prepared.

Decay fungi from air-seasoning poles.

Infestation of the poles by decay fungi increases rapidly during air seasoning so that after 1 year nearly all poles contain decay fungi (Table 23). Poria carbonica, the major pole decay fungus, is the second most frequently isolated fungus from poles air-seasoned for 25 months or longer. Infestation of poles on a cores basis provides an estimate of the volume of wood inhabited by decay fungi. As with the number of poles, the number of infested cores increases greatly as the air-seasoning period becomes longer (Table 24). In general, as air seasoning time increases the fungi are infesting more poles and within each pole they are occupying more wood.

Sampling of freshly cut poles in the forest this past year has demonstrated that some poles contain potential decay fungi before they reach the pole yard. Following is a brief characterization of the most frequently isolated decay fungi from the air seasoning poles:

Haematostereum sanguinolentum. This fungus is a white rotter that is very common in the Pacific Northwest. It causes reddish heartrot in living trees and continues to decay the wood after the tree is cut. It accounts for 74% of the rot resulting from wounding of living Douglas-fir. Commonly found on slash and recently down trees, H. sanguinolentum may be seen fruiting in pole yards on untreated poles.

Peniophora spp. This is a group of common white rot fungi that are distinctive as a group, but hard to separate into species. These fungi are capable of decaying wood, but are generally limited to the sapwood in Douglas-fir.

TABLE 23

FREQUENCY OF DECAY TYPE FUNGI ISOLATED FROM DOUGLAS-FIR POLES SEASONED FOR VARIOUS TIME PERIODS IN EIGHTEEN POLE YARDS IN THE PACIFIC NORTHWEST

FUNGI	NUMBER OF POLES CONTAINING DECAY TYPE FUNGI AIR SEASONED FOR VARYING LENGTHS OF TIME (MONTHS)							
	FRESH[1]	UNPEELED	0-6	7-12	13-18	19-24	25+	TOTAL
Haematostereum sanguinolentum	2	4	52	69	83	69	90	369
Peniophora spp.	0	0	11	57	72	56	33	229
Sistotrema brinkmanii (species complex)	1	4	34	50	34	33	37	193
Poria carbonica	0	0	4	23	31	41	70	169
Epicoccum nigrum[2]	1	8	19	31	39	37	18	153
Poria placenta	1	2	7	18	21	28	24	101
Coriolus versicolor	7	5	13	7	24	7	14	77
Stereum hirsutum	0	2	5	12	18	13	10	60
Phanerochaete sordida (species complex)	4	0	2	6	13	17	5	47
Gloeophyllum saepiarium	1	1	2	0	5	10	13	32
Schizophyllum commune	2	1	4	1	13	3	2	26
Fomitopsis cajanderi	1	5	5	6	3	2	3	25
Cystostereum pini-canadense	0	0	8	0	0	0	0	8
Fomitopsis pinicola	1	0	2	0	0	0	1	4
Poria cinerascens	0	0	1	0	3	0	0	4
Phlebia "A"	1	0	0	1	2	0	0	4
Type 10[3]	0	0	0	0	4	0	0	4
Heterobasidion annosum	0	0	1	1	0	1	0	3
Phlebia radiata	1	0	0	0	1	1	0	3
Poria xantha	0	0	0	0	0	1	1	2
Phlebia gigantea	0	1	1	0	0	0	0	2
Type 14[4]	2	0	0	0	0	0	0	2
Antrodia serialis	0	0	0	0	0	1	0	1
Crustoderma dryinum	0	0	0	0	0	0	1	1
Phlebia albida	0	0	0	0	0	1	0	1
Unidentified basidiomycetes	18	8	27	62	59	52	67	293
Unidentified without clamps	69	17	37	19	35	18	27	222
Total number of poles with fungi[5]	95	48	154	193	152	141	161	
Total number of poles samples	274	211	283	268	164	154	186	1,540
Percentage of poles with fungi	34.7	22.7	54.4	72.0	92.7	91.6	86.6	

[1] These poles were sampled within 4 weeks of cutting.
[2] A non basidiomycete fungus that influences wood strength.
[3] Type 10 is a white rot fungus probably a Peniophora sp.
[4] Type 14 is a clampless brown rot fungus with fiber hyphae.
[5] The sum of these totals does not equal the total of the final column because individual poles may have yielded more than one fungal species.

