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PRESERVING WOOD BY BRUSH, DIP, AND SHORT-SOAK METHODS
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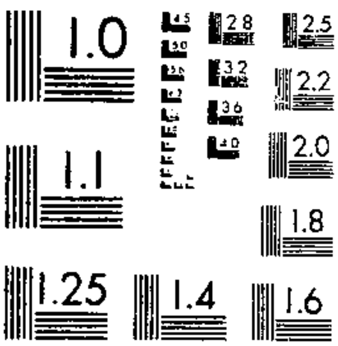
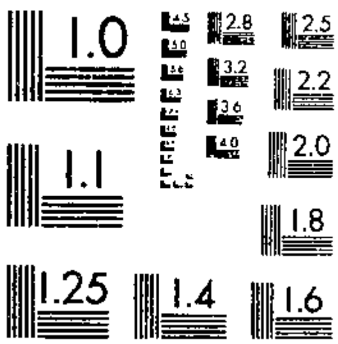


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

PRESERVING WOOD

by BRUSH, DIP, and SHORT-SOAK METHODS

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INTRODUCTION

Preservatives are extensively used to protect wood from the ravages of fungi, insects, and marine borers. Many preservatives are used; each has different physical and chemical properties, and each meets a specific need.

The effectiveness of each preservative depends on the relationship of the kind of treatment to the degree of hazard to which the treated wood is exposed. For example, posts, poles, marine piling, bridge timbers, and crossties of most wood species will give long service only if they are well impregnated with a suitable preservative, while items like interior trim seldom need preservative treatment. In between are many situations where surface applications provide adequate protection. Items of intermediate risk are siding, exterior trim, sash, and other parts subject to wetting by rain seepage, particularly when the worst hazard has been avoided by designing the building to limit rainwetting and to permit rapid drying between showers (*36*, *38*).

This bulletin reports results of experiments on the effectiveness and limitations of brush, dip, and short-soak methods. The experiments are of two main categories: penetration and absorption of preservatives and decay protection. Particular attention is given to water-repellent preservatives because much of the wood which can be protected from decay by simple applications also needs protection against stain, paint peeling, warping, and other defects frequently associated with relatively minor rain seepage. This minor wetting is effectively controlled by water repellents (*38*).

WATER REPELLENCY

Water-repellent preservatives were introduced about 1940 to protect sash and other millwork from rapid changes in moisture content. Several southern sawmills are now dipping general construction lumber in a water-repellent preservative, primarily to minimize rainwetting during shipment, storage at the building site, and construction.

Water repellents consist of waxes and synthetic resins which reduce wettability and thus curtail the capillary movement of water into joints and into the wood proper. Water repellents suitable for the uses covered by this bulletin should meet the standards of the National Woodwork Manufacturers Association or Federal Specification TT–W–572, i.e., have a repellency of at least 60 percent by the Swellograph test. The effectiveness of commercial water repellents in oil solutions varies considerably (*22*).

Manufacturers and distributors do not disclose the composition of the water repellents added to their preservative solutions. However, extensive trials at the Forest Products Laboratory (*7*) showed that it was not possible to achieve the repellency desired for siding and other exterior woodwork in a single application without incorporating a moderate proportion (about 1 percent) of a hydrocarbon wax such as paraffin wax or ceresin. Vegetable waxes and other true waxes were much less effective, and resins or varnishes still less so.

Paraffin wax emulsions added to water solutions of preservatives impart significant resistance to rainwetting (*37*) and are now commercially used to keep framing and sheathing lumber dry during transit, storage at the building site, and construction.

More must be learned about the paintability of wood treated with wax emulsions before they can be recommended for use on wood to be painted.

Properly formulated water-repellent preservatives in oil solutions interfere with the subsequent painting only if excessive absorption occurs (as is likely with fungus-infected wood) or if insufficient time is allowed for solvent evaporation.

Experience has suggested that application of water repellents to sash produces a marked beneficial effect. Recently, this has been substantiated by the accumulation of much experimental evidence. A dip in a water repellent greatly curtails rainwetting of siding (*1*, *38*), sash (*22*), and other wood products (*37*), and thus minimizes decay, stain, paint failure, warping, checking, and nail rusting.

Water repellents are most useful in protecting siding and other exterior woodwork exposed to limited rainwetting (*36*, *38*). Even when water-repellent treated wood is exposed to severe rainwashing under conditions hindering drying between showers, wetting is greatly restricted for as long as several months (*37*). However, the wood eventually becomes saturated.

Water repellents will not prevent losses or gains of moisture resulting from fluctuating humidities. They reduce the rate of change but eventually the wood reaches equilibrium with the average relative humidity.

PENETRATION AND ABSORPTION STUDIES

MATERIALS AND METHODS

Both dry and green southern pinewood was used.

The commercial kiln-dried lumber used was free of obvious fungus infections, knots, resin pockets, and similar defects. No attempt was made to exclude slightly off-grain boards, except for special tests on radial, tangential, and longitudinal penetrations. Unless otherwise noted, the samples were all sapwood. In most cases, wood species could not be determined, but the lumber originated in Arkansas, southern Mississippi, and central Alabama, and probably all the important southern yellow pine species were represented.

The green wood was either freshly sawn lumber secured at mills or cut from freshly felled longleaf pine trees. The green lumber was air-dried or kiln-dried and handled to exclude or to favor fungus infections, whichever was desired. Except for special comparisons, samples were surfaced after seasoning as in commercial practice.

In general, lumber was cut into 1- by 1-inch or 1- by 2-inch strips of sufficient length to furnish one sample 3 to 10 inches long for each test category. Within a strip, samples were randomly distributed among treatments. In tests with many categories, the samples for longitudinal and lateral absorptions were cut from adjacent strips. Usually 10 samples were used for each test category.

After drying or special preparation, samples were strip-piled on a laboratory shelf until they attained a uniform moisture content of 10 to 14 percent, depending on season of the year, except in special tests where variable moisture contents were desired.

Usually absorptions were restricted to certain surfaces, for example, end or lateral surfaces. Nontest surfaces were coated with an oil- and water-resistant vinyl chloride paint that excluded all water or oil.

Thirty-three of the 36 tests of oils were with ready-to-use commercial preparations containing 5-percent pentachlorophenol in mineral spirits. Two were with concentrates diluted with kerosene. When solutions with and without water repellents were compared, both were furnished by the same manufacturer and presumably were essentially identical except for the presence or absence of the water repellents.

For studies of the penetration and absorption of water, no toxicants or water repellents were added.

To stain the wood for penetration measurement, Du Pont oil red [1] was added to oil solutions and aniline blue to water. Absorption rates of dyed and undyed solutions were not significantly different, but it can only be assumed that the penetrations of the dye and preservative were the same. Penetrations were determined after 1 week or more of open-piled drying of the treated wood. The samples were split, and the longitudinal and radial limits of the dyed wood were measured. A few tangential measurements were also taken. With water the dye limits were sharp and easily measured, but with the oil the dyed wood varied from deep red near the surface through varying shades to the straw color of the wood. Thus, measurements of oil penetration should be interpreted as relative rather than absolute values.

Before the preservative was applied, the samples were weighed and placed in racks holding them apart. They were then immersed in 3 or 4 inches of solution and reweighed after being wiped with a cloth to remove excess solution. Weights were taken to 0.01 gram.

When samples were numerous, the temperature of the treating solution varied slightly between the start and finish of treatment. To equalize this and other treating errors among all categories, the matched samples from one or two strips were treated simultaneously, except where special test factors prevented such treatment.

DIRECTION OF GRAIN

The capillary structure of normal coniferous wood (*31*) consists of (*a*) the transient spaces around the micelles, (*b*) tracheid cavities in series with pit chambers and pit-membrane pores, and (*c*) resin ducts and rays. The transient cell-wall capillaries are operative only with water and other liquids that swell wood. Thus, they are not important in treatment with petroleum oils. Even with water, the

[1] The mention of commercial products or trade names in this publication is solely for information purposes. Endorsement of any commercial product is not intended and must not be inferred.

transient cell-wall capillaries probably are a very small part of the effective capillary structure. In woods without extensive resin ducts or conducting rays, the ratio of longitudinal to transverse penetration approximates the ratio of the length to width of the average tracheid lumen.

Longitudinal penetration generally is greater than transverse penetration (*21*, *31*, *32*, et al.), and in most conifers tangential penetration is greater than radial (*21*). Bordered pits are usually much more prevalent on radial walls, thus facilitating tangential penetration. However, radial penetration is greater than tangential in pines, probably because pines have well-developed radial resin ducts that are quite permeable (*25*, *33*) and well-developed ray tracheids. There is no evidence that ray parenchyma are important in radial penetration.

In most penetration studies of wood, diffusion or pressure-permeability calculations have been used (*12*, *16*, *25*, *31*, *32*). Soaking involves capillary rise and liquid flow, as does pressure treatment (*31*). The same principles ought to apply to both pressure and dip treatments, but rates and differences may not be the same. A major difference in simple treatments is that treating depths are insufficient to create appreciable hydrostatic pressures. Without external pressure the buildup of back pressure of air within wood should cause the rate of capillary rise to decline rapidly. Lindgren (*17*) reported that aqueous solutions applied as 10-second dips penetrated shortleaf pine 1.5 to 3.5 mm. transversely and 5 to 10 mm. longitudinally. Brown et al. (*6*) found that the relative rate of penetration and absorption of mineral-spirits solutions into ponderosa pine sapwood varied with toxicants, moisture contents, and specific gravities of the wood. In general, a 10-minute soak resulted in radial penetrations 1.5 to 3.20 times and in longitudinal penetrations 30 times the tangential penetration.

The relative permeability of lateral and end surfaces is best measured by absorptions, because lateral penetrations cannot be measured accurately. All comparisons between end and lateral absorptions are summarized in table 1. In each comparison the difference is significant statistically at the 1-percent level.

Although the tests varied widely in time, source of wood, specific gravity, seasoning condition, straightness of grain, etc., the data indicate that the ratio of end to lateral absorption is roughly 10 or 11 to 1 for the specimen sizes used. For the infected material, the ratios in 10 of the 14 individual comparisons were less than for the matched uninfected wood. The ratios for 5 seconds were lower in all five tests than for the matched 3-minute samples. The lower ratio for kiln-dried wood may also be significant; at least it was observed in the two matched comparisons as well as in the unmatched comparisons.

The data of tests in which absorptions and penetrations in the three directions were separately considered are summarized in table 2. Mean ratios of absorption through tangential, radial, and end surfaces agreed closely with ratios of penetration in radial, tangential, and longitudinal directions. These were 1:1.7:12.6 and 1:1.6:11.4, respectively. As the greatest differences were between the two results with pentachlorophenol in mineral spirits without a water repellent, there apparently are only minor differences, if any, in the ratios for the different solutions.

TABLE 1.—*Average absorptions of water and oil solutions through end and lateral surfaces*

Wood condition and immersion period	Tests	Comparisons		Solution absorbed per 10 sq. cm.[1]		End / lateral
		Oil	Water	End	Lateral	
Unmatched comparisons:						
Uninfected sapwood:	*Number*	*Number*	*Number*	*Grams*	*Grams*	
5 seconds	5	5	0	6.2	0.8	7.8
3 minutes	15	18	3	13.9	1.3	10.6
10 minutes	7	8	1	15.0	1.7	8.8
15 minutes	2	2	0	10.4	1.8	10.8
30 minutes	5	6	0	18.6	2.0	9.3
1 hour	5	5	0	21.1	2.2	9.6
Uninfected sapwood, 3 minutes:						
Kiln-dried	10	12	1	13.3	1.4	9.5
Air-dried	5	5	2	15.2	1.2	12.7
Oil	15	15	-------	14.4	1.4	10.3
Oil plus water repellent	3	3	-------	11.5	1.1	10.5
Water	2	-------	3	14.3	1.4	10.2
Matched comparisons, 3 minutes:						
Uninfected heartwood	1	1	0	6.2	.8	7.8
Uninfected sapwood	1	1	0	18.7	1.6	11.7
Infected sapwood	3	10	4	43.9	4.4	10.0
Uninfected sapwood	3	10	4	20.4	1.7	12.0

[1] All differences between end and lateral absorptions are significant at the 0.01 level.

TABLE 2.—*Relative absorptions and penetrations with 3-minute dips*

Solution	Absorption ratio—radial:tangential: end surfaces	Penetration ratio—tangential:radial: longitudinal directions
Pentachlorophenol in mineral spirits:		
Test 1	1:**1.8:**16.7	1: 1.3:**14.7
Test 2	1: *1.4:**11.3	1: 1.0: **8.9
Pentachlorophenol plus water repellent in mineral spirits (test 2)	1:**1.6:**12.5	1:**1.4:**10.3
Water plus aniline blue (test 3)	1:**1.9:**10.8	1:**3.2:**12.4
Geometric mean	1: 1.7: 12.6	1: 1.6: 11.4

*Value is significantly greater at the 0.05 level than the value for radial.
**Values are significantly greater at the 0.01 level than the values for radial (absorption) and tangential (penetration).

Penetration in vertical resin ducts was usually several times as great as in the adjoining wood tracheids. (Resin-duct penetration was ignored in measuring penetration.) The treating solution did not penetrate the parenchymatous border of the resin ducts or enter the tracheids.

Teesdale (*33*) and Scarth (*25*) reported that creosote or mercury under pressure spread out longitudinally from the radial resin ducts in some pine species. Because radial penetration was generally better than tangential penetration in the current tests, it is assumed that the rays were important. As with the vertical resin ducts, the ray ducts were penetrated to greater distances than the ray tracheids, but the solution seemed to be confined to the ducts. The ray tracheids apparently are more effective avenues for radial treatment than are ray resin ducts.

VARIATION AMONG BOARDS AND TREES

Analyses of variance were made of data from six tests on permeability differences among trees or boards.

In four of these tests, commercially kiln-dried lumber was used. It was not known from how many trees the boards came or even whether all boards in a test were of the same pine species. A significant variance was ascribable to board source, regardless of whether the boards were from one mill or from widely separated mills.

For the fifth test, the wood was from six longleaf pine trees which grew in close proximity. Samples from each tree were dipped in pentachlorophenol, in pentachlorophenol plus a water repellent, and in water. No significant variance was ascribable to tree source.

Samples for the sixth test were taken from the outer rings at different heights in three longleaf pine trees from different stands on the Harrison Experimental Forest in southern Mississippi. Permeability differed significantly among the trees (table 3), but not at different heights or among samples at a given height in an individual tree.

In most tests, variance due to board or tree source was exceeded only by that between infected and uninfected and between end and lateral surfaces. It is not known how much of this variance is due to differences among tree species. However, important differences did occur among samples of the same species.

SPRINGWOOD vs. SUMMERWOOD

In most species, summerwood generally treats better under pressure than springwood, or at least allows a greater penetration (*3, 33*). The springwood of rapidly grown southern pine reportedly is particularly low in penetrability (*34*). In contrast, pressure-flow studies show that longitudinal flow through southern pine sapwood (*12*) is greater in springwood than in summerwood. Even though summerwood is more easily penetrated, springwood has a greater void volume and can retain more preservative. Springwood of freshly pressure-treated southern pine sapwood usually contains more solution per unit volume of treated wood than does summerwood (*8*).

In the three tests in which separate measurements were taken, the penetration in summerwood was usually double that in springwood. This relation held for pentachlorophenol alone or with a water repellent, and for treatment with dyed water. Differences were marked in fast-grown wood but were small or absent in slow-grown, even-textured wood. Lateral penetration was greatest when summerwood was exposed on the surface of the lumber. In samples heavily infected with *Trichoderma* or *Penicillium*, penetration of springwood and summerwood was equal.

HEARTWOOD vs. SAPWOOD

In many species, including the pines, heartwood is much more resistant to pressure impregnation (*33*) than is sapwood, but pressure-flow studies (*12*) suggest that the ratios of penetrability of sapwood and heartwood vary greatly among species. With shortleaf pine (*3*), dips and cold soaks penetrate sapwood further than heartwood.

