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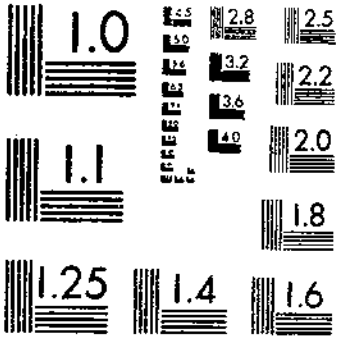

MICROCOPY RESOLUTION TEST CHART
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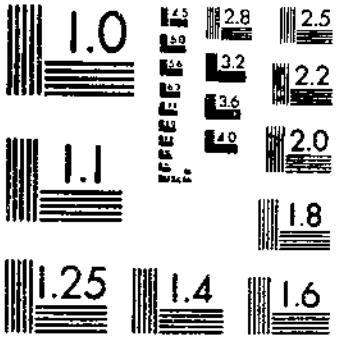

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Research on Chemical Control of Fungi in Green Lumber, 1940–51 [1]

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INTRODUCTION

Extensive tests on the chemical control of fungi in green lumber during air seasoning, by Scheffer and Lindgren (7) [2] and associates of the Bureau of Plant Industry, in 1928 to 1933, led to the general adoption by the lumber industry of the more important producing

[1] Submitted for publication May 18, 1951.
[2] Italic numbers in parentheses refer to Literature Cited, p. 57.

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countries of certain organic mercurials and chlorinated phenolates for fungicidal treatment of green lumber. Among the organic mercurials, ethyl mercuric chloride was first used but later was replaced by the more water-soluble and less volatile ethyl mercuric phosphate. Among the phenolates, sodium tetrachlorophenate and sodium pentachlorophenate are most extensively used. In addition to these, borax is used in certain countries, but in the United States its use is largely as an adjuvant to permit reduced concentrations of chlorophenates or to maintain alkalinity.

Each of these chemicals has limitations. Under certain conditions, the organic mercurials permit molding (*13*). The phenolates tend to cause skin irritation. Sodium tetrachlorophenate is not always effective on southern pine, and for certain uses, as on wood for food containers, it is likely to impart objectionable odor and taste. Borax is effective only on hardwoods and is usually considered too bulky for general use. Furthermore, any of the currently used chemicals occasionally permit objectionable stain development during protracted periods of warm, wet weather that are conducive to rapid fungus development and slow seasoning.

The studies here reported were made in an attempt to improve chemical control by (1) a search for new chemicals, (2) exploring more fully the effectiveness of mixtures of two or three components, and (3) appraising more accurately some of the factors influencing the effectiveness of chemical control.

The literature up to the mid-1930's on stain, mold, and decay occurring on green wood and their control was exhaustively summarized by Scheffer and Lindgren (*7*). More recent literature has been reviewed by Verrall (*12*). Consequently, no general literature review is included in this bulletin.

METHODS

Types of Tests

All the tests were essentially the same. Fungicidal values were determined by exposing to natural infections freshly sawed green sapwood that had been dipped for 5 to 10 seconds in water solutions of the fungicides. The amount of stain, mold, and decay developing in 4 to 6 weeks, or occasionally longer, was used as the index of fungicidal effectiveness. Although untreated control material was included in each test, the main comparisons were made against one or more chemicals in current widespread commercial use.

Three types of tests were used: Open-piled and close-piled small-scale tests and large-scale tests. For the open-piled small-scale test, 1- by 2- by 14-inch wood samples were used and the treated wood was placed in miniature seasoning piles. The piles were placed outdoors on platforms about 4 inches high (fig. 1). The test pieces in each horizontal layer were spaced one-fourth to one-half inch apart, and succeeding courses were separated by dry wood strips about one-fourth to one-half inch in cross section. All treatments under test were placed in one pile but so distributed[3] within the pile as to minimize

[3] Detailed information on equalizing variations within and among treatments is discussed in the Appendix.

FIGURE 1.—Small-scale open-yard tests. *A*, Test samples stacked and covered with roll roofing. *B*, Completed test piles fully exposed to the warming effect of sun for a winter test. During the summer test piles were shaded with an elevated canopy of palm boughs to prevent excess overheating.

effects of position in the pile on the comparison of different treatments. Usually 10 pieces per treatment were used, but sometimes 15 to 20 were used, particularly for the treated controls. Nontest green pieces were placed at the ends of each course and over the entire top course.

To reduce the drying rate, the completed pile was covered with roll roofing, usually extending over the upper one-third to one-half of the pile, and the rest covered with boards. Winter test piles were left fully exposed to the warming effect of the sun, whereas summer test piles were shaded to prevent excessively high temperatures within the pile.

Small-scale close-piled tests were like the open-piled, except that the samples for each treatment were placed in one or two groups with as little air space as possible between samples. Thus, the samples were subjected to severe moisture conditions. Also, larger sizes of test samples (1 by 4 by 24 to 1 by 8 by 24 inches) were used in some cases. These tests were designed to simulate conditions encountered in shipping green lumber or in bulk piles of lumber waiting to be placed in seasoning piles. Records were taken after 4 to 6 weeks, and the samples repiled for 2 or more months in order to get data on decay control. In some tests samples were withdrawn periodically from close piles for subsequent air seasoning or strength tests.

For the large-scale tests full-size lumber was treated and stacked in commercial seasoning yards. Piling methods prevailing at the particular yard were followed, except that boards were spaced somewhat closer together horizontally to reduce air circulation and drying rate (fig. 2). All test piles were roofed to prevent rainwash. Readings were taken after 60 to 90 days.

Large-scale tests are often unsatisfactory because: (1) Usually no more than 6 to 8 treatments can be included in a single test if boards

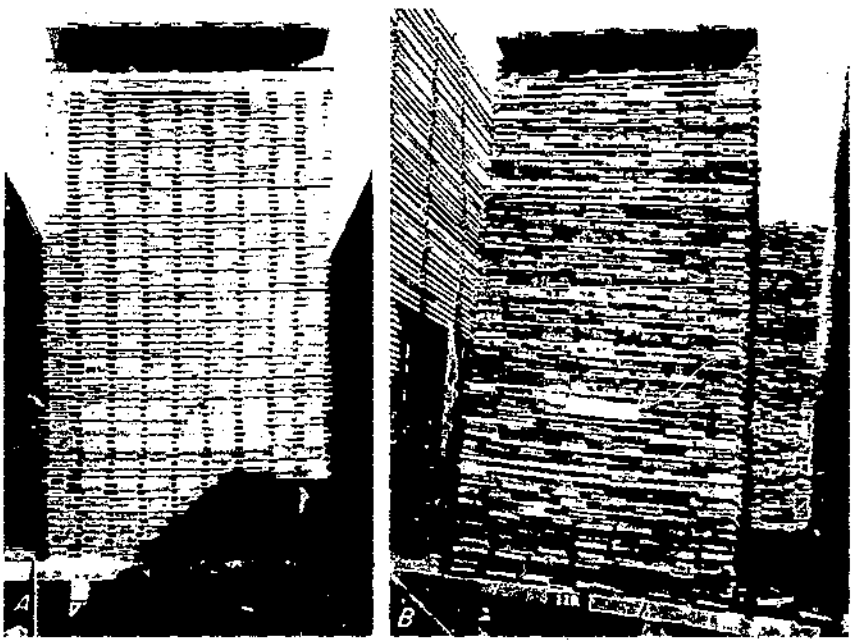

FIGURE 2.—Large-scale test piles of pine (*A*) and sweetgum (*B*) in commercial seasoning yards. The methods of piling are conventional, except that the horizontal spacing of the boards is closer than in commercial operations.

with different treatments are to be subjected to comparable drying conditions; (2) there is difficulty in getting uniformity of wood among treatments; (3) they are time consuming; and (4) there is no assurance that conditions will be severe enough to get valid comparisons in more than half the tests.

The small-scale test removes many of the disadvantages of the large-scale test. The objection has been raised that the small-scale tests are too severe, but this objection was removed by including in all tests standard reference treatments with which all other treatments were compared. The small-scale test may eliminate some treatments that would give fair control under most commercial conditions, but improvement in fungicidal effectiveness is needed mainly for the occasional severe conditions conducive to slow drying. Of course, it must be remembered that neither the small-scale nor large-scale tests here described yield final conclusions as to the commercial suitability of treatments. It is believed, however, that the small-scale test is the cheapest and fastest means of sorting out ineffective treatments and of devising new treatments up to the stage where they are ready for commercial trial.

In both small-scale and large-scale tests, relatively large volumes of treating solution were used so that in dipping test samples no appreciable reduction in volume of the solution occurred. This eliminated from the tests the effect of reduced concentrations caused by adsorption of solutes as occurs in commercial continuous-dipping operations (*4*).

In addition to the regular stain-control tests, a number of special tests were made, the descriptions and results of which are discussed later in this bulletin or have been published separately. The methods were similar to those described for the small-scale tests, except that certain variations were introduced to study specific problems.

Wood Used

The test material consisted mostly of sapwood of southern yellow pine and sweetgum (*Liquidambar styraciflua* L.). The species of pines seldom could be determined but probably were mostly longleaf (*Pinus palustris* Mill.) and slash (*P. caribaea* Morelet), although loblolly (*P. taeda* L.), shortleaf (*P. echinata* Mill.), and spruce pine (*P. glabra* Walt.) were used in some tests. A few tests included oak (*Quercus* spp.), ash (*Fraxinus* spp.), dogwood (*Cornus florida* L.), hickory (*Carya* sp.), and yellow-poplar (*Liriodendron tulipifera* L.). Sweetgum was chosen as the main test hardwood because of its high sapwood content and the readiness with which it stains. As chemical control of fungi is easily attained with hardwoods, however, most tests were made with the more refractory pine.

Except for some of the large-scale tests, the boards were from fresh green logs free of visible fungus infections. In order further to avoid deep-seated infections a maximum time of 36 hours was set for the interval between sawing from the log and chemical treatment. In most cases the interval was less than 12 hours. The longer delays were considered permissible only for winter tests. Throughout the establishment of a test, the wood was kept covered with roll roofing as much as feasible to delay surface drying.

Number and Location of Tests

Experience has shown that there is considerable variation in stain level and in effectiveness of a given treatment from test to test. Consequently, a large number of tests involving relatively few samples per treatment were made rather than a few tests of many samples each.

Although the majority of tests (52 of 88) were established near Saucier, Miss., others were made at Pisgah Forest, N. C.; Port Saint Joe, Fla.; Bellamy and Chapman, Ala.; Crossett, Ark.; and Tallulah, Clarks, Oakdale, and Natalbany, La. At most locations tests were established during both summer and winter. They extended over the period 1937–49. This distribution of tests sampled differences in effectiveness of treatments caused by possible variations in fungus floras, wood, and environmental conditions as they were influenced by location, season, and year.

Types of Infections Recognized and Methods of Rating Amount

STAIN

Stain included any fungus infection discoloring the wood below the surface. From limited culturing and from observations on surface fruiting there was no reason to believe that the blue stain encountered in both treated and untreated wood was not largely caused by the common staining fungi (*10*). In a number of tests a purple stain occurred. This was separated out from blue stain because it is seldom encountered in commercial operations. *Fusaria* have been reported isolated from pink to purple blotches on pine (*2, 3, 6*) and also were isolated from purple stain in these tests. In some cases stain was somewhat obscured by molds, but by spot checking under the molded surface this difficulty was largely overcome.

Stain was rated on the basis of percentage of unplaned surface visibly stained. In the first tests percentage of area stained was estimated directly. For most of the tests, stain was measured in square inches of surface and converted to percentage of area. A check on these two methods indicated close agreement. In general, the stain ratings are believed subject to only small errors of estimate.

DECAY

Because of the slower development of decay fungi many early infections were probably missed or classed as "miscellaneous molds," particularly in tests of less than 6 weeks' duration. Most decay ratings were based on wefts of visible mycelium or color changes, particularly bleaching of stained areas. Softening was used in some instances. In general, the estimates of decay were probably low.

MOLDS

Molds included fungi that impart color mainly by the presence of surface growth, which is removed when the lumber is planed. The chief molds recorded were *Penicillium* (probably mostly *P. cyclopium*

Westling), *Trichoderma viride* Fr., *Alternaria*, and an unidentified orange mold. *Alternaria* is a borderline fungus between a mold and a stainer. The orange mold is seldom found in commercial seasoning piles.

Other molds and miscellaneous fungi, many of which were unidentified and usually in too small amounts to be separated out, were classified as "miscellaneous molds." The total amounts of miscellaneous molds were usually insignificant except on untreated controls.

The data from the current tests on the specificity of molds for certain chemical treatments have been reported separately (*13*).

Mold occurrence was rated on an area basis in the first few tests, but this proved difficult. An arbitrary scale, therefore, was devised which was based on area molded and luxuriance of growth. Six classes were used: 0 (none), 1 (very light), 2 (light), 3 (medium), 4 (heavy), and 5 (very heavy).

In general, the mold ratings are considered less reliable than those for stain. The ratings could not well be standardized and had to be based on the judgment of the individual making the readings. In order to minimize the influence of personal variation in judgment, all treatments in any particular test were rated by the same person.

Chemicals Used and Methods of Designating Concentrations

Most of the chemicals used in mixtures were those that have been used commercially for stain control and for which effective concentrations for usual seasoning conditions have been determined. For simplification, these usual concentrations were considered "full strength" and concentrations in mixtures were expressed as fractions of these.

The main chemicals used and their full-strength concentrations are listed in table 1.

TESTS OF CHEMICALS

A number of chemicals were tested in a search for one that might equal or surpass in effectiveness those in commercial use for stain control and at the same time have fewer objectionable properties. Chemical manufacturers and others, asked to suggest chemicals, responded generously, and a large number of samples were available for trial. These included several of the newer fungicides on the market for other purposes and a number of chemicals in the developmental stage.

All the new chemicals were tried in small-scale tests on pine and, in many cases, also on gum. The results are presented in table 2.

None of the new chemicals tested proved sufficiently suitable to be recommended for general use on wood or to justify further trials at the present time. Cost, lack of solubility, or objectionable chemical coloring of the wood militated against some chemicals, while others lacked sufficient fungistatic value against the fungi that attack wood. Most were tested at concentrations expected to involve costs of one and two times those of the currently used treatments, and it could well be that some of these fungicides would be effective at higher concentrations. Earlier tests (*7*) showed that the general fungicides,

as bordeaux mixture and lime sulfur, are ineffective on lumber when used at concentrations costing about the same as currently used treatments.

Many of the listed chemicals were tested but once, and there may be some doubt of the justification of excluding them from further trials. In most cases, however, chemicals showing any promise of superior fungicidal value and having the other desirable qualities were retested at least once. A few treatments listed in table 2 might, after further testing, prove usable on green lumber for certain purposes.

TABLE 1.—*Chemicals used and their full-strength concentrations*

Chemical	Trade name	Composition of commercial product [1]	Full strength, amount per 50 gallons
Mercurials:			
Ethyl mercuric phosphate.	Tagnasan	6.25 percent ethyl mercuric phosphate plus 93.75 percent inerts (metallic mercury 4.79 percent).	1 pound (.015 percent mercurial).
Other organic mercurials			.015 percent mercurial.
Chlorinated phenolates.			
Sodium pentachlorophenate.	Dowicide G or Santobrite.	75 percent sodium pentachlorophenate plus 15 percent of other chlorophenates, and excess alkali.	4 pounds.[2]
Other chlorophenolates.	Various Dowicides.		Do.[3]
Adjuvants:			
Borax		Technical powdered borax	16 pounds.
Soda		Mixture of technical sodium carbonate and sodium bicarbonate.	29 pounds.
Commercial products	Permatox 108	Technical sodium pentachlorophenate 40 percent, plus borax 60 percent.[4]	5 pounds.
	Nontaint	Technical sodium pentachlorophenate 20 percent, borax 48 percent, and soda 29 percent.[5]	Do.
	Meksan	Technical sodium pentachlorophenate 50 percent, ethyl mercuric phosphate 1.56 percent, inerts 48.44 percent.	2 pounds.
Miscellaneous new chemicals.			[6]

[1] Composition based mainly on data from container labels. In some instances these data were modified by further information received from the manufacturers.

[2] Dowicide G and Santobrite are ordinarily used at the rate of 3.5 pounds per 50 gallons. In most of the tests 3.5 pounds were used in reference treatments, but in some early tests 4 pounds were used. Because there was very little difference in the effectiveness of the two concentrations, both were included as "full strength." All reduced concentrations in mixtures are expressed as fractions of 4 pounds.

[3] In commercial practice the various chlorophenolates are used at rates of 3 to 4 pounds per 50 gallons. However, for these tests full strength was considered 4 pounds in all cases, so that all would be comparable to sodium pentachlorophenate.

[4] After these tests were started, the composition of Permatox 108 was changed to technical sodium pentachlorophenate 35 percent, plus borax 65 percent.

[5] The manufacturers stated that the proportions of the ingredients are being changed.

[6] No full-strength concentrations were established. Concentrations expressed as percentages.

SCREENING TESTS PRELIMINARY TO THE STUDY OF MIXTURES

Because several chlorinated phenolates, organic mercurials, and adjuvants were available for use in stain control, the number of possible combinations of chemicals and concentrations was enormous. Therefore, it was necessary to select the most likely chemicals and relative proportions of these for use in extensive testing. The test data upon which selections of adjuvants, phenolates, and mercurials were based are included in this section.

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TABLE 2.—*New treatments unsatisfactory on green lumber at the concentrations indicated*

Compound	Concentration [1]	Tests	Area stained			Mold rating [2]	Remarks
			Pine	Gum	Pine, treated control [3]		
Inorganic compounds	*Percent*	*Number*	*Percent*	*Percent*	*Percent*		
Ammonium thiocyanate	2.4	1	10	.....	13	4.5	Bulky, favored mold.
Cadmium chloride	.12	1	59	.....	3	1.5	
Copper oxide	.36	1	31	.....	4	1.2	Colored wood green.
Copper oxychloride	.51	1	8	.....	4	(+)	Colored wood green. Insoluble.
Copper silicofluoride	1.2–2.4	1	5–7	.....	.....	4–5	Corrosive to metal. Favored mold.
Iodine	(4)	1	61	.....	2	3	Slightly corrosive to metal.
Magnesium silicofluoride	1.7–2.9	1	4–5	.....	1	5	Bulky, favored mold.
Potassium iodide	.24	1	74	86	8	2	
Silver nitrate	.01–.02	2	5–13	.....	2–4	+–1.5	Unstable, heavily adsorbed. Will not mix with phenolates.
Do	.03–.06	4	1–9	3	1–4	(+)	Do.
Sodium silicofluoride	1.9–2.9	1	2–10	.....	1	5	Bulky, favored mold.
Trisodium phosphate	3.6	1	35	60	.....	.....	Bulky, poor mold control.
Zinc silicofluoride	.72	1	51	.....	.....	4.5	Favored mold.
Organic compounds							
Alcohol, higher (Du Pont B-24)	.12–.48	2	62–69	86–95	8	.....	Mixture of alcohols boiling at 160°–200° C.
Alkyl (C8-18) dimethyl-benzyl-ammonium chlorides	.05–.3	3	14–43	.....	1–3	1–3.5	Expensive. Roccal.
Alkyl (C14-18) dimethyl-benzyl-ammonium chlorides	.14–.29	1	47–53	.....	2	2.5–3	
Amine AMAC-Coco-C	.48–.72	2	47–79	67–83	8	.....	Mixture of primary amines with alkyl chains corresponding to fatty acids in coconut oil.
Amine AMAC-118.5-B	.48–.72	2	47–87	42–96	8	.....	Mono-n-octadecyl 25 percent, mono-n-hexadecyl 25 percent, and mono-n-octadecenyl 50 percent amine acetates.
Amine salt, substituted high molecular weight	.05	1	47	.....	7	1.6	Nuodex 100 WD.
Antimony and potassium tartrate	.48	1	24	.....	1	5	Favored mold.
Benzene hexachloride	.4	2	12–17	.....	1–3	1.2–3.3	Concentration as percent of gamma isomer.
Copper hydroxy naphthenate	.24	1	5	.....	2	3	25 percent copper. Discolored wood bluish green.
Dichloro diphenyl trichloroethane	8	1	33	.....	9	2.2	Wettable DDT.
Dimethyl dichlor benzyl lauryl ammonium chloride	.16	1	51	.....	7	1.4	
Dimethyl lauryl benzyl ammonium chloride	.12	1	52	.....	7	1.4	Germ-I-Tol.
Dimethyl-b-octadecenyl ethyl ammonium bromide	.03–.12	1	53–61	.....	2	1.5	Two forms tested.
Dinitrophenol compound	.3–.72	2	3–20	89	8	1	Nitro Kleemup. Colored wood yellow.
2,4-dinitrophenyl thiocyanate	.24	5	1–39	69	1–8	(+)	Three emulsions and dispersions tested. Colored wood yellow.
Disodium ethylene bisdithiocarbamate	.08–.48	2	9–55	.....	2–4	+–2.2	Dithane.
2-nitro 2-methyl 3-hexanol	.6	1	51–79	83–96	8	.....	
O-aminophenol	.12–.24	2	5–15	.....	3	1–2.5	Discolored wood bright yellow to orange brown.

