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Chronicle of 65 Years of Wood Finishing Research at the Forest Products Laboratory

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Abstract

For 65 years, the Forest Products Laboratory (FPL) in Madison, Wisconsin, has had a continuous and extensive program of research on finishing wood for outdoor use. The research has stressed the fundamental aspects of wood weathering and the interactions of pretreatments and finishes on wood surfaces.

This report outlines the history of the FPL wood finishing research program, including the perspective of Dr. Frederick L. Browne, the program's leader during the strategic years from 1922-1963. We describe the early research that established the important role of the wood substrate in finish performance and resulted in a classification of the paintability of wood by species, surface texture, ring orientation, and defects. We then follow the evaluation of wood finishing research at the FPL up to the present.

The results of research on the degradation mechanisms in finishes, wood, and wood-based materials are described. This information has been useful in improving paint and finish systems for better performance and reduced maintenance costs. A major topic is how various finishes protect wood from moisture. The report describes the FPL Natural Finish, which was developed to provide homeowners with a more durable and reliable natural finish than the finishes available at that time. All the FPL research on wood finishing is documented in detailed lists of

publications, arranged both alphabetically and chronologically.

The report concludes with a discussion of continued research efforts that stress simple, economic, safe, and stable techniques for protecting the wood surface and enhancing the performance of wood in outdoor exposure.

Keywords: Coatings, finishes, finishing, wood composites, weathering, durability, paints, stains, varnishes, water repellents.

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Modern house finished with the Forest Products Laboratory Natural Finish, a semitransparent penetrating oil-based stain formulation (1979). (M 147 331-5)

Chronicle of 65 Years of Wood Finishing Research at the Forest Products Laboratory

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Introduction

Forest Products Laboratory Purpose

The Forest Products Laboratory (FPL) was established by the Forest Service of the U.S. Department of Agriculture in 1910 in Madison, Wisconsin. It was to serve as a centralized wood research laboratory to ensure that our Nation's forest resources would always provide the greatest good for the greatest number in the long run.

As a national laboratory, the mandate of the FPL was broad: to explore the field of wood utilization for the benefit of the people and for the perpetuation of the resource. The approach was threefold:

1. To increase the serviceability of wood products
2. To develop new uses of wood and improve existing ones
3. To augment the usefulness and quality of all wood species

Even as early as the 1880's, the Forest Service recognized that efforts toward "conservation through efficient use" would have to be directed at increasing the durability of wood products in use. That attitude toward wood preservation, a major force in the development of a national laboratory, gave preservation and protection an emphasis that is still central among the thrusts of FPL research today.

From its earliest work on preservatives for railroad ties, telegraph poles, and mine timbers, the Forest Service has focused on protecting wood from decay. When FPL ushered in its first visitors in 1910, the Section of Wood Preservation Research showed off complete facilities for fundamental and applied research.

Initial Wood Finishing Research

Recognizing the need to expand its research on wood protection, the FPL formed the wood finishing research project in 1922. Until then, no one had investigated the complex interactions between wood and coatings that affect outdoor wood performance. Therefore, the FPL had been

unable to adequately respond to the numerous and continuous inquiries about proper wood finishing techniques.

The ultimate objectives of the research were to

1. discover the factors affecting finish performance,
2. develop reliable procedures for wood finishing, and
3. transfer this information to the public through technical and semitechnical publications, presentations at scientific meetings and practical workshops, and individual and group contacts.

The first research plan was prepared by George M. Hunt, leader of the Section of Wood Preservation Research (later Director of FPL), who defined the following work areas:

1. Effect of coatings on changes in moisture content of wood
2. Durability of paint on different species of wood
3. Painting of treated wood
4. Value of paint in reducing fire hazard
5. Effectiveness of paint in protecting wood from weather

Dr. Frederick L. Browne was appointed head of the new wood finishing research project in September 1922. During his 40 years of leadership, the direction of wood finishing research at the FPL was guided by the changing needs of the public, as well as those of the paint and forest products industries. Dr. Browne's description of the early history of the wood finishing research project has been included in this report because it reveals insight to the encouragement offered by and the strong resistance occasionally given by segments of the industry when the FPL embarked on new areas of research.

After 1922, the wood finishing research group made strides in characterizing wood surfaces, clarifying the functions of primers and paints, and understanding the interaction of wood and moisture in paint failure. These principles proved to be the group's greatest contribution to the Armed Services efforts in World War II, saving money in the maintenance of thousands of buildings used to house troops, equipment, and materials.

Recent Wood Finishing Research

Housing needs in the 1950's demanded the attention of wood finishing researchers. The wood finishing research group worked with wood preservation researchers in developing guidelines for aboveground decay control, onsite treatments during construction, the FPL Natural Finish for redwood and cedar siding, and maintenance and repainting procedures.

Environmental concerns in the 1970's initiated a new look at preserving and protecting wood by treatments with reduced toxicity and with greater selectivity in their action. This led to detailed studies on manipulating wood characteristics to interrupt the weathering and decay cycles.

Outlook

In the 1980's, the FPL continues to have a major role in exterior wood finishing research. The work is stimulated by the lack of knowledge about the fundamental chemical and physical factors that affect exterior finish performance on different wood species, composites, and new wood-based products. Many new wood products and many new, relatively untried wood finishes are being introduced into construction markets. Misinformation about these products and finishes abounds.

Wood finishing research has the major task of informing the producer and consumer about the outdoor use of wood products. Research stresses the fundamental aspects of wood weathering and chemical interactions of pretreatments and finishes on various wood surfaces (Fig. 1). Future research will focus on developing treatments to make wood stable under ultraviolet light. Studies

History of Wood Finishing Research from 1922 to 1963 by Dr. Frederick Browne



In May 1960, Dr. Frederick L. Browne (Fig. 2) wrote an account of the wood finishing research he helped originate and direct at the FPL. His report listed the climate of wood use, the origins of wood finishing research, and the practical and political implications of some research studies. This account has never been published. It is included here to indicate, in Dr. Browne's words, "that it should be helpful to know something about 'how we got that way.' "

Here, in full, is Dr. Browne's account entitled "The Origin and Early History of the Paint Section," May 18, 1960.

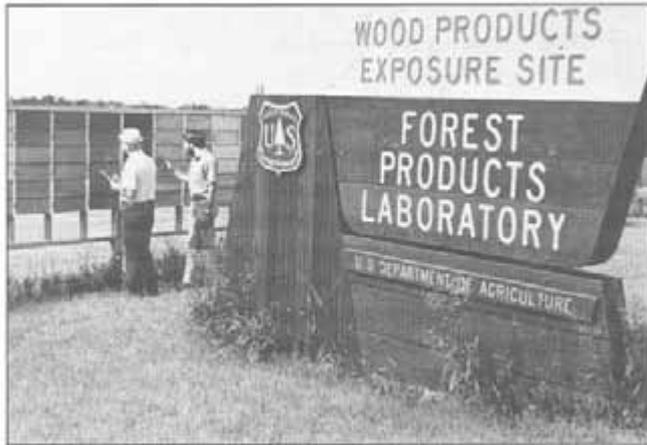


Figure 1—Technicians Edward A. Mraz and Peter G. Sotos inspecting paint test panels at the Wood Products Exposure Site in Madison, Wisconsin (1978). Similar sites are located in Saucier, Mississippi, and Olympia, Washington (M 146 491-8)

of the interactions of the wood surface with treatments and finishes, the finishes themselves, and pretreatments for stability against moisture are aimed at more reliable finish systems for exterior wood. The role of the environment, especially the problem of acid deposition, and wood and finish performance will be studied in depth.

Publications

Wood finishing research at the FPL has produced a large number of publications over the past 65 years. In addition to technical literature, semitechnical or practical literature has always been prepared to assist the direct user of the wood and wood finishes. Chronological and alphabetical lists of all formal FPL publications on wood finishing are given at the end of this report. Not all publications are cited in the text. Cited references have special relevance to the topic at hand.



Figure 2—Dr. Frederick L. Browne, head of the wood finishing research project from 1922 to 1962 (1951 photograph). (M 88440)

Earliest Interest in Coatings

When the FPL opened its doors in 1910, none of the present work of the Timber Processing Division appeared in its program of work. But work on fire retardance was started very soon because in January 1914 Robert E. Prince, working under Clyde H. Teesdale in the Section of Wood Preservation, wrote his first progress report on "Inflammability of Untreated Wood and of Wood Treated with Fireproofing Compounds." Prince's studies included paints as fire retardants and led to development of a zinc borate paint suitable for exterior exposure. Another narrowly

specialized interest in paint and varnish coatings appeared in Project L-134-5 on "Swelling and Shrinking of Wood as Influenced by Various Treatments and Coatings," for which Norman Betts wrote a first progress report in November 1914. The coatings tested included a house paint, shellac, a varnish, a Bakelite (early phenolic) resin varnish, and paraffin. Impregnants included sugar solution, creosote, and "glutrin."

The military needs of the First World War greatly expanded the Laboratory's personnel and field of work in 1916 to 1919. To the Section (later to become Division) of Wood Preservation were assigned the problems of laminating wood for gunstocks and airplane propellers, the production of plywood for airplane parts, and the development of glues and gluing techniques for such purposes. George M. Hunt was then assistant chief of the Section. Among those added to the staff were Thomas R. Truax, Matthew E. Dunlap, and Frederick L. Browne. In July 1917 Clyde Teesdale and Dunlap wrote a brief memorandum on "Paints and Wood Preservatives for Army Cantonments" in which they said that exterior paint for fire protection was unnecessary for the tar-paper-and-wood-batten walls of temporary barracks and recommended water paint (calcimine) for interior surfaces. Because of the need for retarding dimensional changes in wood airplane propellers, Dunlap expanded Project L-134-5 into an extensive study of paints, varnishes, electrodeposited metals, and other coatings, which led to the aluminum leaf process and then to the discovery of the effectiveness of aluminum paint. Our "moisture-excluding effectiveness" test originated at that time.

After the war, although there was a substantial reduction in staff, the new areas of work were continued but pointed toward broader peacetime uses. Browne entered the Graduate School of the University of Wisconsin, but his appointment was continued on a per diem basis until July 1921, when he was required to resign to become a National Research Fellow. One of his part-time assignments was to review the literature on house paints and make recommendations for painting practices in the Forest Service,

particularly for the type of wood signs then in use. This began a series of reports on "Forest Service Paint Problems" that continued until 1928. The first report, dated January 16, 1920, concluded with a brief work plan for "experimental work which could be profitably undertaken by the Laboratory," indicating that Hunt, who had become chief of the Section when Clyde Teesdale resigned in 1919, entertained some hope of support for serious work on painting. The work plan proposed systematic studies, including exposure tests in various climates, of paint formulations, of commercial paints, of the effects of wood species, type of surface, and moisture content, of the techniques of paint application, and of the "relation of the durability of the paint to its other physical properties."

It may be noted that the last item did not receive serious attention until 1952. The report contained a sentence that foreshadowed Browne's paper in 1959 on "Understanding the Mechanisms of Deterioration of House Paint," namely, "water alone can cause the saponification of linseed oil, and this fact together with the basic nature of the most important pigments is probably chiefly responsible for the final failure of all paints that are exposed to the weather." The rather bold postulate proved substantially correct although its chemistry required modification.

When Hopes Ran High

In the spring of 1922 Dr. Alva Horton Sabin of the National Lead Company and Cornelius T. Myers, consultant for the Automotive Wood Wheel Manufacturers Association, urged the Laboratory to undertake a broad program of work on wood painting and finishing. Henry H. Kendall, president of the American Institute of Architects, wrote the Secretary of Agriculture about the need for such a study. Director Carlile P. Winslow set aside \$4,000 from Laboratory funds to provide a man and overhead for the work. Hunt wrote an "Outline for an Investigation on the Use of Paints, Varnishes and Other Coatings on Wood," dated March 3, 1922, in which he proposed studies of (1) the effect of coatings on the moisture content of wood, (2) the durability of coatings on different

species of wood, (3) the painting of treated wood, (4) the use of paints to retard fire, and (5) the effectiveness of paint in protecting wood from the weather.

The two most active and long faithful promoters of our paint work were Dr. Sabin and Alfred D. Flinn, secretary of the Engineering Foundation and representative of the National Research Council. Sabin was a college professor of chemistry turned varnish maker, whose business had been purchased and his consulting services retained by the National Lead Company. Sabin visited the Laboratory at least once a year and gave generously of his considerable store of knowledge until a year or so of his death. The Engineering Foundation gave official encouragement to the project and reported its progress in its annual reports for more than 10 years.

On May 3, 1922, a conference was held at the Laboratory to discuss the wood-finishing project (Fig. 3). Winslow, Hunt, Dunlap, and Arthur Heim represented the Laboratory. The others were Sabin; Flinn; William B. Baker, secretary, Association of Wood-Using Industries; John Jaeger, American Institute of Architects; D. S. McDaniel, John Deere and Company (agricultural implements); H. Bornstein (organic chemist), John Deere and Company; P. R. Hicks, secretary, American Wood-Preservers'



Figure 3—Participants at the conference to discuss the wood finishing research project, May 3, 1922. Left to right: Walter K. Schmidt, Alfred D. Flinn, H. Bornstein, Carlile P. Winslow, Alva H. Sabin, George M. Hunt, W.A. Babbitt, John Jaeger, Mathew E. Dunlap, A. Heim, William B. Baker, Edward E. Parsonage, D.S. McDaniel. (M 117 426)

Association; Walter K. Schmidt, Grand Rapids, consultant on furniture finishing; W. A. Babbitt, secretary, National Association of Wood Turners; Edward E. Parsonage, secretary, National Farm Equipment Association; and Arthur Peabody, architect, Madison (later Wisconsin State Architect).

Parsonage, Bornstein, and McDaniel described methods recently adopted by John Deere and Company to introduce quality control of finishing materials and procedures. Schmidt reported work among furniture manufacturers in Grand Rapids to establish quality control of finishes. Jaeger expressed the interest of architects in the education of painters for better craftsmanship. Resolutions were passed endorsing the wood painting project at the Laboratory, and Flinn, Sabin, Baker, and Winslow were elected as an organization committee to select a permanent executive committee for Wood Finishing Research with representatives of architects, railroads, master painters, and makers of agricultural implements, pianos, furniture, and automobile bodies and accessories. The committee sought and obtained sponsorship by the National Research Council.

The work was conceived strictly as a consumer enterprise. Absence of representation of the Paint Manufacturers' Association of the U.S. (now the National Paint, Varnish & Lacquer Association) is significant. A letter of April 18, 1922, to Baker indicates that they were consulted but proved to be "diffident." Henry A. Gardner was director of the association's Scientific Section. Personal relations between Sabin and Gardner were decidedly unfriendly, but the association's coolness was probably a studied policy, as may well be understood from a reading of "Paint Industry: Reminiscences and Comments" by George B. Heckel, long the secretary of the association.

The Executive Committee of the Committee on Wood Finishing Research of the National Research Council met in Chicago on June 24, 1922. It consisted of the following persons: Sullivan W. Jones, American Institute of Architects; Emil Wolff, Music Industries Chamber

of Commerce; Alfred D. Flinn, Engineering Foundation; W. A. Babbitt, National Association of Wood-Using Industries; Maynard Guest, National Council of Furniture Associations; H. J. Sameit, National Farm Equipment Association; J. R. Howard, American Farm Bureau Federation; and C. S. Dexter, National Council of Furniture Associations.

Sabin submitted a suggested program for Wood Finishing Research, dated June 5, 1922. It stated that "the object of this undertaking is to learn and promote the best uses of protective coatings on wood: first, to increase the durability of the wood and of the article made from it; second, to develop better methods for reducing the swelling and shrinking of wood with changes in moisture; and third, to secure economy and intelligent use of coating materials." His program included (1) survey of the literature, including advertising matter, (2) listing the wood species used in different industries with the difficulties experienced with them, (3) survey of finishing practices in various industries, architects' specifications, and experience of painting contractors, (4) discovering of problems needing investigation, and (5) considering "available places and facilities for field tests and tests in factories and shops."

In September 1922 Browne was reappointed to the Laboratory staff to have charge of the new project under Hunt's supervision. Don Brouse joined the staff in 1923, C. E. Hrubesky slightly later, and their time was divided between the paint work and glue work. About 1930 Hrubesky transferred to the Division of Pulp and Paper and was succeeded by Leslie E. Downs. Brouse about that time was assigned entirely to gluing work, and Browne's work on glue formulation was discontinued but he and Downs were responsible for a few years for work on antishrink treatments as well as paint. Don F. Laughnan became a part-time employee in 1936 until he graduated from the University, when he received a full-time appointment.

The Executive Committee for Wood Finishing Research met for the second time in Baker's office in Chicago on October 4, 1922. Members

present were: Flinn, Sameit, Wolff, J. W. Coverdale representing Howard, and Baker representing Babbitt and Guest. Others present as advisers were Sabin, Parsonage, V. R. Hawthorne of American Railway Association, and J. C. Warnes of International Harvester Corp. The Laboratory was represented by Winslow, Hunt, and Browne. Flinn reported that the Bureau of Standards agreed to cooperate and had assigned a Mr. Jumper to the work. It was agreed that the Laboratory would study the effect of finishes on the properties of wood and techniques of finishing, whereas the Bureau would study the chemistry and physics of paint and prepare specifications for paint. Subscriptions to a fund of \$6,000 for financing the preliminary activities of the committee were asked, and assurance was received of several substantial contributions from the organizations represented. The committee decided to send out a questionnaire to the principal industries concerned to learn their most important finishing problems.

At this time it was the understanding that the Association of Wood-Using Industries would raise enough money to enable the Committee on Wood Finishing Research to finance the Laboratory's finishing studies under cooperative agreement as soon as the newly formed association had completed its organization. Presumably the Laboratory would need to use its own funds only for a limited time. It was supposed further that the cooperative support would suffice for substantial expansion of the Laboratory's staff.

Brief Life of the Committee on Wood Finishing Research

The questionnaire authorized at the October 4 meeting was prepared at the Laboratory and 1,863 copies were distributed among 13 associations by the committee in November 1922. By February 1923 there were 108 replies. They were analyzed and the results reported by the committee to those who had replied or expressed interest. Two finishing problems were named in a high proportion of the replies; namely, the process of filling pores in hardwoods and a desire to hasten the drying of varnishes (lacquers

and fast-drying varnishes were not yet widely used).

As a result of the questionnaire, experimental work on wood filling was started in what had been the propeller laboratory during the war. Fred Morehouse was transferred from the Preservation to the Finishing Laboratory for subprofessional assistance. A second questionnaire on staining and filling was sent out by the Committee on Wood Finishing Research. From 950 copies sent to 6 associations, 107 returns were received.

In 1922 and 1923, much of Browne's time was spent in travel to gain information. He visited 17 furniture factories, 6 piano makers, 7 autobody plants, 16 paint and varnish producers, and makers of agricultural implements, railroad equipment, interior woodwork, sporting goods, and toys. The test fences at North Dakota Agricultural College; Sayville, Long Island (National Lead Co.); and Palmerton, PA (New Jersey Zinc Co.) were inspected. An interview was arranged with U.S. Senator Ladd, originator of the North Dakota paint-labeling law. Visits were paid to the Bureau of Standards and to the Scientific Section of the Paint and Varnish Manufacturers' Association of the United States. At a meeting of the Pennsylvania Association of Master Painters the acquaintance was made of some of the leading painting contractors. On May 18, 1923, Henry A. Gardner called a meeting of 46 paint chemists at the Scientific Section laboratory in Washington at which Browne discussed the work planned by the Laboratory, including test-fence studies of the painting characteristics of woods. This was only the second meeting of paint chemists ever held on a national scale. The fact that nearly every paint chemist of consequence in the country was present reveals how little technical guidance the paint industry had at that time. The meeting took the initial steps toward formation of the Paint and Varnish Division of the American Chemical Society, much to Gardner's disappointment because it took the organization out of his control.

As a means of maintaining interest in the Committee on Wood Finishing Research it was decided in the fall of 1923 that the committee

would publish a regular bulletin service, perhaps on a monthly or bimonthly basis. The material, to be prepared by the Laboratory with such contributions from others as it might solicit and published by the committee in looseleaf form, was to be suitable for permanent filing. By the time the Laboratory had prepared the sixth bulletin in January 1924, the Association of Wood-Using Industries was charged by the Federal government with illegal price-fixing activities and was soon forced to disband. Its passing ended the Committee on Wood Finishing Research and the Laboratory's prospects of funds from industry to support its finishing research.

By that time the Laboratory was already committed to the extensive program of paint exposure tests described farther on. A "Five-Year Program for Wood Finishing Research" that had been drawn up in April 1924 had to be drastically revised. Part of Browne's time was diverted to a resumption of his former studies of glue chemistry. The experiments on wood filling were discontinued, and future work was limited to the subject of house painting. The choice was dictated by existing obligations but was further justified by considerations of the quantities of lumber involved, the extent to which difficulties were being experienced, and the fact that users of house paint were seldom in a position to inform themselves in technical matters or to do their own research as well as most users of industrial finishes could do.

Test-Fence Studies Begin

The favorite excuse for failures of house paints in 1922 was the unsuitable nature of the wood painted. The opinions of the paint industry and of painting contractors were highly conflicting, but they might be summarized, with little exaggeration, to the effect that eastern white pine was the only wood fit to paint; but even the white pine then available was not what it used to be. Clearly our first problem in house paints was to discover the facts about the painting characteristics of the various woods and cuts of wood. Recalling our survey of paint problems in the Forest Service, an unsuccessful effort was

made to interest the Forest Service Regions in a study of the durability of paint on edge-grain and flat-grain boards of various species by using their signboards for the experimentation. On the other hand the North Dakota Agricultural College, the National Lead Company, and the New Jersey Zinc Company offered us space on their test fences; and the Pittsburgh Plate Glass Company (recent purchasers of the older Patton Paint Co.), the Scientific Section, and the National Bureau of Standards offered their cooperation.

Meantime some evidence was obtained with little effort. Hunt was exasperated by the clatter of freight trains passing under the window of his office in the old building. He would sit back and gaze disgustedly at the cars until the caboose passed. One day he pointed out that paint nearly always flaked from the bands of latewood and that flat-grain boards were worse than edge-grain boards. Let swivel-chair research not be despised !

A tentative work plan for "A Study of the Painting Characteristics of Different Kinds of Wood" was approved on July 31, 1923, and sent for comment to the eight Forest Service regions and to the following persons:

Alfred D. Flinn, Engineering Foundation, National Research Council; W. T. Pearce, North Dakota Agricultural College; Percy H. Walker, National Bureau of Standards; Henry A. Gardner, Scientific Section; George B. Heckel, Secretary, Paint & Varnish Manufacturers Association; Frank G. Breyer, New Jersey Zinc Company; Robert L. Hallett, National Lead Company; Alva H. Sabin, National Lead Company; L. P. Nemzek, E. I. duPont de Nemours & Company; Clifford D. Holley, Acme White Lead & Color Works (Sherwin-Williams); L. H. McFadden, The Lowe Brothers Company (not yet owned by Sherwin-Williams); Paul R. Croll, Pittsburgh Plate Glass Company; and John R. MasGregor, Eagle-Picher Lead Company.

After the comments were received, a final work plan was approved on December 8, 1923, and detailed instructions were written for the cooperators together with drawings and

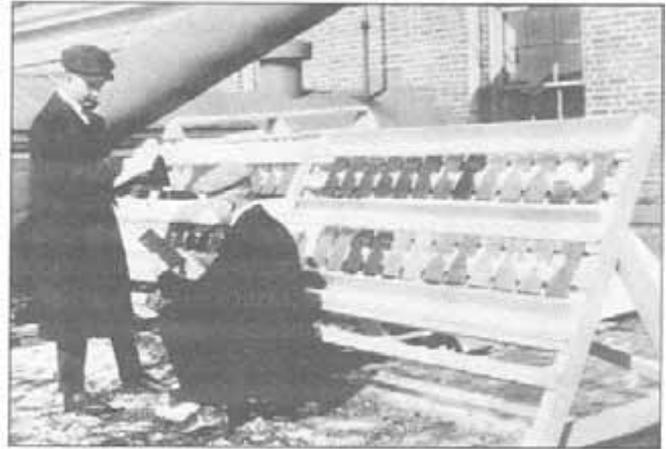


Figure 4—Small test exposure fence on roof of the Forest Products Laboratory building, University of Wisconsin (1929) illustrating exposure techniques for moisture-exclusion tests. (M 111 76)

specifications for construction of test fences at those places where there were no existing fences (Fig. 4).

The plan called for tests of 17 species of softwoods, each species in edge-grain and flat-grain boards and in the lowest select grade so that there would be a limited number of knots to show their effect on paint. All lumber was supplied gratis by the various regional lumbermen's associations. It was cut to a drop-siding pattern at the Laboratory. Two paints were to be applied; pure white lead paint because it was still the paint most often used on new houses and a lead-zinc paint conforming to Federal Specification Board, Standard Specification No. 10. Although the proportions of lead, zinc, and extending pigments in commercial paints varied very widely at that time, there were no other white pigments of importance. New Jersey Zinc Company had just begun to advocate use of light-resistant lithopone, and titanium dioxide was still in the developmental stage.

