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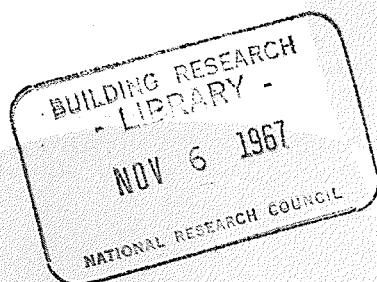
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ANALYZED

NATIONAL RESEARCH COUNCIL OF CANADA  
CONSEIL NATIONAL DE RECHERCHES DU CANADA



CLEAR FINISHES FOR EXTERIOR WOOD  
FIELD EXPOSURE TESTS

BY

H. E. ASHTON

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ESSAIS PAR EXPOSITION AUX INTEMPERIES DE  
PRODUITS TRANSPARENTS POUR LA FINITION DU BOIS

SOMMAIRE

L'auteur décrit les résultats de deux séries d'essais par exposition aux intempéries de produits de finition transparents de composition bien établie. La première série d'essais portait sur des vernis phénoliques, des résines alkydes en solution, et des esters époxydiques en solution. La deuxième série, outre les produits phénoliques et alkydiques, concernait des résines époxydiques à durcissement par catalyse, des uréthanes et dans un but de comparaison, des teintures pigmentées. L'auteur compare les cotes de durabilité à la composition et à quelques propriétés des produits. Il décrit la préparation que doit subir une couche déjà exposée en vue de l'application d'une autre couche pour une exposition subséquente.

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# CLEAR FINISHES FOR EXTERIOR WOOD

## Field Exposure Tests

ANALYZED

By H. E. ASHTON  
National Research Council\*  
Canada

The results of two series of exterior exposure tests of clear finishes of known composition are given. In the first series phenolic varnishes, alkyd resin solutions, and epoxy ester solutions were exposed. The second set, in addition to phenolics and alkyds, included cold-cured epoxies, urethanes and, for comparison, pigmented stains. The durability ratings are discussed in relation to composition and some of the properties of the materials. Preparation of exposed clear finishes for recoating and subsequent exposure results are described.

### INTRODUCTION

For a number of years there has been widespread interest by architects, builders and home owners in the use of clear coatings on the wood siding of homes and other buildings. This interest has been stimulated by the attractive appearance of wood coated with a clear finish, but unfortunately clear coatings on wood have had a history of poor performance or excessive maintenance in comparison with pigmented coatings. The Timber Research and Development, California Redwood, and Western Pine Associations have all tested numerous commercial clear finishes for wood but have not found any that were really satisfactory. For example, it has been reported that 90% of the products tested were unsatisfactory after eight months and the remainder had a maximum life of one and a half years.<sup>1</sup> In general, it is found that failures occur by delamination, cracking or peeling within a year or two of application, leaving a very poor surface for recoating.

As a consequence of such failures the Division of Building Research, which provides a research service for the construction industry of Canada, has been approached many times for advice. To ensure that information supplied by the Division would be on a

sound, unbiased basis, studies were undertaken to determine the relative durability of different types of clear coatings. This information was obtained chiefly from exterior exposures. This paper describes the coating materials, the results of two exposure tests in 1955 and 1960, and the effectiveness of refinishing procedures.

### MATERIALS

The following types of clear materials were used: phenolic varnishes, alkyd resins, epoxy-esters, epoxy resins, urethanes, and three miscellaneous materials. Five pigmented stains were also exposed to compare their performance with that of the clears.

The varnishes were prepared in the laboratory by cooking the phenolic resins with selected oils in a stainless steel beaker. The desired solids content was 50% at a Gardner-Holdt viscosity of B-D. Before use 0.4% lead and 0.04% cobalt naphthenate driers were added in the same proportions as with the alkyd resins, i.e., on solids content instead of an oil content.

The alkyd, epoxy-ester, and urethane samples were prepared by diluting commercially available resin solutions to the desired viscosity or solids content. Commercial materials were used to prepare solutions of epoxy resin and the curing agents.

The water-repellent sealer and three of the stains were prepared in the laboratory, but only one stain required milling of the pigment because the other two were made with colors-in-oil. Three commercial ready-to-use materials were exposed: two stains and an oil-modified urethane.

The composition of materials exposed in 1955 and in 1960 are given in *Tables 1 and 2*, respectively. Except for the stains, the water-repellent sealer, and the acetate-butyrate emulsion all materials were applied in three coats. The first coat was diluted with the appropriate thinner to a Gardner-Holdt viscosity

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\* Organic Materials Section, Division of Building Research, Ottawa, Canada.

Table 1—Composition and Ratings of Materials Exposed in 1955

Formula Number	Oil Type	% Oil	% Solids	Viscosity (G-H)	Durability at 27 months		
					13	27	36
<i>Paraphenylphenolic Varnishes</i>							
372 .....	Linseed	50	51.3	G	8.5	5.5	4.5
373 .....	Linseed	66.7	52	C	10	9	7
374 .....	Linseed	75	50	E	10	7.5	6.5
375 .....	Linseed	80	48.5	C	10	8	6
376 .....	Linseed	83.3	46.2	F	10	5.5	3
371 .....	Tung	50	54.6	A	9	6.5	5.5
430 .....	Tung	66.7	51	C-D	9	6	4.5
429 .....	Tung	75	52.3	F	10	8.5	7.5
428 .....	Tung	80	51.8	G	10	8	7.5
427 .....	Tung	83.3	48	C-D	10	8.5	6
403 .....	Soya	50	53	F	4	—	—
402 .....	Soya	77.8	49.5	C-D	9	6	4.5
401 .....	Soya	83.3	55	J	8	4	—
407 .....	D.H.C.	50	53.8	P	8	6	3
406 .....	D.H.C.	75	53	E	10	8	5.5
404 .....	D.H.C.	83.3	47	B	10	6	4
<i>Alkyd Solutions</i>							
362 .....	Linseed	29	28	D	7	2.5	—
355 .....	Linseed	39.6	38	D	7	4	2
356 .....	Linseed	51	38	D	6	2.5	—
358 .....	Linseed	58.3	52	D	7.5	2.5	—
363 .....	Linseed						
	phenolated	55	39	D	6	2	—
359 .....	Soya	41.7	41	D	8	5.5	4
360 .....	Soya	56.3	45	D	8	6	5
357 .....	Soya	62.5	53	D	9.5	8	5.5
361 .....	D.H.C.	37.5	32	D	8	4.5	2
<i>Epoxy Esters</i>							
365 .....	Linseed	57.5	38	C-D	5	2	—
364 .....	Soya	45	37	C-D	6	2	—
367 .....	D.H.C.	46	32	D	8	3.5	—
Mean rating					8.3	5.3	3.3
Decrease per month					0.13	0.21	0.22

of A-2, except for the cold-cured epoxies, urethanes and a few materials that already had a low viscosity. The stains, the sealer and the emulsion were applied in two coats, with the exception of the Forest Products Laboratories' formulations. For these materials, half of each panel received one coat and half two coats, with the Canadian formula wiped according to instructions.

#### FIRST EXPOSURE SERIES (1955)

The initial program included 28 conventional clear coatings (16 paraphenylphenolic varnishes, nine alkyd resins, and three epoxy resin-fatty acid esters). The solids content of the varnishes varied in many cases from the desired 50% because solvent was decreased or increased to obtain the desired viscosity.

Two different woods commonly used on homes were selected for the exposure test: white pine and western red cedar. Three 30-inch lengths of each wood in the form of drop (or cove) siding were prepared for each coating material. The edges and backs of the test panels were first sealed with sealer and aluminum paint. The complete coating system consisted of one sealer coat and two coats of normal viscosity applied

by brush at intervals of about 24 hours. Each application produced a full, wet coat and the amount applied was determined by weighing the panels.