TABLE 24

FREQUENCY OF DECAY TYPE FUNGI ISOLATED FROM CORES TAKEN FROM DOUGLAS-FIR POLES SEASONED FOR VARIOUS TIME PERIODS IN EIGHTEEN POLE YARDS IN THE PACIFIC NORTHWEST

FUNGI	NUMBER OF CORES YIELDING DECAY TYPE FUNGI AIR SEASONED FOR VARYING LENGTHS OF TIME (MONTHS)							
	FRESH[1]	UNPEELED	0-6	7-12	13-18	19-24	25+	TOTAL
Haematostereum sanguinolentum	2	7	114	154	191	189	204	861
Peniophora spp.	0	0	11	86	162	106	50	415
Sistotrema brinkmanii (species complex)	1	4	70	108	44	50	68	345
Poria carbonica	0	0	6	33	40	69	125	273
Epicoccum nigrum[2]	1	9	22	44	51	63	26	216
Poria placenta	1	2	8	22	24	40	27	124
Coriolus versicolor	10	5	13	10	43	8	17	106
Fomitopsis cajanderi	1	16	13	19	8	11	13	81
Stereum hirsutum	0	2	5	12	21	15	10	65
Phanerochaete sordida (species complex)	4	0	2	6	14	21	5	52
Gloeophyllum saepiarium	1	1	2	0	5	17	16	42
Schizophyllum commune	2	1	10	2	20	3	2	40
Cystostereum pini-canadense	0	0	13	0	0	0	0	13
Fomitopsis pinicola	1	0	3	0	0	0	1	5
Type 10[3]	0	0	0	0	5	0	0	5
Poria cinerascens	0	0	1	0	3	0	0	4
Phlebia "A"	1	0	0	1	2	0	0	4
Phlebia radiata	1	0	0	0	1	1	0	3
Heterobasidion annosum	0	0	1	1	0	1	0	3
Poria xantha	0	0	0	0	0	1	1	2
Phlebia gigantea	0	1	1	0	0	0	0	2
Type 14[4]	2	0	0	0	0	0	0	2
Phlebia albida	0	0	0	0	0	1	0	1
Antrodia serialis	0	0	0	0	0	1	0	1
Crustoderma dryinum	0	0	0	0	0	0	1	1
Unidentified basidiomycetes	23	13	31	89	86	88	122	452
Unidentified without clamps	104	22	53	23	43	23	32	300
Total number of cores with fungi[5]	149	83	373	590	723	643	664	
Total number of cores isolated	3,834	2,528	3,939	3,784	2,350	2,159	2,628	21,222
Percentage of cores with fungi	3.9	3.3	9.5	15.6	30.8	29.8	25.3	

1 These poles were sampled within 4 weeks of cutting.
2 A non basidiomycete fungus that influences wood strength.
3 Type 10 is a white rot fungus probably a Peniophora sp.
4 Type 14 is a clampless brown rot fungus with fiber hyphae.
5 The sum of these totals does not equal the total of the final column because individual poles may have yielded more than one fungal species.

Sistotrema brinkmanii. This is a complex of species grouped under one name. Their natural habitat is quite variable, ranging from decaying sporocarps of other fungi to bark and wood. Although they can live in wood, they probably are not extremely damaging. Both Peniophora and Sistotrema are commonly found fruiting on untreated poles in the yards. These fungi are prevalent in the younger air seasoning poles, but decrease in numbers in the older poles. This suggests that they are inhabiting the sapwood where they don't pose much of a strength loss hazard.

Poria carbonica
Poria placenta. These are the two major decay fungi found in Douglas-fir poles in service. They cause a brown rot which results in rapid strength loss in the early stages of decay. P. carbonica increases with seasoning time until it is one of the most frequently isolated fungi. P. placenta increases to a lower level where it appears to remain.

Epicoccum nigrum. This is a non basidiomycete that is commonly found in wood. Preliminary tests indicate it may be capable of causing strength loss in Douglas-fir.

Coriolus versicolor. This fungus is a common white rotter on many hardwoods and softwoods and is capable of decaying heartwood and sapwood. Strength loss tests indicate this fungus can be highly destructive to wood products.

Fomitopsis cajanderi. This fungus causes a top rot in living trees and can cause a brown rot in logs and timber in service. Like H. sanguinolentum, F. cajanderi occurs in living trees and may continue to be active in poles made from the infected trees.