When the final work plan was approved, seven test stations had been definitely arranged: (1) The University of Wisconsin provided space at the Hill Farms for the Laboratory to erect a fence in Madison, (2) the National Lead Company assigned space on its fences at Sayville, Long

Island, (3) the New Jersey Zinc Company made similar arrangements at Palmerton, Pennsylvania, (4) the North Dakota Agricultural College did the same at Fargo, North Dakota, (5) the Scientific Section financed the erection of a fence on the roof of the Chemistry Building at the National Bureau of Standards and (6) a fence on the campus of the University of Florida (to be supervised by Professor A. P. Black of the chemistry department), and (7) the Pittsburgh Plate Glass Company erected a fence for us on the Howie Farm, 9 miles west of Milwaukee and about one-half mile south of Highway 30.

An analysis of Weather Bureau records showed that none of these stations represented the extremely dry, sunny exposures of much of the Southwest. The Laboratory felt that tests in the West were necessary for adequate climatic coverage. Most of our paint advisors opposed western stations, giving as their reason the sparsity of population there. By the aid and support of the western Forest Service Regions, stations were provided by the spring of 1924 at (8) Grand Junction, Colorado, in the yards of the Denver and Rio Grande Western Railroad, (9) Tucson, Arizona, in the yards of the Southern Pacific Railway, (10) Seattle, Washington, behind the University of Washington's Forest Products Laboratory (supervised by Professor Bror Grondal), and (11) Fresno, California, by cooperation of the W. P. Fuller Company.

More Results Without Work

Establishment of the western test fences had unexpected and surprising consequences. Standard Specification No. 10 of the Federal Specifications Board for "white paint and tinted paints made on a white base" had been adopted on February 3, 1922. It had been written with the advice of a committee of the paint industry whose aim had been to encompass all commercial trade brand paints of "standard" price level then on the market. The content of white lead in the pigment could be anywhere between 45 and 70 percent, the zinc oxide 30 to 55 percent, and the extender 0 to 15 percent. Walker of the Bureau of Standards opposed the specification because he predicted, and was later

able to prove, that deliveries under it were practically always the cheapest and least satisfactory combination, namely 45 white lead, 40 zinc oxide, and 15 extender.

We wrote the 45-40-15 version into our work plan for the lead-zinc paint on the ground that the formulation should be the one in conformity with the specification that differed most markedly from pure white lead paint. Our advisors and the meeting of paint chemists in Washington on May 18, 1923, approved the selection but with obvious reluctance. Holley of the Sherwin-Williams group, however, firmly recommended 60-30-10 instead, on the ground that it was known to make better paint. As soon as we announced that arrangements had been made for test fences in dry regions of the west, we received a letter from Gardner, backed by our other paint advisors, urging us to change to the 60-30-10 formula. This was done.

Since leading chemists of the paint industry had indicated clearly that the 60-30-10 proportions made the best paint in general use, Walker promptly began to urge revision of Federal Specification No. 10. From his records of paint purchases tested for conformity, he was able eventually to prove that 45-40-15 was almost always obtained. But it was not until Federal purchases were sufficiently centralized to make practically all of them large enough for separate manufacture that Specification No. 10 was superseded by TT-P-36 in November 1930, in which the 60-30-10 proportions were mandatory. In July 1938 TT-P-36 was again superseded by TT-P-36a, which gave an option of a 70-20-10 composition (at the buyer's option). In May 1943 the lead-zinc formulations for white paint were superseded by titanium-lead-zinc in Specification TT-P-40, which in turn was superseded by TT-P-102 for titanium-lead-zinc and TT-P-103 for titanium-zinc paint in March 1951. Browne was chairman of the committee that prepared the last two specifications as well as a specification for pure white lead paint, TT-P-104, and a revision of Specification TT-P-25 for house-paint primer.

Further Test-Fence Studies

Browne visited and inspected the test fences at all stations at least once a year. At Fargo, Milwaukee, Sayville, and Palmerton he also observed the paint tests being made by the operators of those stations. When the duPont Company started exposure tests near Wilmington, Delaware, and Miami, Florida, the Aluminum Company of America at Pittsburgh, the Eagle-Picher Company at Joplin, Missouri, and Sherwin-Williams at Chicago, they were frequently included in his itinerary, and most of them were visited fairly regularly after the Laboratory's tests outside of Madison were discontinued. Thus, we kept in touch with all important paint testing. From 1931 to 1939 the Laboratory planned and supervised a test fence at St. Paul, maintained jointly with the Northwest Paint and Varnish Production Club, the Minnesota chapter of the Painting and Decorating Contractors' Association, and the Twin Cities Retail Lumber Dealers' Association.

The work plan for the 1924 exposures provided for further studies of the woods that proved less satisfactory by altering the thinning of the paints for priming coats and by use of special priming paints. Special priming paints for wood had been unknown up to that time, and the idea was regarded unfavorably by the paint industry. By 1925 it was considered possible to select a number of woods for further study. A work plan was written, and additional exposures were installed at all stations. Aluminum paint was included as a special primer in the 1925 tests. There were further tests and repainting tests at all stations up to 1930. By 1935 it was felt that enough had been learned about the effect of variations in climate. All stations except Madison and St. Paul were therefore discontinued.

On the Madison fences many tests not repeated elsewhere were made nearly every year, starting in 1924. Following are some of the subjects on which exposures were made as early as 1924 and 1925:

1. Exposures at 45° angle for comparison with vertical

2. Exposures of unpainted wood and painting of weathered wood
3. Painting with 2, 3, and 4 coats and the relation to film thickness
4. Painting wood at different moisture contents, under different conditions of temperature and humidity, and with different intervals between coats
5. Use of different paint thinners and varying content of driers
6. Painting over knots with and without knot sealers
7. Painting by spray gun instead of brushes
8. Painting Celotex
9. Painting wood treated with wood preservatives and fire retardants

Except for the first and fifth of the above items, these were all subjects on which no previous work had been done. The Laboratory's contribution was not only unique, it led the industry to the development of house-paint primers of the controlled penetration type, to finish-coat paints of higher level of pigmentation, and to the "two-coat system" of painting. In the 1925 primer tests, aluminum primer gave outstanding results on southern yellow pine and Douglas-fir. Many additional tests were made over the years with aluminum primers because the subject became a controversial one.

Before 1930 few paints other than pure white lead and the 60-30-10 lead-zinc-inert paints were tested. But by 1930 the zinc sulfide and titanium dioxide pigments, the first new white pigments since 1845, were coming into use and revolutionizing paint formulations. To keep abreast of developments it became necessary to include increasing numbers of paint formulations. The formulas included in the Laboratory's tests were chosen to represent common practice in the industry. Systematic variations in formulation of the kind to which the paint industry devoted most

of its exposure testing had little or no place in the Laboratory's work until somewhat later years. Instead, knowledge of formulation in the industry was kept up to date by regular visits to the industry's test fences and by collecting and examining a very extensive file of the formulas of trade-brand paints on the market.

The white lead paint for the 1924 exposures was furnished by the National Lead Company and the lead-zinc-inert paint was ground for us by the Pittsburgh Plate Glass Company. The paints were sent to the Laboratory in bulk and then subdivided and sent from Madison to the various stations. At each station painting was done by local painters. A year or so later Hallett of National Lead complained that we had adulterated part of the white lead paint sent to Sayville with zinc oxide because the white lead paint on some of the panels there had alligatored, and chemical analysis revealed a small quantity of zinc oxide in the panels affected. Fortunately, samples of the paints were retained both at Madison and at the Bureau of Standards. The Bureau's analysis revealed no trace of zinc in the white lead paint. The adulteration was traced to the fact that painter Brett at Sayville, to avoid cleaning a bucket and brush after applying second coats of lead-zinc paint, had poured white lead paint into the bucket and proceeded with the white lead paint, using the soiled brush. The resulting alligating was our first observation of what later became the vexed question of incompatibility between dissimilar paints. It also furnished incentive for the Laboratory to install paint-grinding equipment and in future to make all paints used in its tests, except for a few occasions when it became desirable to compare commercial paints with similar formulations ground in the Laboratory (Fig. 5).

“Moisture Problem” and the First Blister-Box

During Browne's trip east in May 1923, Chester Hogue of the West Coast Forest Products Bureau arranged a visit to two new houses at Freeport, Long Island, erected the previous year, on which the white lead paint on redcedar siding had become discolored with cedar extract during the



Figure 5—Don Laughnan shown preparing paint in 1937 on the Forest Products Laboratory paint mill. (M 31184)

winter. Cedar had recently been introduced in the eastern market, and numerous complaints of the same trouble were being received. Hallett of National Lead showed Browne samples during the same trip. One of the houses with photographs is recorded as House No. 0.1 in our record of paint complaints on houses. In another new house at Huntington, Long Island, a very bad case of blue stain in the sapwood of ponderosa pine windows was found, together with the discoloration of paint on the siding outside. Browne attributed both conditions to cold-weather condensation, but several years elapsed before he was able to convince Timber Physics that his diagnosis was correct .

Cases of “moisture failures” rapidly accumulated, and the subject soon became the center of interest in the paint and building industries. On houses painted with pure white lead paint, the complaint was about discoloration with wood extract without blistering or peeling of the paint. On houses painted with zinc-containing paints, the complaint was blistering and peeling usually accompanied by discoloration if the

siding was redcedar or redwood. Mass building of houses began about this time and gave rise to conspicuous cases in which practically all houses of a development gave trouble. Widely publicized examples occurred at Radburn, New Jersey, and Flint, Michigan.

Gardner of the Paint and Varnish Manufacturers' Association (American Paint and Varnish Manufacturers' Association after 1928) paid the expenses for Browne to inspect the Radburn houses. The original paint applied there was a lithopone and leaded zinc oxide paint developed by the New Jersey Zinc Company, known as "40-40-20." The adverse experience at Radburn did much to reduce the zinc sulfide pigments to the status of ingredients for "second grade" paints. When City Housing Corporation, the builders of Radburn, sued for \$3 million damages, the New Jersey Zinc Company retained Browne, with Forest Service approval, as a witness for their defense. Meantime the West Coast Lumbermen's Association hired Otto Hartwig, a former master painter, to travel about the country studying paint failures on houses. His report of examination of more than 1,500 houses was eagerly published in 1929 as Circular 355 of the Scientific Section, American Paint and Varnish Manufacturers' Association. Hartwig drew his technical information chiefly from the Laboratory. His work did much to establish cold-weather condensation as an important cause of paint failures, but it emphasized also the penetration of outside storm water into sidewalls and numerous other causes of trouble.

The Laboratory, working under a cooperative agreement with the California Redwood Association, designed the first successful device for producing moisture blistering experimentally in December 1926 or January 1927. The design was based on the principle of cold-weather condensation. The redwood association's interest was in the discoloration of paint with extractives, but our blister-box promptly showed paint blistering as well as the discoloration. It soon became evident that pure white lead paint resisted blistering, whereas zinc-containing paints blistered readily. Blister-boxes of one kind

or another have been in use at the Laboratory at nearly all times ever since (Fig. 6).

Inspections of Houses

As already pointed out, we began to inspect houses on which there were paint troubles as early as May 1923. Such examinations were recognized at once as an important source of information not obtainable in any other way. Records have been kept of 1,163 cases, many of them with photographs. Our use of house paint complaints, together with that of Hartwig, to derive technical information was new to the paint industry at that time. It effectively fortified our position in some of the discussions that arose.

Opportunities to inspect houses were soon presented in abundance. They came at first through the lumber associations and the paint association. Then as our publications began to make our work known they came from retail lumber dealers, builders, individual paint makers, paint dealers, painters, and individual house owners. The policy of the Laboratory was to make examinations as freely as possible when they could be worked in with official travel for other purposes or when the expenses were paid by a cooperator. Houses in Madison were inspected freely, largely outside of official hours, until the number of requests became too burdensome, after which inspections were made only when diagnosis could not be made by telephone or correspondence and it seemed likely that the Laboratory would gain useful information.

Tension With the Paint Industry

The "diffidence" of the paint manufacturers' association about participating in the conference of May 3, 1922, was noted previously. Once the project was started, however, Gardner and his Scientific Section cooperated cordially, even to the extent of paying the expenses of two test fences for us. The Laboratory was put on the mailing list to receive circulars of the Scientific Section and was given copies of nearly all prior circulars and bulletins back to 1912. The courtesy was withdrawn from 1929 to 1932, but after each of those years Gardner donated bound copies when Browne visited him in Washington. The

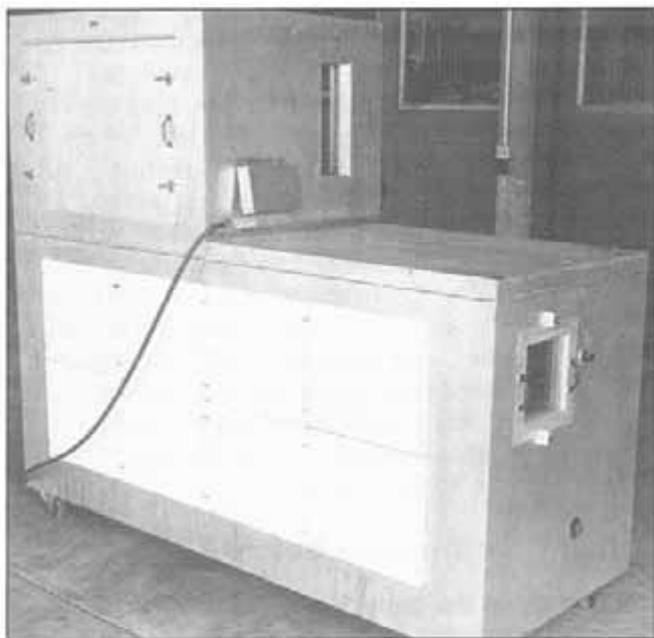


Figure 6—Blister box designed in 1954 by Don F. Laughnan and Frederick L. Browne. Paint panels on front were exposed to extremes of cool dry air on the outside and warm moist air on the inside to induce paint blistering and early failure. (M 96 651)

Laboratory has remained on the mailing list since 1933. Similarly the Laboratory received a free subscription to the Official Digest of the Paint and Varnish Production Clubs from 1929 to approximately 1950, after which we have paid for our subscription.

Gardner also urged us to publish our results in the circulars of the Scientific Section. Circulars Nos. 184 (1923), No. 219 (1924), No. 238 (1925), and No. 290 (1926) were our earliest reports of the test-fence exposures of 1924. Circular No. 317 (1927) contained the first release of FPL Report No. R6, "Some Causes of Blistering and Peeling of Paint on House Siding" (available for distribution until 1960), but it appeared as a mere supplement to a paper by Gardner entitled "Painting Defects on Wood Surfaces." No more contributions were offered for Scientific Section circulars.

The first two papers by Browne presented before the Paint and Varnish Division of the American Chemical Society were rejected for publication in

Industrial and Engineering Chemistry on the advice of an anonymous reviewer. Soon after the second rejection Edwards and Wray of the Aluminum Company of America submitted a paper in which the first sentence of the summary began, "Data are presented in confirmation of the conclusions of Dunlap and Browne." The editor, Harrison E. Howe, sent it to Browne for review with the request that the rejected paper be resubmitted for simultaneous publication in volume 19, pages 975 and 982 (1927). Thereafter all papers submitted to Industrial and Engineering Chemistry were accepted without any evidence of submission to reviewers.

"Preservation" Controversy

Shortly after the first World War the paint industry organized the Save the Surface Campaign with the slogan, "Save the Surface and You Save All." In 1921 they began publishing a monthly Save the Surface Magazine. The slogan was entirely reasonable if properly interpreted, but the magazine and much of the advertising contained such statements as "paint is the only wood preservative; it seals the pores of the wood and prevents the entrance of decay-reducing organisms." Photographs of rot in wood structures were displayed with the assertion that painting would have prevented it.

Our efforts to correct such false claims by direct communication with Save the Surface Campaign and the paint association were strongly resented on the ground that we were attacking a slogan worth \$7 million to the industry. Apparently the harm done to the public and the lumber industry by unsound recommendations was considered unimportant. Fuel was added to the fire when Harry Tiemann, without the knowledge of the Section of Wood Preservation, published an article entitled "Does Paint Preserve Wood" in Scientific American 130(5): 314 (May 1924). (Two decades later, after his retirement, Tiemann published essentially the same article under the title "Does Painting Preserve Wood," Southern Lumberman for June 15 and July 15, 1947). The offense given by the title blinded the paint men to the fact that Tiemann had furnished a sound technical basis for the slogan by explaining how

wood weathers and how paint prevents it. Browne was kept busy for several years thereafter publishing papers in technical and trade journals about the relations of paint to decay and weathering under more acceptable titles such as "Timber Saving by Means of Painting and Preservation," American Paint Journal, November 17, 1924; "Paint and the First Stages in the Weathering of Wood," Scientific Section Circular No. 238 (1925); and "The Role of Paint and Varnish in Wood Conservation," presented before the Louisville Paint and Varnish Production Club and published in American Paint Journal and Drugs, Oils and Paints in August 1925.

In a fruitless effort to reach mutual agreement a number of articles were written for publication in Save the Surface Magazine: "The Painting of Wood," March 1925 and "Weathering and Decay of Wood," June 1925. The latter was published with a picture of rot in wood columns resting on a masonry foundation with a title saying that paint would prevent such decay. We therefore withdrew an article on "A Square Deal for Paint" and sent it to American Paint Journal instead. A second attempt with Save the Surface Magazine was attempted with "Facts about Wood," May 1927; "Neglected Places," June 1927; "Armor Plating Wood," September 1927; and "Paint Retards Weathering," April 1928. But to the editors paint remained the only wood preservative.

After the Save the Surface Campaign was abandoned in 1932, few assertions that paint preserved wood against fungus attack appeared in paint advertising. In the late 1930's there was much talk of resuming industry-wide advertising, but paint men were almost unanimously of the opinion that the emphasis should be on decoration rather than protection. Thus, our efforts proved successful after all. Now, however, the pendulum may have swung too far because the new emulsion paints lack protective power and may call for reemphasis of the need for protection against wood weathering.

Meantime, attention was given to records of old buildings that had remained serviceable without

paint or with long gaps between paintings, many of which were visited. Among them were the Old Fairbanks House at Dedham, MA, Arlington Farms at Arlington, Massachusetts, and the old schoolhouse at St. Augustine, Florida, which stood without paint from the 17th century; Christ Church, Cambridge, Massachusetts, which withstood nearly half a century of paint neglect during and after the American Revolution; and the unpainted buildings in the villages of the Amana Colonies in Iowa, which were visited by Winslow, Browne, Sweet, and French in 1927. Examples of very long, successful paint maintenance also were sought, such as the Longfellow House in Cambridge, Massachusetts, and George Washington's Mount Vernon.

Other Controversies Before 1929

Our study of the behavior of paint on different woods introduced problems of inspection and evaluation that were new to the paint industry. We judged performance by three criteria, appearance, integrity, and protection, each criterion being a summation of applicable details of qualities or defects ("Procedure Used by the Forest Products Laboratory for Evaluating Paint Service on Wood," ASTM Proc. 30(2): 852 (1930)). Objection was made to judging paint for protection on the ground that signs of wood weathering under paint were considered defects of wood, not of the paint. There were objections also to integrating detailed qualities or defects into overall ratings for appearance and protection. This, with the previous attempt to bar publication of the paper on the moisture-excluding test as a measure of the protective power of paints, seemed to indicate that the paint men simply did not wish to have technical means of evaluating paints for protection, despite the "save the surface" slogan.

Favorable results with aluminum priming paint were reported by the Scientific Section and others before the Laboratory's 1925 primer studies. The subject became controversial when the Scientific Section switched sides, and strong opposition sprang up in the paint industry. The Laboratory was caught in the controversy. For 10 to 15 years more exposures were made on aluminum priming than on any other one subject.

Until overlays became practicable after suitable glues were developed, aluminum priming produced the most durable painting found for Douglas-fir and southern yellow pine. The roots of the controversy, however, did not lie in technical considerations.

Two-coat painting of new wood was first practiced by painters against the opposition of paint makers. The Laboratory made the first exposure tests to establish the conditions under which it proved satisfactory. In so doing the importance of correct dry film thickness of paint coatings was demonstrated. Recognition of two-coat painting under any conditions, however, was offensive to the paint industry until Devoe and Raynolds began to sell its "two-coat system" about 1935.

The rivalry between the lead interests promoting pure white lead paint and the paint manufacturers selling mixed-pigment paints was so keen that any presentation of the results of our tests was bound to displease one side or the other. In fact we pleased neither side. As time passed and white lead lost ground, increasingly the lead interests found our position more comforting. It is now interesting to observe the zinc interests in much the same position that the lead interests had at the time in question.

Conference of 1929

On September 13 and 14, 1929, a "Wood Painting Conference" was held at the Laboratory attended by 62 technical men of the lumber and paint industries (Fig. 7). The Laboratory's 114-page Fourth Progress Report on "Study of the Painting Characteristics of Woods" had been widely circulated (at \$1.50 a copy) the previous April. Everyone felt that paint troubles damaged both industries and that further research was needed. The lumbermen found no way in which they could improve the lumber for painting and thought that we should try to improve paint. The paint men saw nothing wrong with the paint and thought that we should try to improve wood. Both found Hartwig's report on the buildings he had examined commendable because it laid so much of the blame on bad practices of builders and

painters, none of whom were present. The conference passed a resolution asking Director Winslow and the joint chairmen of the conference (Donald A. Kohr for the paint industry and Arthur T. Upson for the lumber industry) to appoint a technical advisory committee of lumber and paint men to advise the Laboratory in its research on wood painting.

The Advisory Committee was appointed, but little or nothing came of it. There now seems to be no record of its membership except that Browne's diary shows that Frank Cartwright was a representative for the National Lumber Manufacturers' Association and James S. Long for the paint industry. Browne knows of only one meeting of the committee, in March 1931 at the Indianapolis meeting of the American Chemical Society. Halam and Werthan of New Jersey Zinc Company had just published their paper on "Studies in the Painting of Wood" (Industrial and Engineering Chemistry 23: 226 (1931)). Browne's diary reveals that he gained the impression that Long had been urging New Jersey Zinc to take over the Laboratory's program on wood painting. Earlier that year Sabin on a visit to the Laboratory showed concern about developments and left a memorandum on "Some Considerations Relating to the Testing of Paints Underway at the Forest Products Laboratory" in which he said that "The ultimate purpose is to benefit the owner of wooden buildings;" and "It should not be allowable to shunt off inquiry by arguing that many obscure questions have been and may be raised and that inquiry into the immediately available knowledge should not be begun until all these possible questions are fully decided." By April 1932 Cartwright was convinced that the Advisory Committee was dead.

Painting Chapter in the *Wood Handbook*

Preparation of the chapter on painting and finishing for the first issue of the Wood Handbook was fraught with great tribulation. It met with vigorous criticism by paint men, including the president of the paint association, Ernest T. Trigg, and his top executives. In retrospect it is hard to understand the intensity of



Figure 7—Participants at the Wood Painting Conference, September 13 to 14, 1929, assembled at the Forest Products Laboratory paint test fence, Madison, Wisconsin.

Top row (left to right): H.H. Zimmerman, H.K. Salzberg, J.P. Wentling, H.E. Brown, J.D. Edwards, J.R. Sheppard, P.R. Croll, S.N. Rhue, R.V. Williamson, J. Lurie, R.A. Morrison, F.C. Schmutz, F.G. Oswald, G.D. Patterson, E.J. Probeck, G.W. Cooke, H.A. Nelson, G.M. Hunt, and F.L. Browne.

Middle row: H.T. Morgan, H.A. Gardner, E.J. Seebach, W.H. Schlicke, M. VanLoo, F.E. Dodge, J.W. Iliff, H. Giese, W.I. Wray, P.H. Walker, L.H. Trott, R.L. Hallett, D.W. Edgerly, M. Doniger, F.R. Hodgson, D.A. Kohr, P.E. Marling, P.D. Buckminster, J. Marshall, R.J. Moore, S. Werthan, P.W. Ruppert, O. McG. Howard.

Bottom row, seated: V.A. Belcher, B.R. Ellis, A. Hermann, J.D. Studley, A.T. Upson, O.R. Hartwig, R.F. Adams, C. Ellis, P.H. Cathcart, W.A. Gehardt, C.S. Neal, H.C. Frey, J.T. Clark, J.S. Long, W.A. Ellinger, I.D. Hagar, and E.W. Boughton. (M 12729)

the objections because no great changes were made in the manuscript, and the objections were forgotten by the time the Handbook was revised in 1955. In general, however, the paint men were opposed to our making statements sufficiently specific to furnish effective guidance to paint users.

The Forest Products Better Paint Campaign

In July 1933 Don Critchfield, who had worked with Hartwig for the West Coast Lumbermen's Association, came to the Laboratory for advice and publications to help him in organizing an educational campaign on house painting. He failed to sell his idea to any of the paint companies, but he gained the backing of the West Coast Lumbermen and later of the Lead Industries Association. A house trailer was bought, prominently labeled "Forest Products Better Paint Campaign," and equipped with exhibits and publications based largely on the Laboratory's work. Critchfield traveled about talking to luncheon clubs, painters, lumber dealers, and builders.