After coating, the six boards of each sample were mounted by brass screws to frames which could be attached to exposure racks. The screw holes were counter-sunk and carefully protected with aluminum paint. The panels were mounted vertically, facing south, at the exposure site of the National Research Council in Ottawa. Exposure began August 16, 1955 and ended in August 1958. Observations were made at varying intervals. The mean ratings after approximately one, two and three years are shown in *Figure 1* and are compared with composition in *Table 1*.

It was evident that the kind of wood and its shape had an effect on the life of the coating. Generally, the coatings showed somewhat poorer durability on red cedar than on white pine, although this might be related to the fact that the materials, on the average, were applied at a greater coverage on cedar, thus yielding slightly thinner films. Initial breakdown occurred in almost all cases at the bottom edge of the cove on the siding or in the hollow immediately above it.

The alkyd and epoxy-ester coatings failed much earlier than the pure phenolic varnishes, except for the soya modifications where the alkyds performed better than the varnishes. After one year, when all except three varnishes were in excellent condition, the only alkyd with a rating as high as 9 (where 10 = perfect condition) was the long soya. After 27 months, only five varnishes and the one alkyd had no more than slight defects, which did not detract from their appearance and would not interfere with recoating. The only recoatable surfaces after three years were the 30- and 40-gallon tung oil varnishes.\*

The effect of oil content and type of oil on the durability of the finishes can be seen in *Figure 1*. For the varnishes, tung oil was superior to linseed oil, with one exception, and both were better than dehydrated castor and soya oils. Soya varnishes were generally the poorest. The tung results at 20-gallon oil length appear anomalous; the ratings, as well as being below the corresponding linseed varnish, are lower than the 10- and 30-gallon tung varnishes. Better durability would be expected as the proportion of phenolic resin increases until the resin makes the film too brittle. The linseed varnishes illustrate this relationship quite well. The soya and castor varnishes, although on a more limited composition basis, also exhibit peaks in durability near the mid-range of oil content. The variation in ratings of the short oil varnishes, especially the poor performance of the soya, is rather surprising. One would expect that at the highest resin content the durability of the resin would be the controlling factor and that all four varnishes would perform similarly.

\* Oil lengths are approximate Imperial gallons. To obtain U. S. oil length multiply by 1.2.

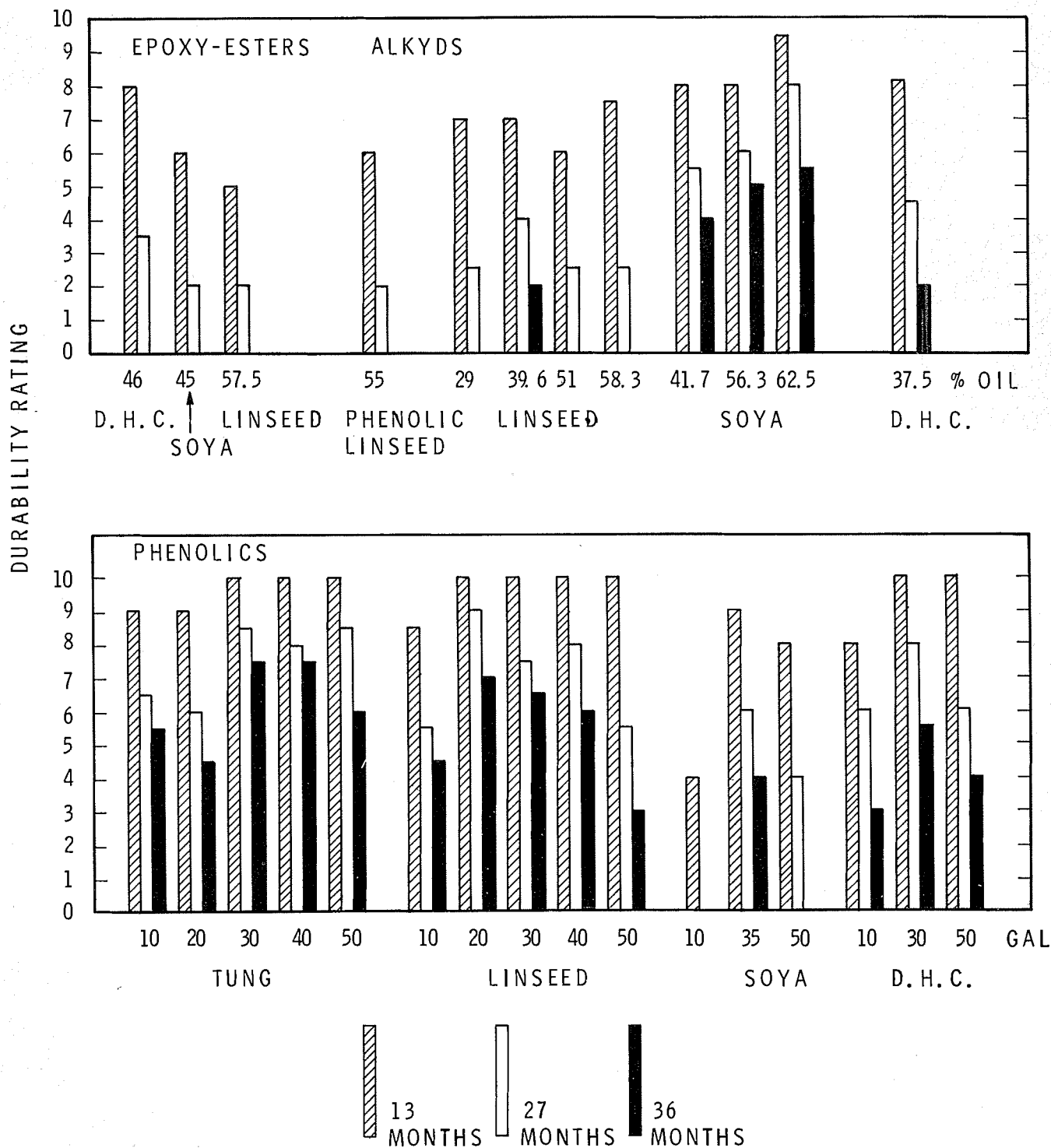


Figure 1—Durability of materials exposed in 1955

With the alkyds, the soya types appear to show a trend toward better durability with greater oil content. As the alkyds were all reduced to the same viscosity, however, those with less oil had much lower solids content; their poorer durability might also be attributed to thinner films. In contrast with the phenolics, the soya alkyds were much better than the linseed alkyds. There may be several reasons for this reversal in performance. Linseed oil is more functional than soybean oil because of its greater unsaturation, which leads to more cross-linking during resin synthesis and drying. The resulting film should be less flexible than that of a soya alkyd and therefore might fail sooner on a wood substrate. Another possibility is that because alkyds fail in a different manner from phenolics when used as clear coatings on wood, the effect of the type of oil could be expected to be different. In addition, the proportion of oil in alkyds is not the same as that in phenolic varnishes. An alkyd containing 60% oil is considered long, whereas a varnish with the same oil content is short (about 18 gallons).

The phenolic-modified linseed alkyd did not perform better than the corresponding straight linseed alkyd, perhaps because the film was more brittle or a less effective phenol was used. Modification with paraphenylphenol might possibly combine the favorable phenolic results with the better flexibility of alkyds. The epoxy esters had poor durability as clear coatings on wood regardless of the type of oil. Their oil and solids content were in the same range as those of the alkyds.