Gloeophyllum saepiarium. This fungus is a brown rotter commonly found on slash and downed timber. It is an important products rot and has been reported as a problem in poles and timbers.

Schizophyllum commune. This fungus is an extremely common white rot fungus which occurs naturally on slash and downed timber. Fruiting bodies are very common in pole yards, however damage appears slight and is probably limited to sapwood.

Stereum hirsutum
Phanerochaete sordida. These two fungi are common white rotters but are probably not a problem in Douglas-fir poles.

From the frequent isolation of the monokaryons of decay fungi (Table 25) it is evident that infection by basidiospores that initiate the monokaryons is occurring in the pole yards. The relatively high percentages of monokaryons of P. placenta and C. versicolor in poles of all age classes

suggest that spores of these fungi infect the poles at relatively constant rates. The prevalence of fruiting bodies of many of these fungi in the pole yards further suggests that the local spore concentration may be fairly high.

Currently, P. carbonica and P. placenta are the major decay fungi found in Douglas-fir poles, but this situation could change as different preservatives and pole production methods are used. Air seasoning poles contain many fungi with potential to decay wood and some of these fungi could become problems in the future.

TABLE 25

FREQUENCY OF DECAY FUNGUS MONOKARYONS ISOLATED FROM CORES REMOVED FROM DOUGLAS-FIR POLES SEASONED FOR VARIOUS TIME PERIODS IN EIGHTEEN POLES YARDS IN THE PACIFIC NORTHWEST

FUNGI	MONOKARYONS AS A PERCENTAGE OF THE TOTAL FUNGAL ISOLATES FROM POLES AIR SEASONED FOR VARYING LENGTHS OF TIME (MONTHS)							
	FRESH[1]	UNPEELED	0-6	7-12	13-18	19-24	25+	TOTAL[2]
Poria placenta	100	0	88	23	42	52	56	48
Coriolus versicolor	90	40	62	40	8	12	29	30
Poria carbonica	0	0	17	6	10	7	3	6
Schizophyllum commune	50	0	10	0	15	0	0	12
Phlebia "A"	100	0	0	100	100	0	0	100
Poria cinerascens	0	0	100	0	66	0	0	75
Fomitopsis pinicola	100	0	33	0	0	0	100	60
Fomitopsis cajanderi	0	0	23	0	0	0	0	4
Phlebia radiata	100	0	0	0	100	100	0	100
Phlebia albida	0	0	0	0	0	100	0	100
Poria xantha	0	0	0	0	0	100	0	50

[1] These poles were sampled within 4 weeks of cutting.
[2] Percentage of the total number of isolates of each fungus that are monokaryons.

Pole coring methodology.

All of the cores from poles in our studies have been taken using a power drill. There is a possibility that the heat generated by repeated boring with the same borer might be influencing the frequency of fungi isolated from the cores. To test this, three untreated pole sections that had been exposed for 1 year at the Northwest Forest Genetics Station, Corvallis, OR were sampled by taking cores in rows spaced 6 inches apart around the circumference of the pole and staggered 6 inches along the length. One set of cores (215) was taken using a power drill and two borers, as per usual, while the second set (215) was taken by hand from the same pole sections using borers which were cooled over dry ice between uses. These cores were taken 1 inch from the holes of the cores taken with the power drill, resulting in two sets of paired cores. The cores were then treated identically through processing and culturing for decay fungi.

Slightly higher numbers for several fungi were obtained from the cores taken by hand (Table 26). Statistical analysis however showed that the frequencies of isolation obtained with the two techniques were not different, and thus we are satisfied that our coring technique did not influence the populations of fungi obtained from the poles.

TABLE 26

FREQUENCY OF DECAY TYPE FUNGI ISOLATED FROM CORES TAKEN BY HAND OR POWER DRILLING OF DOUGLAS-FIR POLES

FUNGI	NUMBER OF CORES YIELDING DECAY TYPE FUNGI TAKEN FROM DOUGLAS-FIR POLES BY EITHER HAND OR POWER DRILLING[1]	
	HAND CORED	POWER CORED
Poria placenta	71	55
Poria carbonica	50	43
Haematostereum sanguinolentum	29	23
Stereum hirsutum	4	1
Coriolus versicolor	1	1
Poria xantha	1	0
Peniophora spp.	0	1
Unidentified basidiomycetes	2	2
Unidentified without clamps	11	14

[1] The results are based on 215 cores taken by hand and 215 by power drilling.