TABLE 3.—*Absorption and penetration of 5-percent pentachlorophenol in mineral spirits, longleaf pine sapwood*[1]

Tree number	Height in tree	Specific gravity	Rings from pith	Absorption per 100 square centimeters		Penetration	
				End	Lateral	End	Lateral
	Feet		*No.*	*Grams*	*Grams*	*Mm.*	*Mm.*
1	0	0.817	18	8.37	0.84	27.9	2.8
	10	.570	17	9.13	.99	31.4	3.1
	20	.533	12	8.97	.99	20.3	3.1
	30	.512	10	8.79	1.02	29.1	3.5
2	0	.609	18	8.63	.91	27.1	3.6
	10	.530	17	8.08	.65	29.3	2.2
	20	.490	11	8.93	.65	29.6	2.0
	30	.455	9	8.46	.70	30.5	2.5
3	0	.704	18	7.13	.73	23.8	1.9
	10	.677	16	6.87	.70	26.5	2.6
	20	.596	12	7.35	.81	23.0	2.2
	30	.537	9	7.38	.82	24.5	1.7

[1] Each value is an average of 4 trials.

Heartwood and sapwood samples were cut from 10 edge-grained pine 2 by 4's from widely separated sources. All comparisons were between sapwood and heartwood from the same board. The transition zone was avoided, but the samples were essentially outer heartwood and inner sapwood. Information on treatments and absorptions is summarized in table 4. In each board the heartwood was less absorbent, both on lateral and end surfaces. However, in both lateral and end absorptions, certain heartwood samples absorbed as much as or more than some unmatched sapwood samples. Apparently, variability within second-growth sapwood or heartwood is sufficiently great so that the two categories overlap in absorptiveness. No penetrations were measured in heartwood. Differences in penetration may be greater than indicated by the absorption data because the latter

TABLE 4.—*Relative absorption of copper naphthenate (0.5-percent Cu) or 5-percent pentachlorophenol in kerosene by kiln-dried southern pine sapwood and heartwood in a 3-minute dip*

Treatment	Grams per sample[1]	Grams per 100 sq. cm.[2]	
		End surfaces	Lateral surfaces
Copper naphthenate:			
Sapwood	4.0		
Heartwood	1.9		
Difference[3]	2.1 ±0.46		
Pentachlorophenol:			
Sapwood		18.7	1.6
Heartwood		6.2	.8
Difference[3]		12.5 ±1.32	.8 ±.12

[1] 4 boards.
[2] 6 boards.
[3] All differences were significant at the 0.01 level.

includes the solution coating the surface and entering tracheid lumens exposed on the surface. Differences between sapwood and heartwood also are probably more pronounced with pressure treatments or long soaks. Teesdale (*33*) found that some heartwood samples reacted like sapwood to pressure treatment.

SPECIFIC GRAVITY

General experience with pressure treatment shows no correlation among species between treatability and specific gravity (*21*). Within a softwood species low-density samples often are the most difficult to penetrate, although density *per se* may not be the determining factor. When pressure-treated to refusal, low-density material usually shows greater retentions than high-density wood. With dips and short period soaks, absorptions of several oil solutions by ponderosa pine sapwood were found to vary inversely with specific gravity (*6*). This relationship held for wood treated at different moisture contents. It was also reflected in longitudinal penetrations, but lateral penetrations were too small to show clear differences.

The studies reported here included only a few determinations of the effect of density on absorption by southern pine. In two of five trials with wood from heterogeneous sources, a weak inverse relationship that was not statistically significant was revealed.

In another trial, samples were taken from the outer 1.5 inch of sapwood of three longleaf pines at approximately 0, 10, 20, and 30 feet above ground. This procedure automatically gave a series of specific gravities, because in southern pine density decreases with height in tree (*18*). An inverse relationship was again found (table 3), but it was neither consistent nor statistically significant. Thus, even with wood of different densities but taken from the same annual rings in an individual tree, no significant correlation between absorption and density could be measured by the techniques used. The data, although inconclusive, suggest that specific gravity is unlikely to have a practical effect.

AIR-DRIED vs. KILN-DRIED WOOD

Kiln-drying pinewood causes resinous extractives to migrate toward the surface (*15*), a process which probably reduces the effective capillary cross-sectional area. With Monterey pinewood, rearrangement of fatty substances during severe drying decreases permeability to water but not to oils (*10*). Kiln-drying also tends to increase pit aspiration (*13, 24*) and hence reduces permeability. However, Sutherland et al. (*32*) report that temperatures above 70° C. or intense drying of wood cause a permanent increase in permeability.

Kiln-drying increased the absorption of an oil solution by ponderosa pine at three moisture contents below fiber saturation (*7*). Perhaps kiln-drying temperatures, with concomitant uneven drying, open minute checks in the cell walls or enlarge the openings in pit membranes and thus more than offset any hindering effects.

In two tests, matched air-dried and kiln-dried samples were compared. Kilning was more severe (75° C. in a forced-draft oven) than in commercial lumber practice. All samples were conditioned to the same moisture content before treatment. In general, kiln-drying increased absorption and penetration of the oil (table 5), but the reverse was true when water was used. These limited data support Davies' finding (*10*) that severe drying changes penetrability but that the direction of change may vary with the type of liquid.

The end surfaces of freshly felled southern pine ooze oleoresin, which, on drying, forms a pitch encrustation. During a 3-minute dip in mineral-spirits solutions, these encrustations prevented most end penetration. General experience in treating fenceposts with cold soaks in heavier oil solutions indicates that the effect is removed with longer immersions.

WOOD MOISTURE CONTENT

With short-period soaks, absorption and penetration of oil solutions by ponderosa pine sapwood are inversely related to the moisture content, both above and below fiber saturation (*6*). Moisture contents below fiber saturation had small effect on lateral penetration (*6*, *30*).

TABLE 5.—*Absorptions and penetrations of water and 5-percent pentachlorophenol in mineral spirits for kiln-dried versus air-dried pine sapwood, after 3-minute dips*

Test and treatment	Average absorption			Average penetration	
	Grams per sample	Grams per 100 sq. cm.		End	Lateral
		End	Lateral		
				Mm.	*Mm.*
Test 1:					
Pentachlorophenol:					
Air-dried	8.5	------------	1.6	5.7	1.4
Kiln-dried	**10.5	------------	**2.0	**17.3	*1.9
Test 2:					
Pentachlorophenol:					
Air-dried	------------	18.6	1.4	53.1	3.3
Kiln-dried	------------	20.0	*1.6	51.3	*4.8
Water:					
Air-dried	------------	*16.1	*1.6	**11.4	.6
Kiln-dried	------------	12.2	1.2	6.9	.5

*Significantly greater at the 0.05 level.
**Significantly greater at the 0.01 level.

Different moisture contents were tested.

In one test, samples were cut from one sapwood board from each of five longleaf pine trees; they were the kiln-dried at 70° C. Matched groups were conditioned over salt solutions until equilibrium moisture contents of 12, 16, and 25 percent were reached. Half the conditioned samples were end coated and half were side coated with vinyl chloride.

In the second test, all samples were from one longleaf pine tree. The lumber was surfaced green and seasoned in one of three ways: (1) Immediate kiln-drying at 70° C., (2) dipping in a stain-control solution and partial air seasoning, and (3) the same treatment as in 2 but with full air-drying. When the samples attained the desired moisture contents, they were made into boxes nominally 3 by 8 by 12 inches (*37*). A fourth group of samples was treated green. Ten boxes of each moisture group were given a 3-minute dip in 4-percent sodium pentachlorophenate plus 4-percent borax in water, and 10 in 5-percent pentachlorophenol in mineral spirits.

In both studies absorptions decreased as the moisture contents increased (tables 6 and 7). The adverse effect was most pronounced at moisture contents above fiber saturation.

ROUGH VS. DRESSED LUMBER

In a small laboratory test with water solutions of a sap stain-control chemical, rough samples removed 1.8 times as much solution from the vat as did planed samples (*40*). Presumably, the roughened surface held more liquid on the surface, and some of this liquid later penetrated deeper, thus influencing the degree of stain control.

TABLE 6.—*Absorption of 5-percent pentachlorophenol plus a water repellent per 100 sq. cm. of pine sapwood at different moisture contents below fiber saturation during a 3-minute dip*

Moisture content when treated (percent)	Through lateral surfaces	Through end surfaces
	Grams	*Grams*
12	0.15	1.72
16	.14	1.59
25	.13	1.54

TABLE 7.—*Effect of moisture content of pine sapwood on absorption of 5-percent pentachlorophenol in mineral spirits and 4-percent sodium pentachlorophenate plus 4-percent borax in water*

Type of seasoning	Moisture content	Absorption per box	
		Oil	Water
	Percent	*Grams*	*Grams*
Unseasoned, green	110	10	31
Partially air-dried	[1] 41	72	67
Fully air-dried	14	106	87
Kiln-dried	9		93

[1] With a moisture gradient from outside (30 percent) to inside (65 percent).

In another test, 10 pairs of matched samples from seven boards were dipped for 3 minutes in 5-percent pentachlorophenol in mineral spirits. Each pair consisted of a rough and a planed sample. After being dipped the samples were drained but not wiped before reweighing. Absorptions per 100 sq. cm. were 2.80 grams for rough samples and 1.69 grams for planed samples. The difference, 1.11 ±0.161, is highly significant and approximately as great (1.7 as compared to 1.8 times) as for the water solutions (*40*).

FUNGUS INFECTIONS

Fungus stains, except perhaps those developing in the living tree, are generally known to increase the permeability of wood to liquids

(*20* and literature cited therein). Lindgren and Scheffer (*20*) found that, with pine sapwood, different species of stain fungi increased absorptions 1.2 to 1.7 times with a 30-minute soak and 2.1 to 2.5 times with hot-and-cold or pressure treatments with creosote.

There is much less information on the effect of decay on permeability. Scheffer (*26*) found that sweetgum that had its specific gravity reduced 10 percent or more by *Polyporus versicolor* (L.) Fr. had a slightly lower fiber-saturation point, a greater water-absorption rate, and a greater evaporation rate.

Lindgren (*19*) reported that the mold *Trichoderma viride* Pers. ex Fr. is particularly effective in increasing permeability to water and oil.

Blew (*5*) showed that in the cold-soaking process the degree of general fungus infection markedly affects absorption by southern pine posts.

Five of the current tests were on the effects of fungus infections. All samples were fresh, green, southern pine sapwood treated and seasoned in different ways to secure the desired infections.

Natural infections were secured in three tests by dipping samples in:

(1) 2- to 4-percent sodium fluoride to induce heavy growth of *Trichoderma viride* (*19*, *35*).

(2) 0.015-percent ethyl mercuric phosphate to induce heavy growth of *Penicillium* (*35*).

(3) A double-strength stain-control chemical to prevent all but small amounts of fungus infections.

The treated samples were placed in miniature enclosed seasoning piles (*40*) and progressively opened to aeration until seasoned. All final preservative treating was done at uniform moisture contents of 12 to 14 percent.

For the fourth test, matched green blocks were surface sterilized in boiling water, placed in sterile glass jars, and inoculated with pure cultures of *Ceratocystis ips* (Rumb.) C. Moreau, *Trichoderma viride*, or *Lenzites saepiaria* Wulf. ex Fr. (representative stain, mold, and decay fungi). Different incubation periods were used to give samples with high and low levels of attack. The blocks were finally air-dried to 14-percent moisture before preservative treatment.

For the fifth test, only *Trichoderma*-molded wood was used. Five-inch-long sections from 10 molded fenceposts were split in half. They were dipped for 3 minutes in 5-percent pentachlorophenol plus a water repellent. Absorption by a radial surface was tested on one piece from each post, and absorption by a tangential surface was tested on the other piece. The infected and uninfected posts were adjacent sections of the same trees.

For both water and oil, all infections increased the absorption rate, and most infections increased the depth of penetration (tables 8–11). The effects of the different types of infection agree well with the known effects of the fungi on wood structures.

Molds.—Trichoderma viride, which grows more luxuriantly on pine sapwood than any other common mold, markedly increased permeability. In the fifth test, the ratio of radial to tangential penetration was 2.8—significantly greater than the average for uninfected wood (ratio 1.6) as given in table 2. Apparently the effect of *Trichoderma* on permeability is greater in the radial than the tangential direction. The pronounced breakdown of ray tissue by *Trichoderma* (*19*) probably facilitates radial penetration more than lateral penetration.

Penicillium grew less luxuriantly than *Trichoderma* and caused no obvious breakdown of ray tissue. It had a less marked effect on permeability.

TABLE 8.—*Effects of mold* (Trichoderma) *and stain on absorption and penetration of 5-percent pentachlorophenol in mineral spirits, into pine sapwood, during a 3-minute dip (test 1)*

Infection	Area stained	Mold rating[1]	Absorption per sample		Penetration	
			All surfaces	Lateral surfaces	Lateral surfaces	End surfaces
	Percent		*Grams*	*Grams*	*Mm.*	*Mm.*
Mold	(2)	2.6	53.4	50.8	[3] 10	[3] 110
Stain	27	3.0	32.4	37.6	[3] 7	[3] 60
Uninfected	(2)	0	8.5	6.2	1.4	5.7

[1] 0=none; 5=very heavy.
[2] Trace.
[3] Some samples were completely penetrated (12 mm. lateral and 140 mm. longitudinal).

TABLE 9.—*Effects of mold* (Trichoderma) *and stain on absorption and penetration of 5-percent pentachlorophenol in mineral spirits and of water, pine sapwood, during 3-minute dips (test 2)*

Infection	Area stained	Mold rating[1]	Absorption per 100 sq. cm.				Penetration			
			Oil		Water		Oil		Water	
			Lateral surfaces	End surfaces	Lateral surfaces	End surfaces	Lateral surfaces	End surfaces	Lateral surfaces	End surfaces
	Percent		*Grams*	*Grams*	*Grams*	*Grams*	*Mm.*	*Mm.*	*Mm.*	*Mm.*
Mold	(2)	3.0	6.2	44.5	4.5	35.0	[3] 12.0	[3] 87	3.9	21.6
Stain	69	0	2.0	20.9	2.0	19.7	[3] 6.0	52.6	.4	8.6
Uninfected	(2)	0	1.4	18.6	1.6	16.3	3.3	53.5	.0	8.0

[1] 0=none; 5=very heavy.
[2] Trace.
[3] Some samples were completely penetrated (12 mm. lateral and 128 mm. longitudinal).

TABLE 10.—*Effect of the molds* Penicillium *and* Trichoderma *on absorption and penetration of 5-percent pentachlorophenol in mineral spirits applied as a 3-minute dip and of water applied as a 10-minute soak to pine sapwood (test 3)*

Mold	Area stained	Mold rating[1]	Absorptions per 100 sq. cm.				Penetration			
			Oil		Water		Oil		Water	
			Lateral surfaces	End surfaces	Lateral surfaces	End surfaces	Lateral surfaces	End surfaces	Lateral surfaces	End surfaces
	Percent		*Grams*	*Grams*	*Grams*	*Grams*	*Mm.*	*Mm.*	*Mm.*	*Mm.*
Penicillium	0.2	3.5	1.9	23.5	3.9	41.9	4.7	[2] 60.0	2.5	14.7
Trichoderma	2.6	4.0	5.7	36.7	9.1	60.3	[2] 9.0	[2] 60.0	4.3	21.3
Uninfected	0	0	1.6	15.2	2.9	22.3	4.0	47.1	2.3	9.1

[1] 0=none; 5=very heavy.
[2] Some samples were completely penetrated (11 mm. lateral and 84 mm. longitudinal).

TABLE 11.—*Effects of level of infection by stain* (Ceratocystis ips), *mold* (Trichoderma), *and decay* (Lenzites saepiaria) *on the absorption and penetration of 5-percent pentachlorophenol in mineral spirits, pine sapwood, during a 3-minute dip (test 4)*

Infection	Area stained	Mold rating [1]	Absorption per 100 sq. cm.		Penetration	
			Lateral surfaces	End surfaces	Lateral surfaces	End surfaces
Stain:	*Percent*		*Grams*	*Grams*	*Mm.*	*Mm.*
Light	35	(2)	2.5	35.6	[3] 6.0	[3] 30
Heavy	94	(2)	2.6	36.0	[3] 10.0	[3] 39
Mold:						
Light	0	1.2	2.5	47.4	[3] 8.0	[3] 39
Heavy	0	2.8	4.5	85.6	[3] 10.0	[3] 39
Decay:						
Light	0	(2)	2.5	35.0	[3] 9.0	[3] 39
Heavy	0	0	11.9	81.7	[3] 11.0	[3] 39
Uninfected	0	0	1.4	23.6	3.7	[3] 39

[1] 0=none; 5=very heavy.