## SECOND EXPOSURE SERIES (1960)

### Original Exposure Results

The second exposure series was designed to check some of the earlier findings and to investigate additional materials. By eliminating the poorer coatings and by using only one kind of wood it was possible to expose a greater number of coatings than in the first series. Materials developed since 1955 or which were claimed to be superior to conventional finishes were exposed. It was also possible to examine in more detail some aspects of phenolics by eliminating the less durable soya, dehydrated castor and all very long varnishes. Durability had also been poorer at the short oil end so that only the 10-gallon tung varnish was used. All varnishes that were retested were cooked again with closer control over the viscosity and solids content.

One factor that was examined with the phenolics was the effect of varnish viscosity as an increase in viscosity is related to an increase in mean molecular weight of the oil-resin molecule. It was of interest to determine whether high molecular weight would be an advantage or whether there would be an optimum viscosity range, since varnish specifications require that viscosity fall within certain limits. Because the 30-gallon tung phenolic had given the best performance

in the first exposure series, it was selected for study. Different batches were cooked for various times to obtain a range of viscosities, with the first sample not being cooked at all; the oil was heated only enough to dissolve the resin. The resulting mixture had a viscosity of B-C at 100% solids. This was reduced to 65% so that it would be more similar to the cooked varnishes and any difference in durability would not be due to film thickness. Fifty per cent butyl acetate had to be added to xylene to keep the resin in solution. There is thus evidence that when varnish is cooked the resin is not merely dispersed but reacts with the oil because even the undercooked varnishes were soluble in mineral spirits with the addition of only 10% xylene.

The phenolic resin used in all the previous varnishes was made from paraphenylphenol. In the second series three other phenolic resins were used to make four varnishes, one of which was known to have been a commercial product. One resin was a reactive type; the others were of the nonreactive para-tertiary butylphenol kind.

In the first series all the alkyds had been reduced to the same viscosity so that the solids content differed by as much as 25% total solids. In reformulating, the solids were kept as close as possible to 50% without making the viscosity abnormally high. To check the effect of oil content more thoroughly a complete range of soya alkyds was used. One linseed alkyd was also tested and, to eliminate at least one variable, all were purchased from the same manufacturer. The Golden Gate Paint and Varnish Production Club had reported that an isophthalic alkyd had good durability when used as an exterior clear finish on wood.<sup>2</sup> One very long oil isophthalic alkyd corresponding to an oil length of 50 gallons was therefore included in the second series.

Three resins of the urethane type which had been promoted on the basis of excellent exterior durability when used as clear coatings on wood were included in the exposure series. One was a two-component type in which a polyisocyanate is cross-linked with castor oil. The other two were oil-modified urethanes where drying occurs through the oil portion; one was a com-

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H. E. ASHTON has been associated with the Paint Laboratory of the Division of Building Research Council, since 1956. His original work was chiefly concerned with paint test methods and special product development for government contracts. More recently, his work has been concentrated on clear and pigmented coatings for wood. Mr. Ashton, a graduate of the University of British Columbia, had been previously connected with General Paint Corp. of Canada, Ltd.

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Table 2—Composition and Ratings of Materials Exposed in 1960

Formula No.		Vehicle Composition			Properties			Remarks	Durability		
Series II	Series I	Resin Type	Oil Type	% Oil	% Solids	Viscosity (G-H)	Sealer Solids		June 1961	June 1962	Nov. 1962
Phenolic Varnishes											
892	371	p-Phenyl	Tung	50	50.0	C-D	37.5	10 gallons	9.7	7.7	6
893	430	p-Phenyl	Tung	66.7	51.0	B	42.5	20 gallons	10	10	8
894	429	p-Phenyl	Tung	75	50.0	C-D	38.2	30 gallons normal cook	10	9.7	7
894F	—	p-Phenyl	Tung	75	50.0	C-D	38.2	Applied on fence	—	9.3	7.3
894SE	—	p-Phenyl	Tung	75	50.0	C-D	38.2	Summer exposure	—	9.3	7
895	—	p-Phenyl	Tung	75	65.0	A-4	65.0	Not cooked	10	8.3	5
896	—	p-Phenyl	Tung	75	49.6	A-1	44.5	Undercooked	10	9.7	8.2
897	—	p-Phenyl	Tung	75	49.5	A-B	40.0	Slightly undercooked	10	9.3	7.5
898	—	p-Phenyl	Tung	75	50.0	F	34.4	Slightly overcooked	10	10	8
899	—	p-Phenyl	Tung	75	50.0	I-J	28.6	Moderately overcooked	10	9.7	6.8
900	—	p-Phenyl	Tung	75	50.4	M	27.0	Overcooked	10	9	6.5
901	428	p-Phenyl	Tung	80	50.0	C-D	40.0	40 gallons	10	9.3	5
901W	—	p-Phenyl	Tung	80	50.0	C-D	40.0	Prewathered panels	10	5.5	3
934	—	p-Phenyl	Tung	80	50.0	C-D	40.0	901 + 0.5 UV absorber	10	9.5	6.3
902	373	p-Phenyl	Linseed	66.7	52.8	C	41.2	20 gallons	10	9.7	7
903	374	p-Phenyl	Linseed	75	49.8	B-C	39.0	30 gallons normal cook	10	8.3	5.5
903W	—	p-Phenyl	Linseed	75	49.8	B-C	39.0	Prewathered panels	10	6.5	2.3
904	—	p-Phenyl	Linseed	75	50.0	J	31.8	Moderately overcooked	10	8.7	6.3
905	375	p-Phenyl	Linseed	80	50.0	D-E	41.8	40 gallons	10	6	2.5
906	—	p-Phenyl	Tung	46	53.8	C	40.0	T-T-V-119 formula	10	9.7	7.5
			Linseed Z-2	23.75							
			Raw castor	2.25							
				72.0							
907	—	Reactive	Tung	73.8	53.2	C	42.0	Possibly p-tert-Butyl phenolic	10	4	2.8
908	—	Non-reactive	Tung	73.8	49.8	C-D	37.2	Possibly p-tert-Butyl phenolic	10	8.7	4.3
909	—	Non-reactive	Tung	66.3	50.5	D	38.2	Possibly p-tert-Butyl phenolic	10	9	3.8
			Linseed Z-2	7.6							
				73.9							
910	—	p-Butyl	Tung	49.5	57.5	C	45.7	Cold-mix varnish	10	9.3	7.5
			Linseed Z-7	16.8							
				66.3							
Alkyd Solutions											
911	—	Isophthalic	Soya linseed	85	55.0	A-3	55.0	V. long; V. low viscosity	9	6.2	4.7
912	357	Phthalic	Soya	62.5	50.2	C	40.5	Long; low viscosity	10	7.7	6
913	—	Phthalic	Soya	62.5	50.2	G	37.5	Long; medium viscosity	10	6	4.7
913SE	—	Phthalic	Soya	62.5	50.2	G	37.5	Summer exposure	—	6.7	4
936	—	Phthalic	Soya	62.5	50.2	G	37.5	913 + 0.5UV absorber	10	6	4.3
914	360	Phthalic	Soya	56	50.0	F	37.5	Medium; med. viscosity	10	7.3	6.3
915	—	Phthalic	Soya	48	42.0	E	32.4	Medium; high viscosity	9.5	6	4.3
916	—	Phthalic	Soya	38.5	40.0	F	30.0	Short; high viscosity	9.7	6	3.7
917	356	Phthalic	Linseed	51	43.2	E	33.2	Medium; high viscosity	10	7.3	4.5
917W	—	Phthalic	Linseed	51	43.2	E	33.2	Prewathered panels	8.5	5	4

mercial clear exterior wood finish supplied by a paint manufacturer.