For several years part of the campaign consisted in having lumber mills insert pamphlets in bundles of siding, giving directions for good painting practices. The directions gave much prominence to pure white lead paint as well as to mixed-pigment paints. Although the Laboratory had no responsibility for starting or continuing the campaign beyond furnishing information freely available to any citizen, the paint industry's resentment of the painting pamphlets and to the campaign was reflected on the Laboratory.

The name "Forest Products Better Paint Campaign" was, of course, easily confused with the Forest Products Laboratory. We soon had evidence that many persons assumed that the campaign was one of the Laboratory's activities. Perhaps Critchfield did not take as much pain as he might have to making the relations clear to the public. In September 1936 we persuaded Critchfield and the Lead Industries Association to change the name to "Lumber Industries Better Paint Campaign."

Approval of Two-Coat Paint System for FHA

Devoe and Reynolds offered the "two-coat" paint system in 1935. It broke previous custom of the paint industry by providing separate paints for priming and finish coats and by recommending that new wood be painted with a total of two coats instead of three. The primer, of the zincless titanium-lead type with "controlled penetration," was developed by Titanium Pigments Corporation, taking its lead from Browne's paper on "Adhesion in the Painting and in the Gluing of Wood" (Industrial and Engineering Chemistry 23: 290 (1931)). The finish coat was of the relatively high pigment level for that time that the Laboratory had been advocating, and the recommended spreading rates conformed to the Laboratory's findings for acceptable two-coat painting. Within a year or two most paint manufacturers were offering similar two-coat systems.

The Federal Housing Administration's minimum requirements demanded three coats on new wood. The FHA was reluctant to accept two-coat systems without safeguards. At their request the Laboratory wrote specifications for acceptable systems based on the classification system for paints that the Laboratory was preparing to publish. Paint manufacturers were required to submit labels bearing formulas and directions for application which were examined by the Laboratory, and the products were approved by FHA if they conformed to the specifications. The paint industry accepted the procedure with surprisingly good grace considering its bitter opposition to the classification system on which it was based. A number of manufacturers, including such large ones as Glidden, altered their original formulations in order to bring them in line with the specifications. It is very likely that this joint action by the Laboratory and FHA at the critical time when house-paint primers were first coming on the market did much to hold the industry's formulations within narrow limits and reasonably uniform quality. There has been little change in the house-paint primers for oil paints since that time, but with the development of emulsion paints new oil primers of a very

different nature are beginning to appear for use with the emulsion paints.

The sudden adoption of oil-restricted paints in 1943, ostensibly as a wartime measure to release linseed oil for shipment to Russia, made it impracticable to meet the requirements of the FHA specification. Since the war the industry's paints have remained oil-restricted. Two-coat painting of prewar quality is now rarely practicable. Yet few builders will have more than two coats applied on new houses. The Laboratory must now recommend three coats even though we know that the third coat will seldom be applied. Makers of the new emulsion paints, widely sold since 1959, all recommend three coats for new work.

Incompatibility Between Dissimilar Paints

Abnormal behavior of pure white lead paint over a previous coat of paint containing zinc oxide was observed first on our test panels at Sayville in 1925 or 1926. As we gained experience in observing paint troubles on houses, it became evident that some of them were due to dissimilarity between old and new paint. On our test fences it was found that a paint that did well over the primer of the same brand sometimes failed over a primer of another brand, even though the second primer with a finish coat of its own brand performed well. We called such abnormal failure "incompatibility." The concept was objectionable to the paint industry because it discouraged house owners from shifting indiscriminately from brand to brand for successive repaintings. That it encouraged brand loyalty was overlooked.

The question of incompatibility necessarily arose in our advice to those who consulted us about paint failures and was discussed privately with paint men for a number of years. About 1935 it began to appear in some of our publications, but it was not mentioned in the 1935 issue of the *Wood Handbook*. There was extensive debate about it in connection with the subject of paint classification described in the next section.

By the time of the second issue of the *Wood*

Handbook in 1955 the existence of incompatibilities became so well established that the subject was included in the chapter on painting without adverse criticism. Mention of it as an accepted principle now occurs freely in the paint literature. Adequate explanation of the reason for incompatibilities, however, was not available until our studies of swelling of paint films in water began in 1952.

Paint Classification

In the course of formulating paints for test-fence exposures, Browne soon recognized that comparisons among paints became much simpler and more significant when the proportions of ingredients were expressed by volume rather than by weight, as was customary in the 1920's. No doubt others soon came to the same conclusion because it was not long before such "volume analysis" became the usual basis for formulation studies. Hickson incorporated it in some of the federal specifications for paints to supplement the "weight analysis" in 1938. The extensive file of label formulas of trade-brand paints that the Laboratory maintained from 1924 until the second World War were all recalculated on the volume basis.

Study of the volume analysis led Browne in 1933 to the concept of a classification of house paints by group, type, and grade that, if properly administered by a central agency such as the paint association, would make it possible to tell paint users how to recognize paints of comparable characteristics and quality, and to furnish specific directions for proper application. The editor of *Paint, Oil and Chemical Review*, R. F. Adams, asked Browne to write a series of articles and was willing to have them deal with a subject that would surely prove controversial. The first three proposed articles were written outside of official hours. When submitted for approval, however, the director decided that the proposal should be published officially despite the certainty of strong opposition.

The proposed classification system was prepared as a Laboratory report for limited distribution and private discussion with paint men, lumbermen,

and others. As expected, there was strenuous opposition by the National Paint, Varnish and Lacquer Manufacturers' Association (NPVLMA), but there was also considerable support among smaller paint manufacturers and paint chemists. Paul D. Buckminster, a past president and prominent leader in the Federation of Paint and Varnish Production Clubs, actively favored the proposal. J. S. Long spoke vigorously in support although 15 years later he became a leader of the opposition. Hickson of the Bureau of Standards was a loyal supporter.

On September 17, 1936, nearly 3 years after the first draft was prepared, the proposal was presented at a well-attended dinner meeting of the New York Paint and Varnish Production Club, which lasted into the small hours of the morning. Discussion was vigorous, but there was a reasonably even division of opinion among the paint men present.

The Laboratory decided to hold a second conference on wood painting similar to that of 1929, in June 1937. Publication of the proposed classification in *Industrial and Engineering Chemistry* also was planned. In February 1937 Ernest T. Trigg, president of NPVLMA, sent word through Felix Wormser of Lead Industries Association asking that both the conference and the publication be abandoned. A meeting at the Drake Hotel in Chicago on March 10 was arranged to discuss the matter among Trigg, Gardner, and Sulzberger for NPVLMA; Wormser for Lead Industries Association; Tate and Dulaney for National Lumber Manufacturers' Association; and Winslow, Hunt and Browne for the Laboratory. It was agreed to substitute for the June wood painting conference a small conference at Madison with a selected group of technical men and to withhold publication pending such conference. The conference was to consider the subject of house painting in general rather than classification alone.

Just before the conference met we received communications from Junius D. Edwards of the Aluminum Company of America and Daniel Edgerly and Erickson of Titanium Pigments

Corporation supporting the proposed classification.

The conference met on April 26 and 27, 1937, and was attended by the following persons:

E. F. Hickson, Bureau of Standards; Albert Hermann, Western Pine Manufacturers Association; H. A. Gardner, NPVLMA; Wayland Rice, Barrelled Sunlight Paint; E. E. Ware and Stowe Neal, Sherwin-Williams Company; Paul Croll and Samuel Rhue, Pittsburgh Plate Glass Company; R. L. Hallett, National Lead Company; Harley Nelson, New Jersey Zinc Company; and John Marshall, E. I. du Pont de Nemours and Company. Laboratory participants were Winslow, Hawley, Hunt, Browne, and Teesdale.

In previous meetings and discussions Gardner, who acted as leader of the paint men, had brushed aside our test-fence evidence as unrepresentative of houses. Therefore the data the Laboratory presented was drawn chiefly from our extensive file of examinations of house owners' difficulties. Teesdale's presentation of the condition of cold-weather condensation and the use of vapor barriers to correct it was seized eagerly and its widespread publication recommended. Our analysis of the many other causes of unsatisfactory paint behavior was denied sweepingly, largely on the ground that our information was "hearsay." (We usually accepted statements of house owners or painters about the kinds of paints they had used and when and how they applied it.) Gardner in particular attacked the evidence of frequent incompatibilities among dissimilar paints although some of the paint men present recognized a limited number of incompatible combinations that were often found. Gardner tried further to limit the justification for our proposed classification to the concept of incompatibilities and argued that under classification every paint dealer would have to stock every possible group, type, and grade of paint, each one in white and a variety of colors.

The proposed classification was published in *Industrial and Engineering Chemistry* 29: 1018 (1937). An editorial in the same issue stated that the paint industry had asked and been granted space in a following issue for reply, but no reply

was offered. During the next few years the proposed classification received practical application as the basis for approval of two-coat systems by FHA. Although the paint association continued to oppose it, there was also substantial encouragement both within and without the paint industry. Preparation of a complete treatment for publication as a USDA Technical Bulletin was started in January 1940. A year later the Secretary of Agriculture approved the labeling of paints with the classification "as recommended by the U.S. Department of Agriculture." Technical Bulletin No. 804 was published in January 1942. (This is the end of Dr. Browne's report.)



Comprehensive Description of Wood Finishing Research

When Dr. Frederick L. Browne was appointed head of wood finishing research at the FPL in 1922, little information was available for ensuring the satisfactory and economical performance of coatings on wood in exterior use. The manufacture of paints and varnishes was still largely empirical. For the most part, it did not take into account how the character of the coating, the method of application, and the condition of the wood interrelated. Paint and varnish chemists had been continuously improving their products toward better service at less cost, yet these improvements had focused on the coatings and had largely ignored the effect of wood properties on finish performance.

Early FPL research centered on applying basic knowledge about wood properties to the problem of finish durability. For example, researchers hypothesized that anatomical differences between wood species would affect the performance of the coating. Some species contain substances such as oils or resins, tannins, and water-soluble constituents, which were suspected to affect the coating, but it was not known to what extent. Therefore, determining the effect of wood species on finish durability became one of the first goals of the wood finishing research group (Fig. 8).

The tendency for wood to shrink and swell as it loses or gains moisture was also identified as a factor that could adversely affect the durability of a coating. On the other hand, researchers hypothesized that the coatings themselves might prevent or reduce dimensional changes in wood by reducing the movement of moisture. Determining the moisture-excluding effectiveness of coatings became another early research goal.

Additional research topics emerged in the course of these early projects. For example, researchers observed that sunlight played an important role in the erosion of wood and degradation of paint films. Subsequent studies focused on physical changes that occur during the weathering process and on protective measures for slowing this process. As new wood-based materials were developed and adapted for exterior use, determining their weathering and painting characteristics was essential for ensuring satisfactory long-term performance.

This section describes the major accomplishments in wood finishing research carried out during the last 65 years at the Forest Products Laboratory.

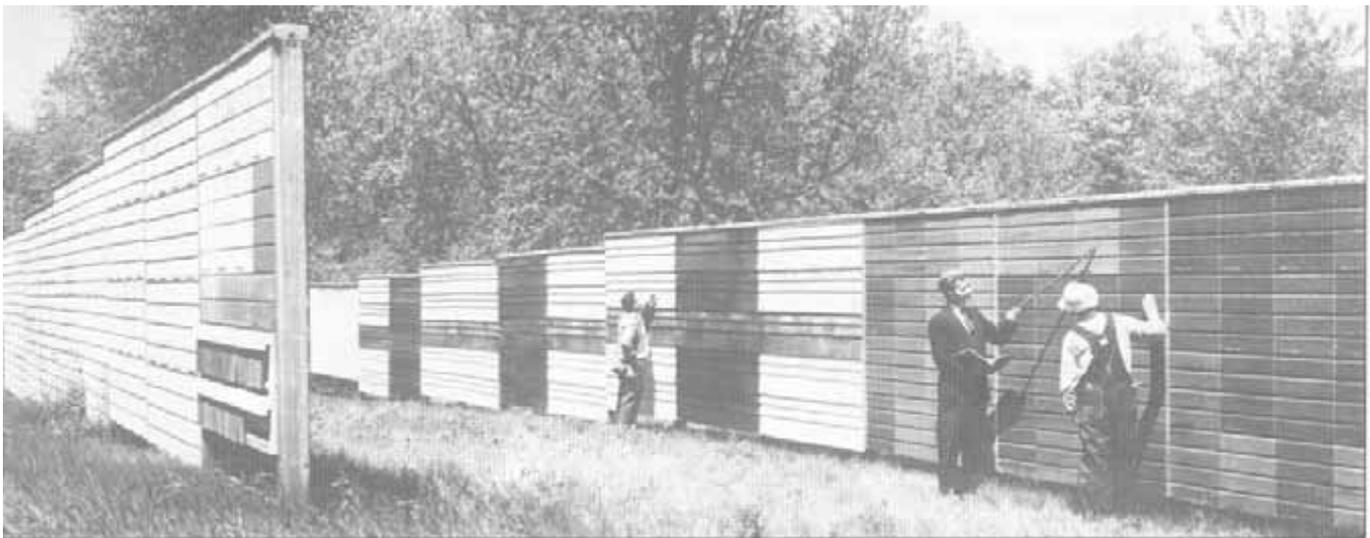


Figure 8—Typical test exposure fence in 1954 used in the Forest Products Laboratory studies on the weathering characteristics of different wood species. (M 94701)

Role of Wood Species and Wood Properties in Finish Performance

To provide reliable information about the role of the wood substrate in finish performance, in 1924 the FPL began an experimental study (Browne 1924) of the painting characteristics of softwoods. Continued studies (Browne 1931d, 1933b, 1934d) resulted in the classification of wood species according to their painting and finishing characteristics. This information was

incorporated into the Wood Handbook originally published in 1935 and technical publications and leaflets (Figs. 9, 10).

Early research also yielded information on wood density and ring size, ring orientation, knots, and extractives, pitch, and oils.

Density and Ring Width

The density of wood (its "weight") is one of the

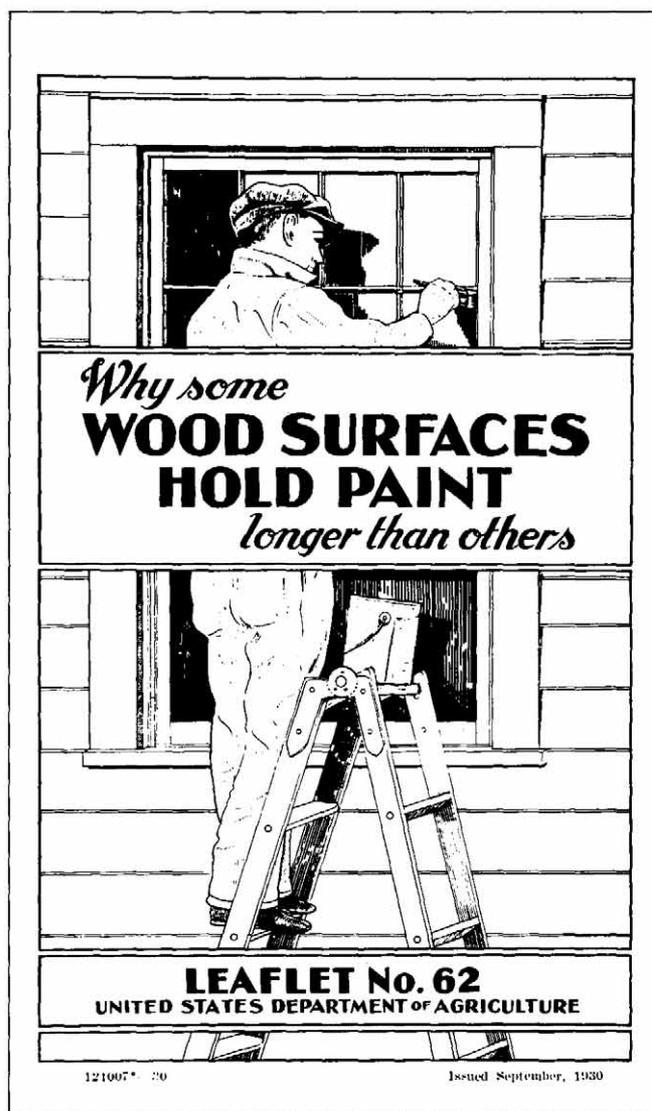


Figure 9—Cover of USDA leaflet on paint-holding characteristics of wood surfaces (September 1930).

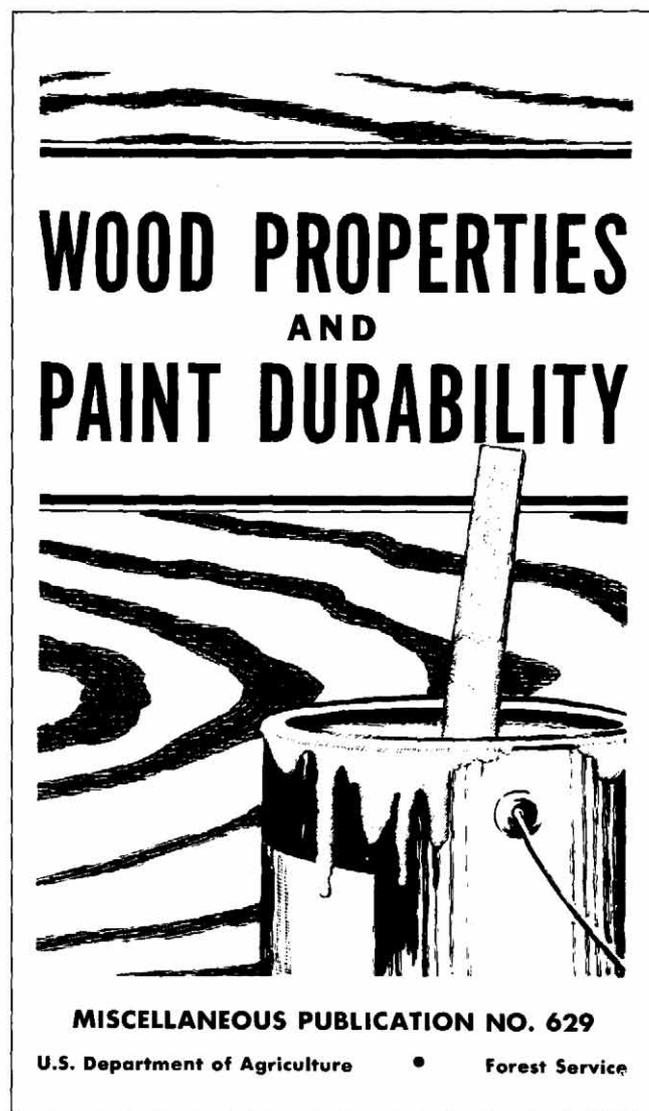


Figure 70—Cover of USDA publication by Browne (7947) describing wood properties and paint durability.

important factors that affect finishing performance. Density varies tremendously from species to species, and it is important because “heavy” woods shrink and swell more than “light” woods. These dimensional changes occur as wood, particularly in exterior applications, loses or gains moisture with changes in the relative humidity and from periodic wetting caused by rain, snow, and dew. Excessive dimensional change in wood constantly stresses a film-forming finish such as paint and may result in the early failure of the finish.

Like density, the presence and amount of latewood (sometimes called summerwood) in soft wood (conifer) lumber affect paint durability. Latewood is denser, harder, smoother, and darker than earlywood (sometimes called springwood), and its cells have thicker walls and smaller cavities (Fig. 11). The wider the latewood rings, the denser the wood. New paint adheres firmly to both earlywood and latewood. However, old paint that has become brittle with age and weathering loses its adhesion and peels from the smooth, hard surface of the latewood first. If the latewood rings are sufficiently narrow, as in slow-growth trees, the coating may bridge the latewood and remain in place longer than it does on wider latewood rings. Wide latewood rings are normally absent from edge-grained cedar and redwood,

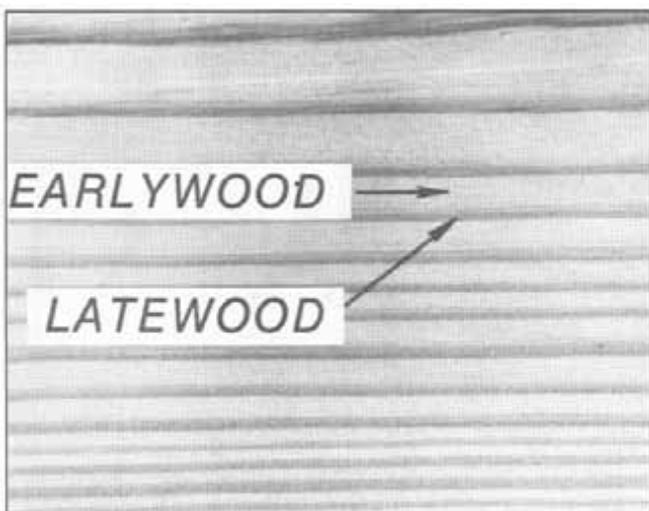


Figure 11—Earlywood and latewood bands in wood. Together, the two bands make up an annual growth ring. (M 830 023)

improving the paintability of these species. However, they are prominent in southern yellow pine and Douglas-fir, two species commonly used for general construction purposes and for the production of plywood.

In contrast to softwoods, growth rate does not seem to significantly affect the ability of hardwoods to retain paint.

Ring Orientation

The manner in which a board is cut from a log affects the orientation of the annual rings and thus the paintability of the board. Lumber is referred to as either flat grained or edge grained (plainsawed or quartersawed in hardwoods) or as a combination of the two (Fig. 12). Most standard lumber grades contain a high percentage of flat grain. Lumber used for board and batten siding and shiplap is frequently flat grained. Bevel siding of redwood or cedar is generally produced in a flat-grained standard grade and an edge-grained premium grade. Flat-grained lumber shrinks and swells more than edge-grained lumber, and it also has wider, darker rings of latewood. Therefore, edge-grained lumber or siding will usually retain paint better than flat-grained material.

Quartersawed hardwood boards also retain paint better than plainsawed boards, but the difference is relatively small compared to the difference between edge-grained and flat-grained softwoods.

Knots and Other Characteristics

The presence of knots and other natural characteristics (such as bark, splits, pitch pockets, and insect damage) in lumber will affect its paintability. The presence of such characteristics is generally a function of, lumber grade; clearer grades are rated higher and allow better finishing. Knots are simply exposed end grain. End-grained wood will absorb more finish than flat- and edge-grained lumber, and this affects the appearance of the coating. Knots in pine often contain a high percentage of resin, which may cause the paint over the knot to discolor. Furthermore, large knots usually check and crack to the extent that a noticeable split or

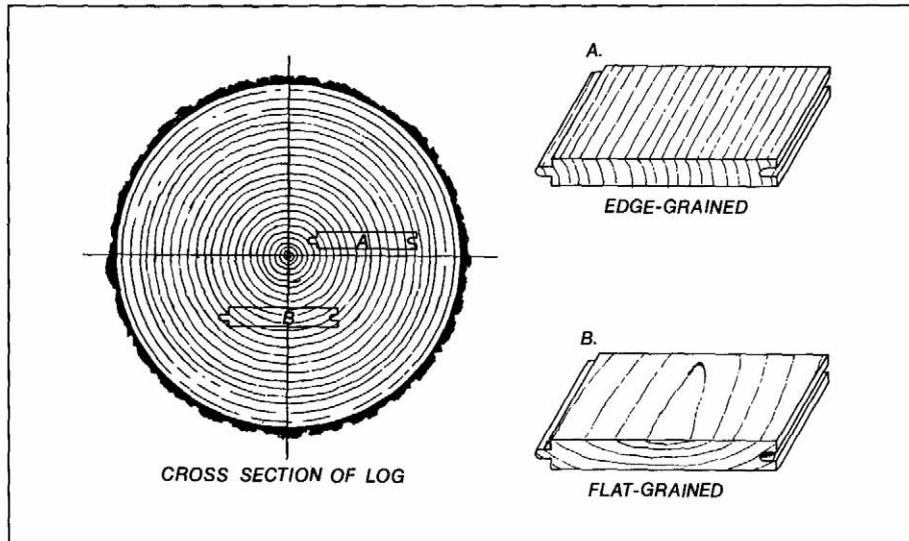


Figure 12—Effect of sawing method on ring orientation in lumber.
(M 148 631)

defect can result in the lumber. Therefore, the higher grades of lumber intended for finishing are generally recommended for maximum paint serviceability.

Extractives, Pitch, and Oils

Depending on the species, wood may contain water-soluble extractives, pitch, or oil. Each of these substances has its own properties and characteristics. Although they constitute only a small percentage of the oven-dry weight of wood, these substances may affect many wood properties, including color, odor, resistance to decay and insects, permeability, density, and hardness. The deposition of extractives, pitch, and oils is generally associated with the formation of heartwood, and, without them, many woods would appear identical except for their anatomical features.