[2] Trace.

[3] Some samples were completely penetrated (12 mm. lateral and 39 mm. longitudinal).

The increased end absorption associated with mold and stain infections presumably is due to enlargement of the pit-membrane perforations by the fungi.

Stain.—Except for the inoculated samples, the stain encountered in these tests was caused by *Ceratocystis pilifera* (Fr.) C. Moreau. In general, stain fungi in coniferous woods are more restricted to the rays than are molds and decay fungi. Stainers do not cause as great a ray breakdown as does *Trichoderma*. The data on absorptions and penetrations of stained wood verify these points. The stained samples, even when deeply penetrated, were not dyed as intensely by the treating solutions as was the wood invaded by *Trichoderma*.

In most discussions of the effects of stain on permeability of wood, a reservation is made that stain developing in dying trees following beetle attack may not increase permeability. Nelson (*23*) reported that stain of the type associated with beetle attack in living shortleaf pine trees caused stoppage of water conduction and that dyes would not pass through stained zones.

During the present studies, a few samples were collected from pines freshly killed by beetles. The samples included wood infected with *Ceratocystis ips*, associated with *Ips* beetle attack, and with *C. minor* (Hedgc.) Hunt, associated with *Dendroctonus* beetle attack. All the wood was readily penetrated with oil solutions after air-drying. All isolations attempted from stained wood from beetle-killed trees yielded *Trichoderma viride*. Nelson (*23*) also found this mold commonly associated with beetle attack.

Nelson's data on occlusion were based on tests of wood stained by artificial inoculation and not by beetles. Apparently, the stain occurring in beetle-killed trees is also commonly accompanied by the mold *Trichoderma* and, at least after seasoning, the wood is readily permeable to preservatives.

Decay.—Incipient infections by *Lenzites saepiaria* increased absorption about as much as did stain. However, visible but not advanced decay increased absorptions as much as or more than did

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Trichoderma. Decay fungi, in addition to enlarging pit-membrane capillaries, also bore directly through cell walls, thus creating new capillaries. The decay fungus used in these tests makes large holes through cell walls and may have increased permeability more than some other decayers would have. For practical purposes the big effects of decay beyond the incipient stage are lessened by the slow growth of these fungi. Except for localized pockets, advanced decay is seldom encountered in wood being treated.

LENGTH OF IMMERSION

Initial absorptions with dip and cold-soak treatments of dry wood are high (*6*, *9*), probably because of the initial unrestricted capillary action (*31*). After this initial spurt, the rate of absorption decreases rapidly with increased immersion time. For treatments in which no artificial external pressure and little hydrostatic pressure are operative, the buildup of back pressure should be particularly effective in decreasing the rate of absorption with length of immersion.

The relation of absorption to length of immersion was determined for lateral and longitudinal penetration in six tests with kiln-dried southern pine sapwood. The data are summarized in table 12.

When these data are plotted on logarithmic paper, the absorptions for immersions longer than 5 seconds fall approximately in a straight line. The average curves for the data from all tests fit the following exponential equations:

Log lateral absorption $= -0.38 + 0.19$ log immersion in seconds.
Log end absorption $= 0.64 + 0.18$ log immersion in seconds.

The coefficients of the log immersion times, indicating slope of curve, show that lateral and end absorptions have the same relation to length of immersion and differ only in the amount of absorption. The end absorption is about 10 times the lateral absorption per unit area.

In two tests the combined absorptions of lateral and end surfaces were secured by using uncoated test blocks. Slopes of the curves were flatter (0.11 and 0.14 log immersion time) than for lateral or end absorptions alone (0.16 to 0.25 log immersion time), perhaps because of differences in the rate of buildup of back pressure or other physical phenomena accompanying simultaneous penetration from both ends and sides. The difference was further shown by two tests (see tabulation) in which the sum of absorptions per block through the ends and sides of matched samples was considerably greater than through ends and sides simultaneously.

In another test, the ends and radial edges of three matched groups of flat-sawn pine sapwood samples were coated with vinyl chloride. In addition, one group was coated on the flat surface toward the pith, one on the flat surface toward the bark, and the third was left with both lateral surfaces uncoated. The pieces were dipped for 10 minutes in 5-percent pentachlorophenol in mineral spirits. Average absorptions were 1.38 grams through the bark-oriented surfaces, 1.34 grams through the pith-oriented surfaces, and 2.18 grams through both simultaneously.

The available data suggest that size of test sample may influence rate of penetration. Therefore, the rates reported here should be considered comparative rather than absolute.

TABLE 12.—*Absorptions of pentachlorophenol in mineral spirits and of water, with various immersion periods, kiln-dried southern pine sapwood* [1]

Solution	5 seconds	10 seconds	30 seconds	1 minute	3 minutes	10 minutes	15 minutes	30 minutes	1 hour
	LATERAL SURFACES (Grams per 100 sq. cm.)								
Pentachlorophenol	1.0	-------	-------	-------	1.2	-------	1.6	-------	2.0
Do	.7	-------	-------	-------	1.2	1.4	-------	1.8	2.0
Do	.8	-------	-------	-------	1.3	1.6	-------	2.0	2.2
Pentachlorophenol plus water repellent	.6	-------	-------	-------	.8	1.3	-------	1.6	1.9
	END SURFACES (Grams per 100 sq. cm.)								
Pentachlorophenol	8.2	-------	-------	-------	15.6	-------	20.7	-------	20.2
Do	6.0	-------	-------	-------	9.5	13.6	-------	18.7	16.9
Do	5.1	-------	-------	-------	8.7	11.2	-------	13.0	15.5
Pentachlorophenol plus water repellent	6.3	-------	-------	-------	12.0	13.5	-------	17.8	24.2
	LATERAL AND END SURFACES (Grams per sample)								
Pentachlorophenol	-------	4.4	-------	-------	5.8	6.6	-------	7.5	-------
Pentachlorophenol plus water repellent	-------	-------	6.7	8.0	9.3	10.1	-------	-------	-------
Water	-------	-------	6.7	7.8	9.2	9.7	-------	-------	-------

[1] Each figure is an average of 10 samples.

Treatment	*Absorption*		
		Test 2	
	Test 1 3-minute dip (grams)	*3-minute dip (grams)*	*10-minute dip (grams)*
End coated	1.71	0.69	0.80
Side coated	1.79	.75	.95
Uncoated	2.24	1.08	1.18
Completely coated	---------	.01	----------

In two tests penetrations were determined for different immersion periods. Because of the small lateral penetration and the difficulty of measuring it accurately, only end penetrations were considered. The following equations were determined for the average exponential curves of the data:

Log end absorption $= 0.58 + 0.22$ log immersion in seconds.
Log end penetration $= 1.01 + 0.21$ log immersion in seconds.

These data indicate a nearly linear relation between rates of absorption and average penetration, at least when no disturbing elements such as fungus infections are involved.

WATER REPELLENTS

Hubert (*14*) states that addition of water-repellent oils and waxes retards penetration and absorption. The type of repellent probably is also influential.

In field tests (*39*), samples absorbed only 53 to 91 percent as much pentachlorophenol plus a water repellent as they did the straight preservative.

The addition of a water repellent reduced absorption (table 13), but interference was less than previously reported (*39*), even though the same solutions were used. In every case the water-repellent solution penetrated less laterally and longitudinally. The differences in absorptions are partly masked by the somewhat higher specific gravity of the water-repellent solutions.

RETREATMENT

The effect of previously applied oil-carried preservatives on subsequent oil penetration was evaluated in three tests.

In one test, kiln-dried samples were immersed for 3 minutes in dyed solutions of pentachlorophenol alone or with water repellents. Three weeks later, after much of the solvent had evaporated, the samples were redipped in the solutions. Because dyed solutions were used throughout, penetrations on retreatment could not be measured. Consequently, only data on absorptions are presented.

The second test was similar to the first test, except that immersions were for 10 minutes and the samples to be retreated were originally dipped in undyed solutions. All retreatment was with dyed solutions.

The third test was similar to the second test, except that the original treatment was a 3-minute immersion and the retreatment a 10-minute soak, and the interval between treatments was 8 months.

Results of all three tests are given in table 14. Wood treated with pentachlorophenol or pentachlorophenol plus a water repellent resisted retreatment for a few weeks. Retreatment after 8 months showed that only those samples previously treated with the water-repellent solution were resistant, and even their resistance was not great.

AIR TEMPERATURES

Most brush, dip, and short-soak applications of preservative are at ambient air temperatures, and if the wood is to be painted the carrier is unlikely to be heavier than kerosene. With light oils there will probably be little change in viscosity with varying weather and little direct effect on absorptions and penetrations. Nevertheless, four tests were designed to determine the direct and possible indirect effects of prevailing temperatures in the Gulf Coast area.

In the first test, pine sapwood was given 5-second and 3-minute dips in 5-percent pentachlorophenol in kerosene. One group of samples and the treating solution were refrigerated for 2 hours, and the other

TABLE 13.—*Absorptions per 100 square centimeters and penetration of pentachlorophenol and of pentachlorophenol plus a water repellent in mineral spirits, pine sapwood* [1]

Solution	Immersion time in minutes—								
	3	3	3	3	5	10	10	10	30
	ABSORPTION								
	Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
Lateral surfaces:									
Pentachlorophenol	*1.3	1.5	--------	--------	*1.6	--------	*1.7	*1.7	*2.5
Pentachlorophenol plus water repellent	1.1	1.4	--------	--------	1.3	--------	1.4	1.4	1.9
End surfaces:									
Pentachlorophenol	*12.0	14.2	--------	--------	*13.4	--------	--------	*15.1	20.8
Pentacholorophenol plus water repellent	9.6	12.1	--------	--------	10.1	--------	--------	12.9	19.7
Total absorption:									
Pentacholorophenol	--------	--------	3.9	*2.6	--------	4.2	--------	--------	--------
Pentacholorophenol plus water repellent	--------	--------	3.3	2.3	--------	4.2	--------	--------	--------
	PENETRATION								
	Mm.	*Mm.*			*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*
Lateral surfaces:									
Pentacholorophenol	*3.0	*3.1	--------	--------	*4.6	1.8	*4.2	--------	*4.4
Pentacholorophenol plus water repellent	2.4	2.3	--------	--------	2.3	1.7	2.3	--------	2.5
End surfaces:									
Pentacholorophenol	*34	22	--------	--------	*29	--------	30	--------	*45.0
Pentacholorophenol plus water repellent	25	19	--------	--------	23	--------	25	--------	36.0

[1] Each figure is an average for 10 samples.
*Significantly greater at 0.05 level or better.

group and the treating solution were stored at room temperature (88° F.) before dipping. Absorptions per sample were:

Immersion time	*50°–54° F. (grams)*	*88° F. (grams)*	*Difference (grams)*
5 seconds	1.95	1.45	0.50 ±0.34
3 minutes	2.26	1.90	** .36 ± .06

**Significant at 0.01 level.

In the refrigerated group the wood probably had a higher temperature than the solution, the effect being that of a mild hot-and-cold bath, which would increase absorption. With the 5-second dip the sample-to-sample variability was too great for a significant difference between the groups.

In another study, one group of pine sapwood samples was dipped for 3 minutes in 5-percent pentachlorophenol in kerosene during December, when the air temperature was 48° F. A matched group was dipped in May, when the air temperature was 77° F. On both occasions samples were dipped after 3 or 4 days of fairly constant temperatures. Absorptions per sample were 4.28 grams at 48° F. and 4.11 grams at 77° F. The difference (0.17 ±0.13) is not significant.

In a third study, one set of pine sapwood samples was wrapped in moisture-proof paper and refrigerated at 40° F., along with sufficient dipping solution (5-percent pentachlorophenol in kerosene) for 30 days. The other set and treating solution were stored in the laboratory at about 77° F. Both were treated at room temperature but before the temperature of the refrigerated samples or solution increased appreciably. The absorptions (per 100 sq. cm.) secured were with 3-minute dips:

	77° F. (grams)	40° F. (grams)	Difference[1] (grams)
Lateral	1.43	1.29	0.14 ±0.12
End	13.80	13.49	.31±1.15

[1] Not significant in either case.

For the last study, samples from 10 kiln-dried boards and the treating solution (5-percent chlorophenols plus a water repellent in mineral spirits) were kept at 80 ±2° F. for 16 days prior to treatment. Wood temperature at the time of immersion was 80° F. Matched lots of 10 samples were dipped for 3 minutes in the solution at 40, 60, 80, 100, and 120° F. This resulted in the mild hot-cold and cold-hot treatments likely to occur with rapid fluctuations of ±20 and ±40° F. in air temperature. The curve of absorption versus temperature is essentially a straight line (fig. 1).

TABLE 14.—*Effect of dips and soaks on subsequent treatment of pine sapwood*

Original and subsequent treatment periods and original treatment solution	Lateral surfaces: Original treatment	Lateral surfaces: Retreatment with Pentachlorophenol	Lateral surfaces: Retreatment with Pentachlorophenol and water repellent	End surfaces: Original treatment	End surfaces: Retreatment with Pentachlorophenol	End surfaces: Retreatment with Pentachlorophenol and water repellent
ABSORPTION[1]						
	Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
3+3 minutes:						
Pentachlorophenol	1.4	0.5	0.4	11.6	2.5	2.0
Pentachlorophenol plus water repellent	1.1	.5	.4	9.5	1.7	1.5
10+10 minutes:						
Pentachlorophenol	1.8	.3	.3	14.9	2.3	2.3
Pentachlorophenol plus water repellent	1.5	.3	.3	13.8	1.0	1.7
3+10 minutes:						
Pentachlorophenol	[2] 2.4	[2] 2.3				
Pentachlorophenol plus water repellent	[2] 2.1	[2] 1.2				
PENETRATION						
10+10 minutes:	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*
Pentachlorophenol	4.2	1.2	1.2	20.6	6.8	6.4
Pentachlorophenol plus water repellent	2.3	.8	.7	24.8	3.8	3.1
3+10 minutes:						
Pentachlorophenol	8.3	7.6		36.0	30.7	
Pentachlorophenol plus water repellent	2.3	3.9		15.0	6.9	

[1] Per 100 sq. cm. except as noted.

[2] Total absorptions, grams per sample.

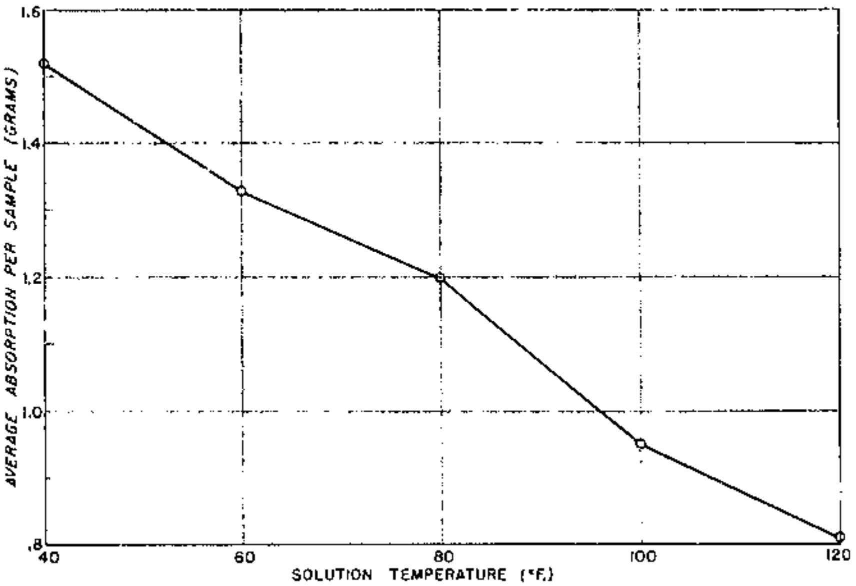


FIGURE 1.—Effect of temperature variation of a chlorophenol–water-repellent solution on absorption by pine sapwood with a temperature of 80° F.

