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Comparison of Preservative Treatments in Marine Exposure of Small Wood Panels

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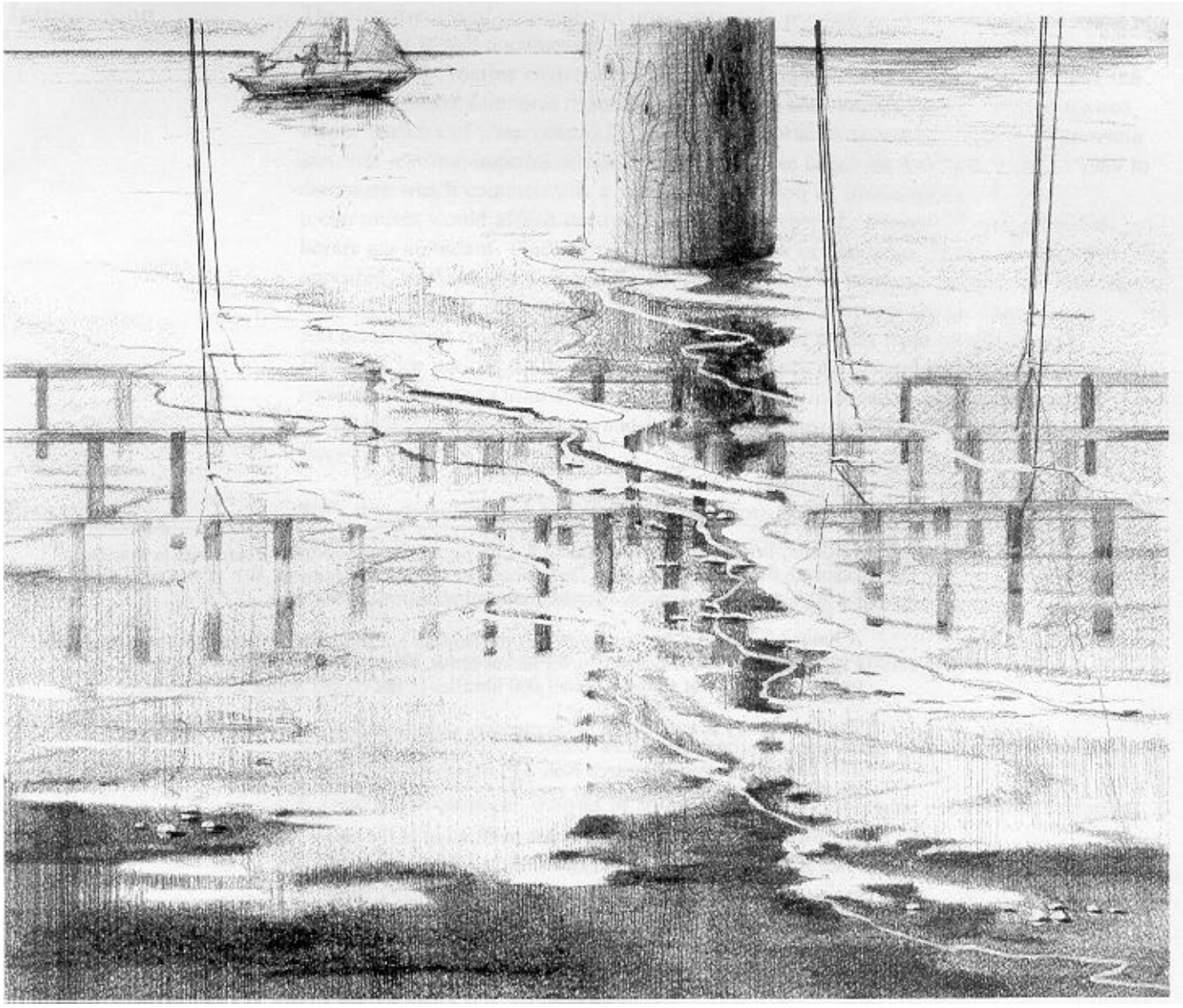

Abstract

Small wood panels treated with many different chemicals have been exposed to limnoriid and teredinid marine borers in the sea at Key West, Florida. These preservatives and treatments include creosotes with and without supplements, waterborne preservatives, waterborne preservative and creosote dual treatments, chemical modifications of wood, and modified polymers. In spite of the accelerated nature of this test, many treated panels remain free of attack after 19 years in the sea. By contrast, untreated panels have been badly damaged by marine borers after 6 to 18 months of exposure.

Keywords: Wood preservation, marine borers, creosote, CCA, chemical modification, *Limnoria*, shipworms, teredinids, durability

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Comparison of Preservative Treatments in Marine Exposure of Small Wood Panels

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Introduction

The effectiveness of conventional preservatives in preventing biodegradation of wood in soil contact is well documented. However, these preservatives may be much less effective in the marine environment. This is especially true in warmer waters where the crustacean borer *Limnoria tripunctata* L. prevails and readily attacks creosote-treated wood. Because of observations that some waterborne preservatives deter *L. tripunctata* and that creosote impedes attack by shipworms, we began an accelerated test in 1969 to determine which commercially available formulation or formulations of these preservatives would afford maximum protection where *L. tripunctata* and teredinid borers are abundant. Since then, as promising new or candidate preservatives have appeared, we have installed additional test specimens in hopes of finding still simpler, lower cost, or more effective treatments. This report compares the effectiveness of 300 preservative treatments in protecting small wood panels from teredinids and *Limnoria* for periods up to 19 years. The report includes several treatments not previously reported (Johnson and Gutzmer 1984) or included in earlier publications on the original study (Johnson and others 1973; Johnson 1977, 1982; Johnson and Gutzmer 1981).

Procedures

With few exceptions, we have followed American Society for Testing and Materials Standard D 2481 (ASTM 1981). Test specimens were prepared as follows:

1. Selection of southern pine sapwood with 6 to 9 rings per inch

2. Machining of wood into 0.25- by 1.5- by 6-in. vertical-grain panels (0.6 by 3.8 by 15.2 cm)

3. Pressure treatment of wood with preservative to calculated gain-in-weight retentions

4. Destructive chemical analysis of some specimens to determine preservative retentions

5. Installation of five replicates per treatment at each test site (except where noted differently in the tables)

From December 1969 to January 1979, panels were exposed under Pier 1 of the Key West Naval Station (now Truman Annex), Key West, Florida. In 1979, we moved all test materials about 1 mile to Key West Bight at the Trumbo Annex. At both harbors, panels were suspended on fiberglass racks near low-tide level. Both harbors have active populations of *L. tripunctata*, *L. pfefferi*, and several species of teredinids, although populations of limnoriids and teredinids have fluctuated over time. We have not observed attack on panels by pholad or *Sphaeroma* borers at either site.

Although the ASTM standard calls for monthly inspections of test panels of the size used in our study, inspections at semiannual intervals have seemed adequate. In 1973 and 1974, we inspected only once each year. At each inspection, we scraped all panels free of fouling and rated them for the type and extent of marine-borer damage. Panels were visually rated as follows:

Rating	Extent of damage
10	None or trace
9	Light
7	Moderate
4	Heavy
0	Complete

Ratings thus ranged from 10, denoting sound wood or trace amount of damage, to 0, denoting total destruction of panel. We also distinguished between types of total destruction and in the tables report destruction as follows: 0-E, destruction by erosion; 0-L, destruction by *Limnoria;* and 0-T, destruction by teredinids (see Appendixes). In some cases, we could not determine to what extent the damage was caused by borers and to what extent by erosion; for example, 0-E,L indicates that panels were destroyed by both erosion and *Limnoria.* Borer activity was monitored by installing untreated control panels at each inspection site (see Fig. 1).