Water-soluble extractives are extraneous materials that are naturally deposited in the lumens, or cavities, of cells in the heartwood of both softwoods and hardwoods. They are particularly abundant in those woods commonly used for exterior applications, such as western redcedar, redwood, and cypress; they are also found in lesser amounts in Douglas-fir and the southern pines. The attractive dark color, good

dimensional stability, and natural decay resistance of many species are due to the presence of extractives. However, these same extractives can cause serious finishing defects both at the time of finish application and later. They are probably the most common reason for discoloration of exterior house paint. Because the extractives are water soluble, they can be dissolved when free water is present and subsequently transported to the wood surface. When this solution of extractives reaches the painted surface, the water evaporates and the extractives remain as a reddish-brown stain. The stain is particularly noticeable in white or very light-colored paints or solid-color stains.

In most pines and Douglas-fir, pitch can be exuded from either the sapwood or heartwood. Pitch (sometimes called resin) is usually a mixture of rosin and turpentine. Rosin is brittle and remains solid at most normal temperatures. Turpentine, on the other hand, is volatile even at relatively low temperatures. With proper kiln-drying techniques, turpentine can generally be driven from the wood, leaving behind only the solid rosin. However, for green lumber or even dried lumber marketed for general construction purposes, different kiln schedules may be used, and the turpentine remains with the rosin in the

wood. As a result, the pitch melts at a much lower temperature than pure rosin, and the mixture can move to the surface. If the surface is finished, the pitch may exude through the coating or cause it to blister. This problem usually develops slowly as the air located in the wood resin ducts and cell lumens shrinks and expands as a result of temperature changes and forces the pitch outward. The most serious problems occur when wood is heated, as when the sun strikes the south side of a house. Once the pitch exudes to the surface of the wood, the turpentine evaporates, leaving beads of hard rosin behind. Or, if the wood is painted, the pitch diffuses through the paint and discolors it.

Aromatic oils are present in some woods, such as cypress, teak, and the cedars (except western redcedar), and can cause finishing problems. These oils are mixtures of liquids or solids that crystallize with difficulty. They are soluble with many common finishes and thus may cause discoloration. Oils may also retard the drying of coatings, leaving them sticky, and they often blister, soften, wrinkle, and generally disintegrate the coatings. In Port-Orford-cedar, oil concentrations apparently run in streaks, which wrinkle the paint.

Some oils have high boiling points and evaporate very slowly, even at the temperatures used in kiln-drying wood. Finishing problems with pitch and oils can generally be reduced through the use of proper kiln-drying schedules. However, some care must be exercised not to reduce the oil too much if the finished product requires the aroma caused by the oil.

Mechanism of Paint Failure

Although the physical characteristics of the wood substrate largely determine the durability of wood finishes, other mechanisms can also cause early paint failure. Studies at the FPL have included fundamental research as well as empirical tests, such as exposure tests, to better duplicate the conditions of paint in service (Fig. 13).

The pitch (resin) in softwoods, such as southern yellow pine, had often been supposed to cause



Figure 13—Test exposure house constructed at Madison, Wisconsin, for studying the effects of climate and interior conditions on exterior paints and other finishes (1964). (M 128 108-1)

early failure of paint. In a study by Browne and Hrubesky (1931), test panels of various pitch contents were coated with different paints and exposed to outdoor weathering. Although marked differences in durability of coatings were observed, the differences bore no relation to the content of pitch but were directly related to wood density and the width of annual growth rings in the boards.

Coatings absorb water (Browne 1954) or moisture (Browne 1955a-c), swell, and become more plastic. Movement of earlywood and latewood rings in surfaces and raising of the grain during swelling and shrinking of softwoods were measured quantitatively (Browne 1957a-c), and they were found to be unrelated to the cracking and disintegration of house paints. In fact, the plasticizing action of water on both coating and wood seemed to greatly facilitate movement without loss of adhesion. Later experiments with paint films exposed under various conditions (Browne 1959b) showed that water, especially in conjunction with ultraviolet light, accelerates chemical deterioration of oil-based coatings. Coatings crack from their own internal stresses as they become embrittled by weathering and lose their initial specific adhesion for wood. Ultimately, flaking initially occurs over wide latewood rings because mechanical adhesion is weaker in the small cavities of latewood than in the larger cavities of earlywood.

Some conditions that lead to early paint failure are unsuitable spacing of paint coats or repaintings, unsuitable thickness of coating, incompatibility between paints, and blistering. Most good house paints serve best when the coating is between 4 and 5 mils (1 mil = 0.001 in.) thick (Browne and Laughnan 1952b, 1953) (Fig. 14). Thin coatings erode rapidly (Browne 1955b) and thick coatings crack perpendicular to the grain regardless of the species or growth ring orientation.

At least three distinctly different kinds of blistering occur: (1) temperature, (2) chemical or "glossy-back," and (3) moisture. A necessary condition that these types of blistering share in common is the development of pressure in a gas or liquid at the paint-wood interface where the blisters are located. Moisture blistering is the most prevalent type of blistering. A device for studying the moisture blistering of paints was designed and used at the FPL in the early 1930's (Browne 1933e) and improved in 1959 (Browne and Laughnan 1960) to better resemble the actual conditions that may occur in houses (Fig. 6).

Temperature blisters are caused when a thin, dry skin has formed on the surface of fresh paint,

and the liquid thinner in the wet paint under the skin changes to vapor and cannot escape. When the direct rays of the sun fall on freshly painted wood, the rapid rise in temperature causes the vapors to expand and produce blisters. Usually only oil-based paint blisters in this way. Dark colors that absorb heat and thick coats are more likely to blister than white paints or thin coats.

"Glossy-back" blisters are characterized by a transparent, glossy, sometimes sticky material that looks like old varnish on the back of the blisters and on the wood surface underneath. These blisters are presumably caused by gases from deteriorating old oil-based paint. New coatings applied over old paint limit the access of oxygen and ultraviolet light and the old paint is degraded, liberating gaseous products that cause the blister. The gloss results from the degradation products that adhere to the back of the new paint. These products are acids that arise from the disruptive oxidation of the fatty acids of linseed oil.

Moisture blisters are also bubble-like swellings on the surface of the paint film. They are found on both oil-based and latex paints. As the name implies, the blisters usually contain moisture



Figure 14—A 110-year-old house, resided in 1930 and maintained with good painting practices (1979 photograph). (M 147 332:12)

when they are formed. They may occur where outside moisture, such as rain, enters the wood. Moisture may also enter because of poor construction and maintenance practices. Paint blisters caused by outside water are usually concentrated around joints and the end grain of wood, particularly in the lower courses of siding. Paint failure is most severe on the sides of buildings facing the prevailing winds and rain.

Paint Classification

By the mid-1930's many States required that house and barn paints on the market list the composition of the formula on each can label. Although labeling proved helpful, it nevertheless did not provide the knowledge of paint composition needed for intelligent selection, application, and maintenance of paint by the user (Browne 1935a, 1937). A paint classification system was therefore proposed by Browne (1937e) to simplify the description of paint composition for laymen by outlining the major characteristics of the paint.

In 1942, the U.S. Department of Agriculture published a procedure for classifying house and barn paints by group, type, and grade in Technical Bulletin No. 804 (Browne 1942b). This system of classification was based on research by the FPL, and it was recommended by the Department of Agriculture as a step towards obtaining more lasting and satisfactory service of paints on wood (Fig. 15). It was intended to aid paint users in correctly identifying the kind of paint needed for specific purposes, the

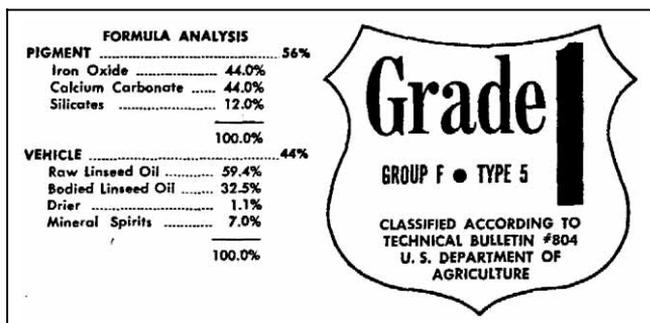


Figure 15—Example of paint formula and grade stamp for paint classification system of Browne (1942).

characteristics of the paint, and the proper methods for applying and maintaining the paint.

Thus the paint classification system was intended to provide a basis for intelligent selection and use of paint. However, although the system did not limit the formulas used by paint manufacturers and left manufacturers free to change and improve their formulas, it was strongly opposed by the paint industry. The Department of Agriculture consequently withdrew the paint classification system because of “representations in advertising which may be construed to imply Department endorsement of a particular paint rather than to a suggested method of classifying these paints” (News Release, August 1953). However, the Department emphasized that their action did not negate the validity of the classification system nor the need for such a system:

It was emphasized that the action on the classification system in no way repudiates the technical facts upon which the classification was based. The need continues for an improved system of classification and the Department has been assured that the paint industry would continue to cooperate with the Department's technicians to the end that a practical classification system for house and barn paints could be developed for use by the entire industry. (News Release, August 1953)

Moisture-Excluding Effectiveness of Wood Finishes

The FPL research on the effectiveness of coatings in retarding moisture and dimensional changes of wood was initiated in 1914, long before the start of wood finishing research in 1922. The work continued for many years. Wood specimens (basswood, western larch) were coated with different finishes (house paint, shellac, varnish, paraffin wax, and linseed oil). After treatment, the coated specimens were hung out of doors under a shed, and weights and measurements were taken for about a year. The specimens were then taken indoors and allowed to dry and shrink under dry and warm conditions (Dunlap 1926). These initial studies demonstrated the wide range of effectiveness of coatings on wood.

During World War I, the FPL was requested by the War Department to study the effectiveness of propeller finishing methods then in use and, if possible, to devise better methods. Airplane propellers were losing their balance and shape as a result of moisture changes. These investigations measured the moisture (water vapor) gain of wood protected on all sides by the finish (Fig. 16), and exposed to a controlled atmosphere of high humidity (Hunt 1930, Browne 1933a,e). Later tests at the FPL used the same methods because the test conditions represented a “real world” situation under non-steady-state conditions (Feist et al. 1985a,b).

The standard FPL test for determining the moisture-excluding effectiveness of finishes is to determine the amount of moisture vapor passing through the finishes and adsorbed by the wood at 30 and 90 percent relative humidity after different intervals of exposure. The moisture-excluding effectiveness against water vapor is calculated by comparison with the weight of moisture adsorbed by the uncoated panels. A value of 100 represents total protection; 0 represents no protection.

The protection afforded by coatings in excluding moisture from wood depends on a great number of variables. Among them are coating film thickness, defects and voids in the film, type of pigment, chemical composition of the vehicle, vapor-pressure gradient across the film, and



Figure 16—Martin E. Dunlap (1929) brushing coatings on test panels for moisture-exclusion tests. (M 111 77)

length of exposure period. The degree of protection also depends on the type of exposure. For example, water-repellent treatments, which may have no effectiveness against water vapor after 2 weeks at 80°F and 90 percent relative humidity, would have an effectiveness of over 60 percent when tested after immersion in water for 30 minutes. The high degree of protection provided by water repellents and water-repellent preservatives during short periods of wetting by water is the major reason they are recommended for exterior finishing. Porous paints, such as the latex paints and low-luster (flat) or breather-type oil-based paints formulated at a pigment volume usually above 40 percent, afford little protection against moisture. These paints permit rapid entry of water vapor and water from dew and rain unless applied over a nonporous primer.

Insulation added to walls of an older home without vapor barriers may cause moisture condensation problems in the outer walls. Paints with high moisture-excluding-effectiveness values serve as adequate vapor barriers when applied to such walls as long as no mechanical humidification is used (Sherwood 1978).

Shrinking and swelling and the accompanying stresses that cause warping and checking in wood and contribute to its weathering are brought about by changes in the moisture content of the wood. Such changes occur whenever wood is exposed to varying atmospheric conditions. The FPL research on moisture exclusion shows that various moisture-retardant finishes effectively protect against fluctuating atmospheric conditions, provided that the finish is applied to all wood surfaces through which moisture might gain access. However, the research has clearly demonstrated that no coating, whether applied by brush, spray, or dip, is entirely moisture proof, and there is as yet no simple way of completely excluding moisture from wood that is exposed to dampness constantly or for prolonged periods (USDA 1987).

Water Repellents and Water-Repellent Preservatives

Water repellents (WR) can be used as a stabilizing treatment before priming and painting (Fig. 17). This stability is achieved by a small amount of wax in the repellent, which decreases capillary movement of water. Water-repellent preservatives (WRP) include a fungicide to inhibit surface mildew (mold) and decay, and a WRP is the basic component of the FPL Natural Finish (see next section).

The FPL, working in cooperation with the National Door Manufacturers' Association (now the National Wood Window and Door Manufacturers' Association), established a research study in 1943 to measure the effectiveness of water repellents. The purpose of the study was to determine which laboratory method for measuring water repellency best reflected the effectiveness of WR solutions (Browne and Schwebs 1944). A later study (Miniutti et al. 1961) included outdoor weathering tests in addition to existing industry standard tests. Two major difficulties in measuring water repellency are the great variability of replicate measurements with any one WR and the length of time needed to complete a series of tests.

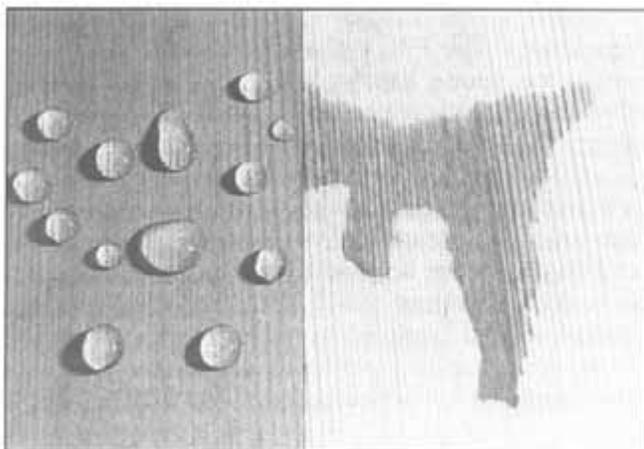


Figure 17—Wood surface brush-treated with water repellent (left) resists penetration by drops of water, whereas untreated wood surface (right) adsorbs water quickly. (M 145 933-16)

After the 1944 evaluation of test methods, Browne and Downs (1945) made an extensive survey of the properties of 55 commercial WRs, WRPs, wood sealers, and preservative wood sealers to determine the character and effectiveness of these products as a guide for the FPL in further WRP studies. Although the primary interest was in WRs, sealers were included in the survey for two reasons: terminology in the field was not standardized, so that a sealer might be obtained when a WR was requested, and the authors wished to compare sealers and WRs.

Later studies involved the effectiveness of WRs and WRPs for specific end uses such as wood siding, window sash and other millwork, and wood boxes, including those used in the food industry.

Researchers recognized that rainwater enters the back of wood siding chiefly by capillary action, working through the lap joint between courses of bevel siding. High winds are a minor cause. Laboratory tests by Teesdale (1959) showed that entry of rainwater through house siding can be minimized or eliminated by treating siding with a WRP before it is nailed to the house or by applying a WRP to the siding of a completed house before the house is repainted. In a 5-year follow-up study by Anderson (1963), the WRP treatment was still effective in preventing movement of rainwater to the back of the siding, and paint retention was noticeably improved on flat-grain siding of certain species.

Outdoor 20-year exposure tests (Feist and Mraz 1978b) showed that WR treatment can protect aboveground millwork from decay and deterioration—at least for northern areas with low risk of decay—without the need for preservative (Fig. 18). Paint applied over WR-treated wood will perform far more effectively than if applied over unprotected or pentachlorophenol-treated wood, and at least as effectively as that applied over WRP-treated wood.

Shipping boxes and crates are commonly made of woods with low natural resistance to fungi and insects. Consequently, containers exposed to the elements are usually attacked by biological



Figure 18—View of test fence at Madison, Wisconsin, (1977) showing untreated and decayed control window unit frames (foreground) contrasted with sound, water-repellent-treated window units (background) being inspected by William C. Feist. (M 145 288-17)

deteriorating agents. Decay fungi and termites cause most loss, but stain and mold can obscure stenciling and attack the liners and occasionally the contents. Outdoor exposure tests (Verrall and Scheffer 1969) showed that 3-minute dip treatments of wood boxes in various wood preservatives with and without WR maintained the boxes in good condition for more than 10 years in both a southern and northern climate. However, the WR usually lost its effectiveness within 5 years.

The WRs and WRPs can improve the service or prolong the life of wood exposed to the weather. Sapwood and other kinds of wood that absorb moisture quickly and rot easily can be particularly

benefited. Structures with joints through which rainwater gains access to unprotected parts of the wood can be improved at their most vulnerable parts. On the other hand, the reader should keep in mind that the effectiveness of WR and WRP products is limited by the method by which they are applied.

The FPL Natural Finish and Other Natural Finishes

Any wood exposed to sunlight and rain will eventually lose its original color. The change is due partly to the loss of water-soluble extractives, which occurs quite rapidly, but mainly to the breakdown of wood components by ultraviolet light and subsequent removal of the breakdown products by rain (see section on wood weathering). In a clean, dry environment this may result in an attractive silvery-gray appearance, but more commonly the surface becomes streaked with dirt and unevenly darkened by fungal and iron stains.

Natural finishes for wood siding began growing in popularity in the late 1930's (Browne 1951) as a result of the homeowners' desire to preserve the rich brown or red colors of western redcedar and redwood siding. The natural finishes can be divided into two categories:

1. Penetrating types such as transparent water repellents, water-repellent preservatives, and semitransparent and pigmented oil-based stains
2. Film-forming types such as varnishes

The FPL Natural Finish (Black et al. 1979; USDA 1957) was developed to provide homeowners with a more durable and reliable natural finish than was currently available (Fig. 19). The formulation is classified as a penetrating, oil-based stain with the characteristics of a water-repellent preservative. Pigments added to the formulation extend the life of the finish by blocking ultraviolet light. A service life of 6 to 8 years is possible when pigmentation is included and the finish is properly applied to rough surfaces. Without the



Figure 19—Don Laughnan (right) points out some natural finish exposure results at the Forest Products Laboratory exposure test fence site in Madison, Wisconsin, to Joe Terry (1956). (M 100 469)

pigments, the finish can be expected to last less than 3 years.

Among the advantages of the FPL Natural Finish are good color retention, good durability on a variety of smooth and rough wood surfaces (Feist and Mraz 1980a; Grantham et al. 1976), and low cost of initial application and maintenance. Unlike paints and solid-color (opaque) stains, properly applied solventborne penetrating finishes do not leave a measurable, surface film and thus cannot fail from blistering; cracking, or peeling. Their normal failure mechanism is one of slow erosion from the wood surface during weathering; thus, the surface can be easily refinished.

Treatments (Especially Chromium)

Recent trends in the use of wood for exterior siding have emphasized natural-type finishes that enhance the texture, grain, and inherent beauty of wood. Although several approaches were investigated toward developing an acceptable natural finish, inorganic surface treatments were extensively studied (Black 1973; Black and Mraz 1974, 1976) for improving the service life of clear exterior finishes (Fig. 20).



Figure 20—John Black inspecting paint failure on wood structure (1974). (M 88 9000)

Treating wood surfaces with aqueous solutions of inorganic chemicals by simple brush applications can

1. retard degradation of the surfaces by ultraviolet irradiation,
2. enhance effective use of polymer coatings transparent to ultraviolet light,
3. reduce the swelling of wood by water,
4. impart some fungal resistance to the wood surface and surface coatings, and
5. serve adequately as natural exterior finishes.

The most spectacular result of research on natural finishes was an exterior finish with a service life of approximately 15 years, achieved by treating the wood surface with an inorganic ultraviolet light absorber and coating it with a clear polymer transparent to ultraviolet light. Effective inorganic treatments were ammonium chromate, ammonium copper chromate, ammonium copper-chrome-arsenate, cupriethylene diamine, copper molybdate, and copper ferricyanide. In addition, chromate treatment improved performance of oil and latex stains, linseed oil-based paint, clear latex

coatings, and oil-based varnishes. Additional studies showed the value of using simple chromium compounds like chromium trioxide (Feist 1979).

Water-soluble extractives in redwood and redcedar were fixed by treating the wood surface with dilute solutions of copper and chromium salts. This treatment permitted direct application of latex paints to the wood (Feist 1977b).

The studies on natural wood finishes also involved measuring the erosion of treated and untreated wood surfaces by leaching and ultraviolet light irradiation in accelerated weathering. A procedure was developed for quantitatively measuring these effects as well as the effects of treating solution composition and wood species on resistance to leaching and irradiation (Black and Mraz 1974). A promising method for improving the fungal resistance, color, and permanence of acid-copper-chromate treatments with resorcinol was also reported.

A serious disadvantage of chromium treatment is the toxicity of the chemicals. However, because the Cr⁺⁶ valence state is apparently the hazardous form of chromium-containing compounds, researchers hypothesized that reducing Cr⁺⁶ to the lower, less hazardous trivalent state (Cr⁺³) might make these compounds attractive as potential treatments for wood surfaces. Investigations (Feist and Ellis 1978, Feist 1979) were thus begun on the fixation and interaction on wood surfaces of compounds containing hexavalent chromium. Almost total fixation of Cr⁺⁶ was achieved by heating wood surfaces, treated with chromium trioxide (CrO₃), for 10 minutes at 135°C. Only traces of chromium of any valence state were detected in water extracts.

Studies showed the degree of protection provided to the wood surface is directly related to Cr⁺⁶ concentrations in CrO₃ solutions (chromic acid). A 4.8 percent CrO₃ solution was most effective at its original pH of 0.5. Surface treatment with CrO₃ reduced dimensional changes in wood exposed to water. Free water uptake by CrO₃-treated wood was decreased compared to water uptake by

WR-treated wood. This decrease in free water uptake was found for treated flat-grained and vertical-grained surfaces but not for end-grain wood, indicating that capillary uptake could still occur. Water repellency was observed in both water-immersion and water-spray experiments. Preliminary studies on CrO₃-treated wood surfaces using electron spectroscopy for chemical analysis showed that Cr⁺⁶ was reduced to Cr⁺³ at concentrations of 1.25 percent chromium. The reduction undoubtedly plays a role in the fixation of Cr⁺⁶ on the wood surface.

Scanning electron microscopy (SEM) studies (Chang et al. 1982) revealed that chromic acid or ferric chloride treatments can protect wood surfaces against ultraviolet degradation. The exact mechanism of protection is not clearly understood. It is speculated that the incorporation of inorganic ions at the wood surface results in wood-ion complex formation, which could interfere with the photochemical reaction either by emitting effective light energy or by shifting the absorbing zone to a short wavelength zone to minimize light absorption. Possibly, the presence of inorganic salts decomposes peroxide intermediates to avoid oxidative chain reactions at wood surfaces.

In related work (Williams and Feist 1983), a trivalent chromium compound was shown capable of fixing to wood to produce nearly the same weathering protection and water repellency as hexavalent chromium compounds. The critical factor was the ability of the chromium to fix or become unleachable, not the oxidative chemistry of the hexavalent chromium ion on the wood.

A further study (Williams and Feist 1984) proved that chromic acid fixes to both wood and pure cellulose. With both materials, complete fixation of chromium resulted in a highly water-repellent surface. The similarity between treated wood and treated cellulose indicated that chromium-cellulose interactions should be included in defining the Cr⁺⁶ stabilization mechanism for wood surfaces and that previously proposed chromium-wood mechanisms based solely on extractives, lignin, and/or hemicellulose were too limited.

Wood Weathering

All wood materials are sensitive to outdoor weathering. Wood exposed to the outdoors without protection undergoes photodegradation by ultraviolet light; leaching, hydrolysis, and swelling by water; and discoloration and degradation by staining and decay micro-organisms (Figs. 21 and 22). Unfinished wood surfaces exposed to weather change color, are roughened by photodegradation and surface checking, and erode. Although physical as well as chemical changes occur because of weathering, these changes affect only the surface of the exposed wood (USDA 1975a). Browne (1960) reported that the weathering process is so slow that "only 1/4 inch (6.4 mm) of thickness is lost in a century," for typical softwoods like pine, fir, and redwood. Erosion values vary greatly with species and wood density (Sell and Feist 1986a). Values from 13 mm/century for western redcedar to 3 mm/century for dense hardwoods were found by Feist and Mraz (1978a).