These four tests support the contention that temperatures likely to be encountered in the South will have little effect on absorption through changes in viscosity of treating solutions when kerosene and mineral spirits are the carriers. However, the tests indicate that the lower heat conductivity of the wood as compared to the treating solution can appreciably affect absorption when temperatures fluctuate. With a falling temperature, the wood may be warmer than the solution, resulting in a mild hot-and-cold bath effect and resultant increased absorptions. With a rising temperature, the effect is reversed.

DECAY PROTECTION STUDIES

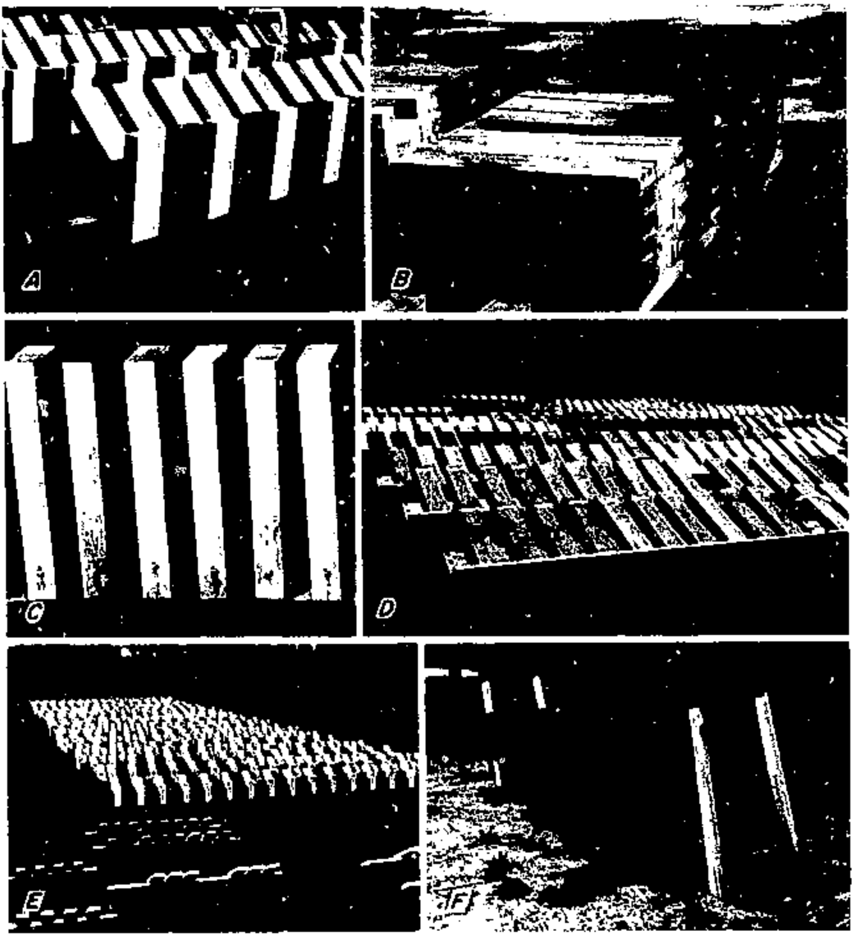
Past experiments (*4*) clearly showed that brush, dip, and short-soak treatments do not afford sufficient protection to warrant their use for wood in contact with the ground. The current studies, therefore, were designed to subject wood to less severe decay conditions, i.e., conditions more commensurate with those on the exterior of buildings where the hazard is created mainly by rain seepage. This purpose required the development of the exposure techniques described immediately below and illustrated in figures 2 and 3.

EXPOSURE UNITS

Step rail.—A 10- to 12-inch length of 2-by-4 lumber nailed at an angle of 45° to the side of a 12-inch 2-by-4 post simulates the joint of step rail to newel post. Rainwater, running down the top of the rail and penetrating the joint, creates a decay hazard as high as any associated with rain seepage. For exposure, the step-rail units were nailed to the side of elevated pressure-treated 2-by-4 rails. This unit proved the most satisfactory for test purposes because it has a high decay hazard and is easy to construct and administer. Each is a completely independent test unit.

Column.—A 13-inch 2-by-4 toenailed to the top of a 2-by-4 sill simulates the porch column, which also has a high decay hazard. Decay developed somewhat more slowly than in the step rail-newel joint, perhaps partly because the sills were of pressure-treated lumber. The column tended to work loose from the sill. This unit was inferior to the step rail and thus was used in only two studies.

Weathering unit.—A 12-inch length of 2-by-4 nailed flat to a 2-by-6 sill of the same treatment permitted the easy exposure of many samples. However, the individual 2-by-4's are not completely independent, because decay developing in the sill may influence other samples on the same sill, and interfere with maintenance of the set.



F—505018, 505016, 505012, 505011, 505013, 505017

FIGURE 2.—Installations for determining effectiveness of simply applied preservatives: *A*, Step-rail joints; *B*, simulated ammunition boxes; *C*, columns; *D*, weathering units; *E*, part of the exposure area for a step-rail study; *F*, board unit.

F–505007, 505008, 505009, 505014, 505010, 505015

FIGURE 3.—Some demonstration units to show the effectiveness of simple preservative treatments: *A*, Exterior steps; *B*, M–22 ammunition shipping boxes; *C*, siding panels; *D*, window shutter; *E*, large porch-flooring units; *F*, small porch-flooring panels.

Board.—Twelve-inch lengths of 1-by-8 lumber are stacked on edge on a treated table or treated sills. This unit was used primarily to study methods of protecting military ammunition boxes. Units given the same treatment were stacked together. Border effects are high, and this unit appears unsuitable for most studies.

Simulated box.—Two 12-inch pieces of 1-by-8 lumber are nailed to peripheral cleats about 1.5 inches wide, and a ⅜-inch hole is bored through each face board to allow ready entry of water. Boxes were exposed in tiers on treated sills; those in each tier were of the same treatment. As with the board unit, the simulated box exposed in close-stacked tiers remains saturated for long periods and thus favors soft rot over regular basidiomycete decay. This unit was used mainly for simulating exposed ammunition boxes (*37*).

Demonstration units.—Units of this class included steps having carriages and treads of 2-by-10 lumber and risers of 1-inch material;

2- by 2-foot units of porch flooring fully exposed; 4- by 8-foot units of flooring exposed under a roof edge; window shutters made of 1-by-6 tongue-and-groove panels and 1-by-4 rails; and ammunition boxes and siding panels. These units were used not only for demonstration but also to study the behavior of treated wood under use conditions. Because of the difficulties of matching wood among test categories and of getting sufficient replication, these demonstration units cannot be recommended for most studies.

Most of the wood was southern pine sapwood purchased on the open market. For some studies other general construction woods were included. Boards with appreciable stain, large knots, and other defects were excluded. Most of the lumber was kiln-dried, but some was air-dried. When possible, the wood was matched among treatments; i.e., one or two units from each piece of lumber were included in each test category. When the number of treatments precluded such matching, lumber for units was partially randomized or matched by groups of related treatments.

TREATING SOLUTIONS

Water repellents.—The U.S. Forest Products Laboratory's formulation WR–7 was used with oil solutions in rail test 3, and in the step test, weathering test, and ammunition box test. WR–7 consists of 8-percent methyl ester of hydrogenated rosin and 2-percent paraffin wax (AMP 125° F.). The hydrogenated rosin is omitted when already present in pentachlorophenol solutions. In other studies the water repellent was a commercial concentrate or one in a ready-to-use water-repellent preservative. The compositions of the commercial products were not disclosed.

The repellent in water solutions was 4-percent paraffin wax added as a 50-percent wax emulsion (*37*).

Oil solutions.—The toxicants were dissolved in—or concentrates of them were diluted with—aliphatic mineral spirits, stove-grade kerosene, or a No. 2 fuel oil sold for use in furnaces. Some special solvents were used for certain toxicants in the box study (*37*).

Pentachlorophenol.—A homemade solution was used in rail tests 3 and 4, the step test, tests of water repellents (table 18 and "no water repellent" columns of table 19, p. 35), the box study, and the mold-infection study (table 24, p. 41). The solution consisted of 5-percent technical crystals of pentachlorophenol, 8-percent methyl ester of hydrogenated rosin, 43.5-percent aromatic mineral spirits, and 43.5-percent aliphatic mineral spirits. Commercial preparations were as follows: a 2-to-1 concentrate in rail tests 1 and 2, shutter test, and column test 2; a 10-to-1 concentrate in the weathering test, and tests of different oil carriers: and ready-to-use solutions in column test 1.

Copper naphthenate.—A semiliquid concentrate containing 8-percent metallic copper unless otherwise indicated in the tables.

Creosote.—AWPA No. 1 coal tar creosote.

Tetrachlorophenol.—Technical crystals.

Zinc chloride.—Technical crystals.

Phenyl mercuric oleate.—A 10-percent concentrate.

The miscellaneous toxicants in the box studies are described in reference 37.

Treatment was by immersion or two brush applications at air temperatures, after the pieces were cut to size but prior to assembly.

The units designated as painted were given two coats of a titanium-lead-zinc oil paint, and repainted at approximately 5-year intervals. The exceptions were the flooring and step units, which were painted with a deck enamel, and the boxes, which were sprayed with a general utility enamel (TT-E-485b, Type II).

EXPOSURE AND EVALUATION

The units were exposed at Saucier, Miss., under partial shade of hardwood or pine trees.

Decay ratings, based on evidence visible on the surface, were made annually, using the following scale:

- 0. None obvious
- 20. Discolorations suggesting that decay had started
- 40. Obvious decay but limited to a small area
- 60. General decay but unit still serviceable
- 80. Advanced decay—wood would be replaced prior to normal repainting
- 100. Complete failure

Comparisons based on these ratings are not entirely satisfactory because 20-, 40-, or even 60-rating decay can occur without external evidence, particularly in painted units. Most reliance in comparing treatments should be on percentage of failures, i.e., proportion of units with decay ratings of 80 or above.

A step-rail unit was considered to have failed when either the newel or rail piece had a rating of 80, for failure of either piece destroys the unit. With porch flooring panels and steps, each board was considered a unit.

At approximately 5-, 10-, and 15-year intervals, 20-percent matched samples of step rail, column, and weathering units were removed for internal examination. Units thus removed were ripped lengthwise to expose a 2-inch-wide surface through the center.

The ratings were based on the class or stage of decay and the number of area units occupied by each class. Decay classes were assigned the following values: 0, decay not apparent; 2, decay definite but relatively light or spotty; 5, decay general but the wood still might be serviceable; 10, wood essentially destroyed. Ten equal-sized area units were designated on each post or rail. To obtain the decay rating, the numerical value assigned the decay class was multiplied by the number of area units affected, and the total points obtained were added.

Decay class		*Area units*		*Points*
0	×	4	=	0
2	×	2	=	4
5	×	4	=	20
		Rating	=	24

In this example the rating is the point total, or 24. The maximum possible rating is 100 (10×10).

In several cases where all units of a treatment had failed, the true average service life corresponded closely to the time required for 60 percent of the units to fail. Therefore, average service life was determined by plotting the data to determine age at which 60 percent had failed—or would fail. No determination was made unless at least 50-percent failure had occurred, except when specifically indicated that the determination was tentative.

The results of the decay protection studies are presented in the following pages under the following nine headings. Some typical results are shown in figure 4.

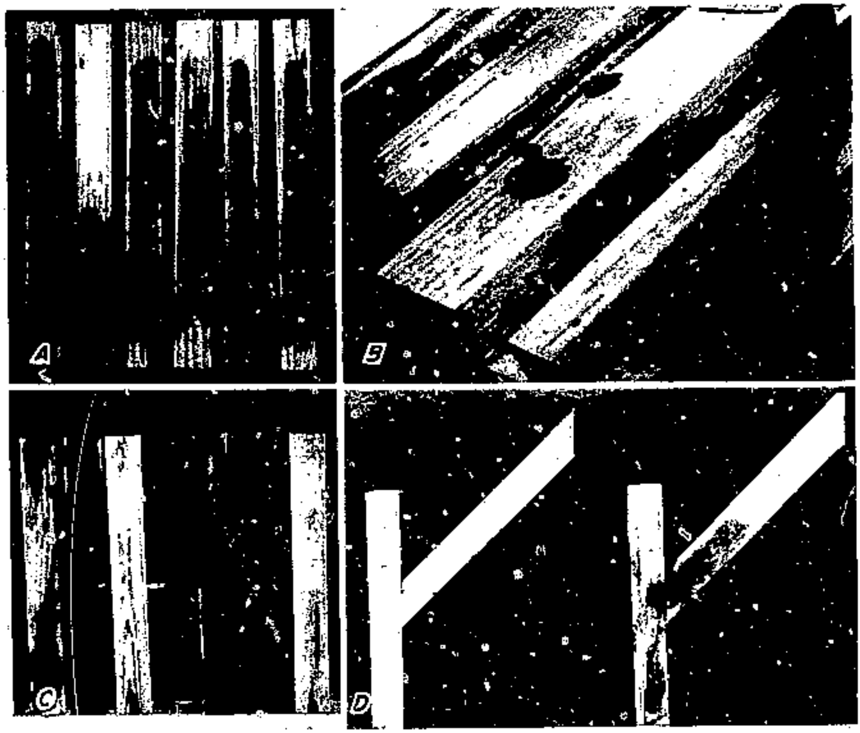


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FIGURE 4.—*A*, Weathering units split after 7.5 years to reveal internal decay in samples given 5-second or 3-minute dips in 5-percent pentachlorophenol. *B*, *Lenzites saepiaria* fruiting on the surface of a treated sample, indicating considerable interior rot. *C*, Decay in a column test revealed by splitting samples after 8 years' exposure. In each group of three the left sample was given a 30-minute soak in 0.2-percent phenyl mercuric oleate, the center piece was untreated, and the right piece was soaked for 30 minutes in 5-percent pentachlorophenol. *D*, Rail units after 4 years' exposure. The right unit was untreated; the left unit was soaked for 30 minutes in 5-percent pentachlorophenol.

TOXICANTS

The effectiveness of a preservative depends not only on its toxicity and endurance but also on the amount that enters the wood and the distribution within the wood. The amount that enters the wood depends on the volume of solution retained during treatment and the concentration of the solution. The severity of the exposure and the organisms present may affect length of service. Therefore, this discussion refers only to wood given dip and short-period soaks and exposed under the conditions of these studies.

Effectiveness under high hazard (*table 15*).—The ammunition boxes in uncovered, closely stacked, outdoor piles (fig. 5) were exposed to a high decay hazard. After 10.6 years' exposure the only 3-minute dips that had not failed when used on unpainted boxes were 5.0-percent copper pentachlorophenate alone or with water repellent and 10-percent tetrachlorophenol with water repellent. However, the following had high effectiveness ratings:

- Copper naphthenate, 1.0 percent Cu when used alone, but not when used with water repellent.
- Copper naphthenate, 2.0 percent Cu alone or with water repellent.
- Copper pentachlorophenate, 2.5 and 5.0 percent alone or with water repellent.
- Pentachlorophenol, 10 percent alone or with water repellent.
- Tetrachlorophenol, 5.0 and 10.0 percent alone or with water repellent.
- Sodium pentachlorophenate, 5.7 and 11.4 percent alone or with water repellent.

In general, the average service life increased with increased concentration of the treating solution. In the box study the toxicants were at concentrations usually recommended and at half and double those recommended. No usual concentration has been set for copper pentachlorophenate, but this was the only phenol or phenate outstanding at 5-percent concentration. The other chemicals required double concentrations for high effectiveness.

The following treatments were inferior, giving average service lives of less than 10 years:

- Copper 3-phenyl salicylate, 1.25, 2.5, and 5.0 percent.
- Copper 8-quinolinolate, 0.15, 0.3, and 0.6 percent.
- Orthophenylphenol, 2.5, 5, and 10 percent.
- Zinc alkyl sulphonate, 2.8 and 5.7 percent.
- Copper ammonium fluoride, 5, 10, and 20 percent.
- Rosin amine-D acetate, 2.5, 5, and 10 percent.

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FIGURE 5.—*A*, Simulated boxes of sap gum after 6 months' exposure. Those given a 3-minute dip in 5-percent pentachlorophenol with a water repellent are free of decay; those left untreated are heavily decayed by *Polyporus versicolor*. *B*, Boxes after 3 years' exposure, from left to right: Untreated, 3-minute dip in 5-percent pentachlorophenol with a water repellent, and 3-minute dip in copper naphthenate (2 percent Cu).