In the first series of exposures, three epoxy esters had been tested and found to have poor exterior durability. In the second series three cold-curing epoxy formulations were included to discover whether they would perform better than the esters. One sample was cured with an amine, one with an amine-adduct, and the third with a polyamide resin.

The use of ultra-violet absorbers for improving the durability of clear coatings has been suggested in commercial literature. Much of the degradation of coatings and plastics is attributed to the ultra-violet portion of daylight. One reason advanced for the poor durability of clear in comparison with pigmented finishes is that there is no pigment to absorb the light and protect the vehicle. If a material that can absorb UV and dissipate it harmlessly is added to a clear organic

polymer, its exterior durability is said to be improved markedly. As there was not sufficient exposure space to make more than a brief study of absorbers, one UV absorber was added to three coatings—an alkyd, a phenolic and a urethane—in the proportion of 0.5% of the solids content. This amount, suggested in formulas for lacquers to prevent bleached wood from darkening, is commonly used in plastics.

Most of the panels for both exposure series were prepared in the laboratory from siding that had been kept indoors. Houses, of course, are not erected under such ideal conditions, and occasionally the siding may be exposed to the weather for a considerable time before it is coated. To determine whether this has any effect on durability an alkyd and two phenolics were applied to panels that had first been exposed to the weather for several days.

Frequently in discussions on exterior durability



Table 2—Composition and Ratings of Materials Exposed in 1960 (Cont'd)

Formula No.		Vehicle Composition			Properties			Remarks	Durability		
Series II	Series I	Resin Type	Oil Type	% Oil	% Solids	Viscosity (G-H)	Sealer Solids		June 1961	June 1962	Nov. 1962
Polyurethanes											
844	—	Oil-modified	Unknown	Unknown	50.0	B	†	844 + 0.5 UV absorber Prepolymer-castor cured	10	8.3	5.3
935	—	Oil-modified	Unknown	Unknown	50.0	B	†		10	7.5	4.5
850	—	Two-component	Modified castor	47.9	50.0	A-2	†		9.7	10	7.3
11459	—	Oil modified	Unknown	Unknown	62.0	A-1	†	Commercial	10	9	6.7
Epoxies											
851	—	—	—	—	50.0	D	†	Amine cured	10	7	4.7
852	—	—	—	—	50.0	G	†	Amine-adduct cured	10	9	6
853	—	—	—	—	50.0	E	†	Polyamide cured	10	6.3	3
Miscellaneous Clears											
846	—	Rosin-Maleic	—	—	16.3	A-4	†	Water-repellent sealer	7	0	0
—	—	Cellulose acetate-butyrate	—	—	31	—	†	Emulsion	5	3	0
—	—	—	Linseed	100	100	—	†	Boiled oil	7	5	1
Stains											
848	—	—	Linseed	87.4	77	28.8	†	U. S. Forest Products	10	9.3	9
849	—	—	Linseed	92.7	100	30.6	†	Canadian Forest Products	10	6.3	4
870	—	Alkyd	Soya	26.2	35.6	23.4	†	1-GP-145, Type I	9.5	10	8.7
			Linseed	58.1							
				84.3							
11505	—	Alkyd	Unknown	Unknown	35.6	27.0	†	Commercial	10	9.3	7
11506	—	—	—	—	45	23.5	†	Commercial Creosote base	9	7	5.3
Mean rating									9.6	7.7	5.3
Decrease per month									0.05	0.10	0.48

\* The oil content of alkyds was calculated from the reported fatty acid content according to Payne<sup>6</sup> except for the isophthalic alkyd which was reported as oil content.

† Not reduced for first coat.

\*\* Krebs-Stormer, seconds for 100 revolutions with 50 g weight.

testing it is suggested that panels should always be exposed at the same time of year. The idea is that films put out in the autumn cure under mild conditions and are thus better able to resist the summer sun than those exposed in the late spring or early summer. Because the panels were exposed in November 1960 another set of two of the finishes was exposed in July 1961. In addition, a third material was immediately subjected to summer weather by applying it in July to newly-mounted siding.

Three sets of panels were included as a matter of interest:

(1) One material that was applied was a water-repellent sealer of the type used on lumber that cannot be painted immediately but requires some protection. This sealer is recommended by the U. S. Forest Products Laboratory<sup>3</sup> for back priming siding to prevent water from wicking behind the siding.

(2) A raw material supplier had suggested an emulsion of a cellulose acetate-butyrate lacquer, since cellulose acetate compounds are resistant to degradation by ultra-violet light. Two pieces of siding were given two coats of the emulsion.

(3) Many inquiries have been received concerning the use of linseed oil as a clear coating for exterior

wood. For direct comparison with the two main conventional coatings, boiled linseed oil was applied to the center of three panels and an alkyd and a phenolic were applied on either side. In this way variations resulting from different woods were eliminated. All three finishes were applied in three coats, with the first coat of the alkyd and the phenolic reduced for sealing.

Finally, it was decided to obtain information on the durability of pigmented exterior stains which are classified as being between clear finishes and paints. Pigmented stains designed for use on wood contain sufficient pigment to color the substrate, although preferably not enough to obscure the grain of the wood. It is claimed that pigment content increases durability of the stain. Based on results of the 1955 exposure series, the DBR Paint Laboratory had been recommending stains in preference to clears for exterior wood, but it was not known from actual exposures whether their performance would be like that of a clear or a paint. Two commercial stains, one with an alkyd vehicle, the other with refined creosote, were used as standards. The Forest Products Laboratories of Canada<sup>4</sup> and the United States<sup>5</sup> have published formulations for stains; these can be made by the

homeowner and are claimed to have very good durability. Both materials were included in the program. Lastly, a stain was formulated in the Paint Laboratory to meet Canadian Government Specifications Board Specification 1-GP-145: Stain: Pigmented, Exterior and Interior, the vehicle of which consisted of an alkyd resin plus linseed oil.

Two species of wood had been used in the first exposure series. Because the failure rate appeared to be slightly higher on red cedar than on white pine it was decided, for the 1960 tests, to use only the former and reduce the number of panels by one half. Bevelled siding was selected because the cove siding previously used had accentuated failures at the leading edge. The clear finishes were applied at a coverage rate calculated to yield a total dry-film thickness close to 2.5 mils. In the second series the panels were not back-primed because this is rarely done in home building. The ends, however, were sealed to reduce their influence on the relatively short lengths. Plywood sheets covered with building paper were used to support the panels on the exposure racks. Nails were driven from the back of the plywood so that the test surfaces were unbroken. To protect the ends and duplicate house construction more closely, strips were fastened to the ends of each assembly of six panels and caulking compound was injected between the panel ends and the strips. A cap is generally placed on top of vertical test fences to prevent rain water from getting behind the panels. In the 1955 series the top panel received considerable protection from such a cap. In the 1960 tests a piece of wood was inserted to increase the distance from the top panel to the cap.

The panels were placed on the exposure racks at the National Research Council on November 21, 1960. As before, exposure was vertical, facing south; the panels were observed periodically during the test. In November 1962 the assemblies were removed to the laboratory and examined independently by two observers. These final ratings were combined and are shown in *Table 2* together with the seven-month and 19-month ratings. The exposure period was of shorter duration in the second series because panels were to be recoated before failure became too extensive.

After seven months' winter and spring exposure only five materials showed any effects besides the expected yellowing of the phenolic varnishes. The butyrate lacquer had turned white and had started to flake; the panels with water-repellent sealer were beginning to look white. There was slight grain raising on the creosote stain panels, and stain 870 exhibited some gloss over summer wood owing to the use of unbodied linseed oil. The boiled linseed oil was sweating or frosting.