The results of our study to date are tabulated in Appendixes A through E; Appendix A includes the effects of oil-type preservatives, B waterborne preservatives, C dual treatments, D chemical modification, and E polymers. Table 1 provides an index to the treatments tabulated in the Appendixes.

Nearly all the treatments were performed at the Forest Products Laboratory (FPL). Further information on preservative composition and treating data is generally available from the FPL contact given in footnotes to the tables. When available, relevant American Wood-Preservers' Association (AWPA) standards are also provided. Retentions are by gain in weight in pounds per cubic foot (lb/ft^3) unless stated otherwise. Retentions may be converted to the metric equivalent in kilograms per cubic meter by multiplying the pound per cubic foot values by 16. Retentions of waterborne preservatives are expressed on an oxide basis.

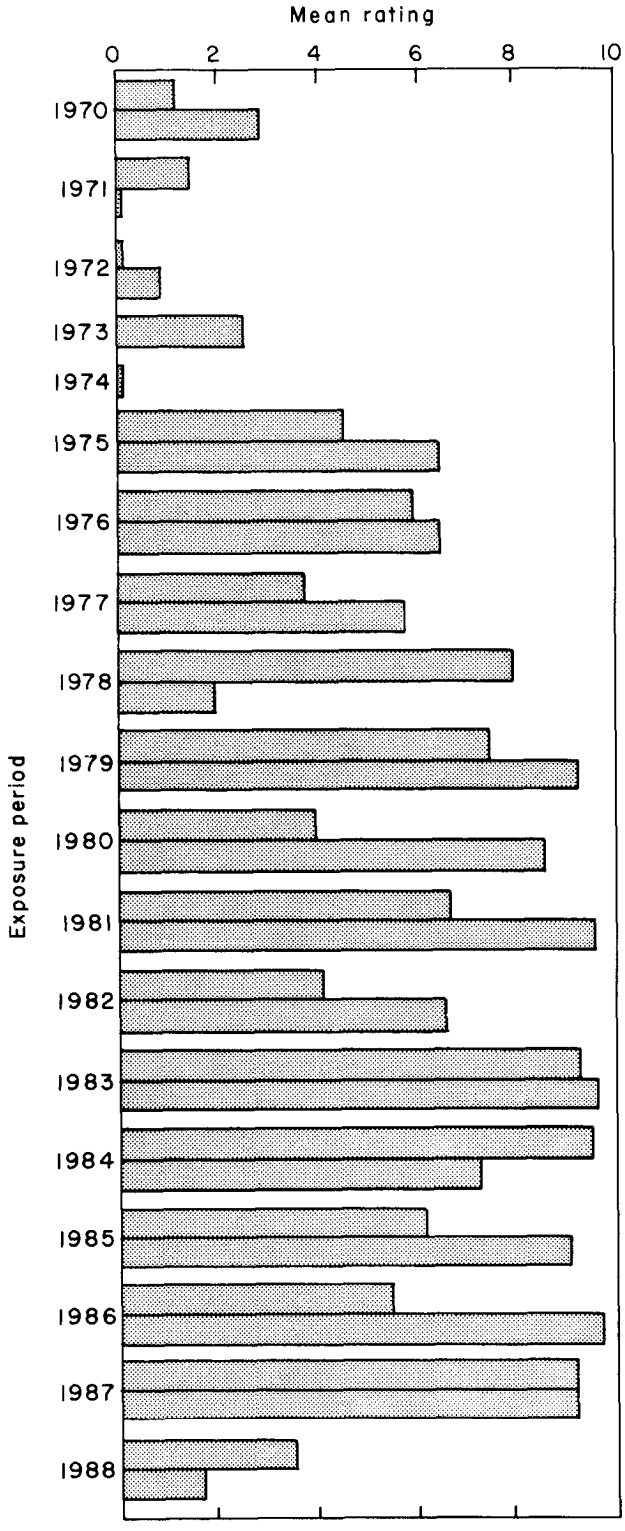

Figure 1 — Ten to 25 control panels were installed every 6 months to monitor marine-borer activity. The average condition of these panels 6 months after installation varied from nearly sound to destroyed, as represented by the bar values. For each year, the upper bar represents the first 6 months of the year and the lower bar the remaining 6 months. Virtually all inspections were made in January and July. (ML90 5310)

Results and Discussion

Inspections were usually, but not always, made in January and July of each year. For example, in the time of exposure column in the tables, 1.5 years may in fact denote 17, 18, or 19 months. The performance of most panels in marine exposure is presented as current extent of damage (average condition as of January 1989), total years of exposure, and years of exposure until the average rating reached < 6 (Appendixes A, C, D, and E, all tables; Appendix B, Tables B-4 through B-11). Hence, where numerical ratings are given, panels are still in test.

In Appendix B, Tables B-1, B-2, and B-3 for chromated copper arsenate Type B, chromated copper arsenate Type C, and ammoniacal copper arsenate, respectively, show individual panel ratings rather than the average condition because of extensive erosion damage to some panels and the commercial importance of these three preservatives. The erosion has been largely due to degradation by soft-rot fungi, and to a lesser extent to degradation by bacteria, coupled with wave action. Some grazing by *Chelura* and *Limnoria* has undoubtedly occurred, but the absence of direct evidence in the form of burrows or tunnels prevents specific attribution of the damage to either organism. The erosion probably would be of little significance except for the thinness (0.25 in.) of the test panels. Note that in some cases, erosion has caused panel failure and has thereby interfered with our objective of evaluating resistance to marine borers. Comparisons between preservative treatments should therefore be made on the basis of marine-borer damage, not erosion.

In all the tables, the column showing time of exposure until the extent of damage reached an average rating of < 6 (or individual rating < 7) is the most useful for comparing preservative effectiveness. Once attack has progressed to this point, it usually continues steadily to destruction of the test panel. The numerical rating of extent of damage and the time of exposure to the < 6 rating reflect only marine-borer attack, not erosion. A rating of 0-E alone denotes total failure caused by erosion. Where failure of a treatment group was attributed to both borers and microbes but some panels within the group failed by erosion alone, that proportion of the group is footnoted in the table. Retention of preservative should also be considered in any comparison of preservative effectiveness.

The ratings of the control panels show that marine-borer activity has fluctuated over time (Fig. 1). Borer activity began to decrease in 1975 and declined further when panels were moved to the new site in 1979. From mid-1986 to mid-1987, no settlement of teredinids occurred. Although limnoriids have been continuously present, a marked increase in their boring activity was noted in January 1989. Hence, the performance of untreated (control) panels should be considered in cases where panels treated with two different preservatives were exposed at different times. Generally, the condition of controls fell below a mean rating of 6 in six to twelve months.