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

Strength-loss tests have been evaluated to rapidly assess the decay potential of fungi isolated from air-seasoning poles. The results of these tests will also focus identification efforts on the more destructive fungi. Douglas-fir heartwood sticks (17 x 6 x 1 mm) were placed on fungal colonies actively growing on nutrient medium in petri plates. One month later, the sticks were removed and tested for toughness by impact breaking and bending radius.

Wood toughness is the total amount of strain the wood can absorb up to complete failure. It is one of the first properties of wood affected by decay fungi and losses up to 50% have been reported at 2% weight loss.

The bending radius of the sticks was measured on a series of 17 mandrels varying in radius from 3.5 to 0.125 inches (89 to 3.2 mm). A stick is bent around succeedingly smaller mandrels until it breaks. A decayed stick will break on a larger radius than a sound one. Impact breaking or energy

absorbed to break a stick was measured by a pendulum device. The swinging arm is dropped and strikes the test stick placed at the bottom of the arc. A pointer moving with the swinging arm remains at the highest point on the arc reached by the pendulum after breaking the stick. The distance the pointer moves up the arc is a measure of the energy absorbed by the pendulum passing through the stick. Thus, the greater the arc traveled by the pointer the weaker the wood in toughness and the larger the indication of its being decayed.

In preliminary experiments we determined that the shortest incubation period of sticks with Poria carbonica and P. placenta that gave strength loss values significantly different from the controls (no fungus) was 2 weeks. However, we have adopted a 1 month incubation period for the tests to allow detection of fungi that might decay wood at a slower rate.

The moisture content of the sticks placed directly on the fungal cultures growing on nutrient medium was generally above 100% and significantly slowed decay by the Poria spp. Soaking the sticks for 5 minutes before putting them on glass supports in the culture plates lowered the moisture content to about 50% and enhanced the decay rate.

Wood toughness is known to be influenced by moisture content and thus our tests were performed at uniform moisture levels. For bending radius tests, oven dry wood gave the best results, but for the impact breaking test, wood above the fiber saturation point (30% MC) was better.

A number of fungi isolated from air-seasoning poles were evaluated in the breaking radius test to determine how the test conditions established for the Poria spp. worked with other fungi. Sticks were placed on the agar or on glass supports and toughness was estimated on the mandrels after various incubation periods.

Generally the sticks were more decayed when incubated on the glass supports giving a lower moisture content (Figure 9). Of the 11 fungi tested, five decayed wood significantly faster when supported. The fungi that decayed wood slower when the wood was supported above the culture surface generally had difficulty reaching the sticks and this has lead to modifications in our methods to aid the contact between the fungus and the wood without increasing the moisture content of the wood.

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

Poria 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. Infection can occur through direct contact with soil-borne hyphae, but air-dissemination by the fungus is also involved. In earlier studies we demonstrated that single, asexual spores (i.e. chlamydospores) are capable of establishing infection under near optimum conditions. 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 current studies are concentrating on understanding basidiospore germination.

Basidiospore germination.

Environmental conditions favoring basidiospore germination are of interest as predictive indicators of high-risk decay periods. The time required for germination and germination percentage were measured to assess the effects of various environmental factors. Basidiospores were aseptically collected from under actively sporulating cultures and the spores were suspended in sterile distilled water. The spore concentration was adjusted