After 19 months all the tung-phenylphenolic varnishes except the 10-gallon and uncooked 20-gallon varnishes were in excellent condition, whereas only the 20-gallon linseed rated as well. The tung-linseed

Table 3—Rating of Better Materials  
After Two Years Exposure

Number	Type	Mean Rating	Lowest Rating
848	U. S. F.P.L. stain .....	9	9
870	NRC 1-GP-145 stain .....	8.7	8
896	30 gallons tung-p. phenylphenolic .....	8.2	7.5
898	30 gallons tung-p. phenylphenolic .....	8	8
893	20 gallons tung-p. phenylphenolic .....	8	8
897	30 gallons tung-p. phenylphenolic .....	7.5	7
910	Cold mix varnish .....	7.5	7
906	TT-V-119 p. phenylphenolic .....	7.5	6
894F	30 gallons tung-p. phenylphenolic .....	7.3	6.5
850	Castor oil cured urethane .....	7.3	6

varnish to U. S. Federal specification TT-V-119 and the tung-linseed cold mix varnish were also excellent. Of the other types of clear materials only the castor-oil cured urethane had no defects. Among the stains, the U. S. Forest Products Formula, the NRC alkyd-linseed material, and the commercial alkyd were still in excellent condition. In addition to the butyrate lacquer, water-repellent sealer and linseed oil, the tung-reactive phenolic varnish and the linseed alkyd applied to weathered boards were in poor condition.

Most of the remainder rated good to very good. The alkyd films were generally in good condition, but there were white spots or areas underneath the film as though air was getting between the wood and the coating. This usually occurred over the spring wood only. Except for one panel the oil-modified urethanes were very good, ranking slightly below the first group. The alkyd and the phenolics applied to weathered panels were in significantly poorer condition than the same coatings on non-weathered panels. The films exposed in July were about the same or slightly better than those put out seven months earlier.

At the end of two years there were only eight clear finishes and two stains that could be classified as good or very good; of the 30 panels only six were rated excellent. The materials are arranged in order of rank in *Table 3*.

There is, of course, no definite line of demarcation between "good" coatings and those of slightly lower rating, but the materials listed in *Table 3* appeared to be superior to the others. Another complicating factor in comparing materials is the variation between different panels of the same coating. Some, such as 893 and 898, gave the same performance on all three panels; others, such as 906, 851 and 844, gave good or even excellent performance on one panel but only fairly good to very poor performance on another. This is illustrated in *Figure 2*. In some cases the poorer durability resulted from too flat a grain in the wood panel. Where there was no obvious explanation for the difference, the material was reduced in rank compared to those that had performed more consistently.

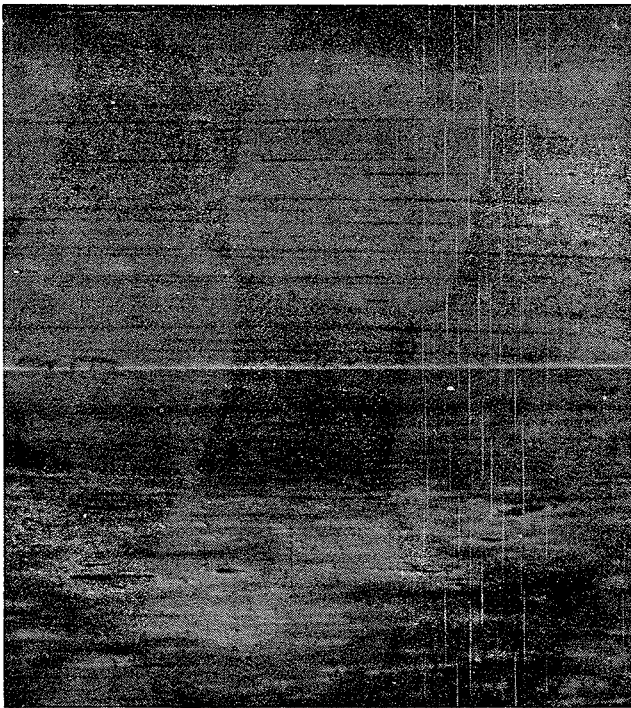


Figure 2—Variation in performance of an oil-modified urethane on different panels

#### Phenolic Varnishes

Phenolic varnishes, generally, had the highest ratings; of the eight best clear finishes, seven belong to this category. None of the newer materials in this exposure series equalled the performance of the better tung-paraphenylphenolic varnishes. The first signs of failure usually shown by phenolic varnishes are spots of light yellow that contrast with the normal deep yellow color. On close inspection the spots are found to be associated with small craters, but it is not known which forms first. As time progresses the craters open up into small cracks running in the same direction as the grain lines. When the cracks get larger the film peels back from the edges, although if it is brittle it may flake off in pieces rather than peel. If allowed to progress too far this type of failure requires removal of most of the film—a difficult task to carry out on the siding of a building.

The effect of oil content and type on the durability of the paraphenylphenolic varnishes is shown in Figure 3. At all oil lengths tung varnishes outperformed linseed varnishes. At 20 gallons the difference was slight, but as the oil content increased the superiority became more marked. In agreement with theory, although in contrast with the results of the 1955 series, the tung varnishes showed a peak in durability around 20 gallons, as did the linseed varnishes in both series. TT-V-119 and cold-mix varnishes, both of which contain a high proportion of tung oil, were also durable.

Although it had been expected that the varnishes with medium or high viscosities would be more dur-

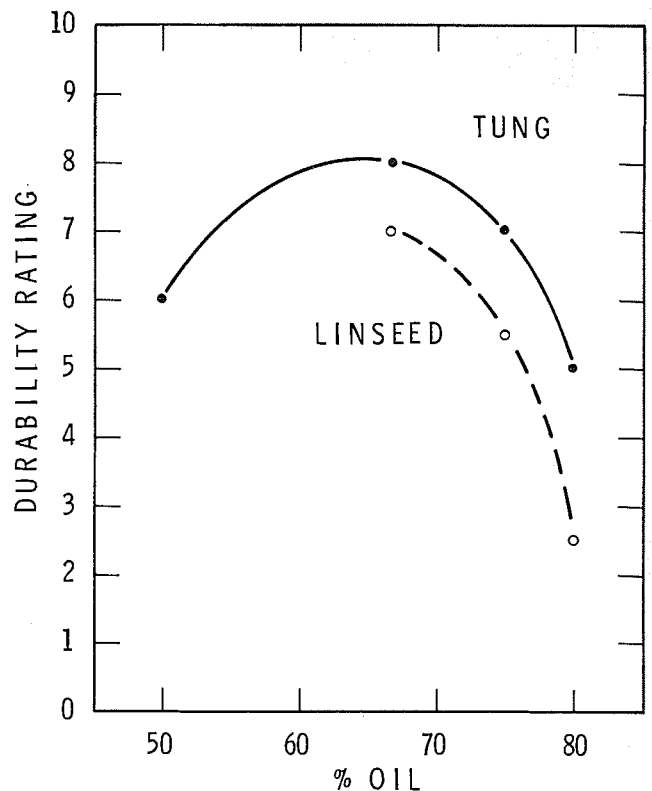


Figure 3—Oil content vs. durability, phenolic varnishes

able, Figure 4 shows a trend to better durability with lower viscosity, although the results from 898 are anomalous. The superiority of the low-viscosity varnishes might be due to the ability of the material with lower molecular weight to penetrate and reinforce the top layer of the wood. Alternatively the first coat of the lighter varnishes contained more non-volatile vehicle at equal viscosity, and there would thus be more material available to bind the wood fibers. Laboratory