Most treatments were intermediate between these two groups and performed satisfactorily at some concentrations. Even some chemicals listed as inferior were fairly satisfactory at some concentration, but these were not always the highest concentrations. Some of the variability may have been due to border effects, as where a treated unit was touching an untreated control, or to the uncontrolled and unknown variability among the commercial boxes.

TABLE 13.—*Effectiveness of preservative treatments in preventing decay of unpainted M–22 boxes under severe exposure for 10.6 years*

Treatment	Solution absorbed per cubic foot		Average service life [1]		Relative effectiveness [2]	
	Water repellent	No water repellent	Water repellent	No water repellent	Water repellent	No water repellent
Oil solutions, 3-minute dips:						
Copper naphthenate:	*Pounds*	*Pounds*	*Years*	*Years*		
0.5 percent Cu	1.0	----------	8.4	----------	2	----------
1.0 percent Cu	1.2	1.2	8.9	10.9	2	3
2.0 percent Cu	.9	1.1	10.7	10.4	3	3
Copper pentachlorophenate:						
2.5 percent	1.4	----------	10.7	----------	3	----------
5.0 percent	1.2	1.2	(25)	(33)	3	3
Copper 3-phenyl salicylate:						
1.25 percent	1.2	----------	8.2	----------	2	----------
2.5 percent	1.1	1.1	6.6	6.6	1	1
5.0 percent	1.2	1.1	9.1	8.7	2	2
Copper 8-quinolinolate:						
0.15 percent	.9	----------	8.2	----------	2	----------
0.3 percent	1.1	1.0	7.6	9.8	2	2
0.6 percent	1.2	1.0	7.4	7.5	1	1
0.3 percent + 0.5 percent gamma BHC	----------	.9	----------	4.7	----------	1
Orthophenylphenol:						
2.5 percent	.9	----------	6.6	----------	1	----------
5.0 percent	1.1	1.0	6.2	4.5	1	1
10.0 percent	1.0	1.1	7.1	4.7	1	1
Pentachlorophenol:						
2.5 percent	1.2	----------	8.9	----------	2	----------
5.0 percent	1.1	1.2	9.7	9.9	2	2
10.0 percent	1.3	1.3	10.4	11.3	3	3
5.0 percent + 0.5 percent gamma BHC	----------	1.1	----------	10.6	----------	3
Phenyl mercuric oleate:						
0.15 percent	1.0	----------	7.5	----------	1	----------
0.3 percent	.9	.9	8.2	10.2	2	2
0.6 percent	.9	.9	9.5	9.8	2	2
Rosin amine-D pentachlorophenate:						
2.75 percent	1.0	----------	8.6	----------	2	----------
5.5 percent	1.0	1.1	8.9	8.7	2	2
11.0 percent	1.0	1.0	8.7	11.5	2	3
Tetrachlorophenol:						
2.5 percent	1.1	----------	9.2	----------	2	----------
5.0 percent	1.0	1.1	10.0	10.0	3	3
10.0 percent	1.1	1.2	(33)	10.7	3	3
Zinc alkyl sulphonate:						
2.8 percent	1.0	----------	7.3	----------	1	----------
5.7 percent	1.0	----------	8.2	----------	2	----------
Zinc naphthenate:						
0.5 percent Zn	1.0	----------	8.2	----------	2	----------
1.0 percent Zn	1.0	1.0	8.8	7.3	2	1
2.0 percent Zn	1.0	1.0	9.1	10.2	2	3

See footnotes at end of table.

TABLE 15.—*Effectiveness of preservative treatments in preventing decay of unpainted M-22 boxes under severe exposure for 10.6 years*—Continued

Treatment	Solution absorbed per cubic foot		Average service life [1]		Relative effectiveness [2]	
	Water repellent	No water repellent	Water repellent	No water repellent	Water repellent	No water repellent
Water solutions, 3-minute dips:						
Copper ammonium fluoride:	*Pounds*	*Pounds*	*Years*	*Years*		
5.0 percent		1.6		7.1		1
10.0 percent	1.3	1.6	8.2	8.9	2	2
20.0 percent		1.6		7.5		1
Rosin amine-D acetate:						
2.5 percent		1.7		6.9		1
5.0 percent		1.7		7.3		1
10.0 percent		1.7		8.2		2
Sodium pentachlorophenate:						
2.85 percent		1.8		8.2		2
5.7 percent	1.7	1.9	10.4	11.2	3	3
11.4 percent		1.7		10.7		3
2.0 percent + borax, 3.0 percent	1.6	1.9	9.5	8.9	2	2
4.0 percent + borax, 4.0 percent		2.0		10.4		3
Sodium tetrachlorophenate:						
2.85 percent	1.7		8.9		2	
5.7 percent	1.7	1.7	10.8	10.2	3	3
Oil solutions, pressure treatment:						
Pentachlorophenol, 5.0 percent	5.5	5.8	(42)	(42)	3	3
Water solutions, pressure treatment:						
Copperized chromated zinc chloride		[3] .70		(0)		3
Tanalith		[3] .29		(22)		3
Celcure		[3] .52		(0)		3

[1] Time required for 60 percent of samples to fail. Figures in parentheses are percent of failure for treatments for which average service life is not determinable.

[2] Relative effectiveness scale:

1. Average service life less than 1.6 times that of untreated.
2. Average service life 1.6 to 2.0 times that of untreated.
3. Average service life more than 2.0 times that of untreated.

[3] Expressed as pounds of dry salt.

Effectiveness under moderate hazard.—The units under moderate hazard were fully exposed to rainwetting, but to promote drying between rains, the piles were made small enough so that each unit was exposed at the edge. The studies under this category varied as to toxicant, water repellents, painting, and length of immersion, each of which affects length of service.

Tables 16 and 17 show amounts of decay at the last reading of each test. The relative effectiveness of the treatments is shown in figures 6 and 7.

Each group in figures 6 and 7 was comparable as to wood, exposure, treating time, and the presence or absence of painting and water repellents. They therefore indicate relative effectiveness of the toxicants at the concentrations listed. On the basis of the data in these curves, phenyl mercuric oleate and zinc chloride appear unsuitable for surface treatments and will be given no further consideration. Five other toxicants warrant comment:

Copper naphthenate.—When the studies were started, 0.5-percent Cu was the commonly recommended concentration for this chemical, but it proved inadequate even when applied as a long soak that gave an absorption or 4 pounds per cubic foot. At 2-percent Cu, copper

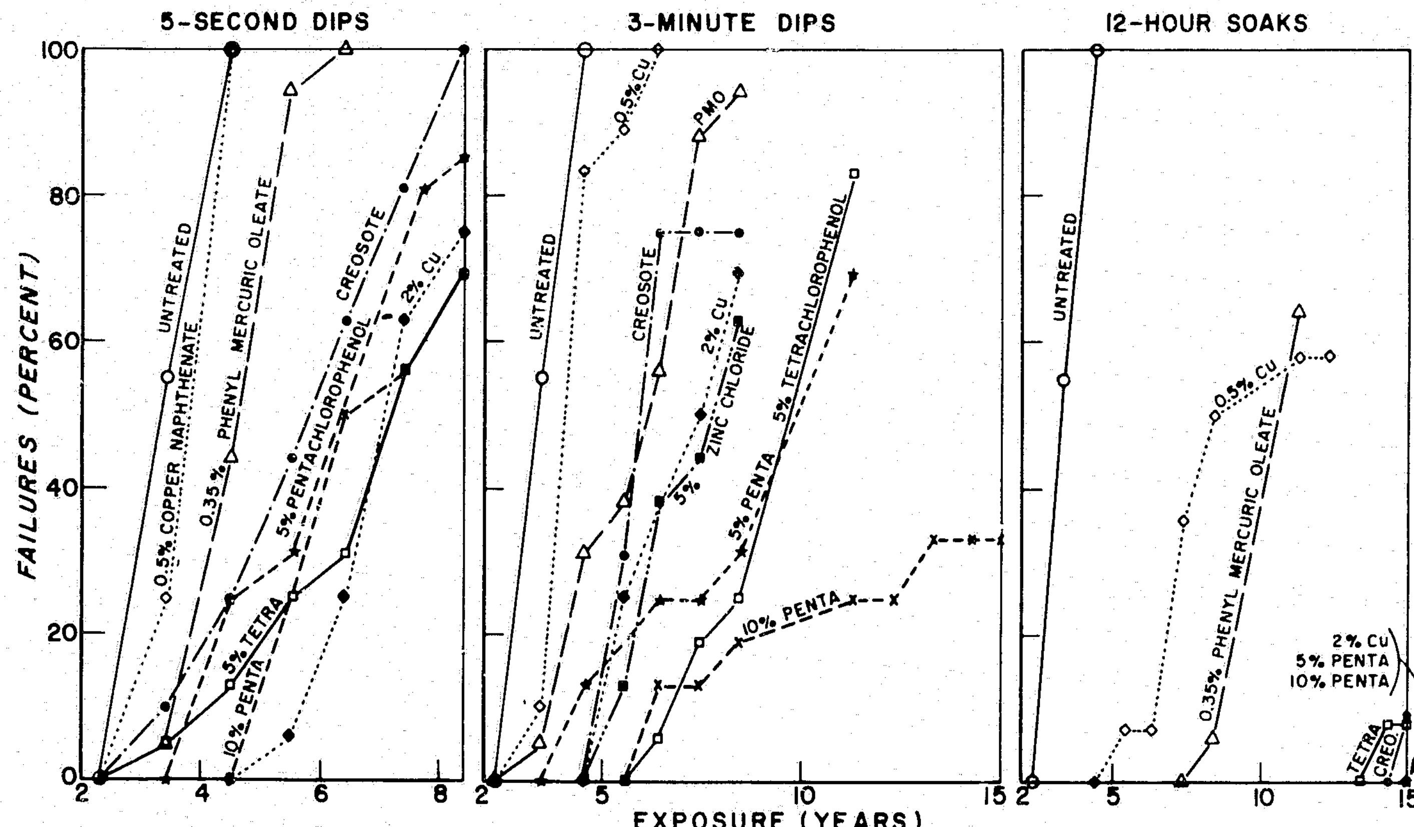

FIGURE 6.—Effectiveness of toxicants in preventing decay in unpainted weathering units.

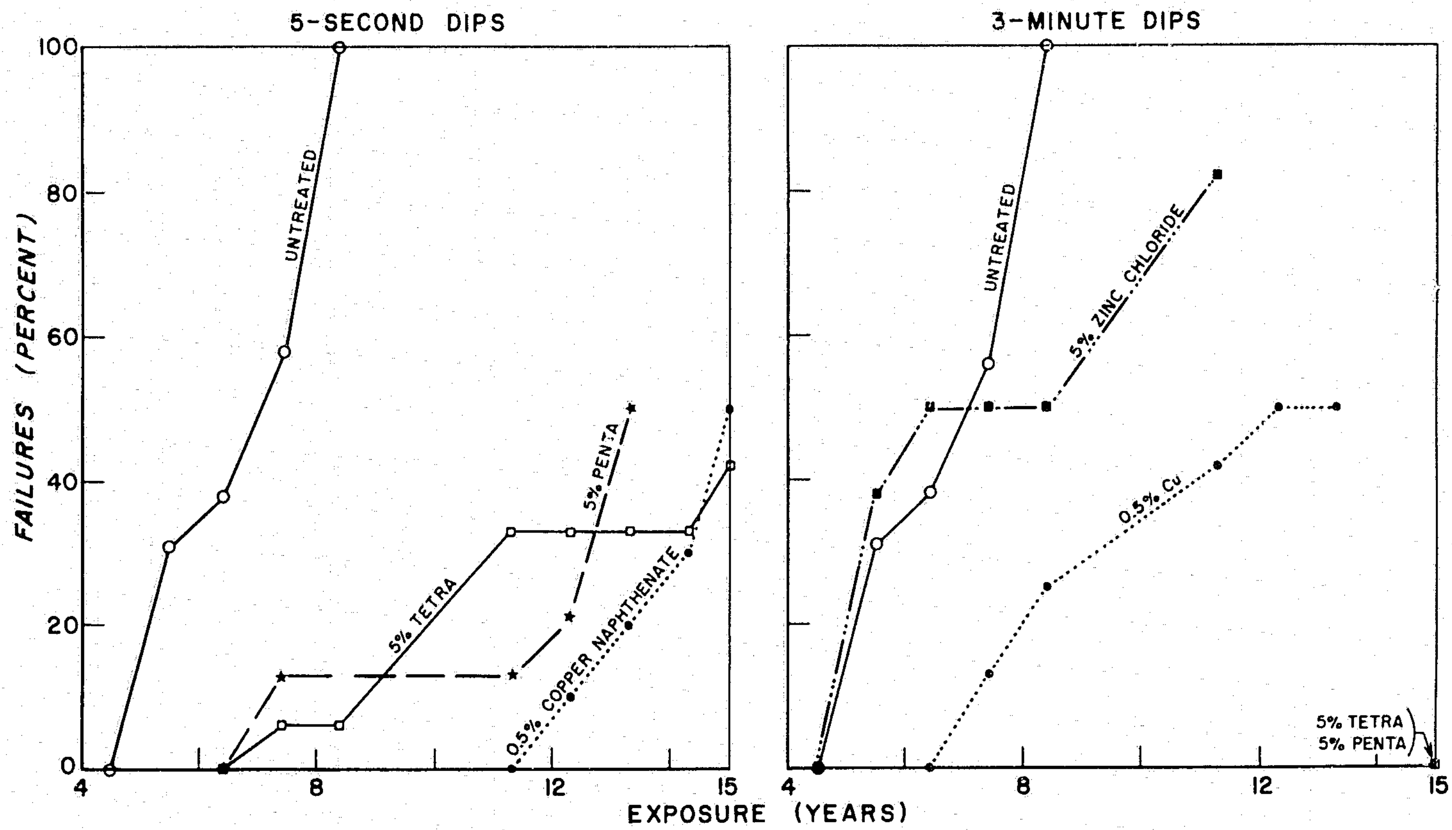

FIGURE 7.—Effectiveness of toxicants in preventing decay in painted weathering units.

naphthenate was satisfactory. Under high-hazard conditions (table 15), 1.0-percent Cu gave protection as good as that obtained with 5-percent pentachlorophenol.

TABLE 16.—*Effectiveness of brush, dip, and soak treatments with oil-carried preservatives in preventing decay of pine sapwood exposed off the ground but subject to rain seepage at joints*

Type of test, preservative, and length of exposure	Condition of lumber when treated	Painted after treatment	Solution absorbed per cu. ft.	Average decay rating [1]	Proportion failed [2]	Average service life [3]
Rail test 1. 20.1 years' exposure:	Kiln-dried, bright.					
5-percent pentachlorophenol in kerosene:			*Pounds*		*Percent*	*Years*
15-minute soak		Yes	1.52	4	0	
30-minute soak		Yes	1.57	2	0	
60-minute soak		Yes	1.79	2	0	
Untreated		Yes		100	100	6.4
Rail test 2. 18.3 years' exposure:	Air-dried, 5 percent stain.					
5-percent pentachlorophenol in kerosene:						
30-minute soak		Yes	([4])	0	0	
2 brush coats		Yes	([4])	31	33	
30-minute soak		Yes	([4])	32	25	
2 brush coats		Yes	([4])	38	44	
Untreated		Yes		100	100	5.8
Do		No		100	100	2.8
Rail test 3. 13.9 years' exposure:	Partially kiln-dried, 6 percent stain.					
5-percent pentachlorophenol in mineral spirits:						
3-minute dip		Yes	([4])	0	0	
End dip+side brush		Yes		15	25	
5-percent pentachlorophenol+water repellent in mineral spirits:						
3-minute dip		Yes	([4])	12	20	
End dip+side brush		Yes	([4])	16	25	
Untreated		Yes		97	100	4.0
Column test 1. 19.0 years' exposure:	Air-dried, 8 percent stain.					
5-percent pentachlorophenol in kerosene, 30-minute soak.		Yes	([4])	52	0	
5-percent pentachlorophenol+water repellent in mineral spirits, 30-minute soak		Yes	([4])	54	0	
Untreated		Yes		100	100	10.6
Do		No		100	100	8.2
Column test 2. 19.8 years' exposure:	Probably kiln-dried, bright.					
5-percent pentachlorophenol in kerosene, 30-minute soak		Yes	1.49	[5] 48	0	
0.2-percent phenyl mercuric oleate in kerosene, 30-minute soak.		Yes	1.25	100	100	16.4
Untreated		Yes		100	100	8.9
Shutter test. 19.0 years' exposure:	Kiln-dried, bright.					
5-percent pentachlorophenol in kerosene:						
30-minute soak		Yes	2.30	0	0	
60-minute soak		Yes	2.54	0	0	
Untreated		Yes		96	98	7.0

See footnotes at end of table.