See footnotes at end of table.

TABLE 2.—*New treatments unsatisfactory on green lumber at the concentrations indicated*—Continued

Compound	Concentration [1]	Tests	Area stained			Mold rating [3]	Remarks
			Pine	Gum	Pine, treated control [2]		
Organic compounds—Continued							
	Percent	*Number*	*Percent*	*Percent*	*Percent*		
Para-tertiary-octyl-phenyl-diethoxy-dimethyl-benzyl ammonium chloride monohydrate	0.06–0.12	2	15–51	.....	3	1–2.5	Phemerol. Expensive.
Phenyl mercuric naphthenate	.1– .3	1	8–9	.....	1	4	Nuocide D–63. Used as emulsion.
Ramplex emulsion	.6	1	26	.....	.....	2.5	Composition unknown. Expensive.
Ramplex solution	[5] .64	1	10	4	.....	.....	Do.
Sodium caprate	.72–1.44	2	22–52	.....	1	1.5–3.5	Neo Fat (90 percent capric, 7 percent lauric, 3 percent caprylic acids). Concentration as percent acid.
Sodium diamylphenolate	1.2	2	35–63	74–95	8	.....	Colored wood yellow. Concentration as percent diamylphenol.
Sodium diethyldithiocarbamate	.18– .5	2	13–22	44	8	2	Namate.
Sodium dimethyldithiocarbamate	.31	3	15–51	78	2–8	1	
Sodium 2-methyl, 5-isopropylphenolate	.12	1	44	.....	3	2	Carvacrol+NaOH. Concentration as percent carvacrol.
Sodium 3-methyl, 6-isopropylphenolate	.6	1	41	.....	1	2.5	Thymol+NaOH. Concentration as percent thymol.
Sodium salt of 2,2' dihydroxy 5,5' dichloro-diphenyl-methane	.24– .6	2	33–43	.....	3	2–3	G4–40.
Sodium salt of 2-mercaptobenzothiazole	.23– .51	3	30–82	.....	1–6	+– .8	
Sodium salt of 2-mercaptobenzothiazole plus sodium dimethyl dithiocarbamate [6]	.23– .45	3	17–85	.....	1–6	+– .8	
Tetrachloro-para-benzoquinone	.24	1	65	91	8	.....	Spergon. Concentration as percent Spergon.
Tetrachlororesorcinol	.48	1	24	.....	1	1	
Urea	4.4–8.7	1	55–57	.....	.....	3.5–4	Bulky (effective at 50 percent concentration).

[1] Percent concentration by weight unless otherwise indicated.
[2] Amount of stain on pine treated with full-strength sodium pentachlorophenate in the same test. In the one test in which it was included on gum, sodium pentachlorophenate allowed only a trace of stain.
[3] On an arbitrary scale of 0 to 5 based on area molded and luxuriance; (+) indicates a trace.
[4] Saturated.
[5] By volume.
[6] Relative proportions not known.

Effectiveness of Different Adjuvants for Use With Mercurials and Phenolates

The comparative effectiveness of borax, soda, magnesium silicofluoride, and trisodium phosphate as adjuvants with ethyl mercuric phosphate and sodium phenolates was determined in a few small-scale tests.

Trisodium phosphate at the rates of 7 and 15 pounds plus sodium pentachlorophenate, 1 pound per 50 gallons, proved ineffective on both pine and gum in one test. This failure, plus the low fungicidal value of the phosphate alone against both stain and mold, seemed sufficient to exclude this material from further trials. This chemical was also listed as ineffective in previous tests (*7, table 24*).

Magnesium, sodium, and copper silicofluorides gave flocculent precipitates when mixed with phenolates. Nevertheless, the following mixtures were included in one test:

Sodium tetrachlorophenate $\frac{1}{4}$ strength plus magnesium silicofluoride, 4 pounds per 50 gallons.

Ethyl mercuric phosphate $\frac{1}{4}$ strength plus magnesium silicofluoride, 4 pounds per 50 gallons.

Ethyl mercuric phosphate $\frac{1}{4}$ strength plus borax $\frac{5}{16}$ strength plus magnesium silicofluoride, 1 pound per 50 gallons.

Effective stain control resulted, but there was no assurance that this was due directly to the dip; with all three treatments it may have been the result of an antibiotic effect of the heavy growth of *Trichoderma* that commonly develops in the presence of fluorides. Because of the low solubility of the reaction product with phenolates plus the heavy mold hazard, the silicofluorides were excluded from subsequent tests.

From the start, the two most promising adjuvants were borax and soda. Both were known to have appreciable fungicidal value on wood (*7*). From previous information, borax seemed best. On hardwoods, borax alone had proved effective while soda had not (*7*). On pine, borax was effective against all fungi but the smoky mold (*Alternaria*); cold solutions of soda were only moderately effective to ineffective. Full-strength solutions of borax when used alone were less bulky than soda (16 pounds as compared with 29 pounds for soda). In order to obtain some experimental data on the comparative effect of borax and soda, comparative mixtures of these with sodium pentachlorophenate and ethyl mercuric phosphate were included in 3 small-scale tests. The results are given in table 3. Of the 18 comparisons listed, borax was better in 11, soda in 1, and the two adjuvants equal in 6. Considering all the data on pine, the better showing of the borax was significant at the 2-percent probability level. It should be remembered that the comparisons listed in table 3 are on a basis of full strengths when used alone, and not pound for pound of borax and soda. This means that the soda concentrations are about 1.8 times those of borax for each comparison.

Considering all the evidence, it was decided that borax was a superior adjuvant to use in duplex and triplex mixtures with mercurials and phenolates. Further trials were therefore limited to borax.

TABLE 3.—*Comparative effectiveness of borax and soda in mixtures with ethyl mercuric phosphate and sodium pentachlorophenate in controlling stain on pine and gum in 8 open-piled small-scale tests*

SODIUM PENTACHLOROPHENATE

Test No.	Location of test	Constituents and solution composition		Average area stained			
		Chemical	Adjuvant (soda or borax)	Pine		Sweetgum	
				Borax	Soda	Borax	Soda
		Strength	*Strength*	*Percent*	*Percent*	*Percent*	*Percent*
5	Saucier, Miss.	1/8	[2] 1/16	11	13		
3	Tallulah, La.	1/8	1/16	2	4	1	8
3	do	1/4	1/8	3	3	2	10
1	Clarks, La.	1/4	1/8	5	21		
5	Saucier, Miss.	1/8	[2] 1/16	1	5		
5	do	1/4	[2] 1/16	3	7		
1	Clarks, La.	1/4	1/4	1	3		
Mean values [3]				3.2	7.1	1.5	9.0

ETHYL MERCURIC PHOSPHATE

5	Saucier, Miss.	1/8	[2] 1/16	1	(4)		
3	Tallulah, La.	1/8	1/16	4	4	1	1
3	do	1/4	1/8	4	13	1	9
1	Clarks, La.	1/4	1/8	4	10		
5	Saucier, Miss.	1/8	[2] 1/16	(4)	(4)		
5	do	1/4	[2] 1/16	(4)	(4)		
1	Clarks, La.	1/4	1/4	4	4		
Mean values [3]				1.8	2.6	1.0	4.0

[1] Concentrations expressed as fractions of full strengths, as listed in table 1.
[2] Soda concentration somewhat higher than indicated.
[3] Mean value computed by converting percentage of stain in each test to the equivalent angle and reconverting the mean of the angles to a percentage.
[4] Trace.

EFFECTIVENESS OF DIFFERENT MERCURIALS

Scheffer and Lindgren (*7, tables 4, 7, 9, 12*) reported tests with several ethyl mercurials and two phenyl mercurials. The ethyl mercurials were somewhat better than the phenyl mercurials, but the differences were not of practical importance. The data showed no practical differences among the ethyl mercurials. A few mixtures of ethyl mercuric chloride or oleate and nonmercurials were reported (*7, tables 6 and 11*), but there was not enough information to be of value in the selection of a mercurial for mixtures in the present tests.

From the available information it was decided to use only ethyl mercuric phosphate to represent the ethyl mercurials. The phosphate is now the only ethyl mercurial used commercially for stain control. It has a much higher water solubility and a lower vapor pressure than the previously used ethyl mercuric chloride, both of which are factors influencing suitability for use in stain control. Because of the lack of information on the stain-control value of different phenyl mercurials, two were chosen for trial, including phenyl mercuric acetate, the cheapest compound and the one from which other phenyl mercurials are manufactured.

Two acetylated mercurials, designated as H and M, were also obtained. Although these appeared satisfactory for stain control in tests conducted by a commercial concern, they have not been developed commercially.

The relative stain-control values for different organic mercurials used alone and in mixture with either borax or sodium pentachlorophenate or with both are listed in table 4. For comparative purposes, the concentrations are given as fractional parts of full strength, which is 0.015 percent mercurial. It is realized that this does not give equal concentrations of metallic mercury, but the data do not indicate a close correlation between toxicity and concentration of metallic mercury. Although analytical data were not available for all samples used, it appeared that the metallic mercury contents were ethyl mercuric phosphate 77 percent, H 78 percent, M 74 percent, phenyl mercuric borate 65 percent, and phenyl mercuric acetate 60 percent. The order of mercury content was not the order of effectiveness as indicated by the data, particularly in the case of mixtures.

Ethyl mercuric phosphate seems to be slightly superior to the other mercurials in stain control. But for practical purposes, the ethyl and phenyl mercurials can be considered of about equal effectiveness. All the mercurials tested were ineffective against *Penicillium*. In stain control the two acetylated mercurials (M and H) were inferior to the other mercurials when used in duplex mixtures with borax or a phenolate; therefore these were not further tested.

As the ethyl and phenyl mercurials appear to have about equal fungicidal values, their relative suitability for stain-control use must be determined by other factors. The following are the comparisons for which the Division of Forest Pathology has information.

TABLE 4.— *Comparative effectiveness of different organic mercurials used alone or in mixtures for stain control on pine in small-scale open-piled tests* [1]

Test No.[2]	Constituents [3] and solution composition			Average area stained				
	Mercurial compounds	Sodium pentachlorophenate	Borax	Ethyl mercuric phosphate in Lignasan	Phenyl mercuric acetate, pure	Phenyl mercuric borate, pure	M (acetylated mercurial compound)	H (acetylated mercurial compound)
	Strength	*Strength*	*Strength*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
19	1			4	9			
21	1			2	4		4	7
25	1			10	13	17		
21	1/10		3/4	11	7		9	22
21	1/8		3/4	7	9		17	20
19	1/8		3/4	7	11			
19	1/4		3/4	7	10			
21	1/4		3/4	8	7		13	20
19	3/8		3/4	5	7			
25	1/8	1/8		19	28	38	49	54
25	1/4	1/4		18	28	20	27	24
28	1/4	1/4		15	9	7		
25	1/8	1/8		2	12	3	8	12
19	1/16	1/16	3/4	10	8			
21	1/16	1/16	3/4	0	2		6	12
18	1/8	1/8	3/4	6	3			
19	1/8	1/8	3/4	7	9			
20	1/8	1/8	3/4	11	7			
21	1/8	1/8	3/4	3	1		5	7
23	1/8	1/8	3/4	3	3			
28	1/8	1/8	3/4	4	5	3		
19	1/4	1/4	3/4	1	10			
21	1/4	1/4	3/4	1	(4)		2	3

[1] A few comparisons of ethyl mercuric phosphate and phenyl mercuric acetate alone and in mixtures on gum all gave low percentages of stain, mostly trace to 1 percent. Only in 1 test were the two matched. In this the percentage stain with ethyl mercuric phosphate 1/8, plus pentachlorophenate 1/8, plus borax 3/4 was +, same mixture with phenyl mercuric acetate, no stain.

[2] All tests were at Saucier, Miss., except test No. 18, which was at Clarks, La.

[3] Concentrations expressed as fractions of the full strengths, as listed in table 1.

[4] Trace.

(1) *Water solubility.*—Ethyl mercuric phosphate, phenyl mercuric acetate, and phenyl mercuric borate are all sufficiently soluble in water in the concentrations needed for use on lumber. Ethyl mercuric phosphate, however, is more soluble than are the phenyl mercurials.

(2) *Wettability.*—Ethyl mercuric phosphate, in Lignasan at least, is readily wettable. The phenyl mercurials, on the other hand, are wetted with considerable difficulty in the pure forms used. This can be overcome by dissolving in hot water and possibly by the use of wetting agents. Two wetting agents tried failed to overcome the difficulty of wetting.

(3) *Solubility of the X-mercuric pentachlorophenates.*—Phenyl mercuric pentachlorophenate is insoluble in water. When a phenyl mercurial and sodium pentachlorophenate are mixed in water, a flocculent precipitate is produced which does not form a good suspension after settling and being restirred.

No definite information on the solubility of ethyl mercuric pentachlorophenate is available. Mixtures of ethyl mercuric phosphate and sodium pentachlorophenate in water do not settle out any more than solutions of the phenolate alone. What sediment does form on standing is easily stirred into a good suspension, which settles out very slowly.

The tests indicated that any of the mercurials tried would give good stain control if used alone. However, in mixtures, ethyl mercuric phosphate would seem the superior mercurial.

Commercial experience with mercurial-phenolate mixtures has been limited to three products. The composition of these mixtures and their effectiveness in small-scale tests are given in table 5.

TABLE 5.—*Comparative effectiveness of 3 commercial mixtures of mercurial and sodium pentachlorophenate in controlling stain on pine sapwood in small-scale open-piled tests*

Product	Concentrations of mixture components			Tests	Average area stained [1]	
	Mercurial	Sodium pentachlorophenate	Inerts		Mixture-treated	Sodium pentachlorophenate-treated [2]
	Lb./50 gal.	*Lb./50 gal.*	*Lb./50 gal.*	*Number*	*Percent*	*Percent*
A	[3] 0.033	0.89	0.077	4	10.7	2.3
A (1.5 strength)	[3] .050	1.34	.116	2	15.4	8.0
B	[3] .033	1.89	.077	[4] 4	11.7	3.9
C	[5] .03	1.0	.97	7	2.8	2.9

[1] Average computed by converting percentage of stain in each test to the equivalent angle and reconverting the mean of the angles to a percentage.
[2] Full strength, 3.5 pounds per 50 gallons of water.
[3] Sodium salts of ortho and para isomers of hydroxy phenyl mercuric hydroxide.
[4] Also tested once on sweetgum, in which case the mixture allowed 10.3 percent stain and full-strength sodium pentachlorophenate, 3.1 percent.
[5] Ethyl mercuric phosphate.

Products A and B were inferior and were soon withdrawn from the market. The outstanding point in these data is the effectiveness of the mixture (C) containing ethyl mercuric phosphate in comparison with those including other mercurials (A and B). This held even for the case in which the nonethyl mercurial mixture contained more phenolate.

EFFECTIVENESS OF DIFFERENT CHLORINATED PHENOLATES

Sodium pentachlorophenate was used as the phenolate in the mixtures tests. Previous tests and commercial experience had shown that sodium pentachlorophenate is more effective than sodium tetrachlorophenate on southern pines, although the two are of almost equal effectiveness on southern hardwoods and some western conifers (*15*).

Sodium tetrachlorophenate has the disadvantage in that it is likely to impart an objectionable odor and taste to foods stored in containers made from treated wood.

Another phenolic material, sodium chloro-2-phenylphenolate, is used commercially for stain control in mixture with sodium tetrachlorophenate. This mixture (Dowicide P) has given satisfactory stain control under commercial conditions but has no advantages over sodium pentachlorophenate. In a few tests, Dowicide P proved less effective than sodium pentachlorophenate in mixture with borax.

Sodium orthophenylphenolate and sodium chloro-2-phenylphenolate were each tested in mixture with borax in a few tests and found inferior to sodium pentachlorophenate.

The Effect of the Relative Proportions of Mercurial and Phenolate in Mixtures

An early question in mixing mercurials and phenolates was whether they should be mixed in equal proportions (as ¼ plus ¼ of full strength) or in unequal proportions (as 1/10 plus ⅖), and if mixed in unequal amounts which constituent should be favored. Some mixtures with unequal proportions were included in two early tests, and it appeared that, within the limits tested, the important factor was the total fractional concentration and not the relative proportions in which the two components were mixed. It was not until later, however, that data were obtained from which direct comparisons could be made. These data are presented in table 6.

Table 6.—*Comparative effectiveness in controlling stain on pine sapwood of mixtures of ethyl mercuric phosphate and sodium pentachlorophenate in which the relative proportions of mercurial and phenolate are 4:1, 2:1, 1:1, 1:2, and 1:4 in terms of full-strength values*

Season [1] and test No.	Concentration [2]			Average area stained		
	Unequal proportions	Total	Equal proportions	Unequal proportions		Equal proportions
				High ethyl mercuric phosphate	High sodium pentachlorophenate	
	Strength	*Strength*	*Strength*	*Percent*	*Percent*	*Percent*
Summer:						
20	1/21 and 1/42	1/8	1/16 and 1/16	24	32	20
20	1/42 and 1/8	1/7	1/8 and 1/8	23	19	16
20	1/6 and 1/24	1/5	1/4 and 1/4	7	10	8
20	1/3 and 2/3	1	1/2 and 1/2	2	7	4
Winter:						
15	1/16 and 1/16	1/8	1/16 and 1/16	41	30	31
23	1/24 and 1/12	1/8	1/16 and 1/16	21	20	17
15	1/20 and 1/5	1/4	1/8 and 1/8	25	21	24
23	1/12 and 1/6	1/4	1/8 and 1/8	13	0	9
15	1/10 and 2/5	1/2	1/4 and 1/4	12	14	13
22	1/8 and 1/4	1/2	1/4 and 1/4	1	1	3
23	1/8 and 1/4	1/2	1/4 and 1/4	8	5	7
15	1/6 and 1/3	1	1/8 and 1/4	5	3	3
22	1/3 and 2/3	1	1/4 and 1/2	(3)	(3)	(3)
23	1/4 and 2/3	1	1/8 and 1/2	1	2	1

[1] Summer tests had their midpoint in the period May to October; winter tests in the period November to April.

[2] Expressed as fractions of full strengths, as listed in table 1.

[3] Trace.

Considering all 28 comparisons without regard to season or to which component was of higher concentration, in 9 cases the unequal mixtures were superior, in 14 cases the equal mixtures were better, and in 5 cases the unequal and equal mixtures were the same. In many of these cases, however, the differences were small, and if the data are all averaged the amounts of stain in the unequal and equal treatments are almost identical.

Of the unequal mixtures in the summer test, the solution with the higher proportion of phenolates was superior in three of the four cases. For the winter tests, in six cases the high mercurial mixture was superior, in two cases the high phenolate was superior, and in two cases the two were equal. This fits into the general picture of greater comparative effectiveness of mercurials during the winter and of phenolates during the summer.

In the summer tests the mixture of equal proportions was superior to those with high mercurial in 3 of 4 comparisons; in the winter tests it was superior in 2 and equal in 2 of the 10 comparisons. The equal-proportion mixture, in summer tests, did not surpass the mixture with high phenolate in any of the 4 comparisons; in the winter tests it was superior in 4 and equal in 3 of the 10 comparisons.

Considering the low magnitude of most of the differences heretofore pointed out, the indications are that in duplex mixtures of mercurials and phenolates in any concentrations likely to be used for stain control it would make little difference which component was used in higher proportional part. For year-round use there might be a slight advantage to mixing the two in equal parts (on a basis of usual concentrations when used alone). An advantage would probably result from using a higher proportion of the mercurial during the winter and a higher proportion of the phenolate for summer, but such a practice probably would not be practical for the average commercial operation.

When borax was added as a third component, the data were limited to two tests (table 7). The limited comparisons in table 7 suggest that the addition of borax does not change the above conclusions.

TESTS OF COMMERCIAL STAIN-CONTROL CHEMICALS AND OF EXPERIMENTAL MIXTURES

The early tests reported in this bulletin were made during World War II with the express purpose of finding means of extending the available supplies of stain-control chemicals (*11*). This pressure, particularly when coupled with the lack of information on the behavior of mixtures, prevented inclusion in most of the early tests of all mixtures for which comparisons are now desirable. Because these tests were established in different localities, years, and seasons, a mass of data was built up in which comparisons between many treatments cannot be validly made with ordinary statistical methods.