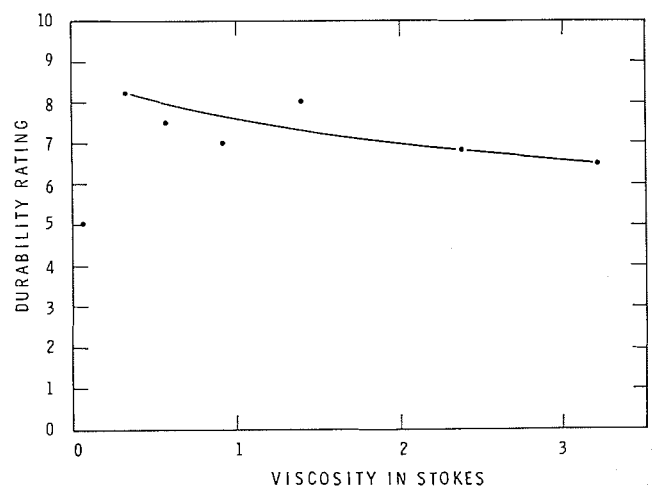


Figure 4—Viscosity vs. durability, 30-gallon tung-phenolic varnishes

tests designed to determine which is the more important property will be described in another paper.

It is also evident that some cooking of the ingredients is required at least with the paraphenylphenolic resin, because the simple mixture had the poorest durability of the seven in this set. The phenylphenol resin cannot be substituted for the butylphenol resin in the cold-mix formula because it is only soluble in strong solvents. The butylphenolic resin gave good results, but varnishes made with two other alkylphenolic resins had poor durability. Reactive phenolic varnish was in poor condition after only 19 months. At the same time formulas 908 and 909 were in good condition, but deteriorated markedly during the second summer of exposure.

These results indicate what ingredients are needed in the normal cooked varnish. The resin should be paraphenylphenolic and the oil should consist mostly of tung oil and comprise 65 to 75% of the solids. This kind of information is of little assistance to the average user because neither he nor the paint dealer knows the composition of the varnish. The name "spar" varnish does not help because of misuse in the trade, and even "pure phenolic" is not specific enough, since failures occurred with two phenolic resins. The only recourse for the buyer or specifier is to ask whether the varnish complies with CGSB specification 1-GP-99 or U. S. Federal specification TT-V-119, which require the use of paraphenylphenolic resin.

#### Alkyd Resins

Alkyds were inferior to paraphenylphenolic varnishes as clear finishes for exterior wood, confirming the results of the first exposure series. Typical alkyd failure starts as small craters and white spots over the spring wood that grow into areas stretching in the direction of the grain. A crack may develop, in which case there is peeling over a small area, but adhesion is usually lost over the adjacent summer wood and

large areas finally delaminate from the surface. This procedure is in marked contrast with the behavior of pigmented coatings, which fail first over the summer wood. Even after delamination the outer surface of the alkyd film appears to be in good condition.

There seemed to be a trend to greater durability with higher oil content (Figure 5) but there is a much stronger relation between solids content and durability. It would be necessary to make alkyds of differing oil contents to the same viscosity in order to determine which is the controlling factor. In addition, there were no alkyds in the range of 65 to 75% oil where the phenolics were most durable.

The two best alkyds were the long soya (low viscosity), and the medium soya (medium viscosity), but after two years they could only be classed as fairly good. Comparison between the two series is difficult, but the shorter alkyds did not appear to fail so badly as on the first exposures, perhaps because of the higher solids content. The isophthalic and orthophthalic alkyds could not be compared directly because of the large difference in oil content. Due to the high oil content the isophthalic alkyd retained considerable dirt on the film. A somewhat shorter resin might be better in this respect because it would not be so soft. Linseed alkyd had the best gloss retention of all clear finishes, and its performance on wood was about the same as that of the soya alkyds in the same oil content range. In spite of their mediocre durability, all alkyds were much better than boiled linseed oil treatment.

#### Urethanes

Performance of the urethanes was rather disappointing, considering the claims made for them. Oil-modified urethane, both with and without UV absorber, showed great variation between different panels, with ratings ranging from very bad to good. The commercial oil-modified urethane and the castor-oil cured type had smaller ranges of 3 and 2, respectively.

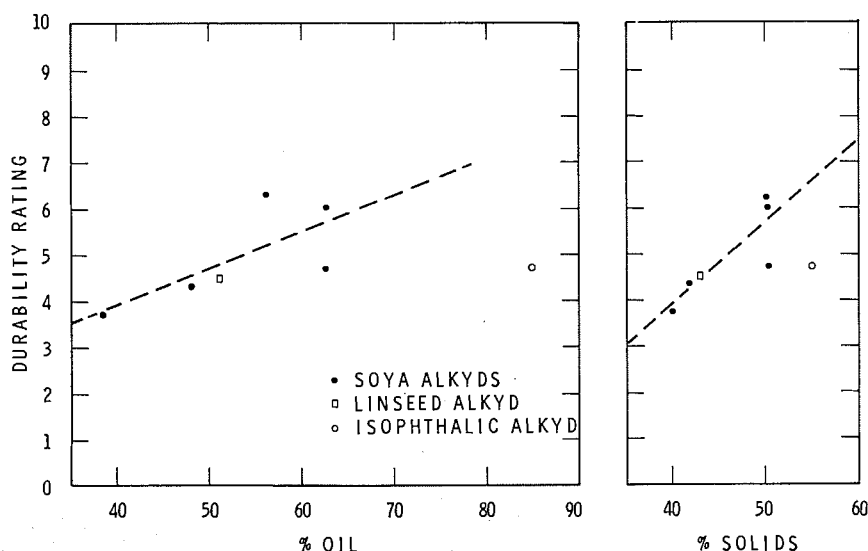


Figure 5—Durability vs. oil content and per cent solids for clear alkyds

Variability appeared to be connected with the high tensile strength of the urethanes: as long as there was no break in the surface, the film remained in quite good condition, but once it was ruptured pronounced peeling followed. The castor-oil polyisocyanate was the only clear material that seemed to fail more at the air interface than at the wood interface. It lost gloss rapidly but otherwise remained in quite good condition.

### Epoxies

The two amine-cured epoxies had only fair durability ratings, which were comparable to the alkyds. The type of failure was entirely different, however, in that the epoxy film degraded. Once a break occurred, extensive flaking followed. Polyamide-epoxy was rated very bad, a surprising development because polyamide is itself resinous and was thought to confer greater flexibility than the short chained amines. Polyamides have been reported to be unstable towards UV light in the presence of air and this could explain the film degradation. The only possibility for improved epoxy performance appears to lie with curing agents that could cause less cross-linking than that obtained with the highly functional amines previously used.

### Ultra-Violet Absorbers

The UV absorbers used at a concentration of 0.5% were not effective in slowing the exterior degradation of an alkyd, an oil-modified urethane, or a phenolic. Because of the many different coatings examined in this study, it was not possible to determine the effect of greater amounts of different types of UV absorbers on the durability of the coatings. It was originally decided to determine first which materials had good durability without modification. It was thought that the performance of inherently durable coatings could be improved by UV absorbers just as well as those which were not very durable. In fact some of the latter, depending upon the mechanism of their failure, might need much greater amounts of absorber to make them satisfactory. A detailed investigation of absorbers in clear finishes for wood is planned for the future.