The marine-exposure test used in our study measures relative effectiveness of preservatives in small sawn specimens at one exposure site. The presence of other species and genera of marine borers at other sites could result in very different performance. Extrapolation of our results to piling is questionable on several counts: (1) the panels provide an accelerated test because more earlywood, which is preferred by *Limnoria*, is exposed in panels compared to pilings, (2) the greater surface-to-volume ratio of small panels permits faster loss of preservative, and (3) the cross section of the panels is small enough that *Limnoria* can penetrate deeply and still obtain good exchange of oxygenated water; by contrast, in piling, wave action and

abrasion from floating debris must break away piling surface areas before *Limnoria* can burrow deeply.

Oil-Type Preservatives

The results of tests with oil-type preservatives are described in Appendix A. Vertical-retort creosote (Table A-1), probably because of its low aromaticity, compared poorly with both land (Table A-2) and marine (Table A-3) grades of coal-tar creosote. Performance of the land- and marine-grade creosotes was improved by increasing retention levels. Increasing the concentration of the creosote components anthracene, phenanthrene, carbazole, and naphthalene (Tables A-4, A-5, A-6) had little effect on the performance of marine-grade creosote. Addition of insecticides has increased the resistance of creosote to *Limnoria.* Of the chlorinated hydrocarbons endrin and dieldrin, the former has been slightly more effective in preserving the wood (Tables A-7 and A-8). The organophosphate chlorpyrifos has also imparted added resistance to *Limnoria* (Table A-9).

Waterborne Preservatives

The results of tests with waterborne preservatives are described in Appendix B. Chromated copper arsenate (CCA) Type B (Table B-1) and Type C (Table B-2) have been equally effective in protecting the wood panels from borers. However, panels treated with Type B CCA were more damaged by erosion, probably because of the lower chromium content of this preservative and consequent greater susceptibility of the wood to soft rot. Until the panels failed because of erosion, ammoniacal copper arsenate (ACA) (Table B-3) was as effective as CCA in deterring borers. For both CCA types, resistance to borers was comparable at retentions of 1.1 and 2.3 lb/ft^3; erosion destroyed the panels protected with 1.1 lb/ft^3 CCA after about 11 years. At retention levels of 1.1 and 2.3 lb/ft^3, both CCA types have afforded better protection against *Limnoria* than have high retentions of marine creosote. After 13 years of exposure, acid copper chromate (ACC) at a retention of 0.6 lb/ft^3 (Table B-4) has performed better than did CCA at 0.6 lb/ft^3. However, the panels treated with 0.6 lb/ft^3 CCA were exposed longer at the more severe original site than were the ACC panels. The ACC panels have also shown better erosion resistance than the CCA panels and much better borer and erosion resistance than panels treated with ammoniacal copper borate (Table B-5) or ammoniacal copper fluoride (Table B-7); panels treated with the latter two preservatives were exposed for only 3 years at Truman Annex before all specimens were moved to Trumbo Annex.

Erosion failure of ACA panels prevents a comparison of ACC and ACA. Chromated copper fluoride (CCF, Table B-8) has not protected against erosion or *Limnoria* as well as CCA, and copper salts of tetra- and pentachlorophenol (Table B-9) were not effective against *Limnoria* or shipworms. Ammoniacal copper zinc arsenate (Table B-10) at a retention of 0.6 lb/ft^3 provided slightly less protection than did ACA; the ACA panels were exposed at a more severe site than the panels treated with ammoniacal copper zinc arsenate (Table B-3). Panels treated with 1.2 lb/ft^3 ammoniacal copper zinc arsenate have been more susceptible to erosion failure than were ACA panels treated to a retention of 1.1 lb/ft^3. The light attack on panels treated with basic zinc sulfate (Table B-11) after only 1 year suggests that these panels will probably fail quickly. Chemical analysis of extra panels indicated that the second stage of the two-stage treatment, ammonium hydroxide impregnation, caused much of the zinc to leach from the panels. (Ammonia gas might have been a better choice.)

Dual Treatments

The effects of dual treatments on wood panels are described in Appendix C. With treatments of CCA (Tables C-1, C-4) or ACA (Table C-7) followed by vertical-retort creosote, increasing the retention of waterborne preservative improved panel performance, but increasing the creosote retention did not improve performance. Subsequent treatment of CCA-treated panels with either land-grade (Tables C-2, C-5) or marine-grade (Tables C-3, C-6) creosote has improved performance compared to that of panels treated with CCA and vertical-retort creosote (Tables C-1, C-4). Unlike the vertical-retort creosote, the land and marine grades of creosote in the dual treatment have provided better protection at higher retentions. Types B and C of CCA have performed about equally well in dual treatments. The dual treatment with ACA (Table C-9) is comparable to the ammoniacal copper borate and marine creosote treatment (Table C-10). The waterborne ACC (Table C-11) and CCF (Table C-12) preservatives at a retention of 0.2 lb/ft^3 have not performed quite as well as CCA in dual treatments (Tables C-3, C-6).

The susceptibility of waterborne treatments to erosion is evident in panels treated with low creosote retentions, but not those treated with retentions above 20 lb/ft^3. Creosote alone has been very susceptible to *Limnoria* damage, and some dual-treated panels have also been damaged by *Limnoria*. This suggests that grazing by *Limnoria* is not a major factor in the erosion of panel surfaces.

Chemical Modification

Appendix D tabulates the effects of chemical modification of panels. Modification with propylene oxide has protected panels quite well against attack by *Limnoria* (Table D-1; Johnson and Rowell 1988). Some panels have remained free of attack for 13.5 years, and others were only lightly attacked by *Limnoria* when failure was caused by erosion at 9.5 years. Panels treated with butylene oxide (Table D-l) have been free of attack for 10.5 to 11 years. Treatment with butyl isocyanate and dimethylformamide has also been effective, but treatments with periodic acid or acetic anhydride have not been effective (Table D-l).

The effects of polymers are described in Appendix E. Impregnation with tributyltin (TBT) oxide (Table E-1), TBT-modified methacrylate polymers (Table E-l), or TBT-modified monomers (with subsequent polymerization) (Tables E-2, E-3) has prevented borer damage for 8.5 to 12 years. Methacrylates modified with pentachlorophenol or pentabromophenol have largely deterred borers for 9 years, although panels treated with pentabromophenol have been lightly damaged (Table E-3).

Concluding Remarks

This marine-exposure test will continue, and promising candidate preservatives may be added over time. We will publish a new edition of this report when enough significant new data are accumulated to warrant an update.

Acknowledgments

Financial support from the Naval Facilities Engineering Command, U.S. Navy, for a portion of this research is gratefully acknowledged. Several chemical and wood-preserving companies have contributed to this work. These firms are identified in footnotes to the relevant tables. The help and support of David Webb and Randall Baileys of Koppers Industries have been especially appreciated. Particular thanks are due Daniel Probert and staff of the Naval Air Development Center, Anti-Submarine Warfare Field Station, Trumbo Annex, Key West, Florida, for use of the exposure site.