This mass of uncorrelated data might have been handled by adjusting the raw-stain percentages to reduce variations due to the differences in stain hazard among the tests. Three possibilities for adjusting were tried in a limited way and the following conclusions reached:

1. Adjusting through the percentage of stain in untreated controls. There was only a weak correlation between severity of a test and the amount of stain in the untreated controls. Consequently, such adjustment did not seem of much benefit; in fact, in some cases the data were more distorted than in the raw-percentage form. Under severe conditions, decay often bleached stain from the controls and abnormally low stain readings resulted. This was definitely shown by periodic readings on the same pieces in bulked material. In other cases it appeared that extraneous organisms exerted an antibiotic effect, and low stain resulted in the controls but not necessarily in the treated wood.

2. Adjusting on the basis of results obtained with standard treatments. Ethyl mercuric phosphate and sodium pentachlorophenate were included in most tests, but it was found that the mercurial varied in relative effectiveness with season. The phenolate seemed more responsive to the severity of test conditions and somewhat less likely to permit occasional, unexplained high stain occurrence. It was felt, however, that an adjustment made on the basis of one treatment followed by a formal statistical analysis would be doubtful.

3. Adjusting by means of several of the better treatments. There were altogether too many tests in which two or more common better treatments were not present to use this method. It would have necessitated the use of a system of interlocking treatments leading to doubtful corrections.

Later, when relatively few mixtures had been selected as most promising, a series of tests were made in which all mixtures to be compared were included in each test. Because of the nature of the data, they are presented in two sections.

1. A tabular summary of all tests, both the heterogeneous and the later matched-treatment tests, in which the average percentage of area stained with each treatment is listed along with the average percentage of area stained in the wood treated with full-strength sodium pentachlorophenate in the same tests. This is given in tables 8 and 9.

2. A tabular presentation of the data from the later tests in which all the better mixtures were included in each test. This is given in tables 10 and 11.

TABLE 7.—*Comparative effectiveness of mixtures of ethyl mercuric phosphate and sodium pentachlorophenate in summer and winter tests when borax was added to mixtures*

Season[1] and test No.	Constituents[2] and solution composition				Average area stained
	Ethyl mercuric phosphate	Sodium pentachlorophenate	Borax	Total	
	Strength	*Strength*	*Strength*	*Strength*	*Percent*
Winter, No. 15	1/5	1/20	3/5	4/5	2
	1/8	1/8	3/8	4/8	2
	1/20	1/5	3/5	4/5	4
Summer, No. 20	1/6	1/12	5/6	6/6	13
	1/6	1/6	5/6	6/6	11
	1/12	1/6	9/6	6/6	6

[1] Summer tests had their midpoint in the period May to October; winter tests, in the period November to April.

[2] Concentrations expressed as fractions of full strengths, as listed in table 1.

TABLE 8.—*Stain [1] on pine sapwood lumber dipped in aqueous solutions of various chemicals compared to amount of stain on lumber dipped in usual concentrations of sodium pentachlorophenate in the same tests*

COMMERCIAL PRODUCTS

Treatment					Number of tests and relative amount of stain						
Constituents [2] and solution composition (A)					Small-scale open-piled tests				Large-scale open-piled tests			
Ethyl mercuric phosphate	Sodium pentachlorophenate	Adjuvants		Amount of chemical per 50 gallons water	Tests	Average area stained [3]		Angle a minus angle b [4] [5]	Tests	Average area stained [3]		Angle a minus angle b [5]
		Borax	Soda			Treatment in column (A)	Sodium pentachlorophenate			Treatment in column (A)	Sodium pentachlorophenate	
Strength	*Strength*	*Strength*	*Strength*	*Pounds*	*Number*	*Percent*	*Percent*		*Number*	*Percent*	*Percent*	
	1			3.5 or 4	38	3.9	2.9	−0.14	3	1.9		
½	¼			2	7	2.8	4.0	1.47	3	6.5	1.9	6.93
1				1	37	5.0	3.3	**8.48	1	.7	4.3	−7.17
	¼	½	1/20	5	15	10.5	1.9	−.12				
	½	⅛	1/10	10	3	1.9	4.4	.88				
	½	3/16		5	17	5.0						
EXPERIMENTAL MIXTURES												
	1/10	¼		4.25	3	11.5	5.9	5.76				
	1/16	⅜		6.25	3	6.6	5.9	.78				
	1/10	½		8.25	3	6.9	5.9	1.22				
	1/16	⅝		10.25	3	6.7	5.9	.90				
	⅛	¼		4.5	3	17.8	5.9	10.90				
	⅛	⅜		6.5	3	7.9	5.9	2.24				
	⅛	½		8.5	3	8.7	5.9	3.08				
	⅛	⅝		10.5	4	6.4	3.9	3.30				
	⅛	⅞		14.5	1	1.7	3.6	−3.45				
	3/16	3/16		3.75	1	2.9	3.6	−1.13				
	¼	¼		5	4	5.4	5.1	.48				
	¼	⅜		7	9	3.1	3.8	−1.09				
	¼	½		9	4	4.3	5.1	−.96				
	¼	⅝		11	5	2.9	2.1	1.48	3	1.4	1.9	−0.97
	¼	¾		13	1	1.0	8.0	−10.69				
	½	5/16		5	17	5.0	4.4	.88				
	½	¼		6	1	7.1	7.9	−.87				
	½	⅜		8	3	1.9	5.9	−6.13				
	½	½		10	1	3.9	7.9	−4.93				
	½	⅝		12	1	5.0	7.9	−3.40				
1/16		¼		4.07	3	8.5	5.9	2.92				
1/16		⅜		6.07	4	8.8	4.5	5.08				

1/16		1/2	8.07	3	9.0	5.9	3.39				
1/16		5/8	10.07	3	7.0	5.9	1.24				
3/8		1/4	4.13	3	7.3	5.9	1.66				
1/8		3/8	6.13	5	7.2	4.0	4.06				
1/8		1/2	8.13	3	8.1	5.9	2.53				
1/8		5/8	10.13	4	4.6	3.9	1.08				
1/8		7/8	14.13	1	4.2	3.6	.89				
1/4		1/4	4.25	4	8.1	4.9	3.76				
1/4		3/8	6.25	11	5.5	3.4	3.02				
1/4		1/2	8.25	4	6.2	4.9	1.60				
1/4		5/8	10.25	6	3.5	2.6	1.40	3	6.5	1.9	6.95
1/4		3/4	12.25	1	4.0	8.0	−4.89				
3/8		3/8	6.38	1	4.6	2.4	3.48				
1/2		3/16	2.5	3	4.8	6.4	−2.03				
1/2		1/4	4.5	1	10.8	7.9	2.87				
1/2		3/8	6.5	3	4.6	5.9	−1.69				
1/2		1/2	8.5	1	7.6	7.9	−.32				
1/2		5/8	10.5	1	7.1	7.9	−.87				
1/16	1/16		.32	3	25.3	7.3	*14.48				
1/8	1/8		.63	5	15.8	7.5	**7.52				
1/8	1/8		.84	1	5.0	8.0	−3.51				
1/4	1/4		1.25	16	5.7	4.3	1.80				
1/8	1/8		1.67	2	4.3	5.6	−1.78				
3/8	3/8		1.88	10	2.7	3.6	−1.46				
1/2	1/2		2.5	18	1.7	4.7	**−5.05				
1/16	1/16	3/8	6.32	6	5.0	3.6	1.93				
1/12	1/12	3/8	6.41	1	3.0	2.9	.17				
1/8	1/8	1/4	4.63	4	4.8	6.1	−1.54				
1/8	1/8	3/8	6.63	26	3.1	3.1	.01	3	1.1	1.9	−1.94
1/8	1/8	1/2	8.63	1	4.4	2.9	2.30				
3/16	3/16	1/4	3.94	12	3.7	4.5	−1.09				
3/16	3/16	1/4	4.94	4	5.8	4.5	1.63				
3/16	3/16	3/8	6.94	1	9.5	9.6	−.10				
1/4	1/4	1/8	3.25	3	5.1	7.3	−2.67				
1/4	1/4	3/16	4.25	9	2.2	3.6	−2.39				
1/4	1/4	1/4	5.25	7	3.7	5.4	−2.38				
1/4	1/4	3/8	7.25	7	2.3	5.0	−4.24				
CONTROLS											
Untreated [6]				38	45.6	3.9	**31.13	3	30.8	1.9	21.26

[1] Each figure is an average of all tests except in the sodium pentachlorophenate column. The latter averages include only tests in which the other treatment being compared occurred.

[2] Concentrations expressed as fractions of full strengths, as listed in table 1.

[3] Average computed by converting percentage of stain in each test to the equivalent angle and reconverting the mean of the angles to a percentage.

[4] *=significance at .5-percent level; **=significance at 1-percent level.

[5] Angles a and b refer to the average angles of the stain percentages for the treatment in column (A) and its corresponding sodium pentachlorophenate control. Negative numbers indicate superior control by the solution shown in column (A) and positive numbers indicate superiority for the straight sodium pentachlorophenate.

[6] In about 1/3 of the cases, the untreated controls were dipped in water. In 6 tests both were used, and the average percentage of area stained was: Undipped, 58.3 percent; water dipped, 55.6 percent.

TABLE 9.—*Stain [1] on hardwood sapwood lumber [2] dipped in aqueous solutions of various chemicals compared to amount of stain on lumber dipped in usual concentrations of sodium pentachlorophenate in the same tests*

COMMERCIAL PRODUCTS

Treatment					Number of tests and relative amount of stain						
Constituents [3] and solution composition (A)					Small-scale open-piled tests				Large-scale open-piled tests			
Ethyl mercuric phosphate	Sodium pentachlorophenate	Adjuvants: Borax	Adjuvants: Soda	Amount of chemical per 50 gallons water	Tests	Average area stained [4]: Treatment in column (A)	Average area stained [4]: Sodium pentachlorophenate	Angle a minus angle b [5]	Tests	Average area stained [4]: Treatment in column (A)	Average area stained [4]: Sodium pentachlorophenate	Angle a minus angle b [5]
Strength	*Strength*	*Strength*	*Strength*	*Pounds*	*Number*	*Percent*	*Percent*		*Number*	*Percent*	*Percent*	
				3.5 or 4.0	0	0.3			3	0.1		
1/2	1/4			2.0	1	.0	3.4	−5.19				
1				1.0	0	4.3	.3	0.01	3	.09	0.01	1.19
	1/1	1/2	1/20	5.0	3	4.6	.5	8.32	1	.05	0	1.28
	1/2	3/10		5.0	8	.8	.3	2.03				

EXPERIMENTAL MIXTURES

	1/8	7/8	14.5	1	1.1	0.2	3.46				
	4/16	13/16	13.75	1	.3	.2	.58				
	1/4	1/4	5.0	1	3.8	.02	10.43				
	1/4	3/8	7.0	2	1.3	.1	4.79				
	1/4	1/2	9.0	1	.02	.02	0				
	1/4	5/8	11.0					3	0.02	0.01	0.37
	1/2	3/16	5.0	8	.8	.3	20.3				
1/8		7/8	14.125	1	.6	.2	1.88				
1/4		1/4	4.25	1	1.9	.02	7.11				
1/4		3/8	6.25	2	1.0	.1	3.99				
1/4		1/2	8.25	1	.02	.02	0				
1/4		5/8	10.25					3	.04	.01	.72
1/2		3/16	3.5	1	1.1	.3	2.88				
1/8	1/8		.625	1	4.1	.2	9.12				
1/6	1/6		.837	1	2.0	.4	4.50				
1/4	1/4		1.25	5	.7	.3	1.52				
1/5	1/5		1.67	1	.3	.2	.58				
3/8	3/8		1.88	5	.4	.4	1.29				
1/2	1/2		2.5	5	.2	.4	1.88				
1/12	1/12	3/8	6.413	1	.5	.02	3.24				
1/8	1/8	1/4	4.625	1	2.1	.02	7.52				
1/8	1/8	3/8	6.625	6	.6	.3	1.20	2	.16	.01	2.04
1/8	1/8	1/2	8.625	1	.2	.02	1.75				
1/16	3/16	3/16	3.938	5	1.0	.4	1.88				
3/16	3/16	1/4	4.938	4	.4	.1	1.62				
1/16	3/16	3/8	6.938	1	.5	.3	.91				
1/4	1/4	3/16	4.25	5	.5	.4	.36				
1/4	1/4	1/4	5.25	4	.1	.1	−.07				
1/4	1/4	3/8	7.25	2	.2	1	.41				

CONTROLS

Untreated				9	75.7	0.3	57.52	3	49.0	0.01	43.93

[1] Each figure is the average of all tests except in the sodium pentachlorophenate column. The latter averages include only tests in which the other treatment being compared occurred.

[2] The lumber was sapgum except in 1 large-scale test (yellow-poplar).

[3] Concentrations expressed as fractions of full strength, as listed in table 1.

[4] Average computed by converting percentage of stain in each test to the equivalent angle and reconverting the mean of the angles to a percentage.

[5] Angles a and b refer to the average angles of the stain percentages for the treatment in column (A) and its corresponding sodium pentachlorophenate control. Negative numbers indicate superior control by the solution shown in column (A) and positive numbers indicate superiority for the straight sodium pentachlorophenate.

TABLE 10.—*Comparative effectiveness of 6 experimental mixtures and 5 commercial products in controlling stain on pine sapwood in 10 small-scale open-piled tests*

COMMERCIAL PRODUCTS

Constituents [1] and solution composition				Average area stained in tests No.—										Mean values [2]			
Ethyl mercuric phosphate	Sodium pentachlorophenate	Adjuvants: Borax	Adjuvants: Soda	24	26	27	29	31	32	33	36	37	38	All tests		Tests 31 to 38	
Strength	*Strength*	*Strength*	*Strength*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Arcsine √%* [3]	*Percent*	*Arcsine √%* [4]	*Percent*
.....	1	.....	.....	0.6	2.7	2.4	3.4	14.2	4.2	0.03	5.5	3.2	1.4	11.27	3.8	10.94	3.6
1	.....	.....	.....	5.6	16.6	8.7	7.4	10.0	6.7	.6	.5	1.2	.2	12.20	4.5	8.56	2.2
.....	1/2	3/16	.....	8.5	1.5	.7	4.6	12.5	2.2	.2	19.8	10.0	.8	12.30	4.5	13.63	5.6
.....	1/4	1/8	1/20	.....	.....	.....	.....	17.7	4.0	.6	20.8	15.2	9.0	.....	.....	18.21	9.8
1/2	1/4	.....	.....	.....	.....	.....	.....	5.7	8.7	.1	1.0	2.6	2.4	.....	.....	9.45	2.7

EXPERIMENTAL MIXTURES

1/8	1/8	3/8	.....	11.0	4.4	3.3	8.7	7.3	4.6	0.6	2.8	2.0	0.7	11.42	3.9	9.18	2.5
3/16	3/16	3/16	.....	5.4	5.5	1.6	6.8	6.7	4.0	.2	1.1	1.2	1.2	9.71	2.8	7.95	1.9
1/4	1/4	3/16	.....	4.7	3.4	1.8	5.4	4.0	3.6	.1	1.0	1.4	.4	8.48	2.2	6.74	1.4
1/4	1/4	.....	.....	6.1	5.7	3.2	4.0	9.3	12.2	.3	1.2	2.8	1.1	11.32	3.9	10.55	3.4
3/8	3/8	.....	.....	2.0	4.8	2.3	4.5	9.8	9.3	.1	.8	.3	1.2	9.41	2.7	8.73	2.3
1/2	1/2	.....	.....	1.5	3.7	2.0	3.5	5.7	4.2	.1	.2	.3	.5	7.59	1.7	6.20	1.2

CONTROLS

Untreated	.....	.....	.....	60.6	40.0	35.0	41.6	49.2	11.1	30.2	63.5	39.0	5.4	.....	36.1	.....	30.8
Test mid-date, month of	.....	.....	.....	May	July	July	Nov.	Aug.	Sept.	Feb.	May	July	Sept.	.....	.....	.....	.....

[1] Concentration expressed as fractions of full strengths, as listed in table 1.
[2] Mean value computed by converting percentage of stain in each test to the equivalent angle and reconverting the mean of the angles to a percentage.
[3] Least significant difference at 5-percent level is 3.42.
[4] Least significant difference at 5-percent level is 4.97.

Table 11.—Comparative effectiveness of 6 experimental mixtures and 3 commercial products in controlling stain on sweetgum sapwood in 5 small-scale open-piled tests

COMMERCIAL PRODUCTS

Constituents [1] and solution composition			Average area stained					
Ethyl mercuric phosphate	Sodium pentachlorophenate	Borax	Test No. 24	Test No. 26	Test No. 27	Test No. 29	Test No. 31	Means of all tests [2]
Strength	*Strength*	*Strength*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
	$\frac{1}{2}$	$\frac{3}{16}$	1.5	0.3	0.1	0.9	1.5	0.7
1			2.7	1.8	.1	.7	38.1	[3] 4.6
	1		.4	.3	0	.1	3.4	.4

EXPERIMENTAL MIXTURES

$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{8}$	1.1	0.8	0.3	0.3	1.8	0.8
$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$	.7	.9	.1	.7	3.3	1.0
$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{16}$	.3	.6	.4	.1	1.7	.5
$\frac{1}{4}$	$\frac{1}{4}$		1.2	.3	.1	.1	3.6	.7
$\frac{3}{8}$	$\frac{3}{8}$		.4	.3	0	.2	1.9	.4
$\frac{1}{2}$	$\frac{1}{2}$		.3	.3	0	.2	.9	.3

CONTROLS

Untreated			96.2	35.9	44.1	87.5	75.9	70.7

[1] Concentrations expressed as fractions of full strengths, as listed in table 1.
[2] Mean value for all tests computed by converting percentage of stain in each test to the equivalent angle and reconverting the mean of the angles to a percentage.
[3] Significantly greater than the other values at the 5-percent level, but this treatment was at a disadvantage because all but one of the tests were made in summer (see section on the effect of season on control).

The percentages of area stained were much higher and more variable in some experiments than in others. If the raw percentages were averaged, the tests with high infection levels would have an excessive influence on the conclusions. Therefore, in order to give the different experiments more nearly equal weights, each raw percentage was transformed to the equivalent angle (arc sine $\sqrt{}$ percentage) before averaging (*8, pp. 447–450*) and the arithmetic mean of these transformed back to a percentage. Because of the progressively cramped distribution of the raw stain percentages at values below 10, the use of the angle transformation increases the validity of significance tests and gives the different tests more nearly equal influence in the conclusions.

The small number of differences that are marked as significant is largely caused by the small number of tests of each individual mixture. In pine the frequency of occurrence of positive differences for the weakest mixtures and negative differences for the strongest ones that contain sodium pentachlorophenate leaves no reasonable doubt that the mixtures with the higher sodium pentachlorophenate content were superior to the full-strength sodium pentachlorophenate that was used as reference treatment, agreeing with the evidence of table 10. The hardwood results in table 9, on the other hand, agree with those of table 11 in indicating that the advantage of the strongest mixtures shown was neither mathematically nor practically significant.

Open-Piled Tests on Pine

COMMERCIAL PRODUCTS

Boards treated with the combination of ¼-strength sodium pentachlorophenate with ½-strength ethyl mercuric phosphate, used in only seven tests (table 8), had the same average amount of stain as boards treated with full-strength sodium pentachlorophenate alone, and in no test allowed as much as 10-percent stain. With the other commercial products used at recommended concentrations, there was more stain. The difference between the standard-strength sodium pentachlorophenate and the other products was large enough to be mathematically significant only for the mixture of ¼-strength sodium pentachlorophenate with borax and soda; when this product was used at a concentration that raised its sodium pentachlorophenate content to one-half strength, the average percentage of stain in the treated boards was the same as for the full-strength solution used alone in the three tests in which this comparison was possible. The degree of consistency of the observed differences can be judged from the stain percentages shown in table 10, which gives the results for each of the individual tests in which all five products had been included.

Four other commercial stain-control products were tested. Two of these were mercurial-phenolate mixtures (table 5) which, because of their ineffectiveness, were withdrawn from the market. Another, sodium salt of 2-mercaptobenzothiazole, proved ineffective (table 2) and was withdrawn from the market. The fourth, containing sodium dimethyldithiocarbamate and sodium 2-mercaptobenzothiazole, also was unsatisfactory on pine in these tests (table 2). One ingredient of this product had previously been reported to have low fungicidal value on green wood (7), and the other ingredient was tested alone in the current tests and found to be of doubtful value (table 2).

MIXTURES OF SODIUM PENTACHLOROPHENATE AND BORAX

Of the 20 mixtures of sodium pentachlorophenate and borax listed in table 8, those with sodium pentachlorophenate ⅛ strength or less were generally poorer and those with sodium pentachlorophenate ¼ strength or more were generally somewhat better than full-strength sodium pentachlorophenate alone. In no case, however, was the difference significant at the 5-percent probability level. Apparently mixtures of this type do not afford the superior protection desired for severe seasoning conditions. Many of the more effective phenolate-borax mixtures listed are too bulky for convenient commercial use.