TABLE 16.—*Effectiveness of brush, dip, and soak treatments with oil-carried preservatives in preventing decay of pine sapwood exposed off the ground but subject to rain seepage at joints*—Continued

Type of test, preservative, and length of exposure	Condition of lumber when treated	Painted after treatment	Solution absorbed per cu. ft.	Average decay rating [1]	Proportion failed [2]	Average service life [3]
Flooring test 1. 11.8 years' exposure:	Kiln-dried, trace of stain.					
5-percent pentachlorophenol in mineral spirits:			*Pounds*		*Percent*	*Years*
3-minute dip		Yes	1.48	44	0	
3-minute dip		No		62	14	
5-percent pentachlorophenol+water repellent in mineral spirits:						
3-minute dip		Yes	.88	42	7	
3-minute dip		No		66	28	
Untreated, plain joints		Yes		100	100	3.1
Flooring test 2. 12.8 years' exposure:	Air- and kiln-dried, 8 percent stain.					
5-percent pentachlorophenol in mineral spirits:						
3-minute full-length dip		Yes	2.30	54	21	
3-minute end dip		Yes		100	100	6.0
5-percent pentachlorophenol+water repellent in mineral spirits:						
3-minute full-length dip		Yes	1.51	68	28	
3-minute end dip		Yes		100	100	3.7
Untreated, leaded joints		Yes		100	100	6.0
Untreated, plain joints		Yes		100	100	2.9
Step test. 14.0 years' exposure:	Partially kiln-dried, no stain, light mold.[6]					
5-percent pentachlorophenol+water repellent in mineral spirits, 3-minute dip.		Yes	([4])	58	27	
Untreated		Yes		100	100	5.0
Do		No		100	100	4.5

[1] On a basis of 0 (none) to 100 (destroyed).
[2] Decay ratings of 80 or above.
[3] Time required for 60 percent of the samples to fail.
[4] Not determined.
[5] Decay limited to top 0.5 inch under the unpainted exposed end surface.
[6] Lumber was wetted by rain in transit and molded during redrying.

Copper 8-quinolinolate.—This material is not promising, but until further data are available its relative effectiveness will be uncertain. Because of low toxicity to humans, it is one of the few preservatives generally accepted for use in refrigerators and in other places close to foods.

Creosote (No. 1 AWPA).—Creosote indicated little promise as 5-second or 3-minute dips but gave good protection when applied as a 12-hour soak. Its odor, color, and lack of paintability limit its utility.

Pentachlorophenol.—At the usually recommended concentration of 5 percent, pentachlorophenol was in the highest protection class.

Tetrachlorophenol.—Except in mixtures with other chlorophenols, tetrachlorophenol is seldom used for millwork or construction lumber. At 5-percent concentration, it compared favorably with pentachlorophenol. Because of this and the ease with which it can be dissolved in the common petroleum oils, it warrants further consideration for dip and short-soak treatments.

TABLE 17.—*Effectiveness of dip and soak treatments on southern pine sapwood and heartwood weathering units after 15 years' exposure*

Solvent and chemical	Concentration	Solution absorbed per cubic foot			Average service life [1]					
					Unpainted			Painted		
		5-second dip	3-minute dip	Soak	5-second dip	3-minute dip	Soak	5-second dip	3-minute dip	Soak
Sapwood:										
Kerosene:	*Percent*	*Pounds*	*Pounds*	*Pounds*	*Years*	*Years*	*Years*	*Years*	*Years*	*Years*
Pentachlorophenol	5.0	0.7	1.2	4.2	6.7	11.0	(0)	13.8	(0)	(0)
Do	10.0	.7	1.2	4.7	7.5	(33)	(0)	------	------	------
Pentachlorophenol with water repellent	5.0	.7	1.2	4.7	12.8	15.1	(0)	------	------	------
Tetrachlorophenol	5.0	.9	1.2	3.9	7.5	10.7	(8)	(42)	(0)	(0)
Phenyl mercuric oleate	.35	.7	1.1	3.7	5.1	6.5	11.3	------	------	------
Copper naphthenate	.5 Cu	.8	1.1	4.1	4.5	4.6	13.0	15.3	13.0	(0)
Do	2.0 Cu	.7	1.1	6.4	7.3	8.0	(0)	------	------	------
Mineral spirits: Pentachlorophenol	5.0	------	1.4	------	------	7.4	------	------	------	------
No. 2 fuel oil: Pentachlorophenol	5.0	------	1.2	------	------	14.4	------	------	------	------
Water: Zinc chloride	5.0	------	1.2	------	------	8.2	------	------	9.2	------
No solvent:										
Coal-tar creosote	------	1.1	1.4	5.7	6.2	6.1	(8)	------	------	------
No chemical	------	------	------	------	------	4.0	------	------	7.2	------
Heartwood:										
Kerosene:										
Pentachlorophenol	5.0	------	.7	------	------	14.9	------	------	(0)	------
Copper naphthenate	.5 Cu	------	.5	------	------	12.4	------	------	(42)	------
No solvent:										
Coal-tar creosote	------	------	1.0	------	------	13.6	------	------	------	------
No chemical	------	------	------	------	------	7.0	------	------	6.4	------

[1] Time required for 60 percent of the samples to fail (i.e., have decay ratings of 80 or more). Figures in parentheses indicate percent of failures in the better treatments for which average service life has not been determined.

LENGTH OF IMMERSION AND DECAY RATE

Under the severe exposure of the ammunition box studies (*37*), there was little or no correlation between decay rate and immersion periods of 5 seconds to 10 minutes.

In the studies with simulated building structures, essentially no decay has occurred in units soaked for 15 minutes to 1 hour in 5-percent pentachlorophenol or copper naphthenate (1 to 2 percent Cu) and exposed for 8 to 20 years (table 16). Material given a 3-minute dip in the better preservative solutions has developed appreciable decay but will have an average service life of at least 7 to 15 years when exposed unpainted and well over 15 years when painted (fig. 8). Even the units given two brush coats of preservative and subsequently painted are more than 50-percent serviceable after 18 years.

Several comparisons were made in the weathering study (table 17). With creosote, phenyl mercuric oleate, and the lowest concentration of copper naphthenate, there was little difference in the effectiveness of 5-second and 3-minute dips in either the painted or unpainted series. Only when the treating time was raised to about 12 hours was ap-

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FIGURE 8.—*A*, Porch flooring after 5.5 years' exposure. The left seven boards were dipped for 3 minutes in 5-percent pentachlorophenol plus a water repellent; the next three were untreated; and the next seven were given a 3-minute end dip (7 inches) in the pentachlorophenol-water-repellent solution. *B*, Window shutters after 11.4 years' exposure: Left, untreated unit; right, unit soaked for 15 minutes in 5-percent pentachlorophenol.

preciable protection provided. With the better preservative solutions, the 3-minute dip was appreciably more effective than the 5-second dip—particularly when the samples were subsequently painted. In the unpainted series, the only 5-second dip affording good protection was 5-percent pentachlorophenol plus a water repellent. In the painted series, all three solutions used as 5-second dips gave good protection.

Thus, the degree of protection expected from different immersion periods depends on several variables: The severity of exposure, the presence or absence of a water repellent, and whether the wood is subsequently painted. In addition, the length of service desired will influence the kind of treatment needed.

WATER REPELLENTS

Water repellents probably are beneficial mainly because they reduce wetting. They also lessen surface checking (*22*) and possibly the loss of preservatives through volatilization. Both checking and volatilization are particularly serious with dip treatments which impregnate only a thin surface layer of wood. On the debit side, water repellents may lower decay protection by hindering absorption and penetration of the preservative.

Under the severe exposure of ammunition box storage, water repellents significantly reduced rainwetting for several months (*37*), but the boxes gradually became wet and then remained wet for long periods. The highly effective water repellent WR–7 had no consistent or important effect on the decay rate or average service life (table 18) of unpainted boxes.

The effect of a water repellent on the decay rate of treated wood was determined in seven studies under less severe conditions than in the ammunition box exposures.

In four of the studies in which the test samples were painted with an oil paint, the water repellent did not improve the performance of

5-percent pentachlorophenol (table 16). The treatments consisted of a 3-minute dip, a 30-minute soak, and a 3-minute end dip plus brush treatment of the lateral surfaces.

In the fifth study with painted units (table 19), water repellents reduced the decay rate of wood given a 3-minute dip in copper naphthenate, pentachlorophenol, and phenyl mercuric oleate.

For the sixth study, unpainted simulated boxes were exposed in smaller, more open piles than in the other box tests. The purpose was to hasten drying between rains (fig. 2*B*). The results are given in table 20. The two water repellents without a preservative increased the average service life of untreated wood from 5.0 years to

TABLE 18.—*Effect of water repellents in preservatives in preventing decay in unpainted ammunition boxes*

Toxicant, concentration, and type of treatment	Solution absorbed per cubic foot		Average service life [1]	
	Water repellent	No water repellent	Water repellent	No water repellent
Oil solutions, 3-minute dips:				
Copper naphthenate:	*Pounds*	*Pounds*	*Years*	*Years*
1 percent Cu	1.2	1.2	8.9	10.9
2 percent Cu	.9	1.1	10.7	10.4
Copper pentachlorophenate, 5 percent	1.2	1.2	(25)	(33)
Copper 3-phenyl salicylate:				
2.5 percent	1.1	1.1	6.6	6.6
5 percent	1.2	1.1	9.1	8.7
Copper 8-quinolinolate:				
0.3 percent	1.1	1.0	7.6	9.8
0.6 percent	1.2	1.0	7.4	7.5
Mineral spirits (aliphatic)	1.0	.9	7.3	4.7
Orthophenylphenol:				
5 percent	1.1	1.0	6.2	4.5
10 percent	1.0	1.1	7.1	4.7
Pentachlorophenol:				
5 percent	1.1	1.2	9.6	9.9
10 percent	1.3	1.3	10.4	11.3
Phenyl mercuric oleate:				
0.3 percent	.9	.9	8.2	10.2
0.6 percent	.9	.9	9.5	9.6
Rosin amine-D pentachlorophenate:				
5.5 percent	1.0	1.1	8.9	8.7
11.0 percent	1.0	1.0	8.7	11.5
Tetrachlorophenol:				
5 percent	1.0	1.1	10.0	10.0
10 percent	1.1	1.2	(33)	10.7
Zinc naphthenate:				
1 percent Zn	1.0	1.0	8.8	7.3
2 percent Zn	1.1	1.0	9.1	10.2
Water solutions, 3-minute dips:				
Copper ammonium fluoride, 10 percent	1.3	1.6	8.2	8.9
Sodium pentachlorophenate:				
5.7 percent	1.7	1.9	10.4	11.2
2.0 percent+borax, 2.0 percent	1.6	1.9	9.5	8.9
Sodium tetrachlorophenate, 5.7 percent	1.7	1.7	10.8	10.2
Oil solutions, pressure treatments:				
Pentachlorophenol, 5 percent	5.5	5.8	(42)	(42)

[1] Time required for 60 percent of the samples to fail (i.e., reach decay ratings of 80 or more). Figures in parentheses indicate percent of failure for the better treatments for which average service life has not been determined.

5.9 and 6.2 years. In 10 of the 14 comparisons, addition of a water repellent to the preservative slowed the rate of decay. This was true for the relatively ineffective preservatives—0.35-percent phenyl mercuric oleate, copper naphthenate (0.5 percent Cu), and 0.3-percent copper 8-quinolinolate—as well as for the better ones.

TABLE 19.—*Decay ratings*[1] *of pine rail units given a 3-minute dip and then painted*

Toxicant	6.5 years' exposure				8.5 years' exposure			
	No water repellent	With water repellent			No water repellent	With water repellent		
		WR-7	No. 1[2]	No. 2[2]		WR-7	No. 1[2]	No. 2[2]
Copper naphthenate:								
0.5 percent Cu	5	-------	0	0	27	-------	11	18
1.0 percent Cu	5	-------	0	0	17	-------	7	40
2.0 percent Cu	12	-------	0	0	20	-------	0	5
Pentachlorophenol, 5 percent	1	0	-------	-------	21	4	-------	-------
Phenyl mercuric oleate, 0.35 percent	(3)	-------	0	-------	18	-------	5	-------
Untreated	19	-------	-------	-------	52	-------	-------	-------

[1] On a scale of 0 (none) to 100 (destroyed). Each figure is an average for 5 rails plus 5 posts removed and dissected.

[2] Commercial repellents of undisclosed composition.

[3] Trace.

The addition of a water repellent significantly increased the service life of unpainted weathering units treated with 5-percent pentachlorophenol (table 17):

	5-second dip (years)	*3-minute dip (years)*	*Long soak*
Without water repellent	6.7	11.0	(1)
With water repellent	12.8	15.1	(1)

[1] No failures in 15 years.

In the other study with unpainted flooring units (table 16), the water repellent did not increase the effectiveness of 5-percent pentachlorophenol. Severe checking occurred even in the flooring with the water-repellent treatment.

Thus, on the basis of decay control alone, the added cost of a water repellent cannot be justified for wood under severe exposure—as ammunition boxes in tight, uncovered. outdoor piles in areas of high rainfall. However, water-repellent preservatives are recommended for ammunition packing boxes (*37*) on the assumption that most exposures, particularly in peacetime, are for short periods, as during transportation. Under these conditions the water repellent is highly effective in preventing rainwetting, and thus reducing the handling and shipping weight.

The simulated building units are subject to a lower decay hazard than is a pile of ammunition boxes, but to a greater hazard than for exterior woodwork of a well-designed building (*36*). In most studies with simulated building structures or exposure units with similar hazard, the water repellents significantly increased the efficacy of the preservatives when the units were left unpainted. Since this was true for the highly nonvolatile copper naphthenate as well as for the more volatile toxicants, the salutary effect probably was reduced surface checking or wetting. The lessened benefits when the treated wood was subsequently painted also suggest that reduced surface checking was a likely cause.

TABLE 20.—*Effect of water repellents on the decay rate of simulated boxes, pine sapwood, given 3-minute dips and exposed unpainted for 8 years*

Toxicants (applied as 3-minute dips)	Solution absorbed [1]				Proportion failed [2]				Average service life [3]			
	No water repellent	WR 1	WR 2	WR 3	No water repellent	WR 1	WR 2	WR 3	No water repellent	WR 1	WR 2	WR 3
	grams	*grams*	*grams*	*grams*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Yrs.*	*Yrs.*	*Yrs.*	*Yrs.*
Phenyl mercuric oleate, 0.35 percent	86	78	94	------	100	80	30	------	6.2	6.9	(4)	------
Pentachlorophenol, 5 percent	94	84	90	95	0	0	0	0	(4)	(4)	(4)	(4)
Copper naphthenate:												
0.5 percent Cu	84	------	84	83	100	------	20	40	5.7	------	(4)	(4)
1.0 percent Cu	82	------	86	91	60	------	0	0	8.9	------	(4)	(4)
2.0 percent Cu	87	------	85	106	0	------	0	0	(4)	------	(4)	(4)
Copper 8-quinolinolate, 0.3 percent	81	------	85	------	100	------	10	------	5.9	------	(4)	------
Copper 3-phenyl salicylate:												
5 percent	89	------	106	------	30	------	10	------	(4)	------	(4)	------
5 percent [5]	96	------	------	116	0	------	------	40	(4)	------	------	(4)
Untreated	0	84	90	------	100	100	100	------	5.0	5.9	6.2	------

[1] WR-1 was WR-7; WR-2 was a commercial concentrate; WR-3 included ready-to-use solutions of water-repellent preservatives.

[2] Samples with decay ratings of 80 or above.