### Stains

Two of the stains had the best ratings of all the materials exposed. That pigment is not the complete answer, however, is shown by the fact that five types of clear coatings were better than the next lower stain. Creosote stain was rated only fair and wiped stain, poor. One reason for the good durability of the U. S. Forest Product's formulation is its very dark color; two coats of the material resemble a paint more than a stain. The Canadian formula does not appear to be practical for use on new wood on a house because it does not dry and must be wiped; even two coats leave a relatively thin covering that requires renewal in about a year's time when the water-repellent qualities

have deteriorated. Maintenance would therefore be excessive. The creosote stain could be ranked lower than the Canadian material because it had two full coats as against two wiped coats. All except the wiped stain hid most of the grain pattern, which is contrary to one purpose of a stain. It is not known whether the results with No. 848 and 870 would be equally good if less pigment or a light-colored pigment were used to make the wood more distinguishable. The pigmented stains should fail by erosion, which would leave a better surface for recoating than a flaked, checked or peeled clear coating.

### Exposure Conditions

Whether panels were exposed in the spring or the fall appeared to make little difference, at least according to the results obtained with a phenolic and an alkyd sample. What does appear to be important is the number of summers to which a coating has been exposed. Panels put out in autumn *appear* to be more durable than spring panels because there is an extra seven months before much degradation occurs.

The period of exposure of the wood before coating is very important. The three materials applied to boards weathered for only one week had an average decrease in rating of about 2 from the same materials applied to panels kept in the laboratory. These results would favor factory coating of lumber, since the siding on a new house is occasionally left for as long as a month before it is coated. Further tests on the effect of light and water on uncoated wood will be described elsewhere.

### SUMMARY OF COATING PERFORMANCE

Two pigmented stains performed best in the second exposure series. One contained linseed oil fortified with wax and preservative; the other was based on an alkyd with additional linseed oil. Of the clear finishes, 20- to 30-gallon tung-paraphenylphenolic varnishes provided at least two years' good service. A cold-mix varnish and a castor-oil cured urethane were also good. With phenolic varnishes the type of oil and the type of resin are both important if adequate durability is to be obtained. The other clear finishes were generally inferior and could not be recommended for exterior wood. Two of the stains were also inadequate.

As expected, because of increased light and heat, both exposure series showed that the summer months are most destructive to clear finishes. It was noted in the first series that the number of coatings declining from acceptable and the number becoming especially poor were about the same for nine chiefly winter months and five subsequent summer months. *Table 2* shows that in the last five months the mean durability rating decreased five times faster than in the previous year. Exposure of the wood before coating had a serious effect on the durability of subsequently applied clear finishes.

### Recoating

Part of the program of the second exposure series was concerned with the problem of recoating clear finishes. This involves two questions: how do materials that have shown good original durability perform when recoated before failing commences; and what is the best way to treat surfaces on which failure has occurred because an inadequate material was used. Refinishing large areas that have deteriorated through weathering is not easy, because the common clear finishes do not lend themselves to recoating when their useful life has ended. The types of failure range from tiny cracks or checks to large white patches or peeled and flaking areas. To refinish a surface, it must be free of all loose film and be as smooth as possible, with no sharp edges. Coatings do not cling well to edges and the film thickness is always reduced at these locations. Feathering the edges of stripped areas with sandpaper reduces the sharpness and helps to blend the repaired area with the surrounding surface.

The clear finishes exposed for two years were divided into four categories:

- (1) Materials requiring little or no touch-up;
- (2) Materials starting to fail;
- (3) Materials with more serious failure;
- (4) Materials completely failed.

Those in the last group were discarded because in actual practice the coatings would seldom be allowed to deteriorate to such a degree. The first group included all the 20- and 30-gallon paraphenylphenolic varnishes, the cold mix varnish, the castor-oil cured urethane, and the commercial oil-modified urethane. The best panel of each material was left untouched to determine the ultimate durability of the original coating system. On another panel any defective areas were hand-sanded to bare wood and the edges of the area feathered. On the third panel hand scraping was followed by light sanding and feathering. These spots were touched up with two coats, the second being spread over a slightly larger area than the first. Each panel then received a coat over the entire face. For all panels in this group the same material as was originally applied was used for recoating.

In the second category hand-sanding was compared with scraping and sanding and with wire brushing and sanding. The coating procedure was the same except for the epoxy, of which all three panels were refinished with the 20-gallon tung-paraphenylphenolic, and the two alkyds, each of which had one panel refinished with this varnish. Only one material had all three panels in the category of more serious failures. This was the 40-gallon linseed phenolic and it was recoated with the more durable 20-gallon linseed phenolic. In preparing the surface, paint remover, scraping, and sanding were used on one panel, a reciprocating power sander on another, and a circular disc

sander on the third. The one oil-modified urethane panel that had failed rather badly was also prepared with the disc sander.

The stains were also touched up. All three of the Canadian Forest Products panels were given a fresh coat of stain. With three other stains one panel of each was not recoated and one panel received a full coat. Half of the third panels of the commercial alkyd stain and the NRC modified alkyd stain were recoated. The commercial creosote stain was in poorer condition than the others so that the third panel had to be given a full coat.

The U. S. Forest Products stain panels originally were half two coats and half one coat. Half of the latter areas on each panel received a second coat. Unfortunately, the panels were left in the laboratory with the discards and were not discovered until after the first summer of re-exposure had ended.

The intention was to recoat the panels on the test fence, but all preparation and recoating had to be carried out in the laboratory because of the early onset of winter in 1962. Preliminary indications on the effectiveness of the different methods of preparation will be given after the ease of preparation has been discussed.

### Methods of Preparation

Hand-sanding is effective where failure is limited to small or scattered areas of lifting, peeling or light-colored streaks. A medium grit garnet paper should be used and feathering can be done with the same paper after it has lost its initial sharpness.

Scraping with a hoe-type scraper is easier and more convenient than sanding for materials that have a greater degree of failure. It reduces the thickness of the coating, thus facilitating feathering. Scraping was most effective with phenolic varnishes and urethanes.

Wire brushing easily removes very loose material, but it is not as efficient as scraping for most coatings. Alkyds can be easily wire-brushed because they fail by delamination, but harder films resist the steel bristles remarkably well. Subsequent sanding and feathering take longer after wire brushing because the wood is often scored, with some spring wood removed.

The common reciprocating sander is rather ineffective, particularly on harder materials. The sandpaper quickly gums up because the sanding dust fills the voids in the paper, reducing its abrasiveness. The disc sander does a better job because the paper stays cleaner. There is some scoring from sanding across the grain but after refinishing close inspection revealed only slight defects. The chief drawback is the weight of the machine, which makes control difficult on a vertical surface. The sanding attachment for a 1/4-inch electric drill is light but rather awkward to handle.

Paint and varnish remover is effective but very laborious. Two applications are often required and scraping with at least a putty knife followed by sanding is necessary for complete removal of the finish.

Most paint removers contain wax to retard solvent evaporation and wood surfaces must be thoroughly cleaned or subsequent coats may not dry. Another consideration is that on exterior work, wind can often increase solvent evaporation, thus reducing the effectiveness of the material. In general, paint removers are not practical for use on buildings.

To summarize, scraping with finishing by sandpaper produces the best results with the least work on surfaces with moderate failure. For more serious defects the disc sander is required because most of the coating has to be removed to bare wood.