In three tests, sodium pentachlorophenate was used at 1/16, ⅛, and ¼ strengths with 0, ¼, ⅜, ½, and ⅝ strengths of borax. Only in test No. 17 was ½-strength sodium pentachlorophenate used with all borax concentrations, and, therefore, for comparative purposes the data for ½-strength sodium pentachlorophenate mixtures had to be adjusted. For each borax concentration the ratio of the average percentage of stain for sodium pentachlorophenate at 1/16, ⅛, and ¼ strengths in tests Nos. 13 and 16 to that in test No. 17 was determined. The geometric mean of these ratios was determined for each borax concentration. These means were used to correct, by proportion, the

percentage of stain for the ½-strength mixtures obtained in test No. 17. An indication that this adjustment was sound is found in the fact that the adjusted percentage of stain for sodium pentachlorophenate ½ plus borax ⅜ derived in this way from its test No. 17 value was almost identical with the average of the percentages of this mixture actually obtained in the three tests, it being the only ½-strength mixture included in all these tests. The average effects of different borax additions to 1/16, ⅛, ¼, and ½ strengths of sodium pentachlorophenate are shown in figure 3. It should be kept in mind that the graph for ½-strength sodium pentachlorophenate is based on only one test, except for the ⅜-borax point.

For all the sodium pentachlorophenate concentrations, marked improvement in effectiveness occurred with the addition of ⅜, ½, and ⅝ strengths of borax, and all three concentrations had about the same effect. For the pentachlorophenate solutions that appear too weak, i. e., 1/16 and ⅛ strengths, borax ¼ allowed appreciably greater staining. For the two better concentrations, i. e., ¼ and ½ strengths, borax ¼ was almost as good as ⅜. There were no tests in which direct comparisons could be made between sodium pentachlorophenate ½ strength plus borax 3/16 (Permatox 10s) and sodium pentachlorophenate ½ strength plus borax ¼ strength. However, it appears that much of the benefit from borax additions to ½-strength sodium pentachlorophenate is derived from the first 3/16 strength of borax; there seems to be no warrant for using more than ⅜ strength.

When both effectiveness and bulk are considered, it appears that Permatox 10s (sodium pentachlorophenate ½ strength plus borax 3/16) represents the most efficient of the sodium pentachlorophenate-borax mixtures for general commercial use.

Should a need arise for a solution particularly low in sodium pentachlorophenate content, as for unusual avoidance of skin irritation, a mixture of sodium pentachlorophenate ¼ plus borax ⅜ would probably give satisfactory control. A mixture similar to this (sodium pentachlorophenate ¼ plus borax ⅝) was recommended for emergency use during the war, when it was doubtful whether sufficient quantities of the phenolates would be available for stain control (*11*).

MIXTURES OF ETHYL MERCURIC PHOSPHATE AND BORAX

In general, the ethyl mercuric phosphate-borax mixtures were less effective than the sodium pentachlorophenate-borax mixtures of the same fractional concentrations. The superiority of the sodium pentachlorophenate-borax mixtures was statistically highly significant for ¼ or ½ strengths plus borax and significant for the ⅛ or 1/16 strengths plus borax in the summer tests. For the winter tests, at the two low concentrations the ethyl mercuric phosphate appeared better than the sodium pentachlorophenate, while at the higher concentrations it was somewhat inferior.

The small numbers of tests involved with most of the individual ethyl mercuric phosphate-borax mixtures listed in table 8 raise doubts as to the significance of their relative effectiveness in comparison with full-strength sodium pentachlorophenate used alone. When grouped on the basis of mercurial content, those containing 1/16, ⅛, and ¼

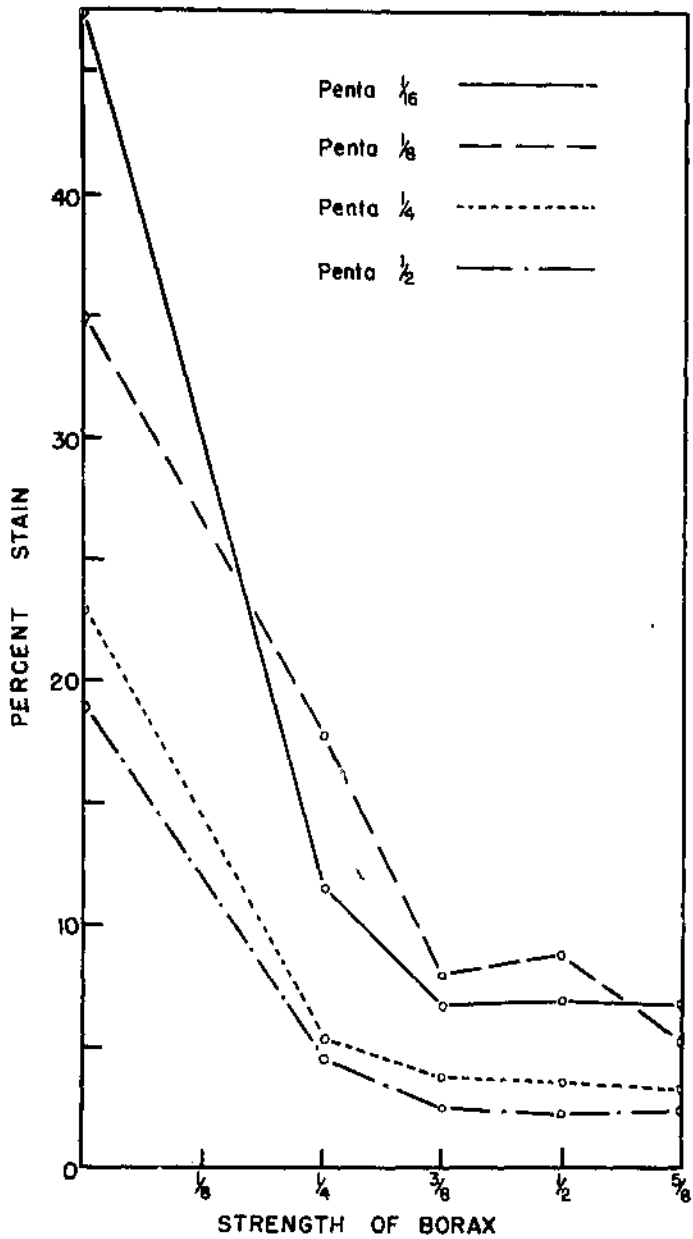

FIGURE 3.—The effect on stain control of additions of ⅛-, ⅜-, ½-, and ⅝-strength borax to 1/16-, ⅛-, ¼-, and ½-strength sodium pentachlorophenate. In the same tests, full-strength sodium pentachlorophenate allowed 7.3 percent stain. (Penta=sodium pentachlorophenate.)

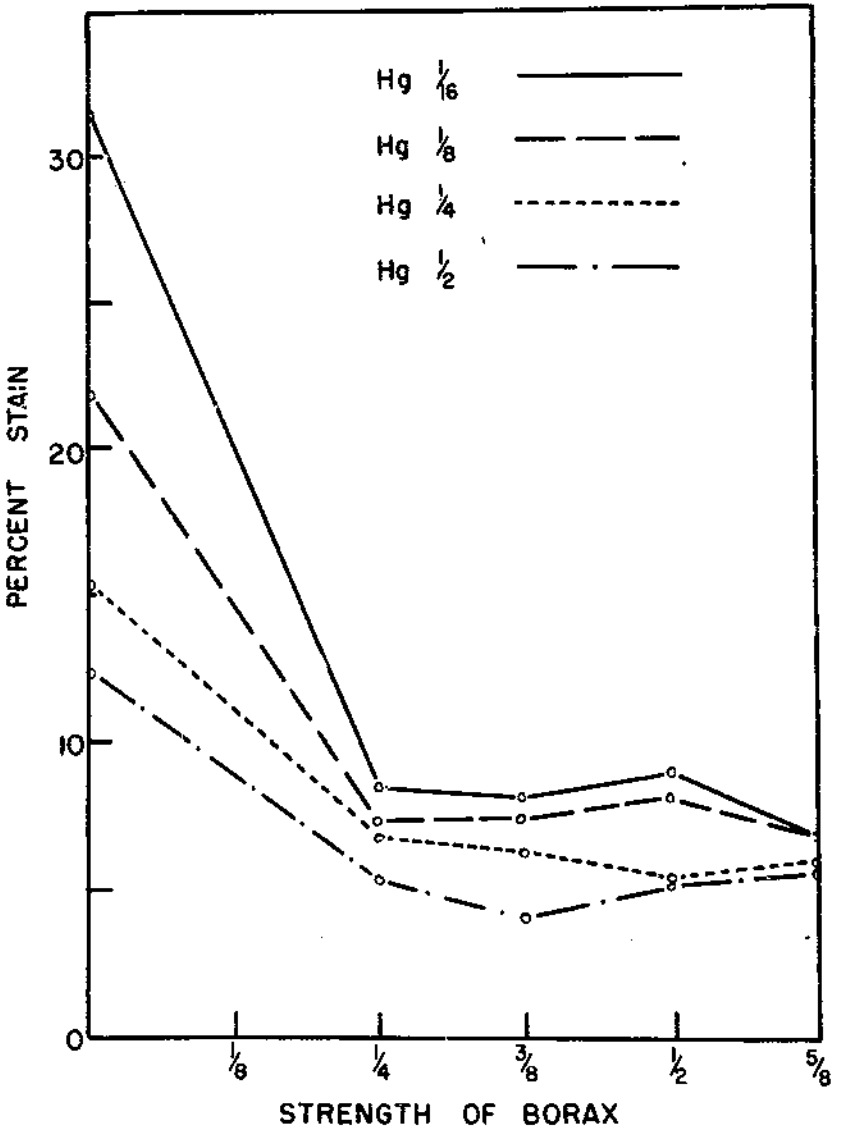

FIGURE 4.—The effect on stain control of additions of ¼-, ⅜-, ½-, and ⅝-strength borax to 1/16-, ⅛-, ¼-, and ½-strength ethyl mercuric phosphate. In the same tests, full-strength ethyl mercuric phosphate permitted 4.1 percent stain. (Hg=ethyl mercuric phosphate.)

strengths are significantly different from full-strength sodium pentachlorophenate.

The effects of different borax additions to 1/16, ⅛, ¼, and ½ strengths of ethyl mercuric phosphate are shown in figure 4, which gives average figures for small-scale tests Nos. 13, 16, and 17. An adjustment was made in percentage of stain for ½-strength ethyl mercuric phosphate

similar to that explained under the sodium pentachlorophenate-borax mixtures in the preceding section. In the case of ethyl mercuric phosphate, the effect of borax additions was more uniform than with the sodium pentachlorophenate. With all concentrations there was a marked improvement in stain control with the addition of ¼-strength borax, and ⅜, ½, or ⅝ strengths of borax did not materially increase the effectiveness.

The ethyl mercuric phosphate-borax mixtures retained the green-mold hazard of the mercurial used alone.

The data indicate that mixtures of ethyl mercuric phosphate and borax offer little promise for superior stain control. They could, however, be used for emergency purposes, with a saving of mercury, as recommended during the war (*11*).

MIXTURES OF SODIUM PENTACHLOROPHENATE AND ETHYL MERCURIC PHOSPHATE

Of the sodium pentachlorophenate-ethyl mercuric phosphate mixtures listed in table 8, those containing 1/16 or ⅛ strengths of each component were significantly less effective, statistically; those containing ¼ or ⅜ strengths were equal; and the one containing ½ strength was significantly superior to full-strength sodium pentachlorophenate on the basis of average percentage of stain for all tests. Had more tests been involved, it is probable that the ⅜ plus ⅜ mixture could also be shown significantly better. In none of the tests did the ⅜ plus ⅜ or the ½ plus ½ mixtures permit an average of 10-percent stain, while full-strength sodium pentachlorophenate permitted 10 percent or more stain in a tenth and a fifth, respectively, of the tests involved in the two comparisons. When the concentrations were reduced to ¼ plus ¼, the mixture permitted 10 percent or more stain in a quarter of the tests, while full-strength sodium pentachlorophenate allowed similar amounts of stain in a fifth of the tests.

One of the commercial products listed in table 1 is a mercurial-phenolate mixture containing ½-strength ethyl mercuric phosphate plus ¼-strength sodium pentachlorophenate. The total concentration of both components is the same as in the ⅜ plus ⅜ mixture. In the data there is little difference in effectiveness between the two. The slightly better showing of the ⅜ plus ⅜ mixture is probably due to the lower mercurial and higher phenolate content of the equal mixture. This would tend to give the equal-proportion mixture the advantage during the summer, when most of the tests were made.

MIXTURES OF SODIUM PENTACHLOROPHENATE, ETHYL MERCURIC PHOSPHATE, AND BORAX

In the few tests in which they were included, triplex mixtures containing sodium pentachlorophenate 1/16 strength, ethyl mercuric phosphate 1/16, and borax ⅜, and another containing sodium pentachlorophenate 1/32, ethyl mercuric phosphate 1/32, and borax ⅜ did not prove markedly inferior to full-strength sodium pentachlorophenate. Nevertheless, such low concentrations could not be considered safe without further trials, in view of the poor showing of such mixtures when used without the borax component.

The mixture of sodium pentachlorophenate 1/8, ethyl mercuric phosphate 1/8, and borax 3/8, which was previously recommended for emergency use (*11*), was extensively tested and found nearly but not quite equal in average effectiveness to full-strength sodium pentachlorophenate.

The mixtures of sodium pentachlorophenate 3/16, ethyl mercuric phosphate 3/16, and borax, and of sodium pentachlorophenate 1/4, ethyl mercuric phosphate 1/4, and borax were generally better than full-strength sodium pentachlorophenate regardless of the borax content. When all borax concentrations were combined, the superiority of the 3/16 plus 3/16 plus borax mixture was not significant at the 5-percent probability level, but that of the 1/4 plus 1/4 plus borax mixture was highly significant.

In order to get a better idea of the effects of various borax additions in triplex mixtures, the data for small-scale tests No. 15, summer; No. 20, winter; and No. 23, winter; were singled out for special analysis. Only in these three tests was there sufficient spread in borax poundages to permit any detailed analysis. The average percentages of stain in pine treated with 1/16 plus 1/16, 1/8 plus 1/8, and 1/4 plus 1/4 strengths of sodium pentachlorophenate and ethyl mercuric phosphate, respectively, with 0, 1/8, 1/4, or 3/8 strength of borax are shown in figure 5. The addition of 1/8, 1/4, or 3/8 strengths of borax greatly improved each mixture. One-fourth strength borax was about as beneficial as 3/8, except with the 1/16 plus 1/16 mixture, where the 3/8 strength still caused improvement over the 1/4.

The inference from figure 5 is that in triplex mixtures there is little advantage in adding more than 1/4 strength of borax per 50 gallons. One-eighth strength appeared to be too low.

In four other small-scale tests on pine and sweetgum, triplex mixtures with 3/16 or 1/4 strength of borax were tried. The data from these tests are given in table 12. Without exception, the mixtures with 3/16-strength borax gave better stain control on pine than those with 1/4 strength. A progressive increase in stain on pine treated with increases in borax concentrations has been observed in a number of tests whether the borax was applied alone or in mixtures. This increased stain is thought to be caused by *Alternaria*, which is resistant to borax (*13*) and perhaps favored by the suppression of competing organisms at the higher concentration. On sweetgum the mixtures with 1/4-strength borax appeared better, but probably this is not of practical importance, as control with the 3/16 strength was nearly perfect.

Open-Piled Tests on Hardwoods

In the hardwood tests (tables 9 and 11), all the commercial products and experimental mixtures gave adequate stain control. Because of the small numbers of tests and the general low average of stain readings, none of the differences found can be considered significant. The data indicate that some of the weaker mixtures may be more effective on sweetgum than on pine.

Experience has shown that good stain control is relatively easily attained with chemical treatment of fresh green sweetgum. It was for this reason that most tests were made with the more refractory pine. In commercial hardwood operations, serious problems of stain

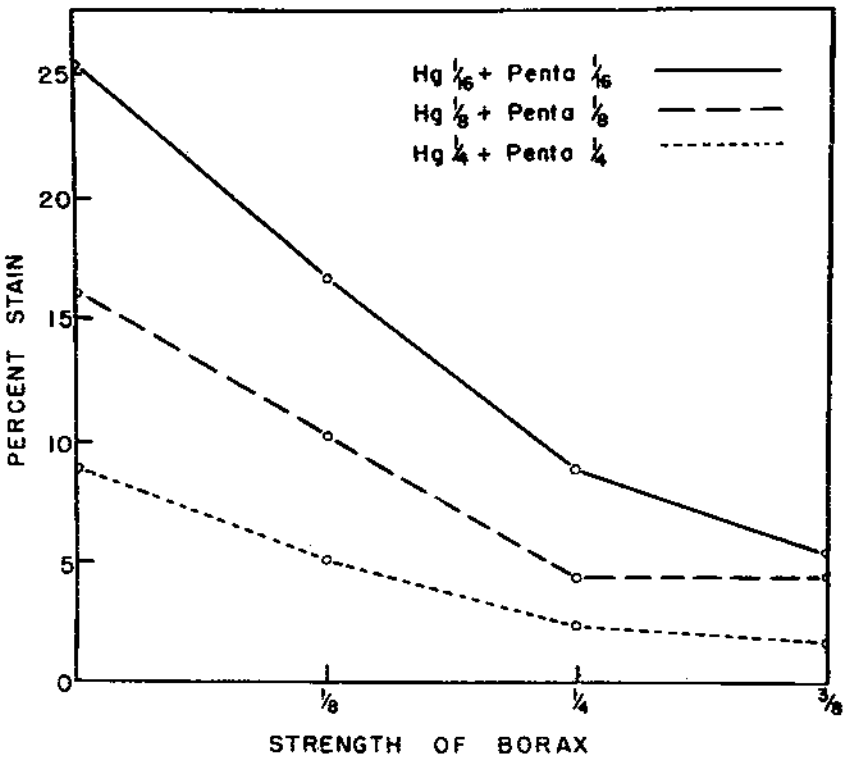

FIGURE 5.—The effect on stain control of additions of ⅛-, ¼-, and ⅜-strength borax to 1/16- plus 3/16-, ⅛- plus ⅛-, and ¼- plus ¼-strength mixtures of sodium pentachlorophenate and ethyl mercuric phosphate, respectively. In the same tests, full-strength ethyl mercuric phosphate and sodium pentachlorophenate permitted 6.0 and 7.3 percent of stain, respectively. (Penta=sodium pentachlorophenate; Hg=ethyl mercuric phosphate.)

TABLE 12.—*Comparative effectiveness of 3/16- and ¼-strength borax in triplex mixtures*

ON PINE

Constituents[1] and solution composition			Average area stained				
Ethyl mercuric phosphate	Sodium pentachlorophenate	Borax	Test No. 24	Test No. 26	Test No. 27	Test No. 29	Means of all tests[2]
Strength	*Strength*	*Strength*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1/4	1/4	3/16	4.7	3.4	1.8	5.4	3.7
1/4	1/4	1/4	5.1	5.7	3.1	6.1	4.9
3/16	3/16	3/16	5.4	5.6	1.6	6.8	4.0
3/16	3/16	1/4	7.3	7.7	2.2	6.9	5.7
ON SWEETGUM							
1/4	1/4	3/16	0.3	0.6	0.4	0.1	0.3
1/4	1/4	1/4	.2	.4	.1	(3)	.3
3/16	3/16	3/16	.7	.9	.1	.7	.5
3/16	3/16	1/4	1.0	.2	.1	.6	.4

[1] Concentrations expressed as fractions of full strengths, as listed in table 1.
[2] Mean value for all tests computed by converting percentage of stain in each test to the equivalent angle and reconverting the mean of the angles to a percentage.
[3] Trace.

control arise. In the South most hardwood logs come from areas in which continuous logging is difficult. This has necessitated, or at least encouraged, heavy logging during favorable periods and longer periods of log storage. Hardwood logs stain rapidly, and as a result much hardwood lumber is already infected at the time of sawing. Surface treatments do not kill such infections. It is possible that a superior treatment, as sodium pentachlorophenate ½ with ethyl mercuric phosphate ½, would be more effective in preventing internal infections from being manifested on the surface. Nevertheless, the hardwood-stain problem probably does not call for better treatments as much as for better handling procedures.

Close-Piled Tests on Pine and Hardwood Lumber

Freshly treated lumber is commonly close-piled for periods varying from a few hours to a few days before being placed in seasoning piles. Also, during periods of lumber shortages and to a less extent in normal times, lumber may be shipped green. When ocean transportation is involved, the lumber may be close-piled in a green condition for a month or more. Several small-scale tests were established to determine the effectiveness of chemical control under these severe conditions.