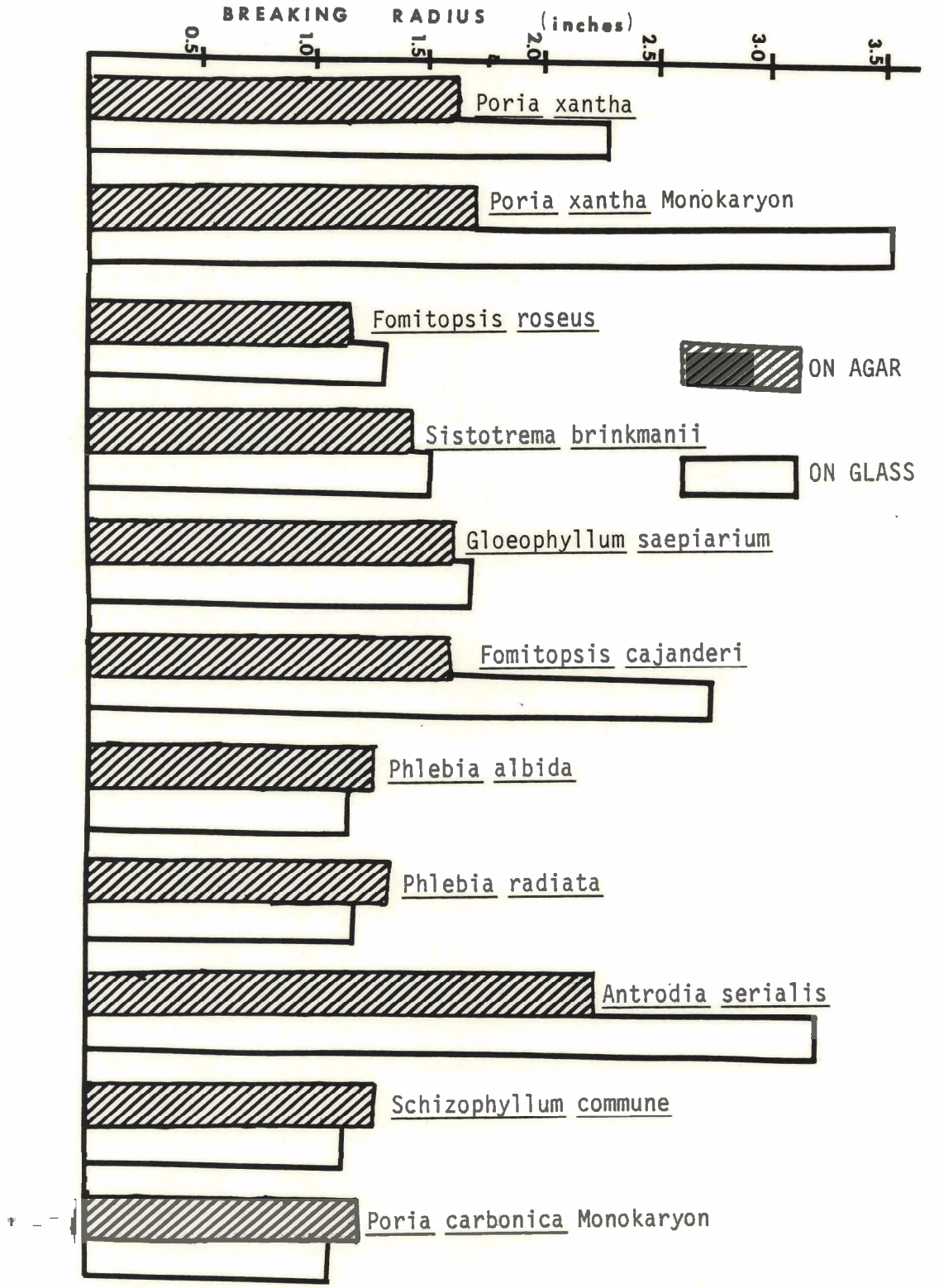


Figure 9. The influence of decay fungi on the breaking radius of Douglas-fir heartwood sticks placed directly on the culture surface or raised above the surface on glass rods

to $1x10^5$ spores/ml, and 25 µl drops were placed on a malt agar medium (12.4 g malt extract and 15 g agar/liter). The plates were incubated at room temperature (22°C) and monitored periodically for spore germination. Germination was defined as the time when the germ tube length equalled the spore length. Fields of view were examined until at least 100 spores had been counted.

After 18 hours about 6.4% of the spores had germinated and by 96 hours 17.3% had germinated. Although quite low, this percentage germination is similar to that of some other decay fungi. After 96 hours, mycelial growth obscured the ungerminated spores making them difficult to examine accurately.

One major determinant in infection success is the moisture content of the wood and to study this, two methods are needed: a system for placing the spores on wood and a method for observing the spores on the wood. A drop of water containing spores adds too much moisture to the wood consequently, we developed a system in which the basidiospores drop from a fruiting body directly onto the wood surface. This system has the advantage that it closely parallels natural infection.

There are several approaches to observing the spore on the wood surface, one of which is to use extremely thin (e.g. 60 micron) sections that can be mounted and observed with a light microscope. This method is unacceptable however, because it is too difficult to accurately control and measure the moisture content in thin wood sections. Initially we are using blocks 1 cm^3, with one surface planed with a microtome to give a smooth surface for viewing.