[3] Time required for 60 percent of samples to fail.

[4] Average service life has not been determined for these treatments, but it exceeds 9 years.

[5] Commercial ready-to-use solutions.

Apparently the usefulness of a water repellent is inversely proportional to the severity under which the treated wood is exposed. Under the moderate to low decay hazard of most siding and exterior trim, a 3-minute dip in a water-repellent preservative is highly effective in preventing rainwetting (*38*). There is little doubt that the main effectiveness of the treatment arises from the repelling of rainwater and that the preservative is merely an added safety factor.

SUBSEQUENT PAINTING

Good maintenance of paint films often is advocated for the preservation of exterior woodwork. Paint reduces such weathering defects as grain raising and checking and prevents rain seepage into the painted surfaces. However, paint only temporarily seals joints (*38*)—eventually water will enter joints unless the wood is protected from rainwash. It is this rain seepage at joints that results in most decay of siding, trim, and other exposed woodwork. Moreover, once wood is wet, paint greatly retards drying, and thus, under some conditions, may increase the decay hazard. If the wood is treated with a preservative, paint may reduce the decay rate by preventing seasoning checks through which rain and fungi can penetrate the treated shell, and by reducing loss of the preservative by evaporation or solution in rainwater.

To determine the effect of painting, some untreated and treated samples were painted, and others were left unpainted. The results are summarized in tables 21 and 22.

Paint had no clearcut effect on the decay rate of untreated units—decay was less in four comparisons and more in two. None of the differences were marked.

Paint definitely enhanced the effectiveness of the preservative treatments. In 16 of the 18 comparisons with ammunition boxes (table 21), less decay occurred in painted boxes, though many of the differences were small in terms of average service life. Because the decay hazard was very severe, the results for 5.1 years are probably more applicable to exterior woodwork of houses than are the service lives based on longer exposures. Decay was first observed in the exposed tops of boxes. Unpainted boxes developed multiple seasoning checks through which water and decay fungi could penetrate into untreated wood; painted boxes were largely free of those checks after 5.1 years. In most cases the painted boxes had appreciably less decay at 5.1 years.

TABLE 21.—*Effect of two coats of paint, applied after treatment, on rate of decay of M–22 boxes*

Treatment (3-minute dips unless noted)	Proportion failed after 5.1 years [1]		Average service life [2]	
	Painted	Unpainted	Painted	Unpainted
Oil solutions:	*Percent*	*Percent*	*Years*	*Years*
Copper naphthenate (1.0 percent Cu)+water repellent	0	17	(33)	8.9
Copper 3-phenyl salicylate, 2.5 percent+water repellent	0	42	(33)	6.6
Copper 8-quinolinolate, 0.3 percent+water repellent	8	8	8.7	7.6
Mineral spirits (aliphatic), 100 percent	33	67	6.9	4.7
Orthophenylphenol, 5.0 percent+water repellent	8	75	9.1	6.2
Pentachlorophenol, 5.0 percent+water repellent	0	8	(33)	9.6
Phenyl mercuric oleate, 0.3 percent+water repellent	0	25	10.2	8.2
Product containing 23 percent zinc naphthenate, 2.5 percent (coco) dodecyl-amine salt of tetrachlorophenol, and 28.5 percent water repellent, 37.5 percent	17	25	8.9	7.3
Rosin amine-D pentachlorophenate, 5.5 percent plus water repellent	0	17	10.3	8.9
Zinc alkyl sulphonate, 5.7 percent+water repellent	8	33	10.0	8.2
Zinc naphthenate (1.0 percent Zn)+water repellent	8	17	8.8	8.8
Water repellent (10 percent solids)	8	46	9.7	7.3
Water solutions:				
Copper ammonium fluoride, 10.0 percent	0	17	10.6	8.9
Rosin amine-D acetate, 5.0 percent	25	17	7.5	7.3
Sodium pentachlorophenate, 5.7 percent	0	8	(33)	11.2
Sodium pentachlorophenate, 2.0 percent+borax, 3.0 percent	0	17	(25)	8.9
Sodium tetrachlorophenate, 5.7 percent	0	25	(17)	10.2
Oil solution: [3] Pentachlorophenol, 5 percent	0	8	(8)	(42)
Untreated	21	61	7.4	5.0

[1] Average decay ratings (scale 0 to 100) of 30 or more.

[2] Average service life is elapsed time at 60-percent failure. Figures in parentheses are percent of failure after 10.6 years for treatments in which average service life has not been determined.

[3] Pressure treatment.

With the simulated building units (table 22), painting usually greatly reduced the decay rate. Because most comparisons were for preservatives without water repellents, it is assumed that the salutary effect of the paint was not water exclusion but the maintenance of an unbroken shell of treated wood through which decay organisms could not penetrate.

TABLE 22.—*Effect of paint, applied after treatment, on the decay rate of southern pine test units*

Type of unit [1] and treatment	Extent of treatment	Length of exposure	Proportion failed [2]		Average service life [3]	
			Painted	Unpainted	Painted	Unpainted
		Years	*Percent*	*Percent*	*Years*	*Years*
Step rail, untreated	-	6.3	72	100	5.8	3.0
Column, untreated	-	10.3	67	100	10.0	8.2
Porch flooring:						
Pentachlorophenol, 5.0 percent	3-min. dip	11.6	0	14	-	-
Pentachlorophenol with water repellent	3-min. dip	11.6	7	28	-	-
Step, untreated	-	5.0	79	71	4.5	5.0
Weathering: Sapwood:						
Pentachlorophenol, 5.0 percent	5-sec. dip	15.0	100	100	13.8	6.7
	3-min. dip	15.0	0	100	-	11.0
	3 to 4 lb./cu. ft.	15.0	0	0	-	-
Tetrachlorophenol, 5.0 percent	5-sec. dip	15.0	42	100	-	7.5
	3-min. dip	15.0	0	100	-	10.7
	3 to 4 lb./cu. ft.	15.0	0	8	-	-
Copper naphthenate, 0.5 percent Cu	5-sec. dip	15.0	50	100	15.3	4.5
	3-min. dip	15.0	[4] 50	100	13.0	4.8
	3 to 4 lb./cu. ft.	15.0	0	[4] 58	-	13.0
Zinc chloride, 5.0 percent	3-min. dip	15.0	[4] 92	[4] 63	9.2	8.2
Untreated	-	15.0	100	100	7.2	4.0
Weathering: Heartwood:						
Pentachlorophenol, 5.0 percent	3-min. dip	15.0	0	[4] 50	-	14.9
Copper naphthenate, 0.5 percent Cu	3-min. dip	15.0	42	[4] 58	-	12.4
Untreated	-	15.0	100	100	0,4	7.0
Simulated boxes:						
Pentachlorophenol, 5.0 percent	3-min. dip	4.6	0	0	-	-
Copper naphthenate, 0.6 percent Cu	3-min. dip	4.6	0	50	-	5.6
1.0 percent Cu	3-min. dip	4.6	0	0	-	-
Copper 8-quinolinolate, 0.18 percent	3-min. dip	4.6	50	70	4.9	3.5
0.3 percent	3-min. dip	4.6	50	60	4.8	4.6

[1] Sapwood unless otherwise specified.
[2] Unit was considered a failure when its decay rating was 80 or more.
[3] Time required for 60 percent of samples to fail.
[4] Ratings made and samples removed before the end of the exposure period.

The results leave little doubt that the effectiveness of dip treatments is enhanced by the subsequent painting of the treated wood. Previous studies (*38*) showed that siding given a 3-minute dip in a water-repellent preservative and then painted after attachment is particularly resistant to rainwetting and fungus attack.

TYPE OF OIL CARRIER

In soil burial tests Blew (*4*) found that, with solution retentions of approximately 4 pounds per cubic foot, pentachlorophenol was somewhat less effective in Stoddard solvent than in No. 2 fuel oil.

The difference can be explained largely by the toxicities of the oils alone; the average service life was 2.2 years for stakes treated with Stoddard solvent, 4.4 years for those treated with No. 2 fuel oil, and 2.2 years for untreated stakes. Some heavier oils gave an average service life up to 6.7 years and furnished correspondingly better pentachlorophenol solutions. In test stakes (*2*), appreciably more pentachlorophenol was lost when treatment was with a mineral spirits solution than with kerosene or No. 2 fuel oil solutions. Differences in viscosity may affect distribution of the preservative in the wood. With the lighter oils, as mineral spirits, blooming or concentrating of the toxicant near the surface may increase volatilization.

In laboratory soil block tests, Duncan (*11*) found that the effectiveness of pentachlorophenol and copper naphthenate varied with the petroleum oil used. The lower the boiling point, the higher the retentions needed to prevent decay.

Three studies were established to secure information on how the type of oil carrier affects results from preservatives applied as dips to units exposed above ground and subject to rain seepage. Three petroleum oils were used: Aliphatic mineral spirits, stove-grade kerosene, and No. 2 fuel oil. The last oil probably is heavier than any oil likely to be used on wood to be painted. All solutions were prepared with equal weights of toxicant (as a 10-to-1 concentrate) per volume of solvent, so the stated percentage concentrations are only nominal.

In the first study, weathering units were dipped for 3 minutes in 5-percent pentachlorophenol and exposed unpainted. The results were:

Carrier oil	*Absorption per cubic feet (pounds)*	*Average service life (years)*
Mineral spirits	1.18	7.8
Kerosene	1.27	11.0
No. 2 fuel oil	1.16	14.4

For the second study, simulated boxes were dipped for 3 minutes in solutions of four toxicants in mineral spirits and No. 2 fuel oil.

The units were exposed unpainted, and were stacked so they would become and stay waterlogged. Therefore, the results (table 23) probably are not typical of building exposures. The data, however, suggest that weight of oil may affect toxicants other than pentachlorophenol.

OIL vs. WATER CARRIERS

Four toxicants normally applied as oil solutions were tested with water as the carrier. These were the sodium salts of tetra- and pentachlorophenols, ammoniacal solutions of copper naphthenate, and an emulsion of copper 8-quinolinolate.

In the main box tests, 5.7 percent solutions of the sodium salts of pentachlorophenol and tetrachlorophenol were slightly more effective than 5 percent of the corresponding phenol in oil (table 15). In two studies with simulated boxes, water and oil solutions of 5-percent pentachlorophenol applied as 3-minute dips were about equal. The percentages of units that failed were:

	Study 1, After 8 years (percent)	*Study 2, After 3.8 years (percent)*
5-percent pentachlorophenol in oil	22	0
5- and 5.7-percent sodium pentachlorophenate in water.	20	10

TABLE 23.—*Decay in unpainted simulated boxes after 4.5 years*

Toxicant	Absorption per cubic foot		Average decay rating [1]		Proportion failed [2]	
	Mineral spirits	Fuel oil	Mineral spirits	Fuel oil	Mineral spirits	Fuel oil
	Pounds	*Pounds*			*Percent*	*Percent*
Copper naphthenate, 1 percent Cu	1.8	2.1	44	36	0	0
Copper 8-quinolinolate, 0.3 percent	1.6	1.8	68	52	20	0
Orthophenylphenol, 5 percent	1.9	2.2	72	62	60	20
Pentachlorophenol, 5 percent	2.0	1.9	46	46	0	0

[1] 0 (none) to 100 (destroyed).
[2] Decay ratings of 80 or above.

Copper naphthenate, applied as a 3-minute dip to 1- by 8- by 12-inch pine sapwood boards, was slightly more effective in ammoniacal water solution than in mineral spirits during 3 years' exposure:

	Copper content (percent)	*Solution absorbed per sample (grams)*	*Average decay rating* [1]	*Proportion failed (percent)*
Oil	4	23.9	22	0
Water	4	22.4	10	0
Oil	2	21.9	44	0
Water	2	21.9	36	0

[1] 0 (none) to 100 (destroyed).

In another study simulated boxes given 3-minute dips in 0.3-percent copper 8-quinolinolate in mineral spirits and in water emulsion decayed at the same rate; they also had the same average service life of 4.8 years.

These studies do not establish the usefulness of water-carried forms of the preservatives now generally applied in oil solution. However, they do suggest that the cheaper water-carried forms have sufficient promise to warrant further trial.

PRIOR FUNGUS INFECTIONS

As already shown, fungus infections have a profound effect on the treatability of wood. At comparable moisture contents, both penetrations and absorptions are greater in infected wood; the amount of the increase depends on the type and intensity of the infection. This does not mean, however, that infected wood is necessarily more treatable. If, during pretreatment seasoning, the infected wood is exposed to rain, it may absorb more water than uninfected wood and become markedly less treatable. Fungus infections probably cause much of the variability in commercial treatment (*19*).

The most conspicuous infections in lumber prior to treatment are stains and molds which have little effect on strength (*28*). But less obvious incipient decay infections often accompany moderate to heavy staining. Many of the common decay fungi remain viable but dormant for years in dry wood and revive when the wood is rewetted (*27*). Revival can occur beneath the thin treated shell of wood given dips or short-period soaks unless the infection is such that deep penetration of the preservative results.

Infections prior to attachment are an important cause of rapid deterioration of wood siding (*38*). In one study 10 matched pairs of kiln-dried pine columns were drilled to receive pine dowels 1¼ inches long and five-eighths inch in diameter. The dowels were at the lower ends of the columns, i.e., those nailed to the exposure sills. In each pair one dowel was sterile and the other had incipient dormant infection of the decayer *Lenzites saepiaria.* After 3 years' exposure the average decay rating was 59 with infected dowels and 30 with sterile dowels. The difference, 29.0 ±6.40, is highly significant.

Studies of the durability of treated infected wood are confounded by the increased decay rate and the increased treatability of infected wood—both of which are influenced by the type and degree of infection.

Half the samples of 1- by 8- by 12-inch green pine sapwood boards for one study were dipped in 4-percent sodium fluoride and wrapped in waterproof paper for 3 weeks to insure a heavy growth of the mold *Trichoderma viride* (*19*). The molded wood was then air-dried to 12-percent moisture. Matched samples were dipped in an antistain solution and quickly air-dried to 12 percent. No visible fungus attack occurred. After receiving a 3-minute dip treatment, all samples were exposed on edge on a treated sill.

Luxuriant growth of *Trichoderma* reduced the initial rate of decay, possibly by competition or the production of an antibiotic. This effect had almost disappeared in 6.3 years. The heavily treated molded wood remained free of visible decay, while appreciable amounts developed in treated samples of the originally uninfected wood (table 24). The molded and unmolded treated wood absorbed the same amounts of rainwater during the first 6 months' exposure (*37*).

TABLE 24.—*Effect of mold infections on the rate of decay of treated and untreated pine sapwood*

Treatment [1]	Preservative solution absorbed per cubic foot	Average decay rating [2]		Proportion of failure [3]	
		3.3 years	6.3 years	3.3 years	6.3 years
Molded wood:	*Pounds*			*Percent*	*Percent*
Copper naphthenate	8.0	0	0	0	0
Pentachlorophenol	9.3	0	0	0	0
Untreated		68	88	0	100
Uninfected wood:					
Copper naphthenate	1.6	0	26	0	0
Pentachlorophenol	1.8	4	28	0	0
Untreated		80	96	70	100

[1] Three-minute dips in copper naphthenate (2 percent Cu) with water repellent and in 5 percent pentachlorophenol with water repellent.

[2] 0 (none) to 100 (destroyed).

[3] Unit was considered a failure when its decay rating was 80 or more.

In another study the lumber was cut from one longleaf pine log. Part of the lumber was given an antistain treatment, and part was air-seasoned without fungicidal treatment, to permit the development of stain, mold, and decay fungi. Half the lumber was air-dried to an average moisture content of 40 percent and half to 14 percent. Moderate amounts of stain and mold, and presumably incipient decay, developed during seasoning on the wood not treated with an antistain solution. The treated groups remained free of visible infections.

The boxes made from the lumber were exposed unpainted after being given a 3-minute dip in 4-percent sodium pentachlorophenate with 4-percent borax or in 5-percent pentachlorophenol with a water repellent and exposed unpainted.

The multiple-species infection did not have a marked effect on absorptions of solution (table 25).

The rates of decay of the different groups of boxes are shown in figure 9.