Sweetgum was used in two summer tests and two winter tests. Oak and hickory were each included in one winter test. The amount of stain that developed in these tests is listed in table 13 and the amount of decay in table 14.

TABLE 13.—*Comparative effectiveness of various fungicides in controlling stain on hardwood lumber close-piled for 5 to 10 weeks in 2 summer and 4 winter tests*

Constituents [1] and solution composition					Average area stained [2]	
Ethyl mercuric phosphate	Sodium pentachlorophenate	Sodium tetrachlorophenate	Adjuvants: Borax	Adjuvants: Soda	5 to 8 weeks	10 weeks
Strength	*Strength*	*Strength*	*Strength*	*Strength*	*Percent* [3]	*Percent* [4]
	1				1	1
		1			1	9
1					1	1
	½		⅛	⅛	2	1
	1		1	1		
¼	¼				[3]	[3]
⅛	⅛				[3]	[3]
½	½				[3]	[3]
⅛	⅛		⅛		1	1
1/16	1/16		1/16		[3]	[3]
¼	¼		1/16		[3]	[3]
Untreated controls					88	[4] 52

[1] Concentrations expressed as fractions of full strengths, as listed in table 1.
[2] Average computed by converting percentage of stain in each test to the equivalent angle and reconverting the mean of the angles to a percentage.
[3] Trace.
[4] Stain bleached by decay.

Mold was too light to warrant listing; it averaged none to very light for the various treatments. In individual tests, mold ratings exceeding 1.0 percent occurred only on oak treated with ethyl mercuric phosphate (2.1), on untreated oak (1.9), and on untreated sweetgum (1.4 in one of four tests).

TABLE 14.—*Comparative effectiveness of various fungicides in controlling decay in hardwood lumber close-piled for 5 to 30 weeks*

Constituents [1] and solution composition					Average area showing decay [2]				
Ethyl mercuric phosphate	Sodium pentachlorophenate	Sodium tetrachlorophenate	Adjuvants		Summer [3] (2 tests)		Winter [3] (4 tests)		
			Borax	Soda	5 weeks	19 weeks	5 to 8 weeks	10 weeks	30 weeks
Strength	*Strength*	*Strength*	*Strength*	*Strength*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
	1	1			0	14 (50)	0	0	1 (25)
1							0	[4] (5)	1 (40)
					0	5 (35)	0	0	4 (40)
	$\frac{1}{2}$		$\frac{3}{10}$		0	3 (25)	0	0	[4] (25)
$\frac{1}{4}$	$\frac{1}{4}$		$\frac{1}{7}$	$\frac{1}{20}$			0	0	10 (70)
$\frac{3}{8}$	$\frac{3}{8}$				0	8 (45)			
$\frac{1}{2}$	$\frac{1}{2}$				[4] (5)	3 (30)			
$\frac{1}{8}$	$\frac{1}{8}$		$\frac{3}{5}$		0	1 (5)			
$\frac{3}{16}$	$\frac{3}{16}$		$\frac{3}{10}$		[4] (5)	2 (15)			
$\frac{1}{4}$	$\frac{1}{4}$		$\frac{3}{10}$		[4] (5)	8 (45)			
					[4] (5)	7 (40)			
Untreated controls					1 (50)	37 (85)	1 (39)	11 (95)	69 (100)

[1] Concentrations expressed as fractions of full strengths, as listed in table 1.
[2] Figures in parentheses are percentage of number of samples showing decay.
[3] Summer tests had their midpoint in the period May to October; winter tests in the period November to April.
[4] Trace.

All the treatments were effective in preventing stain for 5 weeks and, with the exception of ethyl mercuric phosphate, for periods of 10 weeks also. The data are insufficient to warrant any distinction in effectiveness among the treatments. There was no difference in stain-control level between summer and winter conditions in these tests.

In the winter tests all treatments effectively controlled decay for 5 to 10 weeks. For most treatments, small amounts of decay were observed with 30 weeks of close piling. The mixture containing soda seemed least effective. In the summer tests, small amounts of decay appeared in 5 weeks, and the test samples seemed to be well infected by 10 weeks. Softening was evident in many of the infected samples, also.

Although data were obtained from eight tests with close-piled pine, a number of the treatments were included in only one or two tests. Also, there was considerable variation in stain level among the different tests. In all tests, readings were taken after 1 month's exposure; in some cases no readings were taken at 2 months, and after longer periods usually decay ratings only were recorded because stain was bleached by decay fungi. Therefore, average values for stain and decay are of little value in comparisons except with similar averages for wood treated with full-strength sodium pentachlorophenate and exposed in the same tests.

The average amounts of stain and decay occurring in close-piled pine are listed in tables 15 and 16. All comparisons should be made with the averages for full-strength sodium pentachlorophenate in the same tests.

During the winter practically no stain developed within 1 month, except in the untreated samples and those treated with the mixture containing soda. Two months' exposure allowed relatively small amounts of stain to develop, except in those dipped in the mixture containing soda.

In the summer tests with pine, the stain level at 1 month roughly equaled that at 2 months in the winter series and usually was high after 2 months. Most of the mixtures appeared superior to sodium pentachlorophenate or ethyl mercuric phosphate at full strength after 1 month's and 2 months' exposure.

Mold ratings usually were slightly less than those listed in table 18 for open-piled pine. The only exceptions were for lumber treated with ethyl mercuric phosphate, full and double strength, which showed a higher mold rate. With the exception of ethyl mercuric phosphate alone and in mixture with borax, mold control was good.

No visible decay occurred in any of the treated pine during the winter after 1 month. Visible decay occurred only with that pine treated with the sodium pentachlorophenate-soda-borax mixture after 2 months, and with ethyl mercuric phosphate and the sodium pentachlorophenate-soda-borax mixture after 4 months. Similarly, in the summer tests no decay or only insignificant amounts developed in 1 and 2 months. Four to 5 months' exposure allowed some decay, which in a few cases amounted to 40 to 100 percent of the number of samples; after 7 to 8 months, only double-strength sodium pentachlorophenate, the higher strengths of triplex mixtures of sodium pentachlorophenate, ethyl mercuric phosphate, and borax, and the higher strengths

TABLE 15.—*Stain developing on pine sapwood lumber dipped in various solutions compared to that on lumber dipped in sodium pentachlorophenate: close-piled for 1 and 2 months*

Constituents [1] and solution composition (A)				Average area stained [2]							
				Summer [3] (5 tests)				Winter [3] (3 tests)			
				After 1 month		After 2 months		After 1 month		After 2 months	
Ethyl mercuric phosphate	Sodium pentachlorophenate	Borax	Soda	Treatment in column (A)	Sodium pentachlorophenate [4]	Treatment in column (A)	Sodium pentachlorophenate [4]	Treatment in column (A)	Sodium pentachlorophenate [4]	Treatment in column (A)	Sodium pentachlorophenate [4]
Strength	*Strength*	*Strength*	*Strength*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1/8	1/8	3/8		2	4	6	20	5 1	(6)	2	5
3/16	3/16	3/16		4	8	10	50				
3/16	1/4	1/4		3	8	7	30				
1/4	1/4	3/16		4	8	20	50				
1/4	1/4	1/4 or 3/8		2	4	3	20				
1/4	1/4			5	8	50	50	(5)	(6)	7	5
3/8	1/2			5	8	37	50				
1/4				3	8	16	50	(5)	(6)	(5)	5
1/2		3/8 or 5/8		1	(6)	4	2	(5)	(6)	(5)	7
		3/16 or 3/8		2	5	10	20				
	1/4	1/4 or 3/8		3	5	6	20	(5)	(6)	1	7
	1/2	3/16 or 3/8		6	3	16	12				
1/2				5	2	18	11	(6)	(6)	3	6
				(5)		2	2				
	1/2			2		11		(6)		6	
				(5)	(6)	2	2				
	1/4	1/2	1/20	7	(6)	28	2	5	(6)	38	5
Untreated controls			1/10	3	(6)	6	2				
				33	2	41	14	76	(6)	83	6

[1] Concentrations expressed as fractions of full strengths, as listed in table 1.
[2] Average computed by converting percentage of stain in each test to the equivalent angle and reconverting the mean of the angles to a percentage.
[3] Summer tests had their midpoint in the period May to October; winter tests in the period November to April.
[4] Average amount of stain in lumber treated with full-strength sodium pentachlorophenate in the same tests as the treatment averages in the columns to the left.
[5] Based on 1 test.
[6] Trace.

TABLE 16. *Decay developing in pine sapwood lumber dipped in various solutions compared to that in lumber dipped in sodium pentachlorophenate; close-piled for 1 to 8 months*

Constituents [1] and solution composition (A)					Average area showing decay [2]													
	Adjuvants				Summer [3] (5 tests)						Winter [3] (3 tests)							
					After 1 month (5 tests)		After 2 months (2 tests)		After 4–5 months (2 tests)		After 7–8 months (3 tests)		After 1 month (3 tests)		After 2 months (3 tests)		After 4 months (1 test)	
Ethyl mercuric phosphate	Sodium pentachlorophenate		Borax	Soda	Treatment in column (A)	Sodium pentachlorophenate [4]	Treatment in column (A)	Sodium pentachlorophenate [4]	Treatment in column (A)	Sodium pentachlorophenate [4]	Treatment in column (A)	Sodium pentachlorophenate [4]	Treatment in column (A)	Sodium pentachlorophenate [4]	Treatment in column (A)	Sodium pentachlorophenate [4]	Treatment in column (A)	Sodium pentachlorophenate [4]
Strength		*Strength*	*Strength*	*Strength*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
	1/8	1/8			0	5 (3)	0	1 (20)	* 2 (10)	4 (10)	1 (30)	* 1 (55)	* 0	0	* 0	0	0	0
	1/16	1/16			0	1 (10)	* 0	1 (20)	* 2 (10)	4 (10)	* 0	1 (50)						
	1/16	1/16			0	1 (10)	* 0	1 (20)	* 0	4 (10)	* 0	1 (50)						
	1/8	1/4			0	1 (10)	* 0	1 (20)	* 0	4 (10)	* 0	* (50)						
	1/4	1/4	1/4 or 1/8		0	1 (10)	* 0	1 (20)	* 0	4 (10)	* 0	* (45)	* (55)					
	1/4	1/4			0	1 (10)	* 1 (30)	1 (20)	* 10 (100)	4 (10)	* (50)	* (50)	* 0	0	* 0	0	0	0
	1/8	1/8			0	1 (10)	* 0	1 (20)	* 18 (60)	4 (10)	* (50)	* (50)						
	1/2	1/2			0	2 (10)	* 0	1 (20)	* 0	4 (10)	* (50)	* (50)	0	0	* 0	0	0	0
	1/4		1/8 or 1/8		0	0					10 (100)	1 (60)	0	0	0	0		
	2		1/16 or 1/8		0	1 (10)	* 0	1 (20)	* 8 (40)	4 (10)	* 18 (100)	1 (60)						
			1/8 or 1/8		0	0					* 13 (70)	1 (60)	0	0	0	0		
			1/2	1/16 or 1/8	0	* (3)	0	* (10)	1 (5)	2 (18)	* (25)	1 (75)						
	1				0	* (3)	* (10)	* (10)	2 (50)	2 (18)	3 (87)	2 (70)	0	0	0	0	1 (50)	0
	2										8 (100)	1 (60)						
		1			3		* (10)		2 (18)		2 (70)		0		0		0	
		2									* (10)	1 (60)						
			1/4	1/20							* 14 (100)	1 (60)	* 0	0	* (20)	0	1 (100)	0
			1/2	1/10							1 (40)	1 (60)						
Untreated controls					11 (100)	* (3)	51 (100)	* (10)	90 (100)	2 (18)	71 (100)	2 (70)	* (57)	0	* (83)	0	34 (100)	0

[1] Concentrations expressed as fractions of full strengths, as listed in table 1.
[2] Figures in parentheses refer to percentage of number of test samples showing decay.
[3] Summer tests had their midpoint in the period May to October; winter tests, in the period November to April.
[4] Average percent decay in lumber treated with full-strength sodium pentachlorophenate in the same tests as the treatment averages in the columns to the left.
* Trace.
[5] Based on 1 test.

of mixtures of sodium pentachlorophenate and borax gave good decay control. The special effect of borax additions in preventing decay appeared in connection with this treatment.

The above-described tests do not take into account one important factor. At the end of 2 to 3 months in close piles, the wood is still wet enough to stain and decay. Any infections present would have additional time to develop during subsequent air seasoning. In three of the pine tests, samples were withdrawn after various periods of close piling and placed in open seasoning piles. The seasoning piles were partially enclosed with boards to reduce drying rate in an attempt to approximate that of full-size lumber under commercial conditions. The results of these three tests are given in table 17.

TABLE 17.—*Stain developing in close-piled pine sapwood and during subsequent air seasoning*

Season,[1] test No., and treatment [2]	Average area stained after close piling for—				Average area stained after seasoning subsequent to close piling for—			
	2 weeks	4 weeks	6 to 7 weeks	11 weeks	2 weeks	4 weeks	6 to 7 weeks	11 weeks
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Summer, No. 10:								
Ethyl mercuric phosphate 1.0	0.1	0.8			0.7	5.0		
Sodium pentachlorophenate 1.0	.1	.4			.8	4.3		
Ethyl mercuric phosphate ¼ plus borax ⅝	[3]	.9			.2	2.7		
Sodium pentachlorophenate ¼ plus borax ⅝	.1	3.7			.2	8.3		
Untreated, close-piled	63	82			69	63		
Untreated, not close-piled [4]					19			
Winter, No. 11:								
Ethyl mercuric phosphate 1.0			0	0.1			0.6	1.8
Sodium pentachlorophenate 1.0			.1	.9			5.7	10
Ethyl mercuric phosphate ¼ plus borax ⅜			0	[3]			.2	1.2
Sodium pentachlorophenate ¼ plus borax ⅝			3	1.6			2.5	6.4
Untreated			50	96			93	99
Winter, No. 13:								
Ethyl mercuric phosphate 1.0	0	.1	11		.1	1.7	14	
Sodium pentachlorophenate 1.0	0	9	17		.5	7.3	21	
Ethyl mercuric phosphate ¼ plus borax ⅜	0	.1	.7		.3	.1	.5	
Sodium pentachlorophenate ¼ plus borax ⅜	0	.3	.4		.3	.3	.5	
Untreated, close-piled	12	100	96		79	99	93	
Untreated, not close-piled [4]					55	32		

[1] Summer tests had their midpoint in the period May to October; winter tests, in the period November to April.
[2] Concentrations expressed as fractions of full strengths, as listed in table 1.
[3] Trace.
[4] Fresh green sapwood cut at the end of the close-piled period.

At the end of 2 and 4 weeks of close piling, the wood contained essentially the same amount of moisture as at the beginning of the test, judging by general appearance, and in test No. 13, by actual weights. At the end of longer close-piling periods, there had been noticeable moisture loss but not enough to slow fungus activity (79 percent moisture in test No. 13). In tests Nos. 10 and 13, the test samples were air-dry (20 percent or less moisture) after 2 to 4 weeks in the seasoning pile. Even with this rapid seasoning the amount of stain increased appreciably during seasoning. Test No. 11 differed from the other two tests in that the board ends were given a moistureproof coating after the fungicidal treatment to reduce the drying rate. The amount

of stain showed a marked increase during the seasoning period. This test probably indicates what might be expected during commercial air seasoning under conditions more severe than average.

Although the data are not conclusive, they suggest that fungicides at the strengths ordinarily used on lumber will give good fungus control during 2 weeks of close piling followed by air seasoning, but that in the South the fungicides cannot be counted on for longer periods. Even under winter conditions longer periods of close piling may lead to excessive stain during seasoning. Lumber to be kiln-dried directly after close piling probably can safely be close-piled for 1 month during the summer and 2 months during normal winters. If lumber is to be close-piled for more than a few days, the safest procedure would be to treat it with concentrations 1.5 to 2 times those ordinarily used on lumber to be immediately seasoned.

In one pine test started on September 1, matched samples were removed from close piling after 1, 2, 4, 7½, 11, and 14 months, and quickly air-dried. These samples were tested for toughness.[4] The relative toughness values of the treated and untreated material after various periods of close piling are shown in figure 6. The untreated wood showed loss in strength with 1 month's storage, while in the treated material only one treatment showed a slight loss after 4 months. All samples showed appreciable loss after 7½ months' exposure. The strength losses and visual decay ratings for the 4 to 14 months' periods were poorly correlated. This was largely caused by the variations in toughness measurements in entirely sound wood, but also indicated the difficulty of visually determining the amount of decay from surface manifestations.

A further precaution is necessary in interpreting the data of these close-piled tests. All the lumber used was from fresh logs free of infections that would escape killing by fungicidal treatment. This is not always true in commercial operations, particularly with hardwoods that were most easily protected in the tests. Minor infections prior to chemical treatment may not develop to serious proportions during normal seasoning, but if seasoning is delayed by any protracted close piling, serious development may result. Therefore, even though the data indicate that fungicidal treatment may permit close piling for appreciable periods, the safest procedure would be to season lumber as soon as practicable after treatment, and when close piling for appreciable periods is unavoidable better-than-average drying conditions should be provided for subsequent air seasoning.

Mold Control

Previous work (7) and the current tests have shown that the important molds on seasoning lumber in the South are: (1) *Penicillium* on mercurial-treated pine, (2) *Alternaria* on borax-treated pine, and (3) *Trichoderma* on pine treated with fluorides and some other chemicals and also on lumber cut from old logs, particularly those stored for

[4] Scheffer, T. C. and Drow, J. T. toughness of treated and untreated southern pine sapwood after bulk piling green from the saw for 1 to 14 months at Saucier, Miss. Southern Special Test No. 31-0. U. S. Bur. Plant Indus., Soils, and Agr. Engin., and U. S. Forest Prod. Lab. 6 pp., illus. 1947. [Unpublished report.]

long periods in ponds. As was pointed out in a separate report (*13*), these molds are actually favored by some chemical treatments. In commercial air seasoning in the South, molds are seldom bothersome on treated wood except during adverse drying weather.

The average total mold ratings for pine in open-piled small-scale tests are listed in table 18. Also listed are the highest total rating assigned each treatment in an individual test.

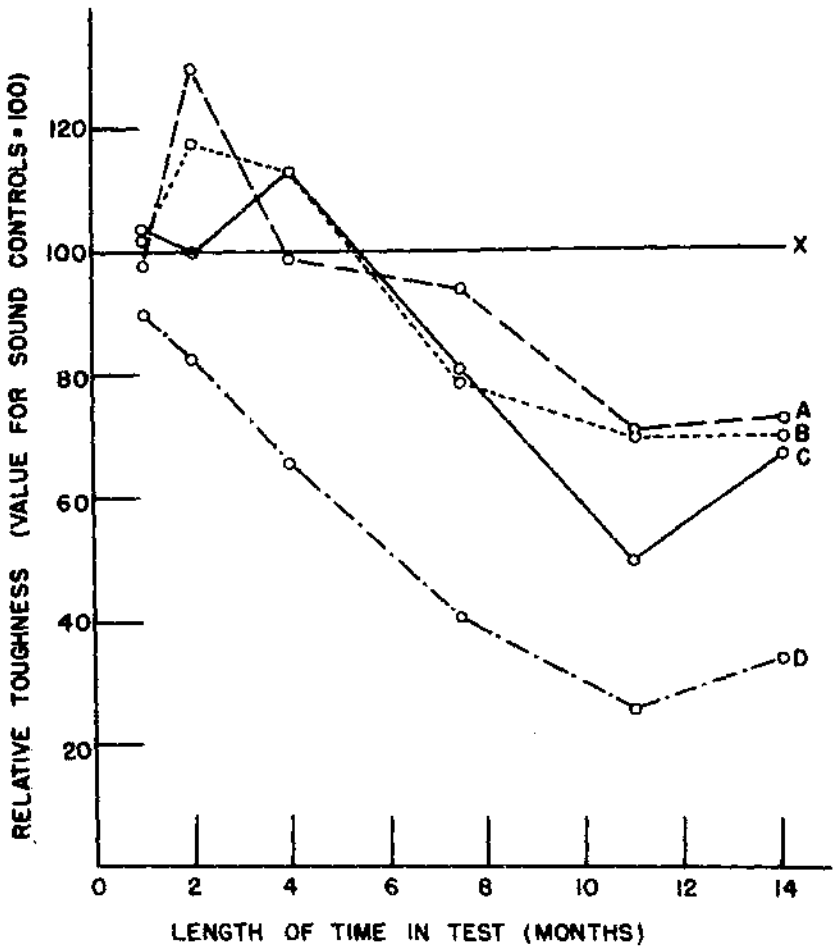

FIGURE 6.—Loss in toughness of pine sapwood treated with full-strength ethyl mercuric phosphate (*A*), half-strength sodium pentachlorophenate plus ¾₀-strength borax (*B*), full-strength sodium pentachlorophenate (*C*), or untreated (*D*); close piled for various lengths of time. These are compared to sound controls (*X*) not exposed to infection. The test was started on September 1.