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Table 1 — Index to treatments tested and tabulated data of their performance

Appendix and treatment	Table no.
A. Oil-type preservatives	
Creosotes	
English vertical-retort	A-1
Coal-tar, land and fresh-water grade	A-2
Coal-tar, marine grade	A-3
Coal-tar, with various supplements	A-4
Coal-tar, supplemented with naphthalene	A-5
Coal-tar solution, alone and supplemented	A-6
Coal-tar, supplemented with endrin	A-1
Coal-tar, supplemented with dieldrin	A-8
Coal-tar, supplemented with chlorpyrifos	A-9
Alsystin chitin inhibitor	A-10
Copper naphthenate	A-11
B. Waterborne preservatives	
Chromated copper arsenate, Type B	B-1
Chromated copper arsenate, Type C	B-2
Ammoniacal copper arsenate	B-3
Acid copper chromate	B-4
Ammoniacal copper borate	B-5
Double diffusion with sodium fluoride plus copper-containing solutions	B-6
Ammoniacal copper fluoride	B-1
Chromated copper fluoride	B-8
Copper tetra- and pentachlorophenol	B-9
Ammoniacal copper zinc arsenate	B-10
Basic zinc sulfate	B-11
C. Dual treatments	
Chromated copper arsenate (B)	
Plus English vertical-retort creosote	C-1
Plus land-grade coal-tar creosote	C-2
Plus marine-grade coal-tar creosote	C-3
Chromated copper arsenate (C)	
Plus English vertical-retort creosote	C-4
Plus land-grade coal-tar creosote	C-5
Plus marine-grade coal-tar creosote	C-6
Ammoniacal copper arsenate	
Plus English vertical-retort creosote	C-7
Plus land-grade coal-tar creosote	C-8
Plus marine-grade coal-tar creosote	C-9
Ammoniacal copper borate plus marine-grade coal-tar creosote	C-10
Acid copper chromate plus marine-grade coal-tar creosote	C-11
Chromated copper fluoride plus marine-grade coal-tar creosote	C-12
D. Chemical modification	D-1
E. Polymers	
Prepolymerized tributyltin methacrylate and methyl methacrylate copolymers	E-l
In situ polymerized tributyltin-modified monomers	E-2
In situ polymerized modified methacrylate impregnants	E-3

Appendix A — Effects of Oil-type Preservatives

Tables A-l through A-11 show the effects of treatment with creosotes, alsystin chitin inhibitor, and copper naphthenate on wood panels exposed to limnoriid and teredinid marine borers.

Table A-1 —English vertical-retort creosote[a]

Installation date (month/year)	Retention (lb/ft^3)	Extent of damage	Exposure (years) Total	Exposure (years) Time to average rating < 6
12/69	9.7	0-L	1.5	1.0
	14	0-L	1.5	1.0
	27	0-L	1.5	2.0
7/82	28	0-L	6.0	3.0
	20[b]	0-L	6.0	3.5

[a] Study supported in part by the U.S. Navy, Naval Facilities Engineering Command (NFEC). FPL contact, Bruce R. Johnson.
[b] Solution of 2 percent diflubenzuron, 48 percent dimethyl sulfoxide, and 50 percent vertical-retort creosote.

Table A-2—Coal-tar creosote, land and fresh-water grade (AWPA P-1 and modified P-1)[a]

Installation date (month/year)	Creosote	Retention (lb/ft^3)	Extent of damage	Exposure (years) Total	Exposure (years) Time to average rating < 6
12/69	P-1	6.6	0-L	2	1
		16	0-L	3	2
		24	0-L	13	3
1/88	Modified P-1[b]	12.8	10	1	–
		34.4	10	1	–

[a] Study supported in part by NFEC and Koppers Company. "Clean creosote" conforming to P-1, except no more than 0.10 percent xylene insoluble, provided by Koppers Company. FPL contact, Bruce R. Johnson.
[b] P-1 modified by reducing the xylene insoluble residue.

Table A-3—Coal-tar creosote, marine grade (AWPA P-13)[a]

Installation date (month/year)	Retention (lb/ft^3)	Extent of damage	Exposure (years) Total	Exposure (years) Time to average rating < 6
12/69	6.5	0-L	2.0	1.0
	15	0-L	4.0	2.0
	28	0-L	5.5	4.0
12/70	39	0-L	13.0	2.5
1/76	15	0-L	6.0	3.5
1/77	20[b]	0-L	3.5	2.5

[a] Study supported in part by NFEC, Koppers Company, and J. H. Baxter and Company. FPL contact, Bruce R. Johnson.
[b] Based on 10 replicates.

Table A-4 — Coal-tar creosote (AWPA P-13) with supplements[a,b]

Installation date (month/year)	Preservative supplement (percent) PAC[c]	Preservative supplement (percent) Naphthalene	Retention (lb/ft^3)	Extent of damage	Exposure (years) Total	Exposure (years) Times to average rating < 6
6/76	10	0	20	O-L	5	2.5
	10	20	18	O-L	4	2.5
	20	20	19	O-L	4	3.0

[a] Study supported in part by Koppers Company. FPL contacts, Lee R. Gjovik and Bruce R. Johnson.
[b] Ten replicates per treatment.
[c] PAC, a fraction of creosote containing a high percentage of crystals, primarily of phenanthrene, anthracene, and carbazole.

Table A-5 — Coal-tar creosote (AWPA P-13) with supplement naphthalene[a,b]

Installation date (month/year)	Naphthalene content (percent)	Retention (lb/ft^3)	Extent of damage	Exposure (years) Total	Exposure (years) Time to average rating < 6
6/75	11	19[c]	O-L	6.5	3.5
12/77		36	7	11.0	—
6/75	20	17[c]	O-L	6.0	2.5
6/76		22	O-L	3.5	2.5
12/77		34	5	11.0	8.5
6/75	30	19[c]	O-L	6.0	4.0
6/76		22	O-L	5.0	2.5
12/77		31	1	11.0	8.5
12/70	40	38	O-L	15.5	11.5
6/75		18[c]	O-L	5.0	3.0
6/76		18	O-L	4.0	2.5
12/77		38	3	11.0	9.5

[a] Study supported in part by Koppers Company. FPL contact, Bruce R. Johnson.
[b] Ten replicates per treatment except 12/70 installation (5 replicates).
[c] Full-cell treatments with toluene dilution of creosote.

Table A-6 — Creosote/coal-tar solution alone (AWPA P-12) and with supplement[a,b]

Installation date (month/year)	Preservative supplement (percent) Sulfur	Preservative supplement (percent) Tar bases	Preservative supplement (percent) Naphthalene	Retention (lb/ft^3)	Extent of damage	Exposure (years) Total	Exposure (years) Time to average rating < 6
7/79	------- None [c] -------			35.0	O-L	8.5	5
	6	0	20	32.8	O-L	5.5	4
	0	6	20	33.9	1	9.5	5
	0	11	20	30.7	O-L	7.5	4

[a] Study in cooperation with and treatments performed by Koppers Company. FPL contact, Bruce R. Johnson.
[b] Ten replicates per treatment.
[c] No preservative supplement.

Table A-7 — Coal-tar creosote (AWPA P-1) with supplemental endrin[a,b]

Installation date (month/year)	Endrin[c] (percent)	Retention (lb/ft^3)	Extent of damage	Exposure (years) Total	Exposure (years) Time to average rating < 6
1/83	0	10.1	O-L	6	3
	0	37.6	9	6	–
	0.1	11.0	10, 0-E[d]	6	–
	0.1	33.6	10	6	–
	0.2	10.4	10	6	–
	0.2	30.9	10	6	–
	0.4	9.9	10	6	–
	0.4	35.2	10	6	–

[a] Study in cooperation with Koppers Company. FPL contact, Bruce R. Johnson.
[b] Ten replicates per treatment.
[c] Endrin: 1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4,-endo-endo-5,8-dimethanonaphthalene.
[d] Two panels failed solely by erosion.