Viewing the spores on the wood surface is a problem now under study. The basidiospores, which are 3x5 microns, are 1/100,000 the size of the period at the end of this sentence and are semi-transparent. Conventional fungal staining techniques were unsatisfactory for this purpose and we are currently experimenting with stains that cause living cells to fluoresce.

Fungal hyphae on the wood surface can be seen by this method, but it remains to be tested on germinating spores. Preliminary experiments indicate that fluorescein diacetate is picked up by germinating basidiospores and not by nongerminating spores of P. carbonica which should allow direct observation of the germination process on the wood.

Infection Study

To study the influence of the environment on how and when poles become infected with decay fungi, sterilized pole sections placed horizontally and vertically are being exposed for 3 month intervals at four locations in the Pacific Northwest. The sections are sampled after exposure and the resulting fungi cultured and identified. Details of the experimental design ('81 Ann. Rept., pages 42-44) and the first year's results ('82 Ann. Rept., pages 45-47) have been reported.

The dramatic increase in infection during Nov.-Jan. '81 at all locations except Arlington, WA did not repeat in that same time period during 1982 (Table 27). There was, however, a continuing low level of infection at all sites during the year with a slight peak of infection in May-July '82 in Arlington WA. We are currently in the process of computer analysis of the infection study data. We will soon be able to study, for example, the correlation between the weather at the four sites and the infection results. This type of analysis may provide leads to a better understanding of the seasonal variation in pole infection by decay fungi.

Decay Development Study

This experiment was designed in 1981 ('81 Ann. Rept., pages 44-45) to determine the volume of wood that might become infested by decay fungi during air-seasoning. In 1982, the first set of pole sections were sampled ('82

Ann. Rept., pages 47-48) and we have cultured the cores and identified most of the decay fungi obtained. Currently we are sampling a second set of pole sections that have been air seasoned for 2 years, and we are working with the computer analysis of the results to provide a three-dimensional estimate of the volume of wood infested each year.

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.

Pole sections treated with ammonium bifluoride from the four exposure sites were sampled in 1982 ('82 Ann. Rept. page 48). The cores have been cultured and decay fungi, when present, have been identified. Currently we are sampling a second set of pole sections that have been air-seasoned for 2 years following treatment. Results of these treatments will be computer analyzed along with the results from the decay development pole sections.

This summer the first set of cores will be removed from the pole sections treated with encapsulated chloropicrin or methylisothiocyanate to protect the pole sections from decay fungi during air seasoning.

TABLE 27

INCIDENCE OF BASIDIOMYCETES AND SUSPECT FUNGI IN DOUGLAS-FIR POLE SECTIONS EXPOSED FOR 3 MONTH PERIODS AT FOUR LOCATIONS IN THE PACIFIC NORTHWEST

YEAR AND PLOT LOCATION	FRACTION[1] AND PERCENTAGE OF CORES WITH BASIDIOMYCETES AND SUSPECT FUNGI[2] FROM 2 AND 4 FT. POLE SECTIONS EXPOSED FOR 3 MONTH INTERVALS							
	May - July		Aug. - Oct.		Nov. - Jan.		Feb. - Apr.	
	Fraction	%	Fraction	%	Fraction	%	Fraction	%
1981-'82								
Arlington, WA	9/219	4.1	12/215	5.6	15/304	4.9	5/286	1.7
Scappose, OR	17/335	5.1	15/211	7.1	48/288	17	16/288	5.5
Eugene, OR	----------[3]		18/209	8.6	99/288	34	6/280	2.1
Oroville CA	7/183	3.8	12/222	5.4	118/302	39	19/288	6.6
1982-'83								
Arlington, WA	28/267	10.5	10/317	3.2	6/253	2.4		
Scappoose, Or	8/257	3.1	8/257	3.1	5/261	1.9		
Eugene, OR	2/281	0.7	2/281	0.7	8/293	2.7		
Oroville, CA	4/266	1.5	9/261	3.4	0/275	0		

"Fraction" is the number of cores with basidiomycetes or suspect fungi over the total number of cores.

[2] Suspect fungi are isolates that have most of the morphological characteristics of basidiomycetes but positive identification is pending.

[3] Core cultures lost due to extensive contamination of the cultures by non-basidiomycete fungi.