The high ratings for mold, when lumber was treated with ethyl mercuric phosphate, reflect the tolerance of *Penicillium* for mercurials. This tolerance of *Penicillium* was shown also when ethyl

mercuric phosphate mixtures were used as control treatments. However, when the mixtures were used, the molds that developed were molds other than *Penicillium*, whereas *Penicillium* molds showed the highest rating of incidence where mercurials alone were used.

TABLE 18.—*Comparative effectiveness of different treatments in controlling mold on pine sapwood in open-piled small-scale tests*

Constituents [1] and solution composition				Mold rating [2]		
Ethyl mercuric phosphate	Sodium pentachlorophenate	Adjuvants		Average [3]		Maximum
		Borax	Soda	Summer [4]	Winter [4]	
Strength	*Strength*	*Strength*	*Strength*			
1	1			2.4	2.0	4.2
				.3	.2	1.3
$\frac{1}{4}$		$\frac{1}{4}$ to $\frac{3}{4}$		2.3	1.7	4.6
$\frac{1}{2}$		$\frac{3}{16}$ to $\frac{3}{8}$		2.4	3.1	3.3
	$\frac{1}{2}$	$\frac{1}{4}$ to $\frac{3}{4}$		.0	.0	1.0
	$\frac{1}{8}$	$\frac{3}{16}$ to $\frac{3}{8}$		.5	.3	1.2
	$\frac{1}{4}$	$\frac{1}{32}$	$\frac{1}{20}$	.5	.3	1.6
$\frac{1}{4}$	$\frac{1}{4}$			.3	.4	1.1
$\frac{3}{8}$	$\frac{3}{8}$			.4	.6	1.0
$\frac{1}{2}$	$\frac{1}{2}$			.2	.2	.7
$\frac{1}{2}$	$\frac{1}{2}$			.4	.8	1.3
$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$		.7	.5	3.3
$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$		.4	.5	1.0
$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{16}$		.3	.3	.8
Untreated controls				1.2	2.1	4.5

[1] Concentrations expressed as fractions of full strengths, as listed in table 1.
[2] Mold ratings on an arbitrary scale of 0 (none) to 5 (very heavy).
[3] Based on 24 summer tests and 10 winter tests. All treatments were not included in all tests. Most averages based on 5 or more tests.
[4] Summer tests had their midpoint in the period May to October; winter tests, in the period November to April.

With the exception of ethyl mercuric phosphate alone or with borax, the proprietary chemicals and experimental mixtures afforded adequate mold control, averaging a trace to very light infection. The highest mold ratings for treatments containing sodium pentachlorophenate were for orange mold. This mold was found largely on phenolate-treated wood. Only traces of orange mold have been observed in commercial operations. The data here presented, in addition to that in a previous report (*13*), suggest that increased concentrations of mercurials increase molding, increased concentrations of sodium pentachlorophenate reduce molding, and that borax has less adjuvant value against molds than against stain, and especially decay fungi.

In general, molds seem of less importance on hardwoods than on pine in most commercial operations. This observation was substantiated by the uniformly low mold ratings on hardwoods in the current tests. For treated wood, ratings averaged 0 to 0.6, with the maximum rating of 1.0 in any individual test. Untreated hardwoods averaged 1.0, with a maximum of 2.0.

Molding of treated close-piled wood was somewhat less than on the open-piled, with the exception of that treated with ethyl mercuric phosphate. This chemical permitted somewhat more molding on close-piled pine and hardwood.

THE EFFECT OF SEASON ON CONTROL

Commercial experience has shown that, in general, stain development is greater during the warmer months. Extensive observations

in both commercial seasoning yards and in tests clearly prove, however, that in the Gulf States control measures cannot be relaxed during the winter if degrade by stain is to be prevented. Some operators do not dip during the cooler months, preferring to save the expense of dipping even though this periodically permits appreciable staining. By contrast, at a number of mills regular-strength solutions are used during the winter and 1.5 to 2 times regular strengths are used during the summer.

The relative effectiveness of different chemical solutions against mold during the summer and winter has not been reported previously. Therefore, the test data were analyzed to determine whether important seasonal differences in effectiveness do exist. A preliminary analysis had shown that ethyl mercuric phosphate was less effective during the period May to October, and more effective during the period November to April, inclusive, than was sodium pentachlorophenate. Consequently, all the tests whose midpoint occurred during the period May to October were arbitrarily classed as summer tests and all those with a midpoint November to April were classed as winter tests. The data for 12 treatments in small-scale open-piled pine tests are given in table 19.

For all treatments except borax, stain and decay were appreciably less in winter tests. Among the molds, *Alternaria* was distinctly more prevalent during the winter on borax-treated wood and *Penicillium* was somewhat more prevalent in winter tests. For the other molds, the ratings were generally slightly higher during the summer, but the ratings as a whole were so low and the differences generally so small that they probably are of no significance. The significantly lower average stain ratings for winter tests strongly suggest that in averaging stain data from different tests, season must be considered.

The data in table 19 show the relative development of stain, mold, and decay in winter and summer but do not show reliably the comparative effectiveness of different treatments in different seasons, as the figures are not always based on the same tests. Other analyses showed that when compared with full-strength sodium pentachlorophenate in the same tests, the only treatment that showed a clear difference in relative effectiveness with season was ethyl mercuric phosphate. However, when ethyl mercuric phosphate and the sodium pentachlorophenate were used together in mixtures of unequal proportions (as mercurial 1/3 and phenolate 2/3, or mercurial 2/3 and phenolate 1/3), there was an indication (table 6) that those with a higher proportion of ethyl mercuric phosphate were more effective in winter tests and less effective in summer tests than were those with a higher sodium pentachlorophenate content. This was also true when borax was added as a third component. There was also an indication of the same difference in relative effectiveness with season when mercurial-borax and phenolate-borax mixtures were compared.

In order to bring out more fully the seasonal differences for ethyl mercuric phosphate and sodium pentachlorophenate, the data were analyzed from 49 small-scale and large-scale open-piled and close-piled tests in which both chemicals were included. Figure 7 shows that in the majority of tests on pine, ethyl mercuric phosphate gave better stain control than sodium pentachlorophenate during the winter, and the reverse was true during the summer. The type of test did not

TABLE 19.—*Stain, mold, and decay on treated and untreated open-piled pine in winter (W) [1] and summer (S) [1] small-scale tests [2]*

Constituents [3] and solution composition				Tests		Average area with—						Average mold rating [4]									
Ethyl mercuric phosphate	Sodium pentachlorophenate	Adjuvants		S	W	Blue stain [5]		Purple stain		Decay		*Alternaria*		Orange mold		*Penicillium*		*Trichoderma*		Miscellaneous molds	
		Borax	Soda			S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W
Strength	*Strength*	*Strength*	*Strength*	*Number*	*Number*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*										
		[6] 1		6	4	9.9	23.9	3.4	0.1	(7)	0	0.9	2.3	0.5	(7)	0.4	1.1	0	0.3	1.0	1.6
1				24	15	7.7	1.5	.2	0	0.2	(7)	.2	(7)	.2	0	2.1	2.6	.1	.2	.2	.1
	1			23	15	4.3	2.0	.3	(7)	(7)	0	(7)	0	(7)	(7)	(7)	.1	.1	.1	.1	.1
	1/4	1/2	1/20	5	6	9.2	4.0	.6	0	(7)	0	(7)	0	.1	0	1	.1	.1	.1	.2	.1
	1/2	3/16		12	3	4.5	1.5	.3	0	0	0	(7)	0	.1	.1	(7)	.1	.1	0	.4	.2
1/4	1/4			8	5	8.8	4.4	.3	(7)	(7)	0	0	0	.1	(7)	(7)	(7)	(7)	0	.3	(7)
3/8	3/8			5	2	5.1	1.5	(7)	0	0	0	0	0	(7)	.3	0	(7)	.1	0	.2	.1
1/2	1/2			7	6	3.3	1.0	.2	0	0	0	0	0	(7)	.1	(7)	.1	(7)	(7)	.2	.1
1/8	1/8	3/8		12	12	5.4	2.3	.5	(7)	0	0	(7)	(7)	.2	(7)	.2	.3	(7)	(7)	.3	.1
3/16	3/16	3/16		5	2	4.4	2.4	.2	0	0	0	0	0	(7)	.2	.1	0	(7)	0	.5	.3
1/4	1/4	3/16		5	2	3.4	1.8	.2	0	.3	0	0	0	(7)	(7)	(7)	0	0	0	.3	.2
Untreated controls				28	23	45.9	51.6	1.0	(7)	6.9	0.4	.1	.1	.3	(7)	.2	.2	.3	.9	.8	.8

[1] Summer tests had their midpoint in the period May to October; winter tests, in the period November to April.
[2] Molds were not separated out by species in the 1949 tests. Therefore, these tests are excluded from the table.
[3] Concentrations expressed as fractions of full strengths, as listed in table 1.
[4] Mold ratings: 0 (none) to 5 (very heavy).
[5] Average computed by converting percentage of stain in each test to the equivalent angle and reconverting the mean of the angles to a percentage.
[6] In the case of borax, there was some difficulty in separating *Alternaria* and blue stain. Therefore, the ratings for these two categories are less positive than for other ratings. *Alternaria* causes a smoky mold, shallow staining.
[7] Trace.

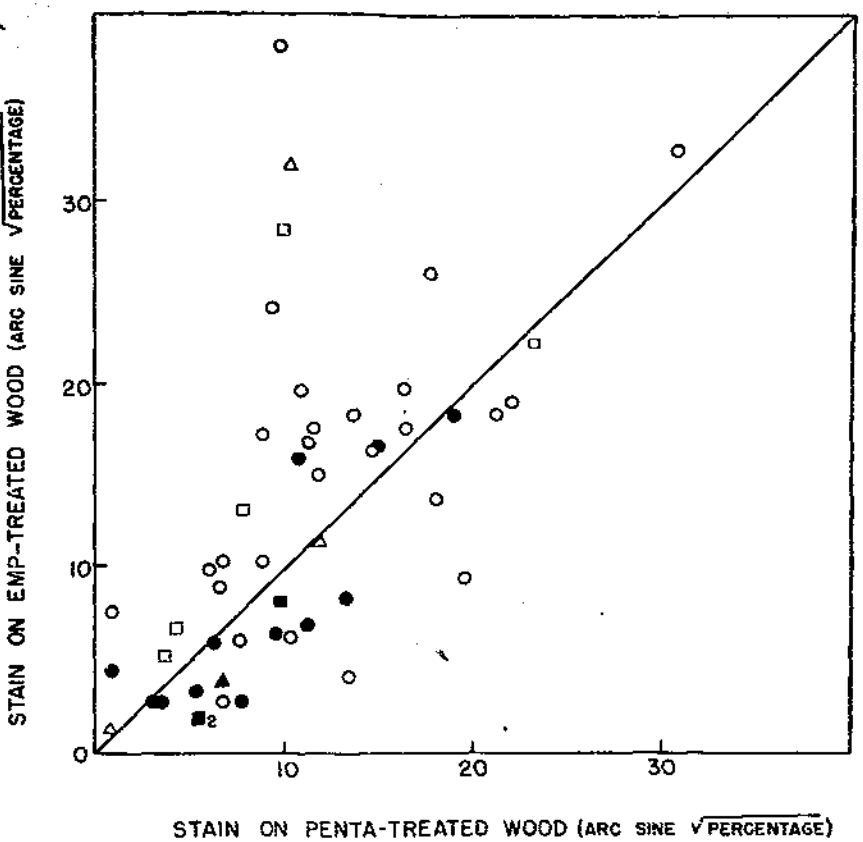

FIGURE 7.—The comparative effectiveness of full strengths of ethyl mercuric phosphate and sodium pentachlorophenate in controlling stain on pine during the summer (May to October, inclusive) and winter (November to April, inclusive). Solid symbols show winter tests, open symbols summer tests. Circles indicate small-scale strip-piled tests; squares, closed-piled tests; and triangles, large-scale tests. (Penta=sodium pentachlorophenate; EMP=ethyl mercuric phosphate.)

seem to influence the relationships. The superiority of sodium pentachlorophenate in the summer tests was significant at the 2-percent probability level; the superiority of the mercurial in the winter tests was almost significant at the 5-percent level (t=2.095, $t.05$=2.131). The difference for the winter tests probably would have been more significant had more tests been involved, because a larger proportion of the winter tests followed the trend than did the summer tests. The seasonal relationship in effectiveness of the mercurial and phenolate also held for hardwoods.

Of the 23 tests on pine for which temperature records were obtained, 5 summer tests did not correspond to the stain-season relationship when separation of season was on a calendar basis. When the separation was made on the basis of temperature during the test period (average daily temperature of more than 70° F. considered summer,

and less than 70°, winter), three of the reversals were corrected but two new ones appeared. Most of the irregularities came with tests whose midpoints occurred near the beginning or end of the arbitrarily set summer season. Variations in the amount of shading of test piles and in the methods of covering (whether with roll roofing or boards) would influence temperatures inside test piles. Had temperatures been recorded inside piles rather than for outside air, a closer correlation of amount of stain and temperature probably would have been obtained.

The testing methods did not result in appreciable reductions in solution volumes and the resultant gradual reduction in strength (*14*) as occurs in commercial use. The lowering of the concentration of ethyl mercuric phosphate in a commercial dipping operation could easily counterbalance the greater relative effectiveness of the mercurial at full concentration during the winter.

SPECIAL CONSIDERATIONS

The Influence of Delayed Dipping

The delay in dipping, i. e., the interval between sawing from the log and chemical treatment, is an important factor in lumber stain control. It is essential that the fungicide be applied before fungi have penetrated the wood sufficiently to avoid being reached and killed by the fungicide. Previous laboratory (*5*) and field (*7*) studies have indicated that with a 24-hour delay, stain fungi will rarely penetrate deep enough to escape killing by fungicidal dips. These studies led to the general recommendation that the maximum delay permissible is 24 hours, but it is recognized that under some winter conditions longer delays might still permit adequate control.

With the trend in the South toward the small mill whose output is trucked to concentration yards for treatment and seasoning, the problem of delayed dipping has become increasingly important. Some further test data, particularly in relation to season, seemed desirable. A separation of season is important, not only because temperatures vary but also because of the seasonal differences in fungus floras. Isolations have shown (*10*) that some of the fastest growing stain fungi, notably *Diplodia natalensis* P. Evans and *Ceratostomella ips* Rumbold, are more prevalent during the summer months.

METHODS

All tests were small-scale tests with pine. These varied from the regular small-scale tests as follows:

1. Each board furnished one test piece for each treatment to eliminate variation due to differences in susceptibility of different boards.
2. The pieces were close-piled for varying lengths of time before treatment.
3. After treatment the samples were again close-piled until all treating was completed, then open-piled as in a regular test.
4. Stain readings were taken, after 4 to 5 weeks, on the exterior surfaces. Then the test pieces were cut lengthwise, and the amount of internal stain read on the 1- by 14-inch internal surface exposed.

RESULTS

The results of the four tests, all at Saucier, Miss., are given in table 20. Surface stain control was adequate in all tests, regardless of delay in treatment. With the summer tests, objectionable interior stain resulted during a 24-hour delay, but not in a 12-hour delay in one test in which this interval was included.

TABLE 20.—*Stain developing in green pine sapwood dipped at various intervals after being sawed from the log*

Treatment [1] and delay in hours [2]	Average area stained							
	Summer tests				Winter tests			
	August 1946		August 1947		November 1946		February 1947	
	Exterior stain	Interior stain [3]	Exterior stain	Interior stain [3]	Exterior stain	Interior stain [3]	Exterior stain	Interior stain [3]
Ethyl mercuric phosphate ¾ plus sodium pentachlorophenate ¼:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0 hour	2	4	(4)	(4)	(4)	1	(4)	0
12 hours			(4)	(4)				
24 hours	5	26	1	12	(4)	5	(4)	0
36 hours	6	33						
48 hours	7	24	1	12	1	15	0	0
60 hours	6	24						
72 hours								
Sodium pentachlorophenate ½ plus borax ½:			1	0	3	8	0	(4)
48 hours	6	10						
60 hours	7	11						
Sodium pentachlorophenate ¼, plus ethyl mercuric phosphate ½, plus borax ½:								
0 hour					(4)	(4)		
24 hours					1	2		
48 hours					3	13		
72 hours					3	13		
Untreated controls	40	12	15	8	60	53	13	3

[1] Concentrations expressed as fractions of full strengths, as listed in table 1.
[2] Delay refers to number of hours between sawing from the log and fungicidal treatment.
[3] Interior stain on a plane cut through the center exposing a 1- by 14-inch surface.
[4] Trace.

With the first winter test, objectionable interior stain occurred during 48 hours' delay but not in 24 hours; in the second winter test even a 72-hour delay did not permit appreciable stain. This difference reflects the variability of winter staining conditions in the South. During the first test the weather was warm, with maximum daily temperatures of 70° F. recorded during much of the test period. In contrast, the other test coincided with a cold spell with freezing temperatures during many nights and maximum temperatures seldom exceeding 50°.

Sweetgum was included in the February test, but since only traces of stain occurred the data are not presented. In one laboratory test 1- by 1- by 2-inch blocks of fresh sweetgum sapwood, surface sterilized in boiling water, were inoculated (5 blocks per fungus) with spore suspensions of *Ceratostomella pluriannulata* Hedgc., *Graphium* sp., *Diplodia natalensis* P. Evans, *Endoconidiophora virescens* Davidson, *E. moniliformis* (Hedgc.) Davidson, *Alternaria* sp., and *Curvularia geniculata* (Tracy & Earle) Boed. Twenty-two hours later the blocks

were dipped in a 1-percent solution of a 50–50 mixture of sodium tetrachlorophenate and sodium 2-chloro-ortho-phenylphenate and incubated in glass jars for 7 days. The temperature during both incubation periods was 80° to 85° F. At the end of the incubation the interior of practically every block was completely stained and the inoculated fungus reisolated. This one test is not conclusive, particularly because of the small blocks with a disproportionate amount of end grain that were used. However, it suggests that sweetgum may react to delayed dipping in the same manner as does pine.

The evidence here presented indicates that for best stain control lumber should be dipped the day it is sawed from the log or with a maximum delay of 12 hours. It is not desirable to make separate recommendations for summer and winter conditions in the Deep South because of the uncertainty of winter weather. However, under most winter conditions a delay of 24 hours would be safe, and when maximum daily temperatures do not exceed 50° F., delays of 48 to 72 hours should be safe.

Should conditions preclude dipping within 12 hours or even 24 hours after lumber is sawed, dipping should still be beneficial because the slower growing decay fungi might be killed or greatly reduced. When the delay is more than 24 hours, seasoning practices favoring more rapid drying are desirable.

In a concentration-yard operation it would seem that every effort should be made to induce the producing sawmill to treat the lumber at the sawmill rather than delay treatment until the lumber is transported to the concentration yard. When treatment at the sawmill is not feasible, every effort should be made to insure prompt delivery of the lumber after sawing and prompt treatment after it is delivered to the yard.

The Treatment of Surfaced Green Lumber

During the war and the postwar lumber-shortage periods, appreciable amounts of lumber were surfaced, shipped, and used before seasoning. Under normal conditions a certain amount of lumber is so handled. Offhand, it seemed logical to assume that surfaced lumber would retain less treating solution and, consequently, less effective stain control might result.

In a preliminary laboratory test, 25 small, matched pieces each of surfaced and of rough pine were dipped in a full-strength solution of sodium pentachlorophenate for 10 seconds and the excess solution allowed to drain back into the treating vat. The rough and surfaced pieces had the same surface area. The rough wood removed 1.8 times as much solution as did the surfaced wood.

Three small-scale tests were established at Saucier to get further information on the protection of rough and surfaced pine. These tests were made in conjunction with the four delayed dipping tests, and the procedure varied only in that the "smooth" samples were planed to a depth of $\frac{7}{64}$ of an inch. The results are given in table 21.