Browne and Simonson (1957) found that ultraviolet light cannot penetrate deeper than 75 microns into wood surfaces, and visible light no deeper than 200 microns. Wood exposed to ultraviolet light or sunlight rapidly loses brightness and changes in color. The first sign of deterioration in softwood surfaces is the enlargement of apertures in bordered pits in the

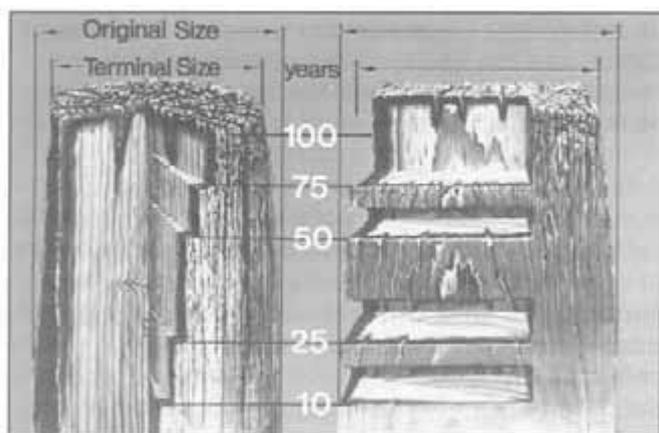


Figure 21—Weathering process for round and square timbers. Cutaway shows that interior wood below the surface is relatively unchanged. (M 146221)

radial walls of earlywood tracheids (Miniutti 1967a,b; 1970, 1973) (Fig. 23). The SEM studies by Chang et al. (1982) showed that most cell walls on exposed transverse surfaces are separated at the middle lamella region, apparently because of lignin degradation. However, tangential surfaces are quite resistant to ultraviolet light, compared to transverse and radial surfaces. Only microchecks were observed at the tangential cell walls.

Free radicals generated in wood during the weathering process play an essential role in surface deterioration and discoloration. Free radicals are generated in wood by ultraviolet light (Kalnins et al. 1966). Wood apparently does not contain any intrinsic free radicals (Hon et al. 1980; Kalnins 1966; Kalnins et al. 1966). However, free radicals were generated by irradiating wood with fluorescent light at ambient temperatures (Hon and Feist 1981; Hon et al. 1980). The rate of free radical formation was enhanced when moisture content increased from 0 to 6.3 percent. Electron spin resonance and ultraviolet studies on the behavior of free radicals generated and their interaction with oxygen molecules to form hydroperoxides revealed that free radicals and singlet oxygen play important roles in the discoloration and deterioration of wood surfaces. The chemistry of weathering and protection was summarized in a technical publication (Feist and Hon 1984).

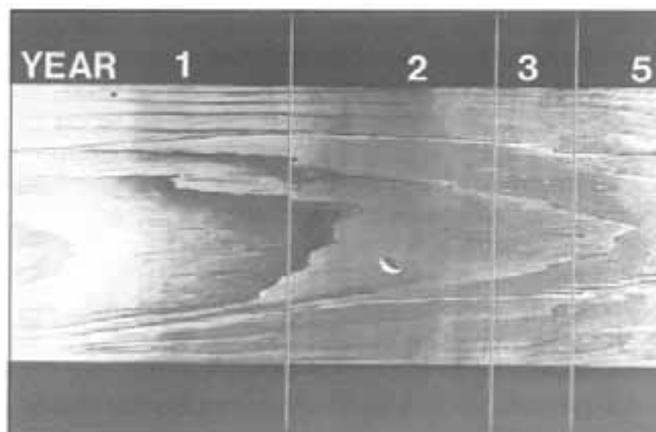


Figure 22—Monochromatic rendition of color changes and surface wood change during the outdoor weathering process for a typical softwood. (M 146222)

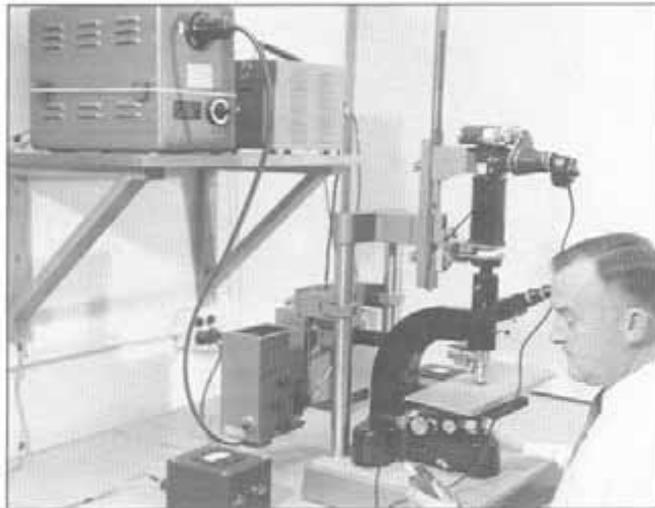


Figure 23—Victor Miniutti investigating wood surface deterioration using an optical microscope (1969). (M 136 316)

Studies on the effect of short periods of weathering before finishing (Williams et al. 1987) showed that adhesion of both an acrylic latex and an alkyd-oil primer to wood was significantly reduced after the wood substrate had weathered for 4 or more weeks before painting. This reduced paint adhesion and increased wood-paint interface failure inevitably results in poor long-term paint and finish performance. These observations prompted the authors to recommend that wood that will be exposed outdoors for more than 2 weeks should be protected with a finish that will prevent photodegradation and water damage.

Wood exposed to the weather can be protected by paints, stains, and similar materials. A number of influencing and stressing factors affect wood/finish performance and result in weathering effects (Fig. 24). Under certain conditions, unfinished wood has been known to survive for centuries (Figs. 25 and 26). These conditions include the selection of decay-resistant wood with good dimensional stability and proper construction practices that will not allow wood to collect or trap water (Browne 1947b; Sell and Feist 1986b). Duncan (1963) showed that micro-organisms are important in the weathering process and can cause wood and finish degradation.

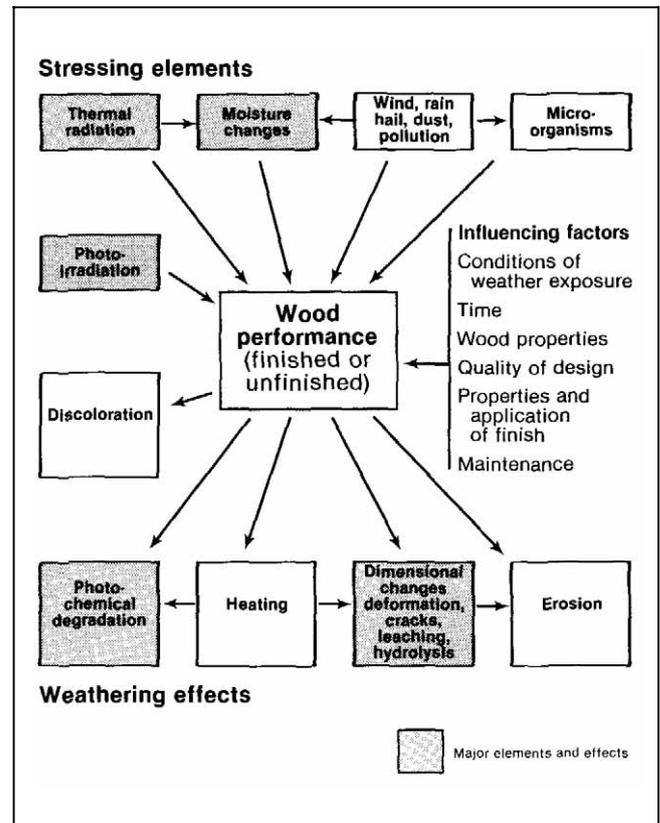


Figure 24—Schematic illustration of factors affecting wood/finish performance and resultant weathering effects. (ML88 5561)

The primary function of any wood finish is to protect the wood surface from the natural weathering elements (sunlight and water) and help maintain appearance (USDA 1987). Paints provide the most protection to exposed surfaces because they are generally opaque to the degradative effects of ultraviolet light and protect wood to varying degrees against water. Paint performance may vary greatly on different woods. Pigmented stains also provide durable finishes for wood exposed outdoors. Treating wood with water-repellent preservatives or certain inorganic chemicals (chromium compounds) before finishing can improve the performance of finishes significantly.

Many aspects of wood weathering are not understood completely. A complete understanding of weathering mechanisms would aid in developing new pretreatments and finishes

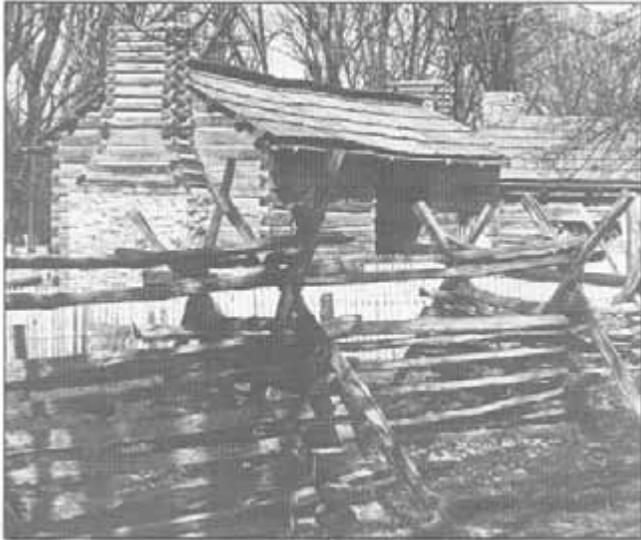


Figure 25—This duplex cabin at the Lincoln Village in New Salem, Illinois, exhibits remarkable craftsmanship and a high degree of development. It illustrates that under certain conditions, unfinished wood can be used outdoors (1982 photograph). (M 86 0072)

to enhance durability (Feist 1987a). The ever-changing wood substrate as well as the increasing use of previously unused species and new adhesive-wood combinations poses particular challenges to modern wood finishes. A detailed study of the various interactions that affect the performance of wood-based materials is needed to develop methods for protecting these products outdoors.

Newer techniques and tools for the study of wood surfaces, such as Fourier transform IR spectroscopy (FTIR), electron spectroscopy for chemical analysis (ESCA), and electron spin resonance spectroscopy (ESR), may provide much insight into the weathering process for both finished and unfinished wood substrates. Use of these techniques will allow indepth study of the treatment of wood surface interactions and the importance of these interactions in the ultimate performance of the wood.

Finish Performance and Weathering of Wood Composites

For many decades, only solid lumber was used as exterior siding. In recent years, wood composites,



Figure 26—Old Fairbanks house at Dedham, Massachusetts, built in 1637. Most of the white pine clapboard siding was replaced in 1903, and it has withstood 85 years without paint (1952 photograph). (M 91 098)

such as hardboard, plywood, waferboard, particleboard, oriented strandboard, and others, have become increasingly important as exterior siding. Hardboard and plywood have dominated the wood siding market for some years in the United States, while the use of solid wood siding has been slowly declining (Feist 1987b). At present, many new panel products made from complex reconstituted wood materials are being introduced in the United States and the world market.

Future siding consumption forecasts for the United States indicate that wood-based products will decline somewhat relative to nonwood materials, especially vinyl, but quantities in excess of 1.3 billion square feet of wood siding are predicted in 1995. Thus, it is important for the FPL to continue to expand its research activities and to include different wood composite substrates in its research program.

An outdoor exposure study (Feist 1982d) of the performance of several finish systems on four wood-based panel products and one solid wood substrate illustrated how the protection of wood composites could be enhanced with two- and

three-coat paint systems. A semitransparent oil stain, partially ultraviolet transparent, gave the least protection to the wood substrate surface. Two-coat systems, comprised of all-latex finishes (stain-blocking acrylic latex primer and acrylic latex topcoat), performed better than the stain and provided the greatest degree of protection. The stain-blocking primers help control extractive movement through latex paints (Feist 1977b).

Variable results were found when a water-repellent preservative was used as a treatment prior to finishing with paint topcoats. The water-repellent preservative pretreatment enhanced finish and substrate performance when applied to aspen waferboard and southern pine board, but it did not protect the aspen waferboard from attack by decay fungi. The aspen waferboard panels proved the most difficult to protect of the substrates evaluated. Although the three-coat systems were effective, white-rot decay fungi were found on two panels finished with alkyd primer and latex topcoats. No decay was observed on panels finished with the all-latex paint systems. These observations led to additional studies with aspen waferboard on the effects of pretreatments on finish performance.

Hardboard siding showed consistently good performance, especially when finished with two or more coats of paint. The all-acrylic latex finish systems showed very good overall performance on this substrate. The semitransparent oil stain and solid-color oil stain provided the least protection for this substrate and resulted in the poorest performance.

Redwood plywood siding with a roughsawn texture exhibited consistently better finish and substrate performance than did smooth, sanded Douglas-fir plywood. Smooth plywood is not recommended for exterior siding. The improved performance for roughsawn surfaces is probably related to both better mechanical adhesion of the finish because of increased surface area and use of a greater amount of finish; roughsawn surfaces absorbed more finish than smooth surfaces when the finish was applied with a brush.

Several highly-detailed studies on the outdoor performance of finished wood substrates were undertaken as a result of Feist's outdoor exposure study. One concerned the use of several different pretreatment systems on aspen waferboard and the substrate performance of three finishes at three exposure sites (Carll and Feist 1987). A similar study involved sanded and roughsawn southern pine plywood (Feist 1987c). Results for yellow-poplar were recently reported (Feist 1987b). The role of water repellents and water-repellent preservatives as pretreatments for wood-based products was further investigated in several studies (Feist 1984b, 1985b). Finishes that vary from fully transparent to almost fully opaque are currently being evaluated on several substrates. Pretreatment effectiveness of several primer and self-primer systems is also being investigated.

Modified Woods and Treated Woods

Many conventional and experimental surface treatments for wood reduce or eliminate the effects of weathering. Studies have addressed the effects of chemical modification on the weatherability of wood and have elucidated the mechanism of ultraviolet light degradation of modified woods (Rowell et al. 1981; Kalnins 1984). Wood subjected to chemical modification of cell walls with butyl isocyanate or butylene oxide, modification by filling the cell lumens with methyl methacrylate, and combined cell-wall and lumen-fill modification was compared to unmodified wood. Physical, microscopic, and chemical changes in the wood surfaces after ultraviolet light irradiation in controlled accelerated weathering experiments were evaluated for earlywood and latewood. The studies also reported the effects of exposure to ultraviolet light and to combinations of ultraviolet light and water.

The earlywood and latewood of southern pine chemically modified with butyl isocyanate or butylene oxide did not resist the degradative effects of ultraviolet light. Surface deterioration, color changes, and small weight losses occurred during accelerated weathering (ultraviolet light and water spray). In another study, accelerated

weathering produced little surface erosion until water washed away degraded wood elements (Feist and Rowell 1982). In both modified and unmodified wood, earlywood degraded to a much greater extent than latewood during accelerated weathering. Latewood erosion was greater for wood modified with butylene oxide than for all other types of specimens. Weight loss increased markedly as lignin degradation products were washed away by water, and chemical modification did not reduce this weight loss. Increasing the dimensional stability of the wood and blocking lignin phenolic hydroxyl groups apparently were not enough to stop the extreme degradative effects of ultraviolet light in the weathering process.

Lumen-fill modification with methyl methacrylate polymer reduced the extent of erosion. The erosion rate of earlywood and latewood and wood substance loss during accelerated weathering were reduced significantly in comparison to chemically modified or unmodified wood. Degradation was minimal in wood exposed to ultraviolet light, even with water spray action. The methyl methacrylate polymer, polymerized within the wood structure, probably reduced water uptake and retarded subsequent leaching of wood degradation products. The polymer can be regarded as a glue-like material, which holds the surface wood fibers in place, even though the natural glue (native lignin) is degraded on the wood surface by the action of the ultraviolet light. As the methacrylate polymer holds the cellulose-rich fibers on the wood surface, the fibers may act as partial screens to protect the underlying wood substance.

Although chemical modification with butyl isocyanate or butylene oxide was not successful in controlling ultraviolet light degradation of wood, a combination of either of these chemical modifications with methyl methacrylate lumen-fill treatment resulted in a modified wood that had good resistance to accelerated weathering. The combination of the lumen-filling polymer and the chemical treatments that modified the cell wall provided dimensional stability that significantly increased weatherability. Weight losses for specimens treated with these combined chemical

treatments were at least 50 percent less than those of the chemically modified specimens, and wood erosion and erosion rates were low.

Understanding the role of chemical modification of wood and wood surface in controlling the weathering process is significant to the future use of wood outdoors. This role will become larger as greater demands are placed on the newer wood-based products. The future of chemical modification lies in the enhancement of end-product properties. Permanently bonded chemicals that provide ultraviolet light stabilization, color control, water resistance, and dimensional stability could greatly enhance the outdoor performance of wood.

Effects of Acid Deposition

The attention given to acid rain (acid deposition) during the last decade has prompted interest in the effect of acids on weathering. The effect of acid rain on painted materials can be seen in at least two phenomena, degradation of the coating and degradation of the substrate. In a study by Williams (1986), the type of pigment and extenders used in paint formulations had a direct bearing on paint performance in an acid environment. The degradation of the substrate also has a direct bearing on coating performance. Because substrate degradation may involve different failure mechanisms, future research should include the reaction of the substrate-coating interface to acid rain.

The effect of acid treatment on the erosion rate of western redcedar was determined using xenon arc accelerated weathering techniques (Williams 1987). Test specimens were periodically soaked in nitric and sulfuric acids at different pH levels during accelerated weathering. Acids with a pH of 3.0 caused a 10 percent increase in the erosion rate compared to the erosion rate of unsoaked controls. At 3.5 pH, the erosion rate increased 4 percent, and no effect was found at a pH of 4.0. The pH levels used in this study were felt to be somewhat conservative, since naturally occurring atmospheric acid concentrations have been reported in the range of pH 2.0.

Future work on acid deposition and other environmental effects will determine which components of wood are most affected by acid or other chemicals and what effect this degradation has on the performance of paint and other finishes. Evaluating lignin susceptibility to degradation by environmental effects may be the key to understanding the mechanisms of degradation.

Technology Transfer

The results of basic and applied research at the FPL on exterior wood finishing have been regularly published in a variety of scientific and trade journals. As most of this research has practical application for painters and homeowners, the FPL has always tried to disseminate the research results in a variety of nontechnical publications, informational guides, and other outlets. As a result, many thousands of individuals have benefited from FPL research—improved exterior finishes have resulted in substantial savings in maintenance time and costs.

Farmers were first provided with painting recommendations in an article by Dr. Browne in the 1932 USDA Agriculture Yearbook (Fig. 27). Similarly, articles in farm journals (Barquest and Black 1966; Black 1966; Browne 1940, 1941b, 1948b) and in a 1977 series of University of Wisconsin-Extension publications (Barquest et al. 1977a-c) offered advice on selecting, applying, and maintaining finishes for wood structures. Additional practical publications were developed in cooperation with Purdue University as part of the USDA Extension Service (Cassens and Feist 1980a-e).

Articles about the painting concerns of homeowners have been published in popular magazines. In addition, the FPL has issued thousands of copies of General Technical Reports and Research Notes free to the public, addressing topics such as exterior finishes for homes and log cabins, proper application procedures, causes and cures for most finish discolorations and failures, and refinishing recommendations.

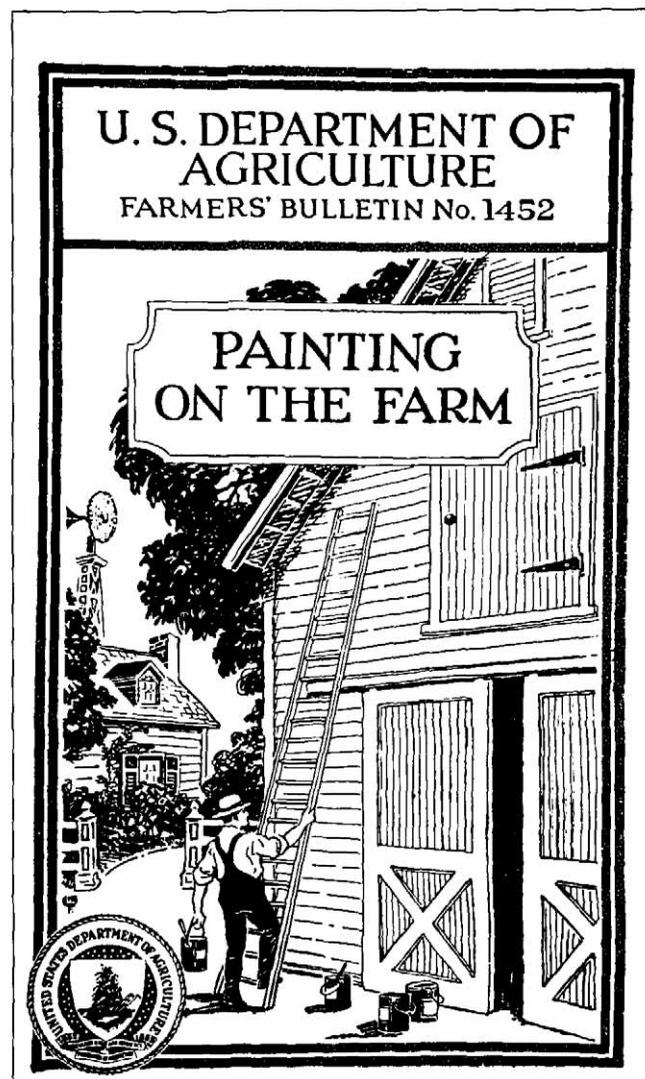


Figure 27—Cover of 1932 USDA publication, *Painting on the Farm*, by Frederick L. Browne.

The results of 65 years of FPL research on exterior wood finishing are brought together in USDA Agricultural Handbook No. 647, *Finishing Wood Exteriors: Selection, Application, and Maintenance* (Cassens and Feist 1986a). This practical handbook is a useful guide for do-it-yourself homeowners, but it also serves as a valuable reference work for professional builders, architects, and wood finishers. Handbook 647 describes the basic characteristics of wood and reconstituted wood-based products, focusing on their finishing and performance characteristics, the ways that various finishes interact with these

characteristics, and manufacturing and construction practices that affect the surfaces to be finished. Detailed information is given on various types of exterior wood finishes, together with proper application procedures. Principal subjects include paints, solid-color stains, semitransparent penetrating stains, transparent coatings, and water-repellent preservatives. Other topics of interest include the weathering of wood, treated wood products, fire retardants, and moisture-excluding finishes. Special applications and treatments needed for wood decks and porches, fences, roofs, log structures, and marine environments are outlined. Methods are also given for diagnosing and correcting finish failures.

The National Wood Products Extension Program was started in 1984 at the FPL in cooperation with the USDA Extension Service, the University of Wisconsin, and other universities. It has served to link wood products research and the National Cooperative Extension network. Through this program, individual statewide Cooperative Extension offices are provided with the latest information on wood finishing, which is relayed to individuals through newspaper articles, seminars, and direct referral by county Extension specialists. As part of this cooperative program, a 24-minute slideltape program was developed at the FPL to provide practical information on exterior finishing of wood and wood products. An updated version is available both in slideltape and in video format through the University of Wisconsin-Extension in Madison, Wisconsin.

The technology transfer efforts will always be an important part of the FPL program on exterior wood finishing and the performance of wood exposed outdoors above ground. These activities are important for conveying basic research information to the general public in an easily understood form. The following list of research topics demonstrates the wide range of material that has been incorporated into practical publications. The information has been separated into three periods that represent distinct phases in the research program over the past 65 years: 1922 to 1963, 1964 to 1975, and 1976 to 1987.

1922 to 1963

Paintability of wood species

Classification of wood for finishing

House structure and construction related to paint performance

Wood properties and paint composition related to paint performance

Diagnosis of house paint problems

Federal paint, stain, and water-repellent preservative specifications

Paint classification system

Role of zinc oxide in paint blistering

Water-repellent preservatives

Assistance in developing industry standards

Development of the FPL Natural Finish

Development of swellograph and swellometer

Moisture-excluding effectiveness of wood finishes

Methods for controlling end checking in lumber and logs

Remedial measures for condensation problems in houses

Barn paints

Wood finishing and painting chapter in the *Wood Handbook*

Painting of overlaid wood

Causes of paint blistering

Exudation of pitch and oils and other extractives

Moisture content of wood for finishing

Multiple-coat house-paint systems

Swelling of paint with moisture

1964 to 1975

Development of durable natural wood finishes

Information on weathering of wood

Microscopic techniques for studying wood surfaces

Water-repellent preservatives as natural finishes

Modification of oil-based stains

Latex stains

Expansion of technology transfer activities

Chromium-containing pretreatments

Revision of chapter on wood finishing and painting in the *Wood Handbook*

Inorganic chemical pretreatments

Fixation of extractives

Alternatives for pentachlorophenol in finish formulations

Effect of machining and surfacing on performance of finishes

Better methods for finishing low quality wood surfaces

Ten-year paint systems

1976 to 1987

Detailed chemical studies on mechanisms of weathering

Chemistry of weathering and protection

Contribution of wood species and characteristics to weathering

Correlations of accelerated and outdoor weathering

Effect of brief weathering of wood on finish performance

Adhesion of paint to wood and weathered wood

Chromium pretreatments and their effect on finish performance

Role of water repellents as wood pretreatments

Moisture-excluding effectiveness of modern finishes on wood

Methods to control the vaporization of pentachlorophenol from wood

Performance characteristics for finished panel products

Chemical modification of wood for improved weathering performance

Surface modification of wood to improve clear finishes

Effect of acid deposition on wood and painted wood

Performance of hardwoods as exterior siding

New techniques for wood surface characterization

Weathering interactions on wood surfaces

Weathering of heat-stabilized wood

Performance of finishes on preservative-treated wood

Rewrite of *Wood Handbook* chapter on finishing

Major reviews on wood weathering and finish performance

Greatly expanded technology transfer activities with universities

New and revised technology transfer publications

USDA Handbook on finishing wood exteriors



Overview

Research Results

The Forest Products Laboratory (FPL) has had a long history of wood finishing research. Over the years, the FPL has made a major contribution to the understanding of the complex processes that affect unfinished wood and finished wood exposed outdoors. The research has resulted in many technical and practical publications of benefit to a wide range of users, including homeowners, builders, architects, the paint industry, the wood industry, and government agencies.