Table A-8 — Coal-tar creosote (AWPA P-1) with supplemental dieldrin[a,b]

Installation date (month/year)	Dieldrin[c] (percent)	Retention (lb/ft^3)	Extent of damage	Exposure (years) Total	Exposure (years) Time to average rating < 6
1/84	0	11.2	2	5	3
	0	23.8	5	3	4
	0.2	10.9	4	5	5
	0.2	35.1	10	5	–
	0.4	9.6	8	5	–
	0.4	32.6	10	5	–
	0.8	11.0	9	5	–
	0.8	33.2	10	5	–

[a] Study in cooperation with Koppers Company. FPL contact, Bruce R. Johnson
[b] Ten replicates per treatment.
[c] Dieldrin: 1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo-exo-5,8-dimethanonaphthalene.

Table A-9 — Coal-tar creosote (AWPA P-13) with supplemental chlorpyrifos[a,b]

Installation date (month/year)	Chlorpyrifos[c] (percent)	Retention (lb/ft^3)	Extent of damage	Exposure (years) Total	Exposure (years) Time to average rating < 6
1/84	0	10.9	0-E,L	5	4.5
	0	36.1	9	5	–
	0.1	12.7	1	5	4.5
	0.1	38.2	10	5	–
	0.5	12.0	10	5	–
	0.5	36.6	10	5	–
	1.0	11.2	10	5	–
	1.0	36.5	10	5	–
	3.0	11.7	10	5	–
	3.0	36.1	10	5	–

[a] Study in cooperation with Dow Chemical Company. FPL contact, Bruce R. Johnson.
[b] Ten replicates per treatment.
[c] Chlorpyrifos: 0,0-diethyl 0-[3,5,6-trichloro-2-pyridyl] phosphorothioate.

Table A-10 — Chitin-synthesis inhibitor Alsystin[a,b]

Installation date (month/year)	Solution formulation	Solution retention (lb/ft^3)	Alsystin retention (lb/ft^3)	Extent of damage	Exposure (years) Total	Exposure (years) Time to average rating < 6
7/87	0.062 percent Alsystin in DMSO[d]	–	0.0124	0-L,T	1.5	1
	0.031 percent Alsystin in 50:50 DMSO and P-l creosote	17.7	0.0110	7	1.5	–

[a] Alsystin supplied by Mobay Chemical Corporation. FPL contact, Bruce R. Johnson.
[b] Ten replicates per treatment.
[c] Alsystin: 2-chloro-N-[([4-(trifluoromethoxy) phenyl] amino) carbonyl] benzamide.
[d] DMSO, dimethyl sulfoxide.

Table A-11 — Copper naphthenate (AWPA P-9)[a,b]

Installation date (month/year)	Solution concentration (percent copper metal)	Carrier	Retention (lb/ft^3)	Extent of damage	Exposure (years) Total	Exposure (years) Time to average rating < 6
1/88	1.5	P9-A	10.8	10	1	–
	1.5	P9-A	30.2	10	1	–
	5.0	Creosote	11.5	10	1	–
	1.5	Creosote	34.8	10	1	–

[a] Copper naphthenate from Interstab Chemicals, 8 percent copper metal. Creosote from Koppers Company, conformed to P-l except no more than 0.1 percent xylene insoluble (see Table A-2).
[b] Type A oil carrier or P-l creosote with reduced xylene insoluble residue.

Appendix B — Effects of Waterborne Preservatives

Tables B-l through B-11 show the effects of treatment with various waterborne preservatives on wood panels exposed to limnoriid and teredinid marine borers.

Table B-1 — Chromated copper arsenate (AWPA P-5 Type B)[a,b]

Installation date (month/year)	Retention (lb/ft^3)	Extent of damage	Exposure (years) Total	Exposure (years) Time to average rating < 7
12/69	0.23	O-L	2.0	2.0
	0.23	0-L,T	2.5	2.5
	0.23	O-L	2.5	2.5
	0.23	O-L	2.5	2.0
	0.23	0-L,T	2.5	2.0
	0.58	O-T	3.0	3.0
	0.56	O-L	5.5	5.0
	0.58	O-L	5.0	5.0
	0.57	O-L	6.5	6.5
	1.1	O-E	10.5	—
	1.1	0-L,E	10.5	—
	1.1	O-E	11.0	—
	1.1	O-E	14.0	—
	2.3	O-E	17.0	—
	2.3	O-E	16.5	—
	2.4	O-E	13.0	—

[a] Study supported in part by U.S. Naval Facilities Engineering Command (NFEC). FPL contact, Bruce R. Johnson.
[b] Data are for individual panels.

Table B-2 — Chromated copper arsenate (AWPA P-5 Type C)[a,b]

Installation date (month/year)	Retention (lb/ft^3)	Extent of damage	Exposure (years) Total	Exposure (years) Time to average rating < 7
12/69	0.25	0-L,T	2.5	2.0
	0.25	0-L,T	3.0	3.0
	0.25	O-L	2.5	2.5
	0.26	O-L	2.5	2.0
	0.60	0-L,T	8.5	6.5
	0.60	O-L	5.0	5.0
	0.60	0-L,T	7.0	7.0
	0.59	O-L	6.0	6.0
	1.1	O-E	11.5	—
	1.1	O-E	11.0	—
	1.1	0-L,E	11.0	—
	2.3	O-E	18.5	—
	2.4	10	19.0	—
	2.4	10	19.0	—
	2.4	10	19.0	—
	2.4	10	19.0	—

[a] Study supported in part by NFEC. FPL contact, Bruce R. Johnson.
[b] Data are for individual panels.

Table B-3 — Ammoniacal copper arsenate (AWPA P-5 Type B)[a,b]

Installation date (month/year)	Retention (lb/ft^3)	Extent of damage	Exposure (years) Total	Exposure (years) Time to average rating < 7
12/69	0.23	O-L	3.0	3.0
	0.24	0-L,T	2.5	2.5
	0.23	0-L,T	3.0	3.0
	0.23	0-L,T	3.0	3.0
	0.23	O-L	2.5	2.0
	0.55	O-E	6.0	–
	0.56	O-E	6.0	–
	0.56	O-E	6.5	–
	0.55	O-E	6.0	–
	0.56	O-E	6.0	–
	1.1	O-E	9.5	–
	1.1	O-E	9.0	–
	0.95	O-E	10.5	–
	1.1	O-E	8.5	–
	1.1	O-E	8.5	–
	1.1	O-E	8.5	–
	2.4	O-E	10.0	–
	2.3	O-E	10.5	–

[a] Study supported in part by NFEC. FPL contact, Bruce R. Johnson.
[b] Data are for individual panels.

Table B-4 — Acid copper chromate (AWPA P-5)[a,b]

Installation date (month/year)	Retention (lb/ft^3)	Extent of damage	Exposure (years) Total	Exposure (years) Time to average rating < 6
6/75	0.25	0-L,E	6	4.5
1/76	0.25	0-L,E	9	3.5
	0.60	4, 0-E[c]	13	–
	1.2	10, 0-E[d]	13	–
	2.8	10	13	–

[a] Study supported in part by Koppers Company. FPL contact, Lee R. Gjovik.
[b] Fifteen replicates per treatment except for 6/75 installation (8 replicates).
[c] Three of 15 panels failed solely by erosion.
[d] One panel failed solely by erosion.