The data show that smooth lumber was more difficult to protect than was rough lumber, even with the higher-than-usual concentrations used. Presumably, this was because of the retention of less solution by the smooth lumber. When lumber is surfaced green, it is almost

TABLE 21.—*Stain development in pine lumber treated rough and lumber treated after surfacing and exposed in small-scale open-piled tests*

Test	Constituents [1] and solution composition			Season [2]	Average area stained			
					Exterior stain		Interior stain	
	Ethyl mercuric phosphate	Sodium pentachlorophenate	Borax		Rough	Surfaced	Rough	Surfaced
	Strength	*Strength*	*Strength*		*Percent*	*Percent*	*Percent*	*Percent*
A	3/4	3/4		Summer	2	8	4	13
A		1		do	7	15	10	15
B	3/4	3/4		do	(3)	3	(3)	5
C	3/4	3/4		Winter	(3)	(3)	1	(3)
C	1/2	1/2	1/2	do	(3)	2	(3)	(3)
D	3/4	3/4		do	(3)	(3)	0	0

[1] Concentrations expressed as fractions of full strengths, as listed in table 1.
[2] Summer tests had their midpoint in the period May to October; winter tests, in the period November to April.
[3] Trace.

invariably shipped or stored in this condition and may not be seasoned until placed in use. Under these conditions the indications are that, in the South, appreciable staining, and possibly incipient decay, can be expected. Nevertheless, treatment is recommended for what protection it affords. Probably concentrations of solutions for use on surfaced green lumber, at least during the summer, should be increased to 1.5 or 2 times those recommended for use on lumber for immediate seasoning.

THE TREATMENT OF LARGE SAWED TIMBERS

The use of fungicidal sprays and dips for treating large sawed timbers has not been widely adopted by the lumber industry in the southern United States. Some mills have installed power sprays to treat timbers with antistain chemicals as they leave the mill; a few use dipping vats for this purpose. Protection has been variable, from good to poor. The main factors responsible for the poor results appear to be:

(1) Use of weak solutions. The common antistain chemicals probably should be used at 1.5 to 2 times the concentrations commonly used on 4/4 lumber.

(2) Incomplete coverage. Most spray rigs observed in operation have been partially clogged with sawdust, splinters, and other debris, so that one or more faces of the timbers were untreated. Adequate screening of the drained solution before being returned to the tank, and frequent cleaning of these screens, should prevent clogging of nozzles and valves.

(3) Dressing or sizing timbers soon after treatment and before the surface moisture content is too low to support fungus growth. Some mills have the conveyors so located that any timbers sized on leaving the mill are re-treated after sizing; this practice is recommended.

(4) Poor storage facilities on the timber deck. Mills obtaining best protection of timbers are those stickering the timbers on the deck to promote rapid surface drying before shipment.

Only one published report of experimental data on the effectiveness of fungicides on large sawed timbers was found. Chapman and

Scheffer (*1*) reported two commercial-size tests in which organic mercurials (1.5 to 4 times full strength) proved relatively ineffective but sodium 2-chloro-ortho-phenylphenolate (1.5 to 3 times full strength) quite effective in controlling stain during shipment of lumber to England.

Two tests were established (December 1943 and April 1944), and several solutions were used on southern yellow pine timbers 4 by 6 by 24 inches in size. The material was largely sapwood and was treated by sprinkling with a watering can within 24 hours of the time of sawing. The ends were coated to reduce water loss. In the first test the pieces were close-piled for 24 days, stickered but fully exposed for 43 days, and then roofed for 19 days. For the second test the material was close-piled and boxed in for 14 days; then close-piled and exposed to full rain for the next 22 days; and close-piled and roofed for 25 days. The material was finally stickered and seasoned for 30 days under a roof. In both tests five samples per treatment were used. The results of the two tests are given in table 22.

These test data support the observational evidence that double strengths of the common fungicides used on lumber are effective on large timbers and that there is no particular problem in protecting timbers. It is necessary only to observe the usual precautions for treating lumber.

Because of the slow drying rate of large timbers and of drying checks that expose the untreated interior, surface treatments cannot be expected to prevent all interior stain and decay during complete seasoning under fully exposed conditions. Seasoning under cover would seem to offer the only possibility of complete protection. Many large timbers are installed as beams in buildings in a partially seasoned condition, so that they are protected from rainwash during much of the actual seasoning period.

TABLE 22.—*Comparative effectiveness of chemical treatments in controlling stain in sawed pine timbers*

Constituents[1] and solution composition			Average area stained						
			Winter test[2]			Summer test[2]			
Ethyl mercuric phosphate	Sodium pentachlorophenate	Borax	Close-piled, first 24 days	Stickered, in open, next 43 days	Stickered, under cover, next 19 days	Close-piled and boxed, first 14 days	Close-piled, fully exposed, next 22 days	Close-piled and roofed, next 25 days	Stickered, next 30 days
Strength	*Strength*	*Strength*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
2			0	1	1	0	(3)	4	1
	2		0	1	5	0	(3)	1	1
1		1	0	1	1	0	1	1	1
	1	1	0	(3)	1	0	1	1	1
½	½	½				0	(3)	(3)	(3)
0	0	0				0	(3)	(3)	(3)
Untreated controls			(3)	87	95	100	81	81	82
Average moisture contents, percent of oven-dry weight[4]						101	81	30	31

[1] Concentrations expressed as fractions of full strengths, as listed in table 1.
[2] Summer tests had their midpoint in the period May to October; winter tests, in the period November to April.
[3] Trace.
[4] Based on periodic weighing of 1 sample per treatment. Converted to oven-dry basis by means of reference blocks.

The Fungicidal Value of Chemical-Seasoning Agents

Chemical-seasoning agents are used to equalize interior and surface drying rates in both air seasoning and kiln drying, and thus reduce degrade by honeycombing and other physically induced troubles associated with rapid drying or with ordinary drying of thick stock. It seemed desirable to obtain some information on the fungicidal value of two common chemical-seasoning agents, urea and sodium chloride.

In one small-scale test, pine was dipped in solutions containing 4.4- and 8.7-percent urea, for approximately one and two times the cost of commercially used stain-control fungicides. At these concentrations urea completely failed to control stain and permitted very heavy mold development. In another small-scale test, pine was dip-treated with urea as commercially used for chemical seasoning, i. e., with a 50-percent water solution plus 0.24-percent borax and 2.16-percent cornstarch, costing in all several times as much as the usual stain-control solutions. The wood thus treated acquired 1-percent stain and a mold rating of 1.3; comparable wood in the same test but treated with full-strength sodium pentachlorophenate acquired 2-percent stain and a mold rating of 0.4. A previous report (*4*) showed considerable fungicidal value of urea at higher concentrations.

A proprietary seasoning agent containing 92-percent sodium chloride plus 8-percent corrosion-inhibiting materials was tried in two tests, one on pine and one on sweetgum. The salt was applied both dry and as a dip containing 8.4 pounds of salt to 24 pounds of water and thickened with starch. Regular small-scale open-piled tests were used, except that the wood treated with the dry salt was close-piled for 4 days to permit diffusion into the wood before being open-piled. In one test, the salt solutions were fortified with borax and sodium pentachlorophenate. The amount of stain and mold occurring after 5 weeks is listed in table 23.

TABLE 23.—*Stain and mold developing on pine and sweetgum sapwood treated with a commercial sodium chloride seasoning agent*

Treatment	Average area stained		Mold on pine [1]
	Sweetgum	Pine	
	Percent	*Percent*	
Dry salt, 50 pounds per thousand board feet	51		
Dry salt, 75 pounds per thousand board feet	37	11	Moderate.
Salt solution [2]	5	25	Do.
Salt solution, plus 0.96-percent borax [2]		19	Do.
Salt solution, plus 0.48-percent sodium pentachlorophenate [2, 3]		4	Light.
Sodium pentachlorophenate, 0.96 percent	(4)	1	Do.
Untreated controls	90	7	Moderate.

[1] No appreciable mold on sweetgum.
[2] Salt solution was about 25 percent of the commercial salt in water thickened with starch.
[3] In this test the phenate was added to the cooled, thickened salt solution and some did not dissolve. This difficulty can be overcome by adding the fungicide to the hot salt solution during its preparation.
[4] Trace.

Apparently the salt alone does not always afford adequate protection to such stain-susceptible species as pine and sweetgum. However, there is a possibility that on less stain-susceptible species it would not permit appreciable staining. The addition of half-strength sodium pentachlorophenate imparted the necessary fungicidal properties. It

is unlikely that chemical-seasoning agents will be generally used except on high-grade lumber. Therefore, the addition of at least half-strength sodium pentachlorophenate would seem advisable and feasible when the lumber is to be air-seasoned. When the salt is applied as dry crystals, the lumber could be dipped in a stain-control solution prior to the salt application.

Effect of Rainwash on Treatment Effectiveness

The common recommendation is that treated lumber be protected from rainwash (*7*). Emphasis has been placed on protection at the green chain, particularly from roof runoff onto buggies of lumber and in the seasoning piles. The only experimental data on the effect of rainwash on stain occurrence are for roofed versus unroofed seasoning piles (*7*). Unroofed seasoning piles permitted appreciably greater staining in the upper parts of piles. The data, however, do not indicate whether this was due to loss of the fungicide or to the action of rain in maintaining moisture conditions conducive to staining for longer periods.

The fungicides used on green lumber are water soluble, and it is assumed that they can be removed by rainwash except insofar as they are altered by physical and chemical changes after application. The organic mercurials probably are strongly adsorbed to wood fibers (*14*), and the adsorbed fraction may be resistant to leaching. It is known that the chlorinated phenolates are readily converted to the much less soluble phenolic form in an acid medium. At pH 6 most, and at pH 5 practically all, of the phenolate is converted to the phenol.[5]

Most wood is acid. Preliminary colorimetric determinations showed that fresh green southern yellow pine sapwood had a pH of 4 to 4.3 for summerwood and 4.6 to 4.7 for springwood, whereas sweetgum has a pH of 4.5 to 5.5. Fungicidal solutions for dipping green lumber are made alkaline in order to keep most of the fungicide in solution, avoid corrosion of dipping and conveying equipment, and avoid iron-tannate discolorations on some species of wood. Dipping solutions usually have an initial pH value higher than 8.

A few colorimetric determinations of pine sapwood treated with ordinary concentrations of sodium pentachlorophenate alone or with borax showed that the moisture at the surface dropped to a pH of 6 or below within an hour or less after dipping. At this pH, most of the phenolate should be converted to the phenol. Higher-than-usual concentrations had more lasting effect on pH and probably take longer to convert to the water-insoluble form. Sweetgum appeared much better buffered than pine. Despite its higher initial pH, treated gum soon after dipping had a lower pH value than pine.

Several leaching tests were conducted at Saucier. With the first three tests no definite records were kept of the time interval between dipping and the beginning of leaching. In two of the tests, and with most if not all treatments in the third test, the time interval exceeded an hour. Therefore, it is assumed that much of the phenolate had been converted to the phenol prior to leaching. For test No. 18, the treated samples were spread on a flat screen and subjected

[5] Information from the Dow Chemical Co.

to washing with tap water (slightly alkaline) from an ordinary shower spray with a gravity fall of 6 feet. Amounts of water calculated to equal ½, 1, and 2 inches of rainfall were used. For tests Nos. 16 and 19, the treated samples were bundled together by treatments but with small wood separators between the pieces. These bundles were immersed for various periods in a slowly flowing freshwater stream with a pH of about 6.0. The average areas stained after 4 to 7 weeks' exposure in the test piles are shown in figure 8.

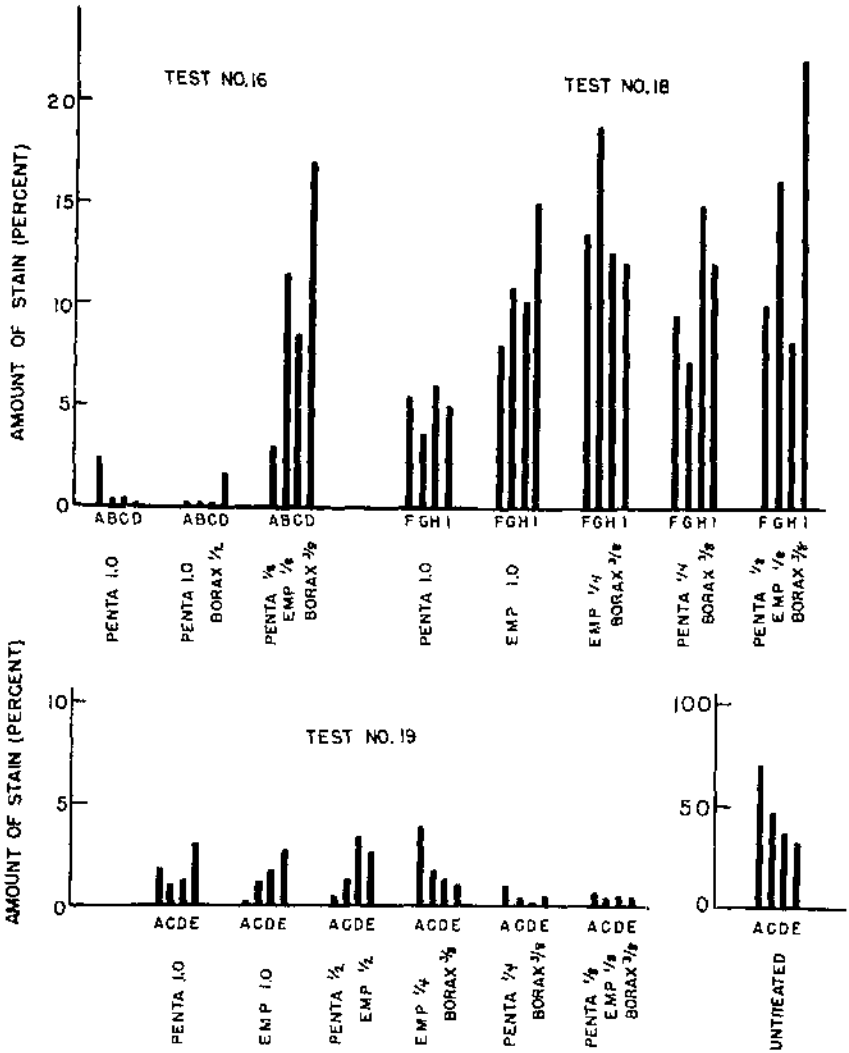

FIGURE 8.—The amount of stain developing on treated pine subjected to leaching about an hour after treatment in running water for 0 (*A*), ½ (*B*), 1 (*C*), 2 (*D*), or 4 (*E*) hours or to artificial rainwash equal to 0 (*F*), ½ (*G*), 1 (*H*), or 2 (*I*) inches and then placed in open-piled, small-scale tests for 4 to 7 weeks. (Penta=sodium pentachlorophenate; EMP=ethyl mercuric phosphate.)

In two subsequent tests (Nos. 37 and 38) the material treated with each solution was divided into three lots: The first was unleached, the second leached for 2 hours after standing for 1 hour (test No. 37) or 2 hours (test No. 38), and the third leached for 2 hours starting 5 seconds (test No. 37) or 3 minutes (test No. 38) after dipping. The samples for test No. 37 were leached in running tap water (slightly alkaline) and for test No. 38 were leached in a slowly flowing stream (pH 6.9). The data for these two tests are given in figure 9.

Although the data from these leaching tests are not altogether consistent, they suggest that treated pine subjected to moderate leaching would not be more stain susceptible than unleached wood unless leaching started soon after treating. There was some indication that pine

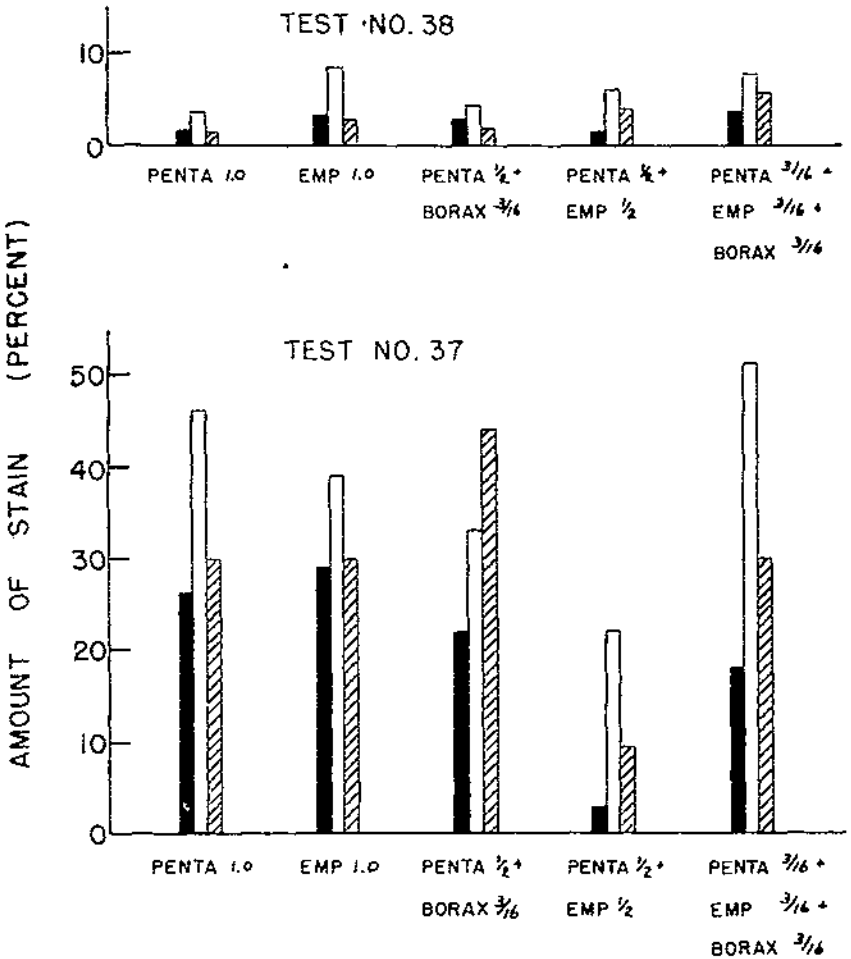

FIGURE 9.—Relative stain development in treated pine unleached (solid bar), leached within 3 minutes or less of the time of treatment (open bar), or 1 to 2 hours after treatment (cross-hatched bar), and then exposed in small-scale open-piled tests for about 30 days. (Penta—sodium pentachlorophenate; EMP—ethyl mercuric phosphate.)

treated with sodium pentachlorophenate, ethyl mercuric phosphate, and borax in duplex and triplex combinations was somewhat more influenced by leaching than that treated with full-strength solutions of sodium pentachlorophenate alone. The differences, however, were mostly small. When leaching was started within 3 minutes of dipping, all treatments showed a loss in effectiveness.

Untreated pine was subjected to leaching in two tests. In one test unleached, untreated samples had 32 percent of their area stained while the samples leached for 2 hours had 8 percent. A progressive decrease in the amount of stain resulted in test No. 19, in which untreated samples were subjected to varying amounts of leaching (fig. 8). It was assumed that this was caused by the removal from the wood of soluble material used as food by staining fungi. This lessening of stain susceptibility in leached, untreated wood complicated the interpretation of the data. There is doubt as to how much of the apparent nonleaching of chemicals was the result of actual retention of the chemical and how much was due to lowering of the stain-susceptibility level of the wood. The comparisons between immediate leaching and delayed leaching (fig. 9) would indicate that chemical retention was the deciding factor.

The data indicate that treated lumber needs most protection from rainwash immediately after dipping. Greatest benefit probably would arise from prevention of roof runoff onto buggies of freshly dipped lumber at the green chain. The data further indicate that the previously reported greater stain hazard in uncovered seasoning piles may be caused more by rain seepage, which maintains moisture conditions suitable for staining, than by actual loss of the chemical.

Skin Irritation Caused by Treating Solutions

Both the mercurials and the chlorophenates are highly poisonous (9). Users should avoid breathing fumes or dust from them or skin contact with them, except with the weak solutions prescribed for dipping. Skin and clothing should be washed with soap after each exposure. In hand dipping at nonmechanized mills, a waterproof apron should be worn for protection against splash. Waterproof gloves are desirable but seldom used; cotton gloves should not be used alone, because the solutions dry in them and become concentrated. Some individuals are especially sensitive to one or another of these chemicals and they should not be employed in handling lumber dipped with solutions that cause them skin irritation.

The mixtures described in this bulletin, in which each of the chemicals is used in reduced concentrations, have much less tendency to cause skin irritation. The mercurials cause less skin irritation than the chlorophenates, but they have been suspected of causing cumulative internal injury. The possibility of internal injury in men who handle dipped lumber has never been thoroughly investigated, but the large-scale use of the chemicals for more than 15 years without any authenticated cases of such injury, even without some of the advised precautions, leads to the belief that when properly used there is no appreciable hazard.

In any consideration of possible hazards, it should be kept in mind that because of the differential adsorption of mercury (14), the solu-

tions in which most of the actual dipping is done contain more nearly 0.006 percent Hg than the 0.012 percent that is initially put into the vat. However, men who regularly handle treated lumber before it is planed should have a health check by a competent physician once or twice a year.