Results from FPL research demonstrate the weathering performance and life expectancy of wood and finished wood products exposed outdoors. The research has always stressed basic studies that lead to practical and useful information. The 65 years of research have included laboratory studies as well as outdoor exposure studies (Fig. 28) in several locations in the United States and have yielded much important information about wood itself and the performance of finished wood.

The FPL's work on wood finishing has provided wood users with basic and practical information on the best ways to finish and protect exterior wood. The following conclusions and recommendations are based on the research results.

1. High-quality, opaque finishes, applied in the recommended number of coats, provide the best overall performance and protection for wood.
2. Paints provide the most protection against weathering for wood surfaces. Two-coat acrylic latex systems (stain-blocking acrylic latex primer and acrylic latex topcoat) perform better than alkyd (oil) primer/acrylic latex paint systems. Three-coat systems (one primer plus two topcoats) always result in the best overall performance and provide the greatest degree of protection for the substrate. The acrylic-latex-primer/acrylic-latex-topcoat paint systems represent the best overall finish system currently available for the variety of

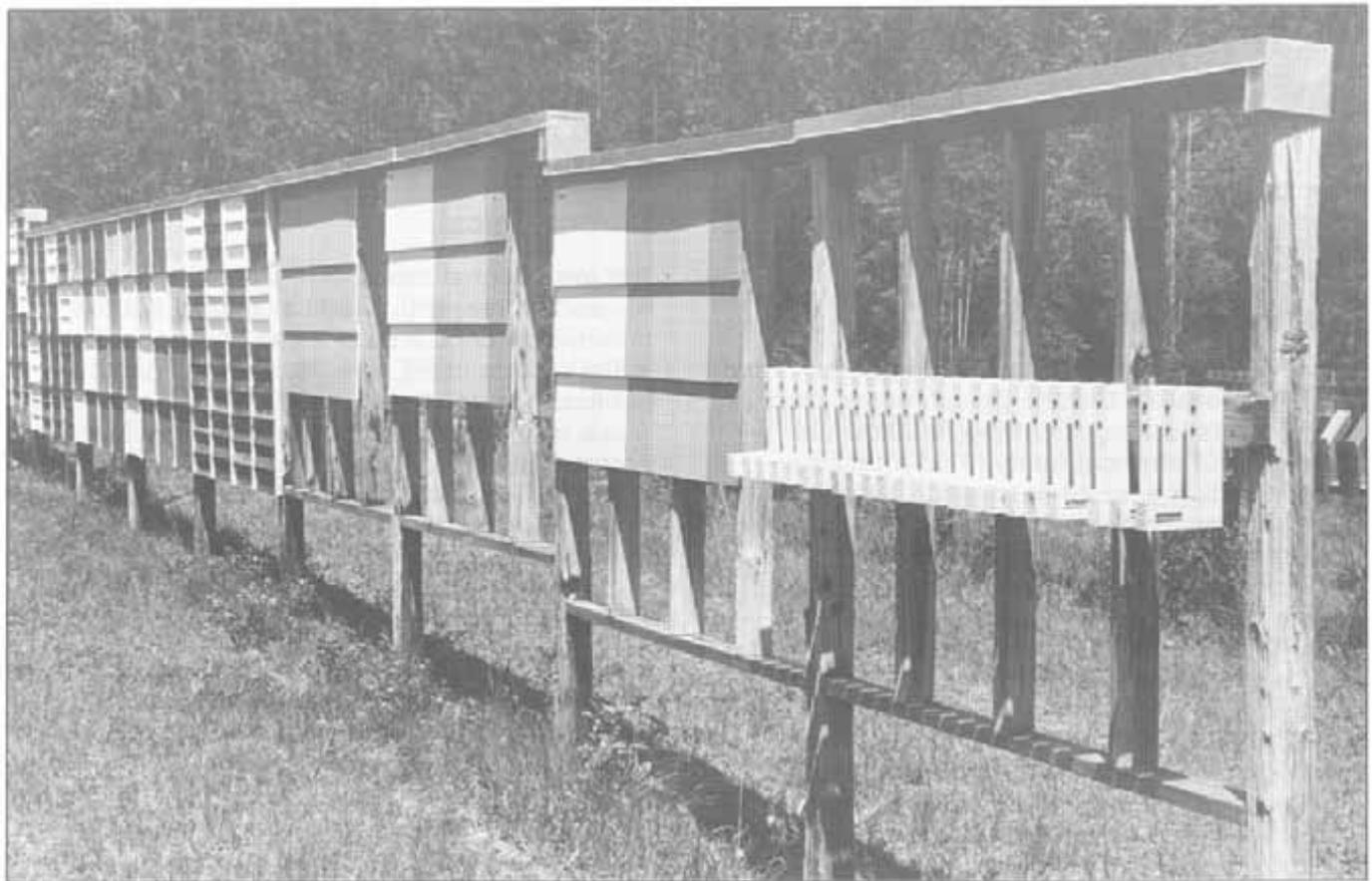


Figure 28—Test fence for wood substrates at the Forest Products Laboratory's exposure site in the Harrison Experimental Forest near Saucier, Mississippi (1985). (M85 0008-16)

wood substrates included in our studies. The acrylic latex paint system is particularly good on wood panel products.

3. Solid-color stains provide protection against ultraviolet light degradation. Their performance falls between that of paints and semitransparent stains.
4. Semitransparent penetrating stains, whether oil or latex, are partially transparent to ultraviolet light and protect the wood substrate surface less than paint systems but more than fully transparent finishes. Adding more pigment improves performance. Semitransparent finishes should never be used on hardboard siding; when used on plywood, they should be refinished regularly to protect the surface from ultraviolet light degradation.
5. Transparent finishes (varnishes, oils, water-repellent preservatives) provide the least protection to the wood surfaces of all the finishes studied. These nonpigmented finishes are therefore NOT suitable for use on wood

panel products because they provide little protection against ultraviolet light degradation. Film-forming finishes (varnish) can fail because the wood may degrade under the finish; the cracking and peeling that result can make refinishing very difficult.

6. Pretreatments with water repellents and water-repellent preservatives are very effective in improving finish and substrate performance on hardwoods, softwoods, and some panel products.
7. Pretreatments can be used to stabilize wood surfaces and improve outdoor weathering performance. Chromium-containing inorganic chemicals have been shown to be especially effective, even though their color and potential toxicity limit their use.

All the observations and conclusions on wood and wood finish performance indicate that the wood products must be installed using the procedures recommended by the manufacturer. Poor or improper installation procedures can



List of Publications and Reports

severely reduce the performance of the finish and cause premature failure.

Future Research Efforts

The FPL will continue its studies in outdoor wood finishing research. Despite the advances, much knowledge is lacking about the fundamental chemical and physical factors that affect the performance of exterior finishes on different wood species, composites, and new, wood-based products. Governmental restrictions and regulations on wood finishes have led to the development of new, largely untried finish systems for wood. These need to be evaluated for their performance and ability to protect wood.

A major task of the FPL is to provide fundamental information on exterior wood finishing to guide producers and consumers in which wood products to use outdoors. Research will continue to stress the fundamental aspects of wood weathering and the interactions of pretreatments and finishes with wood surfaces. Future research will also focus on (1) the role of environmental pollutants, such as acid deposition, in the performance of wood and finished wood; (2) finishing and weathering characteristics of wood modified with preservatives, fire retardants, or chemicals; (3) new methods for increasing the stability of wood surfaces exposed to water, sunlight, micro-organisms, and other outdoor elements that degrade wood finishes; and (4) refinishing of once-finished wood and weathered wood. All of this future work will be oriented toward providing the wood user with basic and practical information for using, stabilizing, and protecting wood exposed outdoors. Research results will be disseminated through technical, semitechnical, and practical publications.

Chronological

Not every formal report that was written over the 65 years of research is still available, but the information contained in those studies is distilled in the reports listed here. Most of the listed publications can be acquired from the publishers. A few early mimeographed reports from the Forest Products Laboratory can be obtained from the Laboratory. Most publications in this list have been annotated to give the reader an overview of the studies.

1923

Browne, F.L. 1923. Wood finishing studies of the Forest Products Laboratory. Proceedings; Scientific Section [Circular], American Paint and Varnish Manufacturer's Association. 184: 278-283.

Summarizes FPL plans to study moisture-excluding effectiveness of coatings, painting characteristics of different species of wood, painting of treated wood, wood fillers, and maximum allowable moisture content of wood for successful painting.

1924

Browne, F.L. 1924. The painting characteristics of different kinds of wood. Proceedings; Scientific Section [Circular], American Paint and Varnish Manufacturer's Association. 219: 125.

Presents early results of a painting characteristics study at Forest Products Laboratory.

Tiemann, H.D. 1924. Does paint preserve wood? Scientific American. (May).

1925

Browne, F.L. 1925a. Paint and the first stages in the weathering of wood. Proceedings; Scientific Section [Circular], American Paint and Varnish Manufacturer's Association. 238: 289.

Describes initial weathering behavior and the influence of paint as protection from weathering. Study concludes that paint cannot

protect wood from decay under conditions that favor decay.

Browne, F.L. 1925b. Role of paint and varnish in wood conservation. *American Paint Journal*. (August).

Study concludes that paint is effective for reducing weathering of wood in exterior applications but good construction is the key to reducing the occurrence of decay.

1926

Browne, F.L. 1926a. Painting characteristics of woods. II. Results after two years' exposure. *Proceedings; Scientific Section [Circular], American Paint and Varnish Manufacturer's Association*. 290: 202-216.

Evaluates paint appearance and film integrity as well as amount of surface weathering for various wood species; includes influence of grain orientation.

Browne, F.L. 1926b. Paintability of different woods. *West Coast Lumberman*. 50(590): 157-158.

Test fence study on the influence of wood characteristics on paintability and the performance of various paints and primers.

Browne, F.L. 1926c. Wood finishing: A glance ahead. *Mechanical Engineering*. 48: 1286.

The future of wood finishing as an art, a craft, and a branch of engineering; emphasizes the need for adequate tests to evaluate finishes.

Dunlap, M.E. 1926. Protecting wood from moisture. *Industrial and Engineering Chemistry*. 18(2): 1230-1232.

Results of tests to determine the relative moisture-excluding effectiveness of various finishes on birch specimens subjected to high humidity.

1927

Browne, F.L. 1927a. Some causes of blistering and peeling of paint on house siding. *Scientific Section [Circular], American Paint and Varnish Manufacturer's Association*. 317: 480-483.

Emphasizes that no paint or primer can protect wood against early failure if large amounts of moisture are allowed access to the unpainted back side of boards. Rain seepage and condensation are highlighted.

Browne, F.L. 1927b. Principle for testing the durability of paints as protective coatings for wood. *Industrial and Engineering Chemistry*. 19(9): 982-985.

Correlates the moisture-excluding effectiveness and durability of paints; suggests that moisture-excluding effectiveness be accepted as a test for paint durability.

Browne, F.L. 1927c. Spreading rate of outside white house paint on different woods. Part 1. *Drugs, Oils and Paints*. 42(7): 230-232.

Examines factors affecting the spread rate of paint, including kind of wood, grain orientation, degree of surface weathering, type of paint, and personal influence of the painter.

Browne, F.L. 1927d. Spreading rate of outside white house paint on different woods. Part 2. *Drugs, Oils and Paints*. 42(8): 268, 270, 272.

Browne, F.L. 1927e. Technical study of wood painting practice: U.S. Forest Products Laboratory investigating woods to discover how different species can be painted most satisfactorily. *American Paint Journal*. 11(17): 20, 22, 24, 26, 28.

Research on painting characteristics of woods, effectiveness of coatings for preventing swelling and shrinking of wood, and how and where paint and varnish prolong the life of wood in service.

1929

Browne, F.L. 1929. Successful painting depends largely on behavior of wood. *American Paint Journal*. 14(13): 24, 26.

Shows striking difference in physical structure of latewood and earlywood in the same board. Deemphasizes the need to develop new paints or painting methods for different types of wood.

1930

Browne, F.L. 1930a. Drying of exterior paints under various weather conditions and over different woods. *Industrial and Engineering Chemistry*. 22(4): 400.

Letter to the Editor challenging a previous article on paint drying. States that cypress and redwood are generally preferred species for siding and that extremely adverse application conditions preclude drawing conclusions about paint performance on wood.

Browne, F.L. 1930b. Effect of priming-coat reduction and special primers upon paint service on different woods. *Industrial and Engineering Chemistry; Industrial Edition*. 22(8): 847-854.

Empirical testing of modified primers to improve their adherence to latewood of softwoods.

Browne, F.L. 1930c. The preservative treatment and staining of shingles. Rep. 761. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Recommends species, finishes, and finish application procedures for shingles and shakes, including treatments for shingles of less desirable woods.

Browne, F.L. 1930d. Procedure used by the Forest Products Laboratory for evaluating paint service on wood. *American Society Testing Materials Proceedings*; 30(2): 852-870.

Describes three steps for evaluating paint. Also describes how and to what extent coatings change during exposure and how this change affects their service life.

Browne, F.L. 1930e. Properties of wood that determine the service given by exterior paint coatings. *Federation of Paint and Varnish Production Clubs; Official Digest*. 95: 106.

Browne, F.L. 1930f. Why wood painting research becomes a problem in forestry. *Journal of Forestry*. 28(8): 1136-1145.

Discusses how the paintability of commercial

lumber might be altered by (a) selection of lumber by species, grade, or density and ring width, (b) improvements in milling and manufacture, (c) special treatment by impregnation, or (d) control of properties through silviculture.

Browne, F.L. 1930g. Why some wood surfaces hold paint longer than others. Leaflet 62. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Hunt, G.M. 1930. Effectiveness of moisture-excluding coatings on wood. Circ. 138. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 28 p.

Summarizes 15 years of Forest Products Laboratory tests on the moisture proofing of wood by coatings and impregnation techniques.

1931

Browne, F.L. 1931a. Adhesion in the painting and in the gluing of wood. *Industrial and Engineering Chemistry*. 23(3): 290-294.

Indicates that knowledge about adhesion between woodworking glues and wood should prove helpful in the quest for permanent adhesion between paint coatings and wood, specifically in regard to adherence of paint to latewood of softwoods.

Browne, F.L. 1931b. Developments in the stabilization of painting practice for wood. *Transactions of the American Society of Mechanical Engineering; 5th National Wood Industries Meeting*: 1-5.

Describes early paint research at the Forest Products Laboratory and points the way for a possible stabilization of painting practice for wood through further research.

Browne, F.L. 1931c. Paint thinners—Part I. Effect of different paint thinners on the durability of house paints in outdoor exposure tests. *Industrial and Engineering Chemistry*. 23(8): 868-874.

Paint thinned with a deliberately oxidized turpentine, which left a considerable residue on evaporation, was more durable than paint

thinned with ordinary turpentine or with petroleum or coal-tar distillates.

Browne, F.L. 1931d. Why some wood surfaces hold paint longer than others. *Building in Canada*. 12(5): 20-21,34.

Describes how painting characteristics depend on wood texture and density, how to select wood based on its paintability, and how to use lumber to best advantage throughout a building.

Browne, F.L.; Hrubesky, C.E. 1931. Effect of resin in longleaf pine on the durability of housepaints. *Industrial and Engineering Chemistry*. 23(8): 874-877.

Shows that density and width of annual growth rings, rather than resin content, affect the durability of coatings.

Salzberg, H.K.; Browne, F.L.; Odell, I.H. 1931. Results of accelerated weathering tests of white house paints reduced with different types of thinners. Part 2. *Industrial and Engineering Chemistry*. 23(11): 1214-1230.

1932

Browne, F.L. 1932. Farm buildings should be repainted before wood weathering begins. In: U.S. Department of Agriculture, *Agriculture Yearbook*: 196-197.

A guide to identifying when a paint system has lost its effectiveness and why prompt repainting is important.

1933

Browne, F.L. 1933a. Effectiveness of paints in retarding moisture absorption by wood. *Industrial and Engineering Chemistry*. 25(8): 835-842.

Study measured moisture vapor absorption of wood and compared effectiveness of various primers, paints, and painting techniques.

Browne, F.L. 1933b. Durability of paint on longleaf and shortleaf pine. *Southern Lumberman*. 146(1844): 20-22.

Variation between different boards of longleaf

and shortleaf pine had greater practical influence on paint durability than average values for the two species.

Browne, F.L. 1933c. Comments on wood finishing papers by M.J. Pearce and by R.H. McCarthy and L.A. Lefcort. In: *American Society of Mechanical Engineering Transactions: Wood Industries Division*.

Advises the industry to continue to emphasize on durable finishes as faster production schedules are developed.

Browne, F.L. 1933d. Priming-coat reductions for painting new wood surfaces. *American Paint Journal*. 18(4): 19-20, 44-45.

The third progress report on proportion of pigment, linseed oil, and turpentine on primer performance, optimum reduction of primer, and need of different wood species for different primer reductions.

Browne, F.L. 1933e. The degree of protection afforded wood against moisture by paint coatings. *Paint, Oil, Chemistry Review*. 95(18): 9-12.

Provides both liquid water and water vapor exclusion effectiveness ratings for various types of paint coatings.

Browne, F.L. 1933f. Testing house paints for durability. Rep. R1011. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Browne, F.L. 1933g. Testing house paints for durability. *Journal of Chemistry Education*. 10(9): 529-538.

Outlines some variables in paint testing and describes a technique for conducting and recording durability tests.

1934

Browne, F.L. 1934a. Durability of paint on wood treated with zinc chloride. *American Wood Preservers' Society Proceedings*; 30: 410-430.

Zinc chloride used as wood treatment prior to

painting with various paints and primers.

Browne, F.L. 1934b. Aluminum priming paint. *Industrial and Engineering Chemistry*. 26(4): 363-376.

Aluminum primers protected against changes in moisture content and improved durability of succeeding coats of conventional house paints.

Browne, F.L. 1934c. Effect of change from linoxyn gel to xerogel on the behavior of paint. *National Symposium on Colloid Chemistry; Colloid Symposium Monologue*. 11: 211-222.

Applies colloid chemical concepts to the characteristics of aging house paints. Emphasizes that checking, cracking, and flaking occur when linoxyn gel reaches the xerogel condition.

Browne, F.L. 1934d. Painting characteristics of hardwoods. *Industrial and Engineering Chemistry*. 27(1): 42-47.

Concludes that specific gravity of the wood and size of pores are the most important properties of hardwoods that affect painting. Compares the behavior of paint on hardwoods with large pores, hardwoods with small pores, and softwoods.

Browne, F.L. 1934e. Painting exterior woodwork. *Pacific Purchaser*. 16(2): 18-19.

Outlines the steps to a successful paint job, addresses the causes of early paint failure (moisture accumulation, paint incompatibility, and bad painting practice), emphasizes the value of aluminum primers for wide bands of latewood, and stresses the need for careful maintenance.

Browne, F.L. 1934f. Priming-coat reductions for painted new wood surfaces. *American Paint Journal*. 19(9): 7-9, 48, 50-51.

Fourth progress report on determining what is the optimum priming coat reduction for applying house paints to softwoods and whether the priming coat should be reduced according to the nature of the softwood.

1935

Browne, F.L. 1935a. How many coats of paint? *Railway Engineering and Maintenance*. 31(4): 241-242.

Letter to the Editor addressing the differences between two-coat and three-coat systems for initial painting.

Browne, F.L. 1935b. Moisture in side wall causes trouble. *National Painters Magazine*. 2(12): 15.

Browne, F.L. 1935c. Effect of extractive substances in certain woods on the durability of paint coatings. Rep. R1073. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Compares eastern hemlock specimens treated with different water- and alcohol-soluble extractives (redwood, cypress, and ponderosa pine) prior to painting and exposed to the weather in various parts of the United States. The physical structure of the wood affected the durability of the paint coatings more than the nature of the extractive, but specimens did acquire some painting characteristics of the wood from which the extractive was taken.

Browne, F.L. 1935d. Exposure test on repainting wood surfaces. *American Paint Journal*. 19(53A): 8, 21.

Summarizes a previous study on the effect of priming coat reductions on performance of painted wood surfaces; describes behavior of new paint coats on repainted specimens.

Browne, F.L. 1935e. Repainting paint-neglected frame houses. Part 1. *National Painters Magazine*. 2(4): 15-17; 2(5): 14-16; 2(6): 6-9.

A guide for professional painters. Outlines the steps for ensuring a satisfactory paint job, including determining the cause of failure in the previous paint system.

Browne, F.L. 1935f. Special priming paints for wood. *Industrial and Engineering Chemistry*. 27(3): 292-298.

In outdoor exposure tests, special primers

containing "leafing" pigments (aluminum powder or flake graphite) in long-oil spar varnish improved paint performance on bands of latewood in southern pine and Douglas-fir.

Browne, F.L. 1935g. A trouble-shooter's view of the gamble in house paint. *Paint, Oil, and Chemistry Review*. 97(21): 28, 30, 32.

Browne, F.L. 1935h. What paint salesmen can do to prevent paint complaints. *Drugs, Oils and Paints*. 50(11): 472-474.

Addresses the causes of early paint failure—moisture accumulation, paint incompatibility, and bad painting practice—and emphasizes the value of aluminum primers for wide bands of latewood and the need for careful maintenance.

1936

Browne, F.L. 1936a. Durability of paint on wood: Effect of extractive substances in certain woods. *Industrial and Engineering Chemistry*. 28(4): 416-418.

Paint durability was more affected by the physical structure of the wood than by extractives. Different extractives (redwood, southern cypress, and ponderosa pine) affected durability either favorably or unfavorably.

Browne, F.L. 1936b. Paints as protective coatings for wood: Variation in effectiveness with length of exposure to the weather. *Industrial and Engineering Chemistry, Industrial Edition*. 28(7): 798-809.

Moisture-excluding effectiveness after 3 years' exposure of test specimens of southern yellow pine, Douglas-fir, northern white pine, and redwood coated with various finishes.

Browne, F.L. 1936c. A kind word for brush marks. *Canadian Paint and Varnish Magazine*. 10(11): 6-7,9.

Response to claims that new enamelized house paints leave no brush marks and are therefore superior to true (lead) house paints. Compares durability, spread rate, and hiding properties of each type of paint.

Browne, F.L. 1936d. Case of hail stone damage to paint. *Paint, Oil, and Chemistry Review*. 98(21):36, 38.

Browne, F.L. 1936e. How painters can prevent painting complaints. Part I: Examining condition of the old paint. *National Painters Magazine*. 3(3): 10-12.

First of a series of articles directed to painters; explains how to recognize the characteristic normal behavior of different paints on the market.

Browne, F.L. 1936f. How painters can prevent painting complaints. Part II: Keeping a written record of paint jobs. *National Painters Magazine*. 3(4): 10-12.

Stresses the importance of keeping records of observations of the old surface to be repainted, extent of preparation, and type of paint used.

Browne, F.L. 1936g. How painters can prevent painting complaints. Part III: Judging the nature of previous paints by inspection. *National Painters Magazine*. 3(5): 18-20.

Browne, F.L. 1936h. How painters can prevent painting complaints. Part IV: Judging the nature of previous paints by inspection. *National Painters Magazine*. 3(6): 16-18, 33.

1937

Browne, F.L. 1937a. House paint problem: Let's stop passing the buck and attack it cooperatively. *Paint, Oil, and Chemistry Review*. 99(4): 9-12.

Browne, F.L. 1937b. Buy house paint for a planned maintenance program. *Pacific Purchasor*. 19(2): 15-16,28.

Describes various maintenance programs specific to type and color of paint as well as kind of building (industrial or residential). Includes arguments in favor of a paint classification system to ensure that the right type of paint is used for a particular purpose.

Browne, F.L. 1937c. The fading of painted surfaces. *Railway Engineering Maintenance*. (Sept.).

Describes the aging process of painted wood surfaces, with recommendations for scheduled repainting.

Browne, F.L. 1937d. Have you a paint maintenance program? *American Home*. 17(5): 41-42, 102, 104, 106.

Outlines a systematic program of maintenance regarding the frequency of repainting, type of paint, and number of coats. Emphasizes the need to prevent excessive moisture accumulation in wood siding.

Browne, F.L. 1937e. Some facts about house paint complaints: A friendly understanding between lumber and paint industries needed. *Southern Lumberman*. 154(1942): 35-37,40.

Points out that cooperation between lumber and paint industries is necessary to discern actual causes of paint failures associated with wood products.

Browne, F.L. 1937f. Proposed system of classification for house paints. *Industrial and Engineering Chemistry*. 29(9): 1018-1026.