The infected samples decayed faster whether treated or untreated. The differences were small, however, except in the partially dried boxes left untreated or treated with the oil solution. After 4.3 years, even these differences had largely disappeared. Under less severe exposure, e.g., siding on a house, larger and more persistent differences would be expected.

Thus, infected wood, if thoroughly dried, probably can be dipped and used where uninfected, dip-treated wood is adequate. However, infected wood may absorb an excess of treating solution, thus increasing the cost of treatment and creating a serious risk that the carrier will bleed through subsequently applied paint. The present informa-

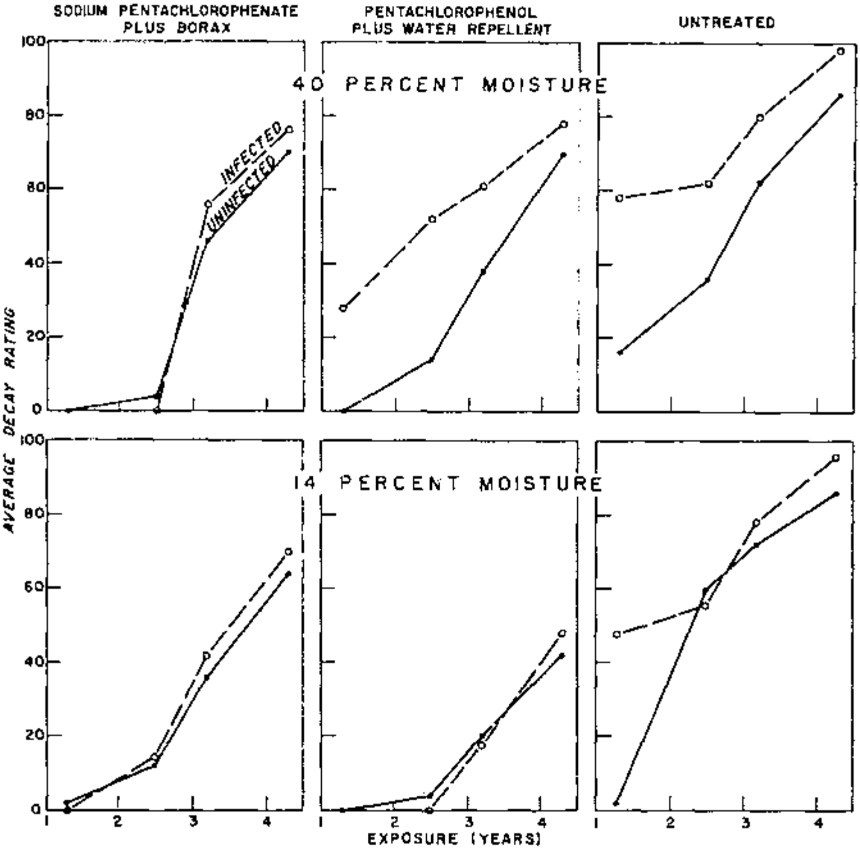

FIGURE 9.—Decay rates of infected and uninfected simulated boxes dried to 40-percent and 14-percent moisture before being given a 3-minute dip.

tion suggests that it is safer to use bright uninfected lumber, even if it is to be treated, and that if infections are obvious the need for treatment is greater.

TABLE 25.—*Absorptions of preservatives by simulated pine boxes*

Condition of wood	Absorption per cubic foot	
	4 percent sodium pentachlorophenate + 4 percent borax	5 percent pentachlorophenol + water repellent [1]
Partially dried:	*Pounds*	*Pounds*
Uninfected	1.5	1.6
Infected	1.7	2.1
Fully dried:		
Uninfected	1.9	2.3
Infected	2.1	2.6

[1] W R-7.

WOOD MOISTURE CONTENT

With short-period soaks, absorption and penetration of preservatives are inversely proportional to wood moisture content, both above and below fiber saturation. The effect is minor within the normal moisture range of lumber used for exterior woodwork, i.e., 9 to 14 percent. Nevertheless, two studies were made to determine the effects of moisture content on decay rate.

TABLE 26.—*Effect of wood moisture content prior to treatment on the amount of decay of M-22 boxes given 3-minute dips and exposed for 7.5 years*

Treatment	Moisture content		Absorption of preservative		Amount of decay	
	Range	Average	Range	Average	Average decay rating [1]	Proportion of failure [2]
Pentachlorophenol, 5 percent, + water repellent:						
Boxes soaked:	*Percent*	*Percent*	*Grams*	*Grams*		*Percent*
Dried 15 minutes	[3] 41–45	43	−40–+20	2	70	40
Dried 1 day	36–40	38	40–100	69	58	20
Dried 2 days	31–39	36	60–120	88	54	10
Boxes not soaked	13–15	14	40–117	74	52	10
Sodium pentachlorophenate, 4 percent, + borax, 4 percent:						
Boxes soaked:						
Dried 15 minutes	[3] 39–42	41	30–50	36	54	20
Dried 1 day	34–42	37	80–140	99	54	0
Dried 2 days	32–36	36	80–140	112	56	20
Boxes not soaked	13–15	14	188–224	199	54	0
Untreated boxes	13–15	14			86	80

[1] 0 (none) to 100 (destroyed).
[2] A unit was considered a failure when its decay ratings were 80 or more.
[3] The surface layers were saturated.

In the first study, air-dry M–22 ammunition boxes were soaked for 48 hours in water to create a moisture gradient similar to that occurring with rainwetting of lumber, i.e., with the highest moisture contents on the outside. Fifteen minutes after they were removed from the water, 10 boxes were dipped for 3 minutes in a water preservative and 10 in an oil preservative. Other lots were treated after 1 and 2 days of drying and at the original air-dry moisture content. Information on treatment and rate of decay is given in table 26.

The measured absorptions for the fully wet boxes are not considered accurate. Undoubtedly the wood lost water during treatment. Also, with the water solution a further uncertainty results from the unknown amount of phenate and borax diffusing from the solution into the water within the wood.

There were no significant differences in decay among the moisture categories with the wood treated with the 4-percent water solution of sodium pentachlorophenate plus 4-percent borax. In contrast, the wet and partially dried boxes dipped in 5-percent pentachlorophenol plus a water repellent in mineral spirits developed significantly more decay than did those at lower moisture categories.

For the second study, simulated boxes were made from green pine sapwood which had been dipped in an antistain chemical. Four matched groups consisted of boxes that were fully green, partially air-dried, fully air-dried, and kiln-dried before treatment with water- and oil-borne preservatives. The partial air-drying created a moisture gradient with the highest moisture content on the inside of the wood. The antistain treatment prevented fungus development during seasoning.

The absorptions of treating solutions varied inversely with the moisture contents (110, 40, 14, and 9 percent). For the water solution they were 0.7, 1.5, 1.9, and 2.1 pounds per cubic foot, and for the oil solution, 0.4, 1.6, 2.6, and 2.1 pounds.

The amount of decay in the wood dipped in the water solution generally decreased with the increases in absorption as influenced by the moisture content of the wood (fig. 10). None of the differences, however, are considered of practical magnitude. The relationships were the same for the oil-treated wood, but the increased amounts of decay in the green and partially seasoned wood probably are significant from a practical point of view.

The second study also included some boxes that were fully and partially air-seasoned without antistain treatment; thus, stain, mold, and incipient decay were permitted to develop during seasoning. The absorptions of water solution were 1.7 and 2.1 pounds per cubic foot by the partially and fully seasoned boxes, respectively, and of the oil solution 2.1 pounds per cubic foot by both groups of boxes.

The relationships (fig. 10) were essentially the same as with the corresponding uninfected boxes. The decay rate differed only slightly between the partially and full air-seasoned wood treated with the water solution. For the boxes dipped in the oil solution, however, significantly less decay developed in those fully air-seasoned than in those partially seasoned.

These data support the penetration and absorption studies in suggesting that wood should be fully air-seasoned or kiln-dried before it is given a simple preservation treatment.

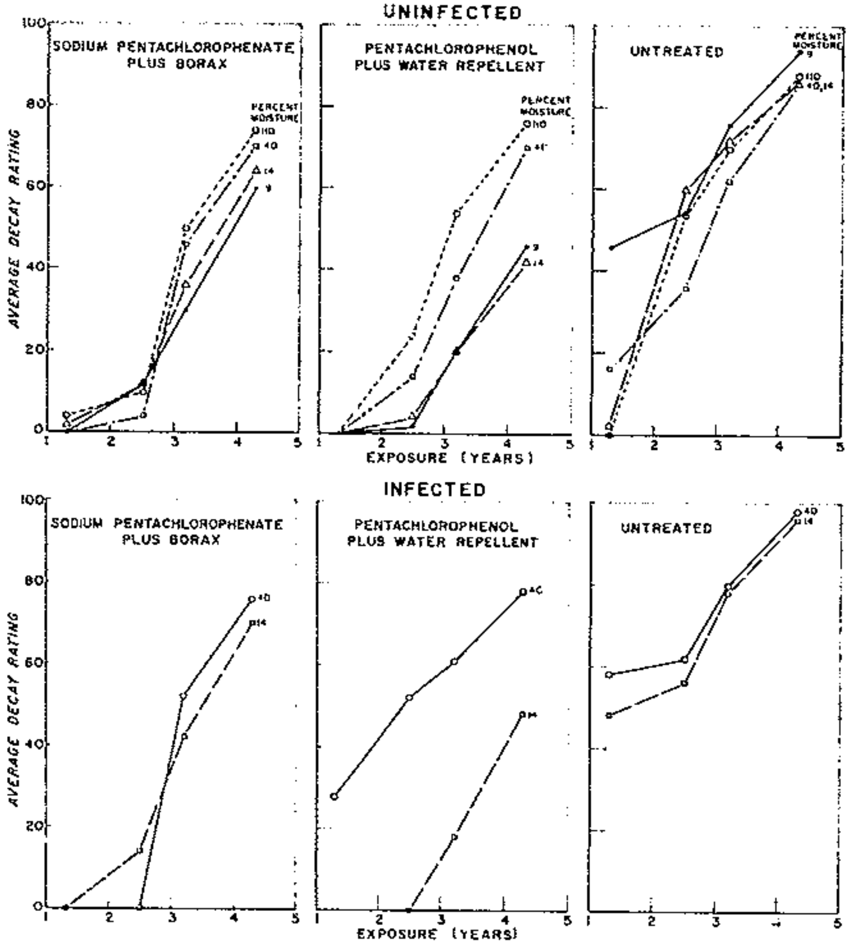

FIGURE 10.—The influence of moisture content at time of treatment on decay rate of uninfected and infected simulated boxes dipped for 3 minutes.

WOOD SPECIES

In the studies of simulated building units here reported, southern yellow pine was the only test wood. A study in progress includes step-rail units of western hemlock, ponderosa pine, Douglas-fir, white fir, and southern yellow pine given a 3-minute dip in 5-percent pentachlorophenol. In addition, porch-flooring units made of western hemlock, ponderosa pine, Douglas-fir, white fir, and southern pine were dipped for 3 minutes in 5-percent pentachlorophenol. Panels of a few wood species were also dipped in copper naphthenate (1 percent Cu) or 5-percent pentachlorophenol plus a water repellent. After 7 years' exposure, only slight differences in decay rate were noted among the treated units of different woods (*29*).

The units in the ammunition box study (*37*) were mainly of eastern white pine. A few southern pine sapwood boxes given 3-minute dips in 5-percent pentachlorophenol with a water repellent decayed somewhat faster during the first 4.2 years than the white pine boxes similarly treated. However, later observations showed approximately the same average service lives, 9.7 years for the white pine boxes and 11.3 years for the southern pine boxes.

Simulated boxes made of eight wood species were dipped for 3 minutes in 5-percent pentachlorophenol with a water repellent. The only important differences were the lower decay rate of the Douglas-fir boxes and the higher decay rate of southern hardwood boxes compared with the rates for southern pine, eastern white pine, ponderosa pine, and western hemlock (*37*).

The data strongly suggest that surface treatments are effective on the coniferous woods commonly used for general building.

SUMMARY AND RECOMMENDATIONS

Even the best preservative will be only as effective as the amount penetrating the wood in relation to the severity of exposure. Brush, dip, and short-period soaks give only limited penetrations; therefore, they offer good protection only under low to moderate hazards. Users of simple treatments should take full advantage of the factors which increase penetration and absorption of the preservative and decrease the decay hazard of the structure in which the treated wood will be used. Of the many factors known to influence treatment effectiveness, the following have practical application:

1. The wood should be fully seasoned to the average moisture content recommended for use in buildings (12 percent or below, depending on geographic region) because penetration and absorption vary inversely with wood moisture content.

2. Because longitudinal penetration is greater than lateral penetration, the best protection will be afforded items on which the decay hazard is mainly at the ends of lumber. A porch column is a good example—decay usually is restricted to the base.

3. Lumber should be relatively free of stain, mold, and decay infections. If it is not, decay may develop in the untreated interiors. Also, infected boards may absorb sufficient solution to lead to objectionable discoloration when the wood is painted. For some uses outside the scope of this bulletin, for example, fenceposts, moderate infections by stain and mold are not detrimental provided the penetrations are sufficient to kill the fungi present.

4. The temperature of the treating solution should be at least as low as that of the wood to be dipped. Dipping in artificially heated solutions or after a rapid rise in air temperature may materially reduce penetrations and absorptions of the low-viscosity solutions used in treating finish lumber.

5. Even though water repellents somewhat reduce both penetration and absorption, their overall effect is beneficial. They definitely reduce the decay hazard of exterior woodwork and also reduce other troubles from rain seepage. Water repellents should be incorporated in solutions for treating siding, millwork, and other wood exposed on the exterior of buildings.

6. Painting, with the usual oil paints, of wood which has been treated by brush, dip, and soak methods will appreciably increase the average service life.

7. If the treated wood is to be used unpainted, a No. 2 fuel oil or one even heavier will enhance effectiveness. If good paintability is desired, a lightweight proven solvent of the aliphatic mineral-spirits type should be used. No oil treating solution will always yield paintable treated wood. Even with a 3-minute dip, an occasional board will absorb excessive oil, which will bleed through subsequently applied paint unless an unusually long drying time is provided. With the normal absorptions by short-period dips, treated wood can be painted safely after 24 to 48 hours of drying. Pieces with obviously high absorptions should be separated for special drying or for use in places where paint discoloration is unimportant.

8. Brush and 3-minute or shorter dip treatments will afford good protection in buildings designed to avoid the worst decay hazards. Good designs provide adequate roof overhang, gutters, and other features that restrict the amount of rainwetting and promote rapid drying when wetting does occur. Where such a design is not possible, soaks of 30 minutes or longer or preferably the use of commercially impregnated lumber is recommended.

9. Pentachlorophenol and copper naphthenate in the water-repellent solution covered by Federal Specification TT–W–572 are highly effective. In addition, copper pentachlorophenate, tetrachlorophenol, sodium pentachlorophenate, and sodium tetrachlorophenate warrant further consideration as water-repellent dip treatments. The last two are applied in water solution and probably will be most valuable for special uses such as the temporary protection of framing and sheathing during transportation, storage at the building site, and construction.

10. In high-rainfall areas any wooden member of a building can be exposed to a high decay hazard unless the building is designed to prevent all but light rainwash over the surface. The 3-minute dip in a water repellent is intended to protect woodwork from decay and other troubles traceable to minor rain seepage. In a well-designed building the following items are benefited by dips:

1. Items of any wood species in all areas: Siding and trim; sash, screens, screen doors, shutters, and louvers; decorative panels; access panel doors and frames to basementless space.

2. Items of any wood species in low-hazard areas: Steps, porches, railings, columns, and balustrades; exposed structural members; fascia and other wood exposed at roof edges; watertables and adjacent siding and trim; gates and fencing (but not posts)

If subject to considerable [illegible]
susceptible wood should [illegible]
of 15 minutes or longer.

In high-rainfall areas, the items [illegible]
susceptible woods, are best commercially impregnated according to Federal Specification TT–W–571. When left unpainted any treatment listed in TT–W–571 will be satisfactory as long as the color and odor of the treated [illegible] are acceptable. For wood to be painted the paintable water-repellent treatments included in the latest revision of this specification are advisable. In lieu of these, the waterborne treatments can be followed after seasoning with a dip in a water repellent, or untreated lumber can be soaked for at least 15 minutes in a water-repellent preservative.

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