Table B-5 — Ammoniacal copper borate[a]

Installation date (month/year)	Retention[b] (lb/ft^3)	Extent of damage	Exposure (years) Total	Time to average rating < 6
6/75	1.3	0-L,E[c]	5.2	4
1/76	0.25	0-L,E[d]	6.5	3
	0.60	0-L,T,E[e]	7.0	6
	1.2	O-E	8.0	–
	2.5	O-E	10.5	–

[a] Study supported in part by J. H. Baxter and Company. FPL contact, Bruce R. Johnson.
[b] Fifteen replicates per treatment; 2 $CuO \cdot B_2O_3$.
[c] One of 5 panels failed solely by erosion.
[d] Two of 15 panels failed solely by erosion.
[e] Eight of 15 panels failed solely by erosion.

Table B-6 — Double diffusion with sodium fluoride and copper-containing solutions[a,b]

Installation date (month/year)	Preservative formulation (percent) NaF	$CuSO_4$	ACC	Duration of treatment (h)	Extent of damage	Exposure (years) Total	Time to average rating < 6
6/75	1.5	1.5	0	96 138	0-L,E[c]	9.5	7
	1.5	0	1.5	96 138	0-L,T	5.5	4

[a] FPL contact, Lee R. Gjovik.
[b] Samples saturated with water, soaked in NaF, then soaked in $CuSO_4$ or ACC. Eight replicates per treatment.
[c] Two of 5 panels failed solely by erosion.

Table B-7 — Ammoniacal copper fluoride[a,b]

Installation date (month/year)	Preservative ratio (CuO/F)	Retention (lb/ft^3)	Extent of damage	Exposure (years) Total	Exposure (years) Time to average rating < 6
1/76	5.6	0.52	10	7.0	–
		0.90	0-L,E[c]	8.5	–
	2.4	0.62	0-L,E[d]	8.0	–
		1.3	O-E	8.5	–
		2.4	O-E	10.5	–
	1.2	0.61	0-L,E[e]	7.0	5.5
		1.2	O-E	8.5	–
		2.6	O-E	9.0	–

[a] Study supported in part by J. H. Baxter and Company. FPL contact, Lee R. Gjovik.
[b] Ten replicates per treatment.
[c] Nine of 10 panels failed solely by erosion.
[d] Six of 10 panels failed solely by erosion.
[e] Five of 10 panels failed solely by erosion.

Table B-8 — Chromated copper fluoride[a]

Installation date (month/year)	Retention (lb/ft^3)	Extent of damage	Exposure (years) Total	Exposure (years) Time to average rating < 7
6/77	0.23	0-L,T	4.0	2.0
	0.60	O-L	5.0	4.5
	1.2	0-L,E	9.5	9.0
	2.5	10	11.5	–

[a] Study supported in part by Simonsen Chemical Company. FPL contact, Lee R. Gjovik.

Table B-9 — Copper salts of tetrachlorophenol and pentachlorophenol[a]

Installation date (month/year)	Preservative formulation (percent)			Retention (lb/ft^3)	Extent of damage	Exposure (years)	
	Tetra-chloro-phenol	Copper oxide	Penta-chloro-phenol			Total	Time to average rating < 6
6/78	3.42	0.58	0	1.7	0-L,T	4.0	2.5
	0.86	0.14	0	0.36	O-L	3.0	2.0
	3.42	0.14	0	1.4	0-L,T,E[b]	4.5	3.5
	0.86	0.14	0	0.28	O-L	2.5	2.0
	0	0.58	3.42	1.5	0-L,E	5.0	3.0
	0	0.14	0.86	0.39	O-L	4.5	2.5

[a] Study supported in part by Reichhold Chemicals, Inc. FPL contact, Bruce R. Johnson.
[b] One panel failed solely by erosion.

Table B-10 — Ammoniacal copper zinc arsenate[a,b]

Installation date (month/year)	Retention (lb/ft^3)	Extent of damage	Exposure (years)	
			Total	Time to average rating < 6
7/82	0.25	O-L	3.5	3.0
	0.6	0-L,T,E[c]	5.5	3.5
	1.2	10, 0-E[d]	6.5	–
	1.6	10, 0-E[e]	6.5	–
	2.0	10	6.5	–
	2.5	10	6.5	–

[a] Study supported in part by J. H. Baxter and Company. FPL contact, Bruce R. Johnson.
[b] Ten replicates per treatment.
[c] One panel failed solely by erosion.
[d] Eight panels failed solely by erosion.
[e] Three panels failed solely by erosion.

Table B-11 — Basic zinc sulfate[a,b,c]

Installation date (month/year)	Treatment formulation (percent)		ZnO retention[d] (lb/ft^3)	Extent of damage	Exposure (years)	
	$ZnSO_4$	NH_4OH			Total	Time to average rating < 6
1/88	12.0	5.0	2.2	8	1	–
	5.3	2.5	1.0	9	1	–

[a] Two-stage treatment of zinc sulfate followed by ammonium hydroxide.
[b] FPL contact, Bruce R. Johnson.
[c] Ten replicates per treatment.
[d] Gain-in-weight retention prior to treatment with NH_4OH, which caused some leaching of zinc.

Appendix C — Effects of Dual Treatments

Tables C-1 through C-8 show the effects of dual treatments on wood panels exposed to limnoriid and teredinid marine borers.

Table C-1 — Dual treatment with chromated copper arsenate (Type B) and vertical-retort creosote[a]

Installation date (month/year)	Retention (lb/ft^3)		Extent of damage	Exposure (years)	
	CCA	Creosote		Total	Time to average rating < 6
12/69	0.25	9.0	0-L,T	4.0	3.0
	0.23	16.0	0-L,T	6.0	5.0
	0.22	27.0	O-L	6.5	2.5
	0.59	7.9	0-L,E	12.0	10.0
	0.58	13.0	0-L,E	10.5	9.0
	0.58	30.0	O-L	10.5	8.5
	1.1	8.1	0-E[b]	16.0	–
	1.1	11.0	0-L,E	17.5	–
	1.1	25.0	O-L	17.0	13.0
	2.4	9.0	10	19.0	–
	2.3	16.0	10	19.0	–
	2.4	24.0	10	19.0	–

[a] Study supported in part by NFEC. FPL contact, Bruce R. Johnson.
[b] One panel failed solely by erosion; 4 panels lost.

Table C-2 — Dual treatment with chromated copper arsenate (Type B) and land-grade coal-tar creosote (P-1)[a]

Installation date (month/year)	Retention (lb/ft^3)		Extent of damage	Exposure (years)	
	CCA	Creosote		Total	Time to average rating < 6
12/69	0.22	6.8	O-L	8.5	6.0
	0.23	14.0	O-L	9.0	8.0
	0.23	25.0	O-L	9.0	8.5
	0.57	7.1	O-L	10.5	9.0
	0.59	18.0	O-L	14.0	13.0
	0.59	19.0	0-L,E	17.5	13.0
	1.1	5.0	0-L,E[b]	17.5	–
	1.1	16.0	7	19.0	–
	1.1	18.0	9	19.0	–
	2.3	5.0	10	19.0	–
	2.4	16.0	10	19.0	–
	2.3	21.0	10	19.0	–

[a] Study supported in part by NFEC. FPL contact, Bruce R. Johnson.
[b] Two panels failed solely by erosion.