1938

Browne, F.L. 1938a. Classification of house paints as a guide to the study of formulation. *Drugs, Oils, and Paints*. 53: 92-95.

Presents the concepts of formulation underlying the proposed system of paint classification.

Browne, F.L. 1938b. Effect of climatic differences on the behavior of house paints. *Pacific Purchaser*. 20(2): 13-14, 28.

Recognizing the dominant climatic factors of sunshine and moisture, study emphasizes that greater concern should be directed toward correctly planned maintenance programs, correct type of paint, and proper application procedures.

Browne, F.L. 1938c. What can be done to make paint maintenance more successful. *Paint, Oil and Chemistry Review*. 100(8): 9-11, 31-35.

Explains the system of lumber classification in relation to painting characteristics, methods to reduce moisture-caused paint failures, proper paint application procedures, paint maintenance programs, and the need for a paint classification system.

Browne, F.L. 1938d. Why a system for classifying house paints is necessary. *Canadian Paint and Varnish Magazine*. 12(4): 16, 18-19.

Describes a classification for exterior paints that emphasizes "the mutual interest of the manufacturer, painter, and owner in defining more closely the conditions for successful use of each kind of paint."

1939

Browne, F.L. 1939a. Casein in milk and its isolation. In: Sutermeister, Edwin and Browne, F.L. *Casein and Its Industrial Applications*. 2d ed. New York: Reinhold Publishing Corp.

Describes the separation and coagulation of casein by various methods; includes concepts of colloid chemistry and an extensive reference list.

Browne, F.L. 1939b. Casein paints. In: Sutermeister, Edwin and Browne, F.L. *Casein and Its Industrial Applications*. 2d ed. New York: Reinhold Publishing Corp.

Includes general principles of paint formulation, describes types of casein paints and the materials used to make them, and identifies the basic manufacturing processes for casein paints.

Browne, F.L. 1939c. Physical chemistry of casein. In: Sutermeister, Edwin and Browne, F.L. *Casein and Its Industrial Applications*. 2d ed. New York: Reinhold Publishing Corp.

Explains the heterogeneity of casein and describes its solubility, electrolytic and optical properties, viscosity, and colloidal behavior.

Browne, F.L. 1939d. Painting your house. *American Forests*. 45(5): 261-263.

Choice of paints as well as application and maintenance recommendations for the homeowner.

Browne, F.L. 1939e. Some causes of blistering and peeling of paint on house siding. *Real Estate Journal*. 40(11): 42.

Summarizes Browne's 1927 article of the same title.

Browne, F.L. 1939f. Modern exterior paints. *Buildings and Building Management*. 39(6): 33-34, 69-71.

Describes alternatives to painting, types of paints, and application and maintenance recommendations.

1940

Browne, F.L. 1940. Aluminum paint—moisture armor. *Ohio Farm Bureau News*. 19(11): 22.

Recommends the use of aluminum paint on interior walls and ceilings as a vapor retarder to prevent exterior paint problems.

1941

Browne, F.L. 1941a. The two-coat system of house painting. *Industrial and Engineering Chemistry*. 33(7): 900-910.

Describes the special primers and thick topcoat paints required to give satisfactory results and how they differ from the more common paints that require two topcoats over a primer.

Browne, F.L. 1941b. Right paint for your job. *Successful Farming*. 39(5): 12-13, 30.

1942

Browne, F.L. 1942a. Painting characteristics of hardwoods. *National Painters Magazine*. 9(8): 24.

Classifies hardwoods by suitability for painting. Outlines painting requirements for each group and discusses special considerations for certain species.

Browne, F.L. 1942b. Classification of house and barn paints. *Tech. Bull.* 804. Washington, DC: U.S. Department of Agriculture, Superintendent of Documents.

Describes the procedure for classifying paints by group, type, and grade, with a view toward obtaining more lasting and satisfactory service of paints on wood.

1944

Browne, F.L.; Schwebs, A.C. 1944. A study of methods of measuring the water repellency of water repellents and water-repellent preservatives for wood. Rep. R1453. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Compares methods for evaluating performance of water repellents and water-repellent preservatives.

1945

Browne, F.L.; Downs, L.E. 1945. A survey of the properties of commercial water repellents and related products. Rep. R1495. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Surveys 55 commercial products to determine their character and range of effectiveness; describes some sealers to distinguish between sealers and water repellents.

1947

Browne, F.L. 1947a. Paintability of various woods: Several factors govern. *Railway Engineering and Maintenance*. 43: 885-886.

Browne, F.L. 1947b. Wood properties and paint durability. Misc. Pub. 629. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Describes some wood properties that affect paint service, selection of favorable woods and boards for painting, and painting procedures for less favorable woods.

1948

Browne, F.L. 1948a. Wood properties that affect paint durability. Rep. 1053. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 23 p.

Comprehensive discussion of wood properties as they affect paint performance.

Browne, F.L. 1948b. Painting the barn. *Hoard's Dairyman*. 93: 517, 527.

Downs, L.E. 1948. Bleaching woods. *Wood Working Digest*. 50(6): 69-72.

Reviews techniques for bleaching wood based on material supplied by makers and users of wood bleaches.

1949

Browne, F.L. 1949a. Painting the farm and city home. In: *Trees, The Yearbook of Agriculture*: U.S. Department of Agriculture: 625-630.

Outlines steps for a planned painting program, types of paints available, and the classification of woods by relative ability to hold paint coatings.

Browne, F.L. 1949b. House paint and outdoor furniture. *Wood Working Digest*. 51(4): 111-112, 116, 122-124.

Describes the system of classifying house paints as presented in U.S. Department of Agriculture Tech. Bull. 804; (1942).

Browne, F.L. 1949c. Water-repellent preservatives for wood. *Architectural Record*. 105(3): 131-132, 174.

Reviews commercial products, treatment methods, and general considerations.

Browne, F.L.; Rietz, R.C. 1949. Exudation of pitch and oils in wood. Rep. 1735. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Recommendations for lumber producers and users of species prone to resin exudation.

U.S. Department of Agriculture, Forest Products Laboratory. 1949. Condensation control in dwelling construction. Washington, DC: Housing and Home Finance Agency.

Recommended methods for condensation control by the use of vapor barriers and ventilation in existing and new construction.

1950

Browne, F.L. 1950. Uses for water-repellent preservatives. *Railroad Engineering and Maintenance*. 46(12): 1140-1141.

1951

Browne, F.L. 1951. Wood properties that affect paint performance. Rep. R1053. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Revision of previous report published in 1948.

1952

Browne, F.L. 1952a. Natural finishes for exterior wood. *Forest Products Research Society Journal*. 2(2): 11-16.

Describes the types of natural finishes available and how to select, apply, and maintain a natural finish.

Browne, F.L. 1952b. Wood siding left to weather naturally. *Architectural Record*. (Nov.): 197-199.

Describes weathering process; indicates that wood siding may be allowed to weather naturally providing that the kind of wood is carefully selected and recommendations for installation and maintenance are followed.

Browne, F.L.; Laughnan, D.F. 1952a. Paint performance on forest products: Modification of wood and plywood to improve paintability. *Forest Products Research Society Journal*. 2(3): 3-24.

Summarizes research on dimensionally stabilized wood, paper, and other coverings, and mechanical treatment of wood surfaces.

Browne, F.L.; Laughnan, D.F. 1952b. How often should a house be painted: An experimental

study of programs of paint maintenance. Forest Products Research Society Journal. 2(5): 173-193.

Recommends a maximum of two coats every 6 years to minimize the expense of removing old paint.

U.S. Department of Agriculture, Forest Service. Forest Products Laboratory. 1952. Uneven coatings on wood cause warping. Tech. Note D-12. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Recommends the application of coatings of nearly equal moisture resistance to all surfaces of wood products to minimize warping.

1953

Browne, F.L. 1953. Swelling of paint films in water. Part I: The absorption of water, swelling and solubility of free films of paint. Forest Products Research Society Journal. 3(5): 108-125, 226.

Tests substantiating that free films of house paints soaked in distilled water absorb surprisingly large amounts of water.

Browne, F.L.; Laughnan, D.F. 1953. Effect of coating thickness on the performance of house paints under different programs of maintenance. Official Digest, Federation of Paint Varnish Production Clubs. 338: 137-159 (Mar.).

1954

Browne, F.L. 1954a. Clear finishes for exteriors of houses. American Paint Journal. 38(36): 88-90, 92, 94-96, 98, 100.

Browne, F.L. 1954b. Swelling of paint films in water. Part II: Absorption and volumetric swelling of bound and free films before and after weathering. Forest Products Research Society Journal. 4(6): 391-400.

Previous methods of studying swelling of paint films in water were improved by including measurements of volumetric swellings of both free films and bound films (coatings on glass). The new technique leads to more precise

measurements and discloses information about the structure of paint coatings.

Laughnan, D.F. 1954. Natural wood finishes for exteriors of houses. Forest Products Research Society Journal. 4(5): 343-345.

Recommends that both penetrating and intrasurface natural finishes be carefully selected, applied, and maintained for satisfactory performance.

Scheffer, T.C.; Browne, F.L. 1954. Tests of some superficial treatments of exposed wood surfaces for their protection against fungus attack. Forest Products Research Society Journal. 4(3): 131-132.

Describes tests for determining the effectiveness of preservatives, sealers, water repellents, and combinations of these, in protecting exposed wood surfaces against fungal attack.

1955

Browne, F.L. 1955a. Swelling of paint films in water. Part III: Absorption and volumetric swelling of bound and free films from air of different relative humidities. Forest Products Research Society Journal. 5(1): 92-96.

Shows that both free and bound films (coatings on glass) absorb moisture from damp air and swell.

Browne, F.L. 1955b. Swelling of paint films in water. Part IV: Effect of thickness of film and pigment volume of paint. Forest Products Research Society Journal. 5(2): 142-146.

Presents systematic data on how absorption of water, swelling, and solubility of free films in water vary with the thickness of films. Discusses how pigment volume affects absorption and swelling.

Browne, F.L. 1955c. Swelling of paint films in water. Part V: Effects of different pigments. Forest Products Research Society Journal. 5(3): 192-200.

Describes measurements of absorption, swelling, and related data for free films of

single-pigment paints tested by soaking in distilled water before and after artificial weathering.

Teesdale, L.V. 1955. Condensation problems in modern buildings. Rep. R1196. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Revision of recommended construction practices from report published in 1949.

U.S. Forest Products Laboratory. 1955. Painting and finishing wood. In: Wood Handbook: Wood as an engineering material. Agric. Handb. Chapter 16. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

State of the art in the characteristics and proper application of finishes for wood.

1956

Browne, F.L. 1956a. Swelling of paint films in water. Part VI: Effects of different oil or oleoresinous vehicles. Forest Products Research Society Journal. 6(4): 152-159.

Discusses the effect of four oil or varnish vehicles on the behavior of free films of paints soaked in distilled water and redried. Measurements included changes of density, absorption of water, swelling during absorption, shrinkage on redrying, loss in weight while soaking, and loss in weight while weathering.

Browne, F.L. 1956b. Swelling of paint films in water. Part VII: Latex vehicles. Forest Products Research Society Journal. 6(6): 235-240.

Discusses the effect of four water emulsion vehicles on the behavior of free films of paints subjected to different amounts of soaking and redrying and/or weathering.

Browne, F.L. 1956c. Swelling of paint films in water. Part VIII: Swelling of linseed oil paints in water and organic liquids. Forest Products Research Society Journal. 6(8): 312-318.

Compares the swelling effect of water and five organic liquids on films of un-bodied linseed oil

and five linseed oil paints. All the oil and paint films absorbed, swelled, and lost soluble ingredients in the organic liquids much as they did in water. The order of increasing swelling power was nearly the same for all films, both before and after artificial weathering.

Browne, F.L. 1956d. Swelling of paint films in water. Part IX: Effects of temperature during soaking and film formation, and repeated soaking and drying. Forest Products Research Society Journal. 6(10): 453-458.

Free films of most linseed oil paints, both artificially weathered and unweathered, absorbed more water, swelled more, and lost more soluble material with an increase in the temperature of the soaking water. Higher temperatures during formation of films reduced water absorption and swelling of unweathered films.

Kurtenacker, R.S.; Scheffer, T.C.; Blew, J.O. 1956. Condition of preservative treated field boxes after 5 years' outdoor exposure. Rep. 2054. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Effectiveness of water repellents against moisture adsorption and mechanical damage caused by repeated dimensional change.

Laughnan, D.F. 1956a. Paints for exterior wood surfaces. Rep. 2069. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

General discussion of exterior finishes, wood paintability, and related construction and maintenance considerations.

Laughnan, D.F. 1956b. Red iron oxide barn paint. Agricultural Engineering. 37(3): 188-189.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1956a. Spray versus brush painting for houses and farm buildings. TP-56. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Explains the steps required for satisfactory spray application of paints.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1956b. Weathering and decay. Tech. Note 221. Madison, WI:
U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Describes mechanisms associated with weathering and decay and recommends protective measures.

1957

Browne, F.L. 1957a. Swelling of paint films in water. Part X: Rate of penetration of water, permeability to water vapor, and penetrability to air in relation to water absorption. *Forest Products Journal*. 7(4): 145-154.

Measurement of the permeability of paint films to water and water vapor.

Browne, F.L. 1957b. Swelling of paint films in water. Part XI: Mixed-pigment paints in linseed oil. *Forest Products Journal*. 7(7): 248-252.

The relation between swelling and paint composition (basic carbonate white lead, zinc oxide, and rutile titanium dioxide extended with magnesium silicate). Also reports studies with antimony oxide as a low-swelling pigment and describes paints with various proportions of bodied and unbodied linseed oil.

Browne, F.L. 1957c. Swelling of springwood and summerwood in softwoods. *Forest Products Journal*. 7(11): 416-424.

Describes shrinking and swelling characteristics of softwoods related to paint film adhesion.

Browne, F.L.; Simonson, H.C. 1957. The penetration of light into wood. *Forest Products Journal*. 7(10): 308-314.

Describes four methods used to measure penetration of light into wood. Ultraviolet light has little penetration; visible and infrared light penetrate roughly in accordance with Beer's

law. Extinction coefficients seem to run parallel to amount of color in wood.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1957. Forest Products Laboratory natural finish. Rep. 2096. Madison, WI:
U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Describes a simple and durable exterior finish developed at FPL, which is classified as a semitransparent oil-based penetrating stain. Includes directions for preparation and recommendations for application to both smooth and rough wood surfaces.

1958

Browne, F.L. 1958a. Preservative treatment of window sash and other millwork. Rep. 919. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Describes various types of preservative treatments and methods of application.

Browne, F.L. 1958b. The two-coat system of house painting. Rep. 1259. Madison, WI:
U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Revision of paper first published in 1941.

Laughnan, D.F. 1958a. Paint peeling, causes and cures. TP-70. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Addresses common causes of paint peeling, with emphasis on moisture-induced paint failures.

Laughnan, D.F. 1958b. Paints for the exteriors of houses. PF, *The Magazine of Prefabrication*. 6(3): 36-39.

Defines weathering and decay, describes the three basic types of finishes, and identifies the common causes of paint failure.

Streng, F.A. 1958. What's new in wood finishes? National Association of Home Builders (NAHB); *Journal of Homebuilding*. 12(5): 41-42.

Recommends painting practice and maintenance programs and describes the FPL Natural Finish.

1959

Browne, F.L. 1959a. Moisture content of wood as related to finishing of furniture. Rep. 1722. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Maximum allowable moisture contents for wood for applying various types of finishes. Also describes the effect of finish on moisture content of the furniture after it leaves the factory.

Browne, F.L. 1959b. Understanding the mechanisms of deterioration of house paint. *Forest Products Journal*. 9(11): 417-427.

Water, especially in conjunction with ultraviolet light, accelerates chemical deterioration. The products of the decomposition cause normal and abnormal failure. Shrinking and swelling caused by water also stress and disrupt paint films.

Browne, F.L.; Rietz, R.C. 1959. Exudation of pitch and oils in wood. Rep. 1735. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Lists typical wood species that exude or bleed pitch. Describes basic finishing problems and recommends kiln-drying procedures to prevent exudation.

Laughnan, D.F. 1959. Effects of wood on durability of finishes. *Forest Products Journal*. 9(2): 19A-21A.

Describes the factors that affect the serviceability of finishes and categorizes wood species according to finishing properties.

Teesdale, L.V. 1959. Water-repellent preservatives reduce rain-caused paint blistering on wood siding. Rep. 1990. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Entry of rainwater can be minimized or eliminated by improved machining of siding and by applying water repellents.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1959. Coatings that prevent end checks. Tech. Note 186. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Hot- and cold-application coatings for use in air drying and kiln drying of lumber.

1960

Browne, F.L. 1960. The preservative treatment and staining of shingles. Rep. 761. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Recommended species, finishes, and finish application methods for shingles and shakes, including treatments for shingles of less desirable woods. Revision of report first published in 1930.

Browne, F.L.; Downs, L.E. 1960. A survey of the properties of commercial water repellents and related products. Rep. 1495. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Reviewed and reaffirmed edition of the original 1945 publication of the same title.

Browne, F.L.; Laughnan, D.F. 1960. A new device for studying blister resistance of house paints. *Forest Products Journal*. 10(3): 141-145.

Describes a box that simulates cold-weather condensation and rain penetration in house siding.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1960. Coatings for minimizing changes in the moisture content of wood. Tech. Note 181. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Test results of the moisture-excluding effectiveness of various interior and exterior wood finishes.

1961

Browne, F.L. 1961a. Floor finishing. Agric. Handb. 204. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Recommendations for finishing and maintaining common floor finishes.

Browne, F.L. 1961b. An attempt to hasten test fence studies of paint failures caused by too-frequent repainting. Rep. 2203. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

This accelerated technique for studying the effects of excessive coating thickness can disclose a maximum coating thickness beyond which paint performance becomes abnormal, but it may not disclose the detailed patterns in which the abnormalities will appear in practice.

Miniutti, V.P.; Mraz, E.A.; Black, J.M. 1961. Measuring the effectiveness of water-repellent preservatives. Forest Products Journal. 11(10): 453-462.

Compares several laboratory methods of measuring water repellency in weathering tests.

Tarkow, H.; Ishaq, S.M. 1961. Effectiveness of stabilized surface layers of wood as moisture barriers. Forest Products Journal. 11(4): 203-204.

Chemical stabilization of the surface layers of wood produced an inefficient moisture barrier. Stabilization eliminated bound-water diffusion, but had little effect on vapor diffusion.

1962

Browne, F.L. 1962. Wood properties and paint durability. Misc. Publ. 629. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Revision of publication issued in 1947. Describes wood properties that affect life of paint and gives advice on selecting the best woods for painting and suggestions for painting the less favorable woods.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1962a. Applying a polyurethane resin finish to wood stabilized with a polyethylene glycol treatment. Wood Finishing Leaflet. 24, TP-124-24. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Application instructions for the only compatible finish for wood treated with PEG-100.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1962b. Crawling of exterior paints for wood. Wood Finishing Leaflet. 14, TP-124-14. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Explains why crawling occurs and how to avoid it.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1962c. Excessive dirt collection. Wood Finishing Leaflet. 9, TP-124-9. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Describes the reasons for dirt collection, types of paint most susceptible, and recommendations for correcting and avoiding the problem.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1962d. Glossy-back blistering of oil-base house paints. Wood Finishing Leaflet. 4, TP-124-4. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Distinguishes the glossy-back blistering from temperature and moisture blisters; recommends removing all paint and repainting.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1962e. Slow drying of oil-base house paint. Wood Finishing Leaflet. 13, TP-124-13. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Describes the factors that can inhibit drying of paint and recommendations for controlling the problem.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1962f. The wrinkling of oil-base house paints. Wood Finishing Leaflet. 15, TP-124-15. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Describes the factors that can cause wrinkling of paint and recommendations for controlling the problem.

1963

Anderson, L.O. 1963. Water repellents improve performance of drop siding. Res. Pap. FPL 4. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Data from 5 years' exposure demonstrated that water repellents will prevent rainwater entry to the backface of drop siding and that paint retention was noticeably improved on flat-grain siding of treated panels in certain species.

Duncan, C.G. 1963. Role of micro-organisms in weathering of wood and degradation of exterior finishes. Official Digest. 35(465): 1003-1012.

Microscopic investigations indicated that micro-organisms have a potential for deteriorating wood surfaces, thus contributing to the degradation of wood finishes.

Fleischer, H.O.; Black, J.M. 1963. Performance of paint on southern pine and overlaid southern pine. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. May 29.

The surface quality and type of paint are major factors in finish performance on southern pine surfaces. Paints performed better on surfaces stabilized by resin-treated paper overlays than on surfaces that were not overlaid.

Miniutti, V.P. 1963. Properties of softwoods that affect the performance of exterior paints. Official Digest, Journal of Paint Technology and Engineering. 35(460): 451-471.

Includes the effect of change in dimension of wood with change in moisture content.

Scheffer, T.C.; Verrall, A.F.; Harvey, G. 1963. On-site preservative treatments: Their effectiveness for exterior millwork of different species used in various climates. Forest Products Journal. 13(1): 7-13.

Data from 7-year-exposure tests in Oregon, Mississippi, and Wisconsin, showed that water repellents augmented the protection given by preservative dip-treatments.

1964

Black, J.M. 1964. Some problems encountered in painting wood. American Paint Journal. 48(55): 9-11.

Miniutti, V.P. 1964. Microscale changes in cell structure of softwood surfaces during weathering. Forest Products Journal. 14(12): 571-576.

Weathering checks found under paint in individual cell walls in latewood explain why paint flakes from tangential surfaces of summerwood before flaking from tangential surfaces of earlywood.

1965

Barquest, G.; Black, J.M. 1965. Penetrating stain for rough and weathered wood [Pamphlet]. Madison, WI: University of Wisconsin-Extension.

Includes four formulations for a red iron oxide, linseed oil base penetrating stain, including application instructions.

Miniutti, V.P. 1965. Painting the outside. In: Yearbook of Agriculture. Washington, DC: Government Printing Office: 25-30.

Informational guide on exterior finishes for the homeowner.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1965. Spray versus brush painting for wood structures. Wood Finishing Leaflet. 18, 65-008 (Formerly TP-56). Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Lists the advantages and disadvantages of each type of application from the perspective of the homeowner.

1966

Barquest, G.D.; Black, J.M. 1966. Steps before painting. *Hoard's Dairyman*. 111(13): 804.

Black, J.M. 1966. Your best paint buys. *Hoard's Dairyman*. 111(12): 755.

Kalnins, M.A. 1966. Photochemical degradation of wood. Part II. Surface characteristics of wood as they affect durability of finishes. Res. Pap. FPL 57. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Kalnins, M.A.; Steelink, C.; Tarkow, H. 1966. Light-induced free radicals in wood. Res. Pap. FPL 58. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Wood specimens were examined by ESR spectroscopy before and after exposure to light, and evidence of light-induced free radicals was obtained. Some indication of their stability in various atmospheres was also observed.

Miniutti, V.P. 1966. Application of reflected light and fluorescence microscopy in studies of the degradation of uncoated and coated wood surfaces. *The Microscope*. 15(3): 367-379.

Describes techniques that allow progressive observations of finished and unfinished wood during artificial weathering and simulated cold-weather condensation.

Tarkow, H.; Southerland, C.F.; Seborg, R.M. 1966. Surface stabilization. Part I. Surface characteristics of wood as they affect durability of finishes. Res. Pap. FPL 57. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Evaluates surface stabilization of wood as a method for improving the durability of clear finishes exposed to severe weathering conditions.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1966a. Wood

finishing: Cross-grain cracking of oil-base house paints. Res. Note FPL-0129. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1966b. Wood finishing: Discoloration of house paint by blue stain. Res. Note FPL-0131. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1966c. Wood finishing: Discoloration of house paints by water-soluble extractives in western redcedar and redwood. Res. Note FPL-0132. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Explains the mechanisms that cause extractive discoloration and ways to prevent and remove discoloration.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1966d. Wood finishing: Finishing exterior plywood. Res. Note FPL-0133. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Describes the common types of exterior plywood products and three types of exterior finishes.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1966e. Wood finishing: Intercoat peeling of house paints. Res. Note FPL-0128. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Explains the causes of peeling and ways to prevent or cure this condition.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1966f. Wood finishing: Temperature blistering of house paints. Res. Note FPL-0126. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Explains the causes of temperature blistering and ways to avoid or correct this problem.

1967

Miniutti, V.P. 1967a. Microscale effects of ultraviolet irradiation and weathering on redwood surfaces and clear coatings. *Journal of Paint Technology*. 4(531): 275-284.

Compares the microscopic surface changes of specimens subjected to in-laboratory ultraviolet irradiation and natural weathering.

Miniutti, V.P. 1967b. Microscopic observations of ultraviolet irradiated and weathered softwood surfaces and clear coatings. Res. Pap. FPL 74. Madison, WI: U.S. Department of Agriculture, Forest Service. Forest Products Laboratory.