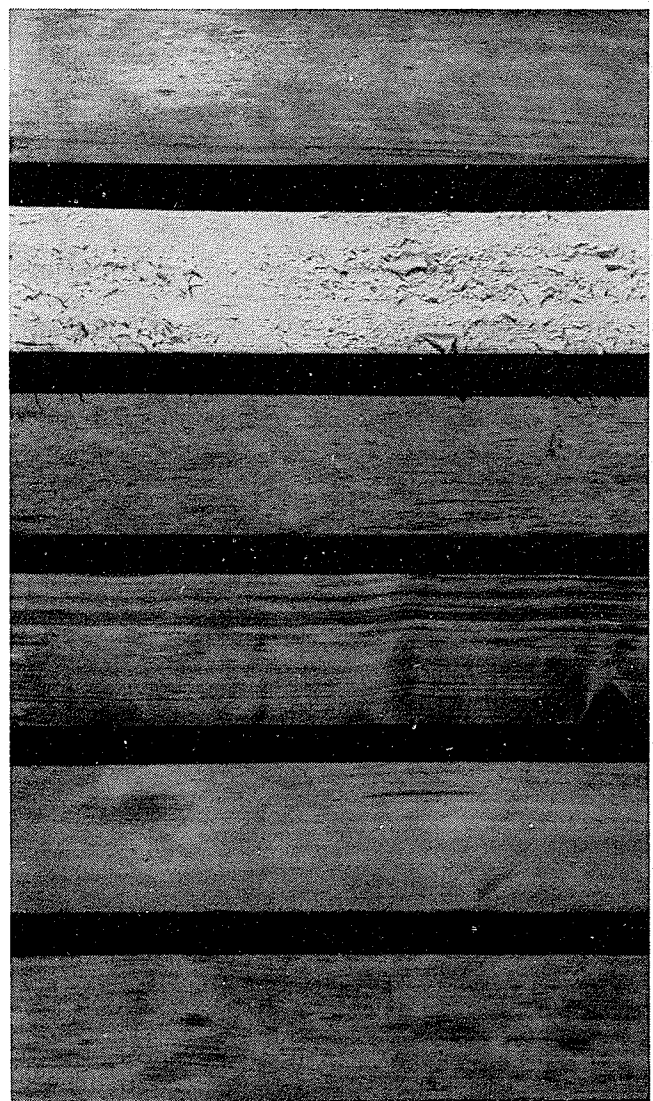
### Performance of Untouched And Refinished Panels

The untouched and refinished panels were re-exposed on March 19, 1963 and observed at six-month intervals. After 18 months they were again removed from the fence and examined in the laboratory. The results are given in *Table 4*.

Table 4—Exposure Rating of Refinished Panels  
18 Months Additional Exposure

Group Number	Material Exposed	Panel Treatment		
		Untouched	Hand Sanded	Scraped and Sanded
1	850 Castor-urethane	6	4	5
	893 20 gallons tung	4	7.5	8
	894 30 gallons tung	2	4	5.5
	896 30 gallons tung	2	5	6.5
	897 30 gallons tung	2	5.5	5
	898 30 gallons tung	3.5	6.5	6
	899 30 gallons tung	2	7	9
	900 30 gallons tung	3	7	8
	902 20 gallons linseed	2	5	4
	903 30 gallons linseed	0	2	4
	904 30 gallons linseed	1	6	8
	906 TT-V-119	4	5	5.5
	910 Cold-mix	3	6.5	6
	934 40 gallons tung + UV	2	4	—
2	11459 Commercial urethane-oil	0	6.5	3
		Wire Brushed	Hand Sanded	Scraped and Sanded
	844 Urethane oil	—	4	4
	852 Epoxy recoated with 20-gallons tung	6	5.5	5
	892 10-gallons tung	5	8	6
	901 40-gallons tung	6	4.5	5
	912 Long soya alkyd	6.5	4	4.5*
	914 Medium soya alkyd	4*	5	4.5
		Paint Remover	Reciprocating Sander	Disc Sander
	844 Urethane oil	—	—	7
	905 40-gallons linseed recoated 20-gallons L.	4	5.5	4
		Untouched	½ Panel Recoated	All Panel Recoated
	849 Can. Forest Prod.	—	—	7, 8, 8
	870 1-GP-145 Type I	7	7	6
	11505 Commercial alkyd	5	7	6
	11506 Commercial creosote	3	—	5, 5

\* Refinished with 893 20-gallon tung.

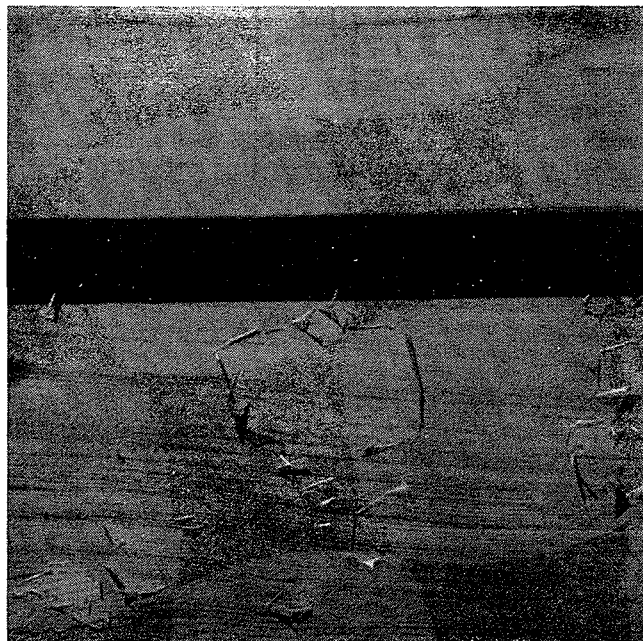


Panels in order are:  
30-gallon tung phenolic, untouched  
Commercial urethane oil, untouched  
Epoxy recoated with 20-gallon tung, wire-brushed  
Epoxy recoated with 20-gallon tung, hand-sanded  
30-gallon tung phenolic, scraped  
TT-V-119 phenolic, scraped

Figure 6—Comparison of untouched panels with refinished panels

Except for castor-oil cured urethane the durability of the untouched panels diminished quickly during the third summer and was quite low at the end of the test. Refinished panels of materials that had little original failure were more durable (*Figure 6*). Generally, scraped and sanded panels were superior to those that had only been hand-sanded. After the second additional summer some 20- and 30-gallon tung phenolics still rated 8 to 9 on the scraped panels. There seemed to be a tendency to better durability with the higher viscosity 30-gallon varnishes, perhaps because in refinishing there was no difference in solids content. The linseed varnishes were again inferior to the tung. The refinished castor-urethane panels were in





Upper panel—30-gallon tung phenolic, hand-sanded  
Lower panel—castor-oil urethane, hand-sanded

Figure 7—Peeling of recoated castor-oil cured urethane

poorer condition than the untouched panel, especially the hand-sanded panel on which severe peeling occurred (Figure 7). This refutes the claim that urethanes fail in a manner suitable for recoating.

Group 2 panels were those that had started to fail in 1962. They did not perform so well either self-recoated or refinished with the 20-gallon tung phenolic. These results emphasize the need for prompt maintenance and initial selection of adequate clear finishes. There was little difference in durability between the different methods of panel preparation, an indication that the easiest method can be used.

With the stains, NRC formula 870 was still in good condition on the untouched panel, the commercial alkyd was fairly good, and the commercial creosote, poor. On the recoated panels the first two materials were about the same. The Canadian Forest Products stain, which had not performed well on the original trial, was quite good, especially considering the condition of the wood when recoating took place. This material appears to be a good type for use over old weath-

ered wood. The recoated U. S. Forest Products stain was in excellent condition but, as noted, had had one summer less of exposure.

After examination the few remaining materials in suitable condition were repaired and re-exposed. On refinishing there was a tendency for touched-up areas of panels to look darker and this might not be acceptable for reasons of appearance.

### Summary—Results of Recoating

The results of recoating can be summarized briefly. It is necessary to select one of the few clear finishes with the necessary durability and to maintain it in good condition. Once the film has been allowed to degrade, even to a limited extent, the chances of restoring it and achieving satisfactory durability are quite poor.

### ACKNOWLEDGMENTS

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