Wood containing appreciable quantities of these chemicals or of borax should not be used in contact with food. Tetrachlorophenate is more likely to affect odor or flavor of foods than is the less volatile pentachlorophenate. Boxcars and ships' holds in which the dipped lumber is being shipped green should be ventilated. Mercury volatilized during fires can be very harmful, but the amount remaining on the lumber after drying is believed to be too small to cause concern on this account.

DISCUSSION AND CONCLUSIONS

No new chemicals were found that combined fungicidal effectiveness and other desirable qualities needed for use in protecting green lumber during the air-seasoning period. Among the commercial products, only those containing sodium pentachlorophenate, sodium tetrachlorophenate, or ethyl mercuric phosphate were effective in small-scale tests. All of the materials that have been thoroughly tested are known to have some disadvantages.

Sodium pentachlorophenate is generally effective against all fungi, but at the usual lumber-dipping concentration it is somewhat irritating to the skin, and at the concentrations needed for very moist situations or for timbers or surfaced lumber it is still more so.

Ethyl mercuric phosphate is effective against all fungi except the mold *Penicillium*. At recommended concentrations this product apparently has caused little skin irritation, but the dry powder can cause severe burns.

Sodium pentachlorophenate $\frac{1}{2}$ *strength plus borax* $\frac{3}{16}$. This product, as tested, was almost as effective as full-strength sodium pentachlorophenate alone. However, the new formulation (table 1) was not included in these tests. This product has removed most of the skin-irritating properties of full-strength sodium pentachlorophenate.

Sodium pentachlorophenate $\frac{1}{4}$ *strength plus ethyl mercuric phosphate* $\frac{1}{2}$ is relatively new on the market and has not been extensively tested. In limited testing, it was highly effective. This product has also been reported as effective in tests on pine in New York (*16*).

Sodium pentachlorophenate $\frac{1}{4}$ *strength plus borax* $\frac{1}{4}$ *plus soda* $\frac{1}{20}$ has low skin-irritating tendencies and has given good mold control. In stain control it was less effective on pine under the severe conditions of the small-scale test, probably because of the low phenolate content. The use during the warm, wet months of increased concentrations should overcome this difficulty. The proportions of the ingredients of this commercial product are being revised (table 1).

Sodium tetrachlorophenate is effective on southern hardwoods and certain west coast coniferous woods, but not on southern pine (*7*). It has less tendency to cause skin irritation than the pentachlorophenate. When wood treated with tetrachlorophenate is used for food containers without preliminary planing, it is more likely than the other chemicals considered to impart objectionable odor and taste to certain foods.

With the exception of the commercial product containing ethyl mercuric phosphate plus sodium pentachlorophenate, which as yet has not been extensively tested, all the commercial products occasionally failed to prevent mold or stain under the severe conditions of the small-scale test. The percentages of small-scale open-piled tests on pine in which each product at the recommended concentration allowed highly objectionable staining (10 percent or more of area) and failed (20 percent or more of area stained) were, respectively: Sodium pentachlorophenate, 13 and 3; ethyl mercuric phosphate, 19 and 5; sodium pentachlorophenate ½ plus borax 3/16, 29 and 6; sodium pentachlorophenate ¼ plus ethyl mercuric phosphate ½, 0 and 0; and sodium pentachlorophenate ¼ plus borax ½ plus soda ½0, 40 and 20. In the case of the mercurial, all cases of objectionable stain or failure to prevent stain occurred in summer tests; in winter tests this product was superior to the pentachlorophenate.

The most satisfactory means found for reducing the frequency of such prevention failures and at the same time for reducing the skin-irritating tendency of the phenolates and the mold hazard of the mercurials was to use mixtures of chemicals. The most effective and otherwise satisfactory mixtures were mixtures of sodium pentachlorophenate with ethyl mercuric phosphate or borax, or with both of these.

Mixtures of ethyl mercuric phosphate and borax appeared to retain the mold hazard of the mercurial alone and showed little or no promise of superior stain control.

Mixtures of sodium pentachlorophenate and borax at the higher concentrations of sodium pentachlorophenate ¼ or ½, plus borax 3/8, or higher strengths, prevented objectionable stain. When both effectiveness and bulk are considered, the commercial product containing sodium pentachlorophenate ½ plus borax 3/16 appeared to be the most efficient mixture of this type. Its advantage was that it reduced skin irritation even though it was not superior in controlling stain.

Mixtures of sodium pentachlorophenate and ethyl mercuric phosphate are superior stain-control treatments, give good mold control, are low in bulk, and have low skin-irritating properties. Although there was some evidence that better stain control with such mixtures might result if relatively higher mercurial content was used in the winter and higher phenolate content in the summer, it is doubtful whether this is practicable and the advantage probably is not great. Therefore, mixtures containing equal relative proportions of the two seem best.

Mixtures containing ¼ strengths of each component were about equal in effectiveness to full-strength sodium pentachlorophenate, while those containing 3/8 or ½ strengths of each component were superior. The latter two never allowed objectionable amounts of stain in any open-piled test. The recently introduced commercial mixture (ethyl mercuric phosphate ½ plus sodium pentachlorophenate ¼) was about equal in effectiveness to the 3/8 plus 3/8 mixture, but it did not show the high degree of superiority that the ½ plus ½ mixture did.

Mixtures containing sodium pentachlorophenate, ethyl mercuric phosphate, and borax also showed considerable promise. The ⅛ plus ⅛ plus 3/8 was equal in average effectiveness to full-strength sodium pentachlorophenate and in the percentage of tests with objec-

tionable stain. The 3/16 plus 3/16 plus 3/16 and the 1/4 plus 1/4 plus 3/16 mixtures averaged more effective than the full-strength sodium pentachlorophenate and only slightly exceeded the latter in bulk (3.9 pounds and 4.2 pounds, respectively, per 50 gallons compared to 3.5 pounds recommended by manufacturers for the pentachlorophenate alone). The 1/4 plus 1/4 plus 3/16 mixture never allowed objectionable stain in any open-piled test; the 3/16 plus 3/16 plus 3/16 mixture in this respect was equal to the 1/8 plus 1/8 plus 3/8 mixture. There was no indication in the test data that increasing the borax concentrations beyond 3/16 strength added to the effectiveness of the 3/16 plus 3/16 plus borax or the 1/4 plus 1/4 plus borax triplex mixtures. The main advantage of the triplex mixtures lies in their high degree of control with very low concentrations of phenolate, and the resultant low skin-irritation hazard.

Theoretically, the high fungicidal efficiency of the better mixtures might be explained as due to synergism. There is no evidence, however, that this occurs in these mixtures, and it would be difficult to prove because of the multiplicity of fungus species attacking green sapwood. The more logical explanation is that individual fungi vary in their tolerance of specific fungicides so that when used alone high concentrations are needed to exclude all harmful fungus species; with mixtures, the species tolerant of any single chemical would be excluded by the other components of the mixture.

The above-discussed differences in effectiveness among treatments were more marked in tests with pine than with sweetgum lumber. A larger number of hardwood tests might have shown some significant differences, particularly in decay control in close-piled tests. Experience with hardwoods indicates that lumber cut from stain-free logs is more easily protected chemically than is pine lumber. The main difficulty with stain control in hardwood-lumber milling operations is not lack of fungicidal effectiveness of chemical treatments but rather handling practices that nullify or reduce the effectiveness of treatments. Chief among these appears to be seasonal logging necessitating long periods of log storage and consequent infection before sawing. Some hardwood species acquire iron-tannate stain where the wet wood comes in contact with iron. When this occurs, additional alkali should be used in the dipping solution to neutralize the wood acids.

There has been only limited commercial experience with mixtures containing phenolates and mercurials, with or without borax. Therefore, mixtures of these types cannot be given unqualified recommendation for general commercial use. However, they warrant commercial trial. Under average conditions and during much of the time in the South as well as in other parts of the country, most of the currently available commercial stain-control chemicals afford adequate protection. When seasoning conditions are abnormally severe for short periods, any of the commercially available treatments are less likely to fail if concentrations are increased. Under such conditions the use of commercial mixtures seems preferable to the use of increased concentrations of phenolates or mercurials alone. With mixtures, superior effectiveness can be attained without increasing skin irritation or mold hazard.

Although fungicides in some tests gave good protection to lumber in close piles for long periods, the data indicate that, for best results, lumber, even with the best treatments, should not be left in close piles. In general, the data suggest that, for good stain and decay control, treated lumber should not be close-piled for more than 2 weeks in the summer or 1 month in the winter if it is to be air-seasoned. Lumber to be kiln-dried probably can be safely close-piled for double these periods. When close piling beyond a few days is unavoidable, treating concentrations might well be increased to at least 1.5 to 2 times those ordinarily used on lumber that is to be seasoned immediately.

With the advent of the concentration yard to which the output of small mills is trucked for treating and seasoning, the problem of delayed dipping has become particularly important. How long an interval between sawing and treating is safe depends mainly on prevailing weather conditions. During the summer, when growth of staining fungi is at a maximum and when some of the faster growing species are more prevalent, stain fungi may penetrate further into wood in 24 hours than do subsequently applied fungicides. Consequently, lumber should be treated the day it is sawed or at the latest the following day. Even in the winter tests, delays of 48 hours led to excessive interior stain in some tests. Treating after delays longer than those listed above should still result in some benefit; stain control might be poor, but the slower growing decay fungi might still be controlled.

The practice of shipping green-surfaced lumber is particularly hazardous because it entails not only the dangers of close piling but also because smooth lumber is more difficult to protect than rough lumber. Surfaced lumber retains much less treating solution on its surface, and it is thought that this is the main reason why it is more difficult to protect. In treating surfaced lumber, concentrations should be 1.5 or 2 times those used on rough lumber.

As far as could be determined from the few tests made and from observations at mills, the chemical protection of large, sawed timbers presents no special problem. With good handling practices and treating solutions 1.5 to 2 times as strong as used on 1-inch lumber, satisfactory protection should result for the usual periods timbers are held at mills. The chemical seasoning agent urea was ineffective at concentrations that would be cost-competitive with the regular stain-control chemicals, but at the much more expensive seasoning concentration (50 percent) proved effective against fungus deterioration. A sodium chloride seasoning agent, although hindering stain development, did not give good protection. The addition of half-strength sodium pentachlorophenate to the salt solution gave good protection in the one test in which it was used.

All the treatments tested seemed to lose some effectiveness when the treated wood was subjected to leaching immediately after dipping. If washing was delayed until an hour after treating, the effect of leaching was remarkably small. It is believed that this resistance to leaching is caused by the conversion of phenolates to the less soluble phenol by wood acids and to the adsorption of mercurials to the wood fibers. There was some evidence that the experimental mixtures containing borax might be somewhat more subject to leaching than sodium

pentachlorophenate alone, but the evidence was not consistent nor the difference sufficient to seem of practical importance. The greatest need for protection of treated lumber from rainwash would be immediately after dipping at the green chain.

Data obtained during these tests but published elsewhere (*14*) showed that solutions of ethyl mercuric phosphate lost strength with repeated use much more rapidly than those of sodium pentachlorophenate or mixtures of these and borax. Reasonably effective strengths apparently can be maintained in dipping vats if replenishments with regular concentrations are made each time the amount of vat solution drops to 80 percent of the full working capacity. As there was very little reduction of solution volume in the small-scale tests, it is likely that the mercurials in comparisons with chlorophenates rated somewhat higher in the small-scale tests than they would in commercial use.

Mixtures of the general types used for the test reported here also have been tried in the Pacific Northwest (*15*). The mixtures and the commercial products tested protected close-piled western coniferous woods against stain and decay for much longer periods than in the southern tests. Whether this is due to differences in fungus floras, in climatic factors, or to both is not known. It is apparent, however, that some of the data presented in this bulletin do not necessarily apply in other sections of the country. Because the South probably presents the most severe conditions, recommendations based on southern tests and experience should, in general, be safe for other parts of the country.

LITERATURE CITED

(1) Chapman, A. D., and Scheffer, T. C.
1933. New chemical treatments for the control of sap stain and mold in southern pine and hardwood lumber. South. Lumberman 146 (1851): [25]–30, illus.

(2) Heddcock, G. G.
1906. Studies upon some chromogenic fungi which discolor wood. Mo. Bot. Gard. Ann. Rpt. 17: 59–114, illus.

(3) Hubert, E. E.
1929. Sap stains of wood and their prevention. U. S. Dept. Com., Natl. Com. Wood Util., 77 pp., illus.

(4) Kaffert F. H., and Behr, E. A.
1942. Susceptibility of wood to decay: effect of urea and other nitrogen compounds. Indus. and Engin. Chem., Indus. Ed. 34: 1510–1515, illus.

(5) Lindgren, R. M.
1942. Temperature, moisture, and penetration studies of wood-staining ceratostomellae in relation to their control. U. S. Dept. Agr. Tech. Bul. 807, 35 pp., illus.

(6) Scheffer, T. C., and Lindgren, R. M.
1932. Some minor stains of southern pine and hardwood lumber and logs. Jour. Agr. Res. 45: 223–237.

(7) ——— and Lindgren, R. M.
1940. Stains of sapwood and sapwood products and their control. U. S. Dept. Agr. Tech. Bul. 714, 124 pp., illus.

(8) Snedecor, G. W.
1946. Statistical methods. Ed. 4, 485 pp. Ames, Iowa.

(9) Stohlman, E. F.
1951. The toxicity of some related halogenated derivatives of phenol. U. S. Pub. Health Serv. Rpt. 66: 1303–1312.

(10) VERRALL, A. F.
1939. RELATIVE IMPORTANCE AND SEASONAL PREVALENCE OF WOOD-STAINING FUNGI IN THE SOUTHERN STATES. Phytopathology 29: 1031–1051, illus.
(11) ———
1943. SAP STAIN CHEMICALS FOR EMERGENCY USE. South. Lumberman 166 (2085): 64–65.
(12) ———
1945. THE CONTROL OF FUNGI IN LUMBER DURING AIR-SEASONING. Bot. Rev. 11: 398–415.
(13) ———
1949. SOME MOLDS ON WOOD FAVORED BY CERTAIN TOXICANTS. Jour. Agr. Res. 78: 695–703, illus.
(14) ——— and MOOK, P. V.
1950. ABSORPTION OF SAP STAIN AND MOLD CONTROL CHEMICALS BY WOOD. Indus. and Engin. Chem. 42: 1350–1355, illus.
(15) WRIGHT, E.
[In press.] PACIFIC NORTHWEST TESTS FOR THE CONTROL OF SAPSTAIN AND DECAY OF GREEN LUMBER. Timberman.
(16) ZABEL, R. A., and FOSTER, C. H.
1949. EFFECTIVENESS OF STAIN CONTROL COMPOUNDS ON WHITE PINE SEASONED IN NEW YORK. N. Y. State Col. Forestry, Syracuse Univ., Tech. Pub. 71, 17 pp.

APPENDIX

SOME FACTORS INFLUENCING THE ESTABLISHMENT OF TESTS FOR THE CONTROL OF FUNGI ON GREEN WOOD

WOOD VARIABILITY

General observations over a period of years indicated that some boards are more susceptible to stain than are other boards of the same wood species. Because this has a distinct bearing on experimental design, 1 small-scale, open-piled test was established in which the wood used consisted of 10 boards from 10 different pine logs. One test piece from each board was used for each of the 16 treatments. Treatments consisted of 3 chemical dips applied at various times after the lumber was cut. In another test, nine boards from five different logs were distributed so that one sample from each board was used for each treatment. The treatments consisted of 5 chemical solutions and 3 leaching periods, or a total of 15 treatments. For both tests the wood came from mills cutting mainly longleaf and slash pine, but the actual species could not be determined.

The average amounts of stain in each board in both tests after 5 weeks' exposure to natural infections are listed in table 24. Analyses of variance of the data are given in table 25.

The data show that the variation in the amount of stain attributable to differences between logs was significant; differences among boards from the same log were not significant. As all the material was from fresh logs and was handled similarly throughout the test, it is assumed that the data show inherent differences in stain susceptibility among the different log samples. The variance between boards, used as the error term for "between logs" in test No. 2, is based on too few degrees of freedom to deserve full confidence. However, the two tests when taken together are regarded as strong evidence. For any refined testing, specimens from different logs should be equally distributed to the different treatments.

TABLE 24.—*Differences in stain susceptibility of lumber cut from different pine logs*

Log No.	Average area stained [1] in—				
	Test No. 1	Test No. 2			
	Board 1	Board 1	Board 2	Board 3	Average
	Square inches	*Percent*	*Percent*	*Percent*	*Percent*
1	13.4	4.5			4.6
2	13.1	4.0			4.0
3	11.6	5.0	3.3	3.9	4.0
4	9.8	2.2	2.0		2.1
5	6.5	1.3	1.1		1.2
6	5.8				
7	5.4				
8	4.9				
9	4.6				
10	3.9				

[1] Every average in test No. 1 is based on 16 pieces, each with a different treatment; in test No. 2, on 15 pieces.

TABLE 25.—*Analysis of variance of data (summarized in table 24) on susceptibility of different boards to staining*

Source of variance	Degrees of freedom	Sum of squares [1]	Mean square [1]	*F*
Test No. 1:				
Between logs	9	2,168.13	240.90	[2] 11.58
Between treatments	15	6,587.15	439.14	21.10
Error	135	2,809.11	20.81	
Total	159	11,564.39		
Test No. 2:				
Between logs (L)	4	714.99	178.75	[3] 14.81
Within logs (B)	4	48.29	12.07	[4]
Treatment (T)	14	1,283.74	91.70	[4]
Error	112	3,469.43	30.98	
T × L	56	2,050.50	36.62	
T × B	56	1,418.93	25.34	
Total	134	5,516.45		

[1] The data were transformed to arc sine $\sqrt{\text{percentage}}$ for analysis.
[2] *F* at 1-percent level=2.56.
[3] *F* at 1-percent level=1.598; at 5-percent level=6.39.
[4] Not significant.

DISTRIBUTING TEST SAMPLES AMONG TREATMENTS

Variations in stainability among different wood samples were equalized among treatments by three methods: (1) All samples were cut from one log or tree, (2) equal numbers of test samples from each board were used in each treatment, or (3) a partial randomization was used. The first method was seldom practicable under commercial mill conditions, and the second method often was eliminated because the time limits or the large numbers of treatments involved precluded any careful matching technique. Therefore, in most cases partial randomization was used.

As the boards were cut into test samples, the samples were placed in vertical tiers. The samples for each treatment were removed in horizontal sequence, thus providing a fair distribution of samples from different boards among the treatments. In each of two tests the pieces from two boards were marked and handled in the usual method followed in partial randomization. The distribution of these marked samples among the treatments was subjected to a chi-square test. The *P*-values for the boards were about 0.9, 0.7, 0.5, and 0.5. Thus the

samples from different boards were not always so well distributed among treatments as might be desired, but it appears that no marked bias was introduced.

With full-size lumber in large-scale tests, it was seldom feasible to distribute samples among treatments so that there would be any assurance that variations between logs were equalized among treatments.

DISTRIBUTION OF TEST SAMPLES WITHIN A PILE

In all types of tests, all treatments were placed in one test pile and distributed, at least as much as was feasible, so as to equalize variations in stain hazard among the treatments.

In a commercial seasoning pile, stain hazard was relatively low with the outside boards in each course and the bottom course or two, reached a maximum at about one-fourth the height of the pile, and above this gradually dropped off until the top of the pile was reached (*7*). Therefore, nontest boards were used for the bottom few courses, the edges of all courses, and when possible several top courses.

For several large-scale tests established in 1937, the treatments were distributed in Latin squares. This procedure proved unduly cumbersome and served no useful purpose, because it was found that in any six to eight adjacent courses in the test part of the pile, the biggest differences in stain occurrence were in the horizontal position in a course and not between courses. Therefore, by restricting the number of treatments to eight or less, making all boards in each horizontal course as one treatment, and using blocks of courses equal to the number of treatments with these randomly distributed in each block, procedure was greatly simplified without bringing any bias into the test.

A partial randomization was used in distributing treatments in small-scale open-piled tests. Oftentimes it was possible to use one piece of each treatment randomly distributed in each horizontal course. Thus the pieces for each treatment were randomly placed horizontally in the pile; the only restriction was that only one piece of each treatment should be placed in each course. When the number of treatments was either too small or great to conveniently use only one piece of each treatment to a course, one piece of each treatment was randomly placed, then the second piece of each treatment, and so on, until the whole pile was completed.

No indication has been noticed of any border effect of one chemical treatment on another. Even when untreated controls or pieces treated with a poor fungicide produced heavy fruiting of stain fungi, no noticeable effect on adjacent treatments was detected in open-piled tests. When material was close-piled, poor treatments sometimes did increase the level of fungus attack on good treatments directly in contact with them. In most cases direct contact between boards with different treatments was avoided.

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