Table C-3 — Dual treatment with chromated copper arsenate (Type B) and marine-grade coal-tar creosote (P-13)[a]

Installation date (month/year)	Retention (lb/ft^3)		Extent of damage	Exposure (years)	
	CCA	Creosote		Total	Time to average rating < 6
12/69	0.23	6.7	O-L	6.5	5.5
	0.23	13.0	O-L	9.5	8.5
	0.23	24.0	O-L	10.5	8.5
	0.59	5.2	0-L,E[b]	13.0	13.0
	0.59	18.0	O-L	17.0	12.5
	0.58	23.0	4	19.0	14.0
	1.1	4.2	O-E	16.0	–
	1.1	18.0	10	19.0	–
	1.1	19.0	10	19.0	–
	2.3	4.8	10	19.0	–
	2.4	19.0	10	19.0	–
	2.4	21.0	10	19.0	–

[a] Study supported in part by NFEC. FPL contact, Bruce R. Johnson.
[b] One of 3 panels failed solely by erosion.

Table C-4 — Dual treatment with chromated copper arsenate (Type C) and vertical-retort creosote[a]

Installation date (month/year)	Retention (lb/ft^3)		Extent of damage	Exposure (years)	
	CCA	Creosote		Total	Time to average rating < 6
12/69	0.23	7.2	O-L	7.5	4.0
	0.23	16.0	O-L	10.5	9.0
	0.24	24.0	O-L	6.5	3.0
	0.60	7.6	O-L	11.5	9.5
	0.60	18.0	0-L,E	17.0	10.0
	0.60	23.0	O-L	10.5	9.5
	1.1	9.2	0-L,E[b]	17.0	14.0
	1.1	13.0	0-L,E	17.5	12.0
	1.1	27.0	2	19.0	12.5
	2.6	9.4	10	19.0	–
	2.6	13.0	10	19.0	–
	2.3	18.0	10	19.0	–

[a] Study supported in part by NFEC. FPL contact, Bruce R. Johnson.
[b] Two of 4 panels failed solely by erosion.

Table C-5 — Dual treatment with chromated copper arsenate (Type C) and land-grade coal-tar creosote (P-1)[a]

Installation date (month/year)	Retention (lb/ft^3)		Extent of damage	Exposure (years)	
	CCA	Creosote		Total	Time to average rating < 6
12/69	0.24	5.7	O-L	5.5	5.0
	0.26	13.0	O-L	9.0	8.5
	0.24	16.0	O-L	11.0	8.5
	0.59	4.8	0-L,T,E	16.5	13.5
	0.62	17.0	O-L	16.5	16.0
	0.61	22.0	4	19.0	19.0
	1.1	7.0	0-E[b]	19.0	–
	1.1	15.0	10	19.0	–
	1.1	23.0	8	19.0	–
	2.6	7.6	10	19.0	–
	2.4	12.0	10	19.0	–
	2.4	21.0	10	19.0	–

[a] Study supported in part by NFEC. FPL contact, Bruce R. Johnson.
[b] Four panels failed solely by erosion.

Table C-6 — Dual treatment with chromated copper arsenate (Type C) and marine-grade coal-tar creosote (P-13)[a]

Installation date (month/year)	Retention (lb/ft^3)		Extent of damage	Exposure (years)	
	CCA	Creosote		Total	Time to average rating < 6
12/69	0.24	5.2	O-L	7.5	6.0
	0.24	11.0	O-L	9.0	8.5
	0.23	19.0	O-L	13.0	9.5
	0.60	4.3	0-L,E	13.0	12.0
	0.60	16.0	2	19.0	12.5
	0.59	18.0	1	19.0	12.5
	1.1	5.7	0-E[b]	19.0	–
	1.1	12.0	10	19.0	–
	1.1	22.0	8	19.0	–
	2.5	6.1	10	19.0	–
	2.5	12.0	10	19.0	–
	2.6	24.0	10	19.0	–

[a] Study supported in part by NFEC. FPL contact, Bruce R. Johnson.
[b] Four panels failed solely by erosion.

Table C-7 — Dual treatment with ammoniacal copper arsenate and English vertical-retort creosote[a]

Installation date (month/year)	Retention (lb/ft^3)		Extent of damage	Exposure (years)	
	ACA	Creosote		Total	Time to average rating < 6
12/69	0.26	8.3	O-L	9.0	6.5
	0.24	12.0	O-L	7.5	6.5
	0.24	26.0	O-L	9.0	7.5
	0.56	8.9	0-L,E	9.5	9.5
	0.57	12.0	0-L,T	8.5	7.5
	0.56	25.0	O-L	10.5	8.5
	1.1	8.4	0-L,Eb	12.5	11.5
	1.1	12.0	O-E	13.0	—
	1.1	23.0	O-L	13.0	11.0
	2.2	8.2	0-L,E[c]	15.0	—
	2.3	11.0	0-L,E[d]	15.0	—
	2.2	27.0	6	19.0	—

[a] Study supported in part by NFEC. FPL contact, Bruce R. Johnson.
[b] One of 3 panels failed solely by erosion
[c] Three of 4 panels failed solely by erosion.
[d] Two of 4 panels failed solely by erosion.

Table C-8 — Dual treatment with ammoniacal copper arsenate and land-grade coal-tar creosote (P-1)[a]

Installation date (month/year)	Retention (lb/ft^3)		Extent of damage	Exposure (years)	
	ACA	Creosote		Total	Time to average rating < 6
12/69	0.22	5.4	O-L	7.0	5.5
	0.24	12.0	O-L	9.0	8.0
	0.23	21.0	O-L	14.0	8.5
	0.56	5.7	O-L	9.0	8.0
	0.58	14.0	O-L	12.5	9.5
	0.57	24.0	O-L	15.5	10.0
	1.1	6.1	0-L,Eb	11.5	11.0
	1.1	12.0	0-L,E[c]	14.5	—
	1.1	26.0	3	19.0	14.5
	2.3	6.1	0-L,E[d]	14.5	—
	2.3	13.0	O-E	17.5	—
	2.4	25.0	8	19.0	—

[a] Study supported in part by NFEC. FPL contact, Bruce R. Johnson.
[b] One of 4 panels failed solely by erosion.
[c] Two of 4 panels failed solely by erosion.
[d] Three of 5 panels failed solely by erosion.

Table C-9 — Dual treatment with ammoniacal copper arsenate and marine-grade coal-tar creosote (P-13)[a]

Installation date (month/year)	Retention (lb/ft^3)		Extent of damage	Exposure (years)	
	ACA	Creosote		Total	Time to average rating < 6
12/69	0.23	5.7	O-L	8.0	6.0
	0.23	12.0	O-L	8.5	7.5
	0.23	24.0	O-L	12.0	9.0
	0.57	6.0	0-L,E	11.5	9.0
	0.57	12.0	O-L	10.5	9.0
	0.57	23.0	O-L	12.0	9.0
	1.1	6.4	0-L,E	14.0	—
	1.1	13.0	0-L,E	15.0	12.5
	1.1	24.0	4	19.0	18.0
	2.4	5.9	O-E	15.0	—
	2.4	13.0	0-L,E[b]	19.0	—
	2.4	25.0	9	19.0	—

[a] Study supported in part by NFEC. FPL contact, Bruce R. Johnson.
[b] Three of 5 panels failed solely by erosion.

Table C-10 — Dual treatment with ammoniacal copper borate and marine-grade coal-tar creosote (P-13)[a,b]

Installation date (month/year)	Retention (lb/ft^3)		Extent of damage	Exposure (years)	
	Ammoniacal copper borate	Creosote		Total	Time to average rating < 6
l/76	0.25	13	O-L	7.5	4.5
	0.60	12	3, 0-E[c]	13.0	10.0
	1.2	15	6, 0-E[d]	13.0	—
	2.5	13	10, 0-E[e]	13.0	—

[a] Study supported in part by NFEC. FPL contact, Bruce R. Johnson.
[b] Fifteen replicates per treatment.
[c] Four of 15 panels failed solely by erosion.
[d] Three of 14 panels failed solely by erosion.
[e] Two of 15 panels failed solely by erosion.

Table C-11 — Dual treatment with acid copper chromate and marine-grade coal-tar creosote (P-13)[a]

Installation date (month/year)	Retention (lb/ft^3)		Extent of damage	Exposure (years)	
	ACC	Creosote		Total	Time to average rating < 6
1/76	0.25	16	2	13	6.5
	0.60	16	9	13	—
	1.2	16	10	13	—
	2.8	16	10	13	—

[a] Study supported in part by Koppers Company. FPL contact, Lee R. Gjovik.

Table C-12 — Dual treatment with chromated copper fluoride and marine-grade coal-tar creosote (P-13)[a]

Installation date (month/year)	Retention (lb/ft^3)		Extent of damage	Exposure (years)	
	Chromated copper fluoride	Creosote		Total	Time to average rating < 6
6/77	0.21	16	O-L	9.5	5.5
	0.57	19	6	11.5	—
	1.1	21	10	11.5	—
	2.3	19	10	11.5	—

[a] Study supported in part by Simonsen Chemical Company. FPL contact, Lee R. Gjovik.

Appendix D — Effects of Chemical Modification

Table D-l shows the effects of chemical modification of wood panels on their resistance to limnoriid and teredinid marine borers.

Table D-1 — Chemical modification[a]

Installation date (month/year)	Reagent	Weight gain (percent)	Extent of damage	Exposure (years) Total	Exposure (years) Time to average rating < 6
12/77	Butylene oxide	23.7[b]	10	11.0	–
6/78		28.5[c]	10	10.5	–
6/75	Propylene oxide	22.1[d]	10, 0-E[e]	13.5	–
		26.6	0-L,E[f]	9.5	–
		31.6[g]	0-L,E[e]	9.5	–
7/80	Butyl isocyanate + dimethylformamide	29.3	10	8.5	–
1/87	Periodic acid	(h)	0-L,T	2.0	1.5
1/84	Acetic anhydride	22.1	4	5.0	5.0

[a] FPL contacts, Roger M. Rowell and George Chen.
[b] Ten replicates.
[c] Twelve replicates.
[d] Three replicates.
[e] One panel failed solely by erosion.
[f] One panel failed solely by erosion.
[g] Two replicates.
[h] Six replicates. No weight-gain data available.

Appendix E — Effects of Polymers

Tables E-1 through E-3 show the effects of polymers on wood panels exposed to limnoriid and teredinid marine borers.

Table E-1 — Prepolymerized tributyltin metbacrylate and methyl methacrylate copolymers in organic solvents[a,b]

Installation date (month/year)	Solution formulation[c]	Retention[d] (lb/ft^3)	Extent of damage	Exposure (years) Total	Exposure (years) Time to average rating < 6
1/77	TBTM/MeM in mineral spirits + P-13 creosote	1.10[e] 2.45[f]	4	12	7
		0.97[e] 2.16[f]	3	12	7
	TBTM/MeM in mineral spirits	13.9 8.20	10 10	12 12	– –
	TBT ester of methyl vinyl ether/maleic anhydride, in cyclohexanone	6.20 3.28	10 10, 0-E[g]	12 12	– –
	TBT oxide (2%) in mineral spirits	1.85	10. 0-E[g]	12	–

[a] Treatments devised and performed by David W. Taylor, Naval Ship R&D Center. FPL contact, Bruce R. Johnson.
[b] Polymerization prior to impregnation of solution into wood. Six replicates per treatment.
[c] TBTM, tributyltin methacrylate; MeM, methyl methacrylate.
[d] After oven drying to constant weight.
[e] Polymer.
[f] Creosote.
[g] One of 6 panels failed solely by erosion.

Table E-2 — *In situ* polymerization of tributyltin-modified monomers[a,b]

Installation date (month/year)	Solution formulation[c]	Retention (lb/ft^3)	Extent of damage	Exposure (years) Total	Exposure (years) Time to average rating < 6
6/77	MeM	29.0	8	11.5	–
	TBTM/MeM	22.8	10	11.5	–
	TBTM/MeM with 1,3-butylene dimethacrylate	29.3	10	11.5	–
	TBTM	35.0	10	11.5	–
12/77		27.0	10	11.0	–
	TBTM in mineral	3.08[d]	10	11.0	–
6/77	TBTM/GMA[e]	13.0	10	11.5	–
		8.4	10	11.5	–
		3.6	10	11.5	–
	TBTM/epoxy, Type 1	6.2	8	11.5	–
12/77	TBTM/epoxy, Type 2	10.7	10	11.0	–
7/80	TBTM/MeM[f]	1.7	10	8.5	–
		0.8	10, 0-E[g]	8.5	–
		0.5	0-L,E[g]	8.5	–
	TBTM/GMA[f]	0.7	10	8.5	–

[a] Treatments devised and performed by David W. Taylor, Naval Ship R&D Center, except as noted. FPL contact, Bruce R. Johnson.
[b] Six replicates per treatment except as noted.
[c] MeM, methyl methacrylate; TBTM, tributyltin methacrylate; GMA, glycidal methacrylate.
[d] Polymer.
[e] Four replicates per treatment. Treatments done by Washington State University for Taylor R&D Center. Percent weight gains were erroneously presented as pound per cubic foot retentions in the previous edition of this report. The values reported here are based on an assumed specific gravity of 0.57.
[f] Three replicates per treatment.
[g] One of 3 panels failed solely by erosion.

Table E-3 — *In situ* polymerization of modified methacrylate impregnants[a,b]

Installation date (month/year)	Solution formulation ratio[c]	Weight gain (percent)	Extent of damage	Exposure (years)	
				Total	Time to average rating < 6
1/80	MeM	80.3	10	9	–
	PCPM:MeM				
	1:4	80.5	10	9	–
	1:8	83.5	10	9	–
	1:16	81.3	10	9	–
	TBTM:MeM				
	1:2	82.6	10	9	–
	1:4	79.6	10	9	–
	1:8	12.6	10	9	–
	PBPM:MeM				
	1:8	82.7	10	9	–
	1:16	87.1	8	9	–
	1:32[d]	80.0	9	9	–

[a] FPL contact, Roger M. Rowell.
[b] Note that retention is expressed as weight gain, not pounds per cubic foot.
[c] MeM, methyl methacrylate; PCPM, pentachlorophenol methacrylate; TBTM, tributyltin methacrylate; PBPM, pentabromophenol methacrylate.
[d] Ten replicates.

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