Indicates the need for treatments that dimensionally stabilize exterior wood surfaces and minimize their photodegradation, and the need to modify clear finishes for greater durability.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1967. Bleaching wood. Res. Note FPL-0165. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

General information from published material and wood bleach manufacturers on commonly used wood bleaches, methods of application, and precautions to be taken during the bleaching process.

1968

Panek, E. 1968. Study of paintability and cleanliness of wood pressure treated with water-repellent preservative. In: *Proceedings of American Wood Preserver's Society*; 64: 178-188.

Describes outdoor exposure tests of southern pine and Douglas-fir specimens that had been painted after pressure treating and conditioning.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1968. Wood finishing: Water repellents and water-repellent

preservatives. Res. Note FPL-0124. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Describes typical formulations, mechanisms of action, application instructions, and use as an exterior natural finish.

1969

Verrall, A.F.; Scheffer, T.C. 1969. Preservative treatments for protecting wood boxes. Res. Pap. FPL-106. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Three-minute dip treatments in various wood preservatives with and without a water repellent were effective in keeping weather-exposed wood boxes in good condition for more than 10 years in both southern and northern climates.

1970

Miniutti, V.P. 1970. Reflected-light and scanning electron microscopy of ultraviolet irradiated redwood surfaces. *Microscope*. 1(8): 61-72.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1970. Wood finishing: Blistering, peeling, and cracking of house paints from moisture. Res. Note FPL-0125. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Advice for homeowners for diagnosing and correcting problems.

1971

Scheffer, T.C.; Verrall, A.F.; Harvey, G. 1971. Fifteen-year appraisal of dip treating for protecting exterior woodwork: Effectiveness on different wood species in various climates. *Material und Organismen*. 6(1): 27-44.

Final assessment of study first reported by these authors in 1963.

1972

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1972. Wood finishing: Painting outside wood surfaces. Res. Note FPL-0123. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Outlines procedures to follow when painting or repainting a house.

1973

Barquest, G.; Black, J.M.; Stith, D. 1973a. Siding and finishes for original construction or replacement. Fact Sheet A2486. Madison, WI: University of Wisconsin.

Lists various wood, metal, and vinyl siding products with finishing systems in regard to comparative suitability, estimated life, and cost of most readily available materials.

Barquest, G.D.; Black, J.M.; Stith, D. 1973b. When paint peels severely from wood. Fact Sheet A2485. Madison, WI: Cooperative Extension Programs, University of Wisconsin.

Black, J.M. 1973. Wood Finishing: Experimental chromate finish. Res. Note FPL-0134. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Describes the effectiveness of a natural finish of various chromate salts for inhibiting surface weathering and mildew.

Miniutti, V.P. 1973. Contraction in softwood surfaces during ultraviolet irradiation and weathering. *Journal of Paint Technology*. 45(577): 27-34.

Microscopic void enlargement during ultraviolet irradiation resulted from cell wall contraction rather than degradation of void edges.

1974

Barquest, G.; Black, J.M.; Feist, W.C. 1974. Painting cement asbestos siding. Fact Sheet A2583. Madison, WI: University of Wisconsin-Extension.

Outlines surface preparation and painting methods and recommends types of paint.

Black, J.M.; Mraz, E.A. 1974. Inorganic surface treatments for weather-resistant natural finishes. Res. Pap. FPL 232. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Brush application of aqueous inorganic solutions prior to applying natural-type finishes improved the performance of all finishes tested.

U.S. Forest Products Laboratory. 1974. Painting and finishing wood. In: *Wood Handbook: Wood as an engineering material*. Agric. Handb. 72 rev. Washington, DC: U.S. Department of Agriculture, Forest Service.

State of the art in the characteristics and proper application of finishes for wood.

1975

Black, J.M. 1975. Wood finishing. In: *Wood Structures, A Design Guide and Commentary*. American Society of Civil Engineers, Structural Division: 41 1-416.

Describes types of and application recommendations for exterior finishes; includes a table on suitability and expected service life for finishes on various kinds of wood and wood-based materials.

Black, J.M.; Laughnan, D.F.; Mraz, E.A. 1975. Forest Products Laboratory natural finish. Res. Note FPL-046. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

A simple and durable exterior, semitransparent, oil-based penetrating stain that effectively retains much of the natural grain and texture of wood exposed to weather. Update of Report No. 2096 (1957).

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1975a. Wood finishing: Weathering of wood. Res. Note FPL-0135. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Describes the mechanism of wood weathering, the benefit of using a water-repellent preservative, and the type of nails to use for finished wood.

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1975b. Wood finishing: Mildew on house paints. Res. Note FPL-0128. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Describes methods for preventing, detecting, and curing mildew. Also describes how paint affects mildew.

1976

Black, J.M.; Mraz, E.A. 1976. Improving paint performance on southern pine by relief of machining stresses and chromic acid treatment. Res. Pap. FPL 271. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Both steam wetting and a brush coat of chromic acid improved durability of an alkyd and a linseed-oil base paint. The already superior acrylic latex paint did not benefit from the treatments.

Black, J.M.; Mraz, E.A.; Lutz, J.F. 1976. Performance of softwood plywoods during 10 years' exposure to weather. Forest Products Journal. 26(4): 24-27.

Compares performance of Douglas-fir and southern pine plywood exposed near Madison, WI, and Gulfport, MS.

Grantham, J.B.; Black, J.M.; Heebink, T.B.; Mraz, E.A. 1976. Natural exterior finishes for wood in the Pacific Northwest. Forest Products Journal. 26(8): 21-27.

Report on ongoing exposure tests of clear water-repellent preservatives, waterborne inorganic salts, and pigmented penetrating stains at Olympia, WA.

Mraz, E.A. 1976. How to refinish wood siding with latex paints. Res. Note FPL-0232. Madison, WI:

U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Includes a simple test to determine whether an old surface will form a satisfactory bond with latex paints and suggestions for preparing the surface to achieve a satisfactory bond.

1977

Barquest, G.; Barrington, G.; Feist, W.C. 1977. Painting galvanized steel surfaces. Fact Sheet A2487. Madison, WI: University of Wisconsin-Extension.

Describes preparation of surfaces and methods of application for various types of finishes.

Barquest, G.; Brevik, T.; Feist, W.C.; Larsen, H. 1977a. Interior finishes for milkhouses and milking parlors. Fact Sheet A2871. Madison, WI: University of Wisconsin-Extension.

Recommends finishes that provide a washable surface for meeting sanitary requirements in milkhouses and milking parlors.

Barquest, G.; Brevik, T.; Feist, W.C.; Larsen, H. 1977b. Interior finishes for stall or stanchion barns. Fact Sheet A2870. Madison, WI: University of Wisconsin-Extension.

Recommends finishes that provide a washable surface for meeting sanitary requirements in stall or stanchion barns.

Barquest, G.; Feist, W.C. 1977a. Semitransparent stains for exterior wood surfaces. Fact Sheet A2483. Madison, WI: University of Wisconsin-Extension.

Describes the advantages of this type of exterior finish and its basic formulation and provides instructions for application.

Barquest, G.; Feist, W.C. 1977b. Steps in successful house painting. Fact Sheet A2482. Madison, WI: University of Wisconsin-Extension.

Describes the kinds of wood that are best suited for painting and procedures for painting new and previously painted surfaces.

Feist, W.C. 1977a. Finishing wood for exterior applications—paints, stains, and pretreatments. In: Wood Technology: Chemical Aspects. Goldstein, I.S., ed. American Chemical Society Symposium Series 43. Washington, DC: American Chemical Society: 294-300.

The chemistry of weathering and how paints, stains, and pretreatments protect wood.

Feist, W.C. 1977b. Wood surface treatments to prevent extractive staining of paints. Forest Products Journal. 27(5): 50-54.

Different water-soluble chemicals used to pretreat the surfaces of redwood and western redcedar prior to painting with water-based latex paints prevented extractive staining to varying degrees.

Feist, W.C.; Mraz, E.A.; Black, J.M. 1977. Durability of exterior wood stains. Forest Products Journal. 27(1): 13-16.

Summarizes research projects that evaluated several oil- and latex-base stains on different wood species exposed to accelerated and natural weathering conditions.

Rowell, R.M., Black, J.M.; Gjovik, L.R.; Feist, W.C. 1977. Protecting log cabins from decay. Gen. Tech. Rep. FPL-GTR-11. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Includes practices for the exterior finishing and maintenance of cabins.

1978

Barquest, G., Feist, W.C.; Stith, D. 1978. When paint peels severely from wood. Fact Sheet A2485. Madison, WI: University of Wisconsin-Extension.

Addresses the causes of peeling and describes corrective measures.

Feist, W.C. 1978. Protecting wooden structures. Chemtech. (March): 160-162.

Explains the need for exterior finishes and describes types of exterior finishes and pretreatments.

Feist, W.C.; Ellis, W.C. 1978. Fixation of hexavalent chromium on wood surfaces. Wood Science. 11(2): 76-81.

Investigates the interaction of compounds containing hexavalent chromium, with emphasis on extraction or leachability by water.

Feist, W.C.; Mraz, E.A. 1978a. Comparison of outdoor and accelerated weathering on unprotected softwoods. Forest Products Journal. 28(3): 38-43.

Artificial and natural weathering of western redcedar showed that accelerated weathering can be a valuable tool for evaluating the rate of outdoor weathering.

Feist, W.C.; Mraz, E.A. 1978b. Protecting millwork with water repellents. Forest Products Journal. 28(5): 31-35.

A water repellent made from paraffin wax, resin, and solvent provided excellent protection against outdoor weathering during 20 years of exposure.

Feist, W.C.; Mraz, E.A. 1978c. Wood finishing: water repellents and water-repellent preservatives. Res. Note FPL-0124. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Describes typical formulations, mechanisms of action, application instructions, and use as an exterior natural finish. Revision of report published in 1968.

Sherwood, G.E. 1978. Paint as a vapor barrier for walls of older homes. Res. Pap. FPL 319. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Test results of three commercially available paint types. Paints were applied to stud walls built to simulate walls of older homes that lack vapor barriers. All the paints prevented condensation during a winter season.

1979

Barquest, G.; Barrington, G.; Feist, W.C. 1979. Aluminum siding—care, cleaning, repainting.

Serial A2481. Madison, WI: University of Wisconsin-Extension.

Includes tips on what to look for when checking siding or damaged sheets.

Black, J.M.; Laughnan, D.F.; Mraz, E.A. 1979. Forest Products Laboratory natural finish. Res. Note FPL-046. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Directions for preparing and applying a simple and durable exterior, semitransparent, oil-based penetrating stain. Revision of Report No. 2096, published in 1957.

DeGroot, R.C.; Feist, W.C.; Eshyn, W.E.; Gjovik, L.R. 1979. Protecting wood fences for yard and garden. Extension Pub. A3052. Madison, WI: University of Wisconsin. 6 p.

Explains how to protect wood fences from decay and termites, and provides recommendations for maintenance and building tips.

Feist, W.C. 1979. Protection of wood surfaces with chromium trioxide. Res. Pap. FPL 339. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Reports the natural weathering resistance of wood surfaces treated with aqueous solutions of chromium trioxide as well as the performance of finishes applied to the treated surfaces.

Feist, W.C.; Mraz, E.A. 1979. Performance of chemicals as mildewcides in a semitransparent stain wood finish. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

1980

Cassens, D.L.; Feist, W.C. 1980a. Wood finishing: Finishing exterior plywood, hardboard and particleboard. North Central Regional Extension Pub. 132. West Lafayette, IN: Purdue University. 6 p.

Includes information on care and preparation before construction as well as finishing and refinishing recommendations.

Cassens, D.L.; Feist, W.C. 1980b. Wood finishing: Paint failure problems and their cure. North Central Regional Extension Pub. 133. West Lafayette, IN: Purdue University. 6 p.

Discusses premature paint failures, such as moisture-induced problems, blistering, peeling, and cracking and recommends repainting procedures.

Cassens, D.L.; Feist, W.C. 1980c. Wood finishing: Discoloration of house paint: causes and cures. North Central Regional Extension Pub. 134. West Lafayette, IN: Purdue University. 6 p.

How to correct problems with mildew, water-soluble extractives, blue stain, iron stain, chalking, and brown stain over knots.

Cassens, D.L.; Feist, W.C. 1980d. Wood finishing: Selection and application of exterior finishes for wood. North Central Regional Extension Pub. 135. West Lafayette, IN: Purdue University. 8 p.

Includes types of wood products, types of finishes, application of wood finishes, and types of refinishes.

Cassens, D.L.; Feist, W.C. 1980e. Wood finishing: Finishing and maintaining wood floors. North Central Regional Extension Pub. 136. West Lafayette, IN: Purdue University. 8 p.

Describes wood properties, surface preparation, finishes, finish application, and finish repair.

Feist, W.C. 1980. Protecting woodwork without preservatives. *Parks*. 4(4): 17-18.

Describes the suitability of a water-repellent formula as an exterior finish, and provides mixing and application instructions.

Feist, W.C.; Mraz, E.A. 1980a. Durability of exterior natural wood finishes in the Pacific Northwest. Res. Pap. FPL 366. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Observations on the weathering performance of 48 experimental finishes, both transparent and pigmented, in a cool, moist climate.

Feist, W.C.; Mraz, E.A. 1980b. Performance of mildewcides in a semitransparent stain wood finish. *Forest Products Journal*. 30(5): 43-46.

Results of outdoor exposure tests in Mississippi, Wisconsin, and Washington with six commercially available chemicals as additives at three concentrations in a semitransparent, oil-based wood stain.

Hon, D.N.S.; Ifju, G.; Feist, W.C. 1980. Characteristics of free radicals in wood. *Wood and Fiber*. 12(2): 121-130.

Formation and behavior of free radicals generated in wood surfaces upon exposure to ultraviolet light irradiation, as related to photo-oxidation in the weathering process.

Ingram, L.L.; McGinnis, G.D.; Feist, W.C. 1980. Effect of selected clear finishes in the vaporization of pentachlorophenol from treated wood. Inf. Series 21. Mississippi State, MS: Mississippi Forest Products Utilization Laboratory, University of Mississippi.

Results of a study to determine the concentration of penta in air exposed to small samples of wood dip-treated in a solution of the chemical and the efficacy of various finishing systems in retarding the vaporization of penta from treated wood.

1981

Barquest, G.; Feist, W.C. 1981. Guidelines for selecting exterior latex (waterborne) paints. Fact Sheet A2484. Madison, WI: University of Wisconsin- Extension.

Instructions for reading and evaluating formulas on paint labels.

Cassens, D.; Feist, W.C.; Clark, L.E.; Kirkpatrick, E.E.; Oskarson, D. 1981. Wood finishing: Finishing exterior wood surfaces and floors. West Lafayette, IN: Cooperative Extension Service, Purdue University.

Collection of radio tape scripts, news releases, and queries and quotes suitable for use by the mass media.

Feist, W.C. 1981. Protecting woodwork without preservatives. Unnumbered Rep., Research and Application Series, 4 p. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

The formulation and use of a water repellent to provide long-term protection to wood exposed above ground.

Hon, D.N.S.; Feist, W.C. 1981. Free radical formation in wood: The role of water. *Wood Science*. 14(1): 41-48.

Electron spin resonance (ESR) studies revealed that more free radical sites were created and distributed in earlywood than in latewood, presumably because of higher lignin content in earlywood.

Rowell, R.M.; Feist, W.C.; Ellis, W.D. 1981. Weathering of chemically modified southern pine. *Wood Science*. 13(4): 202-208.

Cell wall chemical modification, polymer lumen fill treatments, and a combination of these two treatments were studied for their effectiveness in reducing the degradative effects of outdoor weathering caused by ultraviolet radiation and water.

1982

Chang, S.-T.; Hon, D.N.-S.; Feist, W.C. 1982. Photodegradation and photoprotection of wood surfaces. *Wood and Fiber*. 14(2): 104-117.

Scanning electron microscopy (SEM) study of the degradation of southern yellow pine by ultraviolet light, and abatement effectiveness of chromic acid and ferric chloride treatments.

Feist, W.C. 1982a. Finishes for wood. In: Evaluation, Maintenance, and Upgrading of Wood Structures. New York: American Society of Civil Engineers: 277-297.

Distinguishes between types of exterior finishes and describes the interactions of weather, construction variables, and finishes.

Feist, W.C. 1982b. Water repellents in wood. In: *Evaluation, Maintenance, and Upgrading of Wood Structures*. New York: American Society of Civil Engineers: 271-277.

Describes the role of water repellents and water-repellent preservatives in protecting wood; includes formulation and application requirements.

Feist, W.C. 1982c. Weathering of wood. In: *Evaluation, Maintenance, and Upgrading of Wood Structures*. New York: American Society of Civil Engineers: 106-119.

Describes weathering of wood and wood-based products, including the mechanisms of weathering, property changes, and protective measures.

Feist, W.C. 1982d. Weathering characteristics of finished wood-based panel products. *Journal of Coatings Technology*. 54(686): 43-50.

In outdoor exposure studies, two- and three-coat finish systems provided the best protection for four wood-based panel products and one solid wood substrate.

Feist, W.C. 1982e. Weathering of wood in structural uses. In: *Structural Use of Wood in Adverse Environments*. Meyer, R.W.; Kellogg, R.M., eds. Society of Wood Science and Technology. New York: Van Nostrand Reinhold Co.: 156-178.

Discusses mechanisms of weathering as well as protective measures provided by various exterior finishes and construction practices.

Feist, W.C.; Rowell, R.M. 1982. UV degradation and accelerated weathering of chemically modified wood. In: Hon, D.N.-S., ed. *Graft Copolymerization of Lignocellulosic Fibers; Symposium Series 187*. Washington, DC: American Chemical Society: 349-370.

Cell wall chemical modification, polymer lumen-fill treatments, and a combination of

these two treatments had widely varying degrees of effectiveness in reducing the degradative effects of ultraviolet light on wood.

Hon, D.N.-S.; Chang, S.-T.; Feist, W.C. 1982. Participation of singlet oxygen in the photodegradation of wood surfaces. *Wood Science and Technology*. 16(3): 193-201.

In electron spin resonance (ESR) studies, free radicals were formed at the wood surface during irradiation and interacted with oxygen to form peroxide radicals. The mechanism of formation of singlet oxygen and hydroperoxide during photoirradiation is proposed.

Scheffer, T.C.; Eslyn, W.E. 1982. Twenty-year test of on-site preservative treatments to control decay in exterior wood of buildings. *Material und Organismen*. 17(3): 181-198.

Final appraisal of the 1963 study by Scheffer, Verrall, and Harvey.

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Cassens, D.L.; Feist, W.C. 1983. Finishing hardwood floors and millwork. In: Carter, R.M., ed. *Finishing Eastern Hardwoods*; Madison, WI: Forest Products Research Society: 86-95.

Includes sections on wood properties, surface preparation, finishes, and both factory and on-site finish application.

Feist, W.C. 1983a. Outdoor wood finishes: Varnish is pretty, but paint's tougher. *Fine Woodworking*. 43(Sept./Oct.): 66-67.

Summarizes available exterior finishes, including selection criteria and application recommendations.

Feist, W.C. 1983b. Finishing wood for exterior use. In: Carter, R.M., ed. *Finishing Eastern Hardwoods*. Madison, WI: Forest Products Research Society: 185-198.

Describes the weathering characteristics of wood, protection strategies, types of exterior finishes, and finishing practices, with emphasis on hardwoods.

Feist, W.C. 1983c. Weathering and protection of wood. Proceedings of the 79th Annual Meeting of the American Wood Preserver's Association: 79: 195-205.

Distinguishes mechanisms associated with weathering from those associated with decay. Study concludes that performance of wood in exterior use is greatly affected by species, finishes, construction practices, and degree of protection from prolonged wetting.

Feist, W.C.; Oviatt, A.E. 1983. Wood siding—installing, finishing, maintaining. Home and Garden Bull. 203. U.S. Department of Agriculture, Forest Service. 23 p.

Revision of earlier publication; includes details on types of siding, installation, moisture, types of finishes, finishing recommendations, and refinishing.

Ingram, L.L., Jr.; McGinnis, G.D.; Pope, P.M.; Feist, W.C. 1983. Effect of coating systems on the vaporization of pentachlorophenol from treated wood. Proceedings of the 79th Annual Meeting of the American Wood Preserver's Association, 79: 32-41.

Evaluates different coating systems for effectiveness in reducing the levels of airborne penta vaporizing from specimens dip-treated with penta in mineral spirits and pressure-treated with penta in P9 type-A oil or methylene chloride.

Williams, R.S. 1983. Effect of grafted UV stabilizers on wood surface erosion and clear coating performance. Journal of Applied Polymer Science. 28: 2093-2103.

HEBP [2-hydroxy-4-(2,3-epoxypropoxy) benzophenone] grafted to western redcedar reduced the erosion rate (weathering) of untreated wood. Pretreatment with this compound improved coating performance and color retention.

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Feist, W.C. 1984a. The role of water repellents and chemicals in controlling mildew on wood exposed outdoors. Res. Note FPL-0247. Madison,

WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 16 p.

Ponderosa pine sapwood specimens were dip-treated in various natural finish formulations and exposed on test fences in Mississippi, Wisconsin, and Washington.

Feist, W.C. 1984b. Weathering interactions on treated and untreated wood surfaces. Record of the 1984 Annual Convention of the British Wood Preserving Association: 13-23.

Summarizes studies involving the mechanism of outdoor weathering of wood and the weathering performance of exterior finishing systems on various wood and wood-based substrates.

Feist, W.C. 1984c. Painting and finishing wood for use outdoors. In: Proceedings of the 7th Annual Educational Conference; Baltimore, MD: American Society of Home Inspectors: 1-27.

Describes wood properties that affect finishing; types of finishes; interactions between weather, construction variables, and finishes; and application techniques.

Feist, W.C. 1984d. Replacement wood frames and sash: Protecting woodwork against decay. Preservation Tech Note 4; Windows. Washington, DC: National Park Service, U.S. Department of Interior. 4 p.

Describes how the use of water repellents in historic structures can protect woodwork without chemical preservatives.

Feist, W.C.; Hon, D.N.-S. 1984. Chemistry of weathering and protection. In: Rowell, R.M., ed. The Chemistry of Solid Wood. Advances in Chemistry Series 207. Washington, DC: American Chemical Society: 401-451.

Discusses the influence of outdoor weathering on the performance of wood and wood-based materials, including mechanisms of weathering and methods of protection for exposed wood surfaces.

Kalnins, M.A. 1984. Photochemical degradation of acetylated, methylated, phenylhydrazine-modified,

and ACC-treated wood. *Journal of Applied Polymer Science*. 29: 105-115.

Williams, R.S.; Feist, W.C. 1984. Application of ESCA to evaluate wood and cellulose surfaces modified by aqueous chromium trioxide treatment. *Colloids and Surface*. 9: 253-271.

Electron spectroscopy elucidated the surface effects of aqueous chromium trioxide treatment.

1985

Feist, W.C. 1985a. Water repellents and chemicals in controlling mildew on wood exposed outdoors. Part I. *American Paint and Coatings Journal*. February 4: 45-51.

Feist, W.C. 1985b. Water repellents and chemicals in controlling mildew on wood exposed outdoors. Part II. *American Paint and Coatings Journal*. February 11: 40-47.

Feist, W.C. 1985c. The outdoor finish: How and when to paint or stain. *Fine Homebuilding*. June/July; 27: 54-55.

Distinguishes between penetrating and film-forming exterior finishes and describes wood properties that affect finish performance and application details. Includes special considerations for porches and decks.

Feist, W.C. 1985d. Painting and finishing wood for use outdoors. Part I. *American Paint and Coatings Journal*. September 9; 70(8): 44-56.

Describes wood properties that affect finish performance, types of exterior finishes, and interactions of weather, construction variables, and finishes.

Feist, W.C. 1985e. Painting and finishing wood for use outdoors. Part II. *American Paint and Coatings Journal*. September 16; 70(9): 40-47.

Application guidelines for various exterior finishes, including information on finishing of decks, treated wood, and wood exposed to marine environments.

Feist, W.C.; Little, J.K.; Wennesheimer, J.M. 1985a. The moisture-excluding effectiveness of finishes on wood surfaces. Res. Pap. FPL 462. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 38 p.

Ninety-one finishes were evaluated for moisture-excluding effectiveness by exposing finished and unfinished ponderosa pine samples to high relative humidity conditions and comparing moisture adsorption.

Feist, W.C.; Little, J.K.; Wennesheimer, J.M. 1985b. The moisture-excluding effectiveness of finishes on wood surfaces—support data. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 58 p. Available from the National Technical Information Service (NTIS), U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

Three extensive tables present complete data from the large experiments that were summarized and discussed in another paper by the same authors: "The moisture-excluding effectiveness of finishes on wood surfaces" (U.S. Department of Agriculture, Forest Service Research Paper FPL 462).

Hon, D.N.-S.; Chang, S.-T.; Feist, W.C. 1985. Protection of wood surfaces against photo-oxidation. *Journal of Applied Polymer Science*. 30(4): 1429-1448.

Results of a study employing chemical pretreatments and polymeric clear finishes.

Sell, J.; Feist, W.C. 1985a. Verwitterung von CKB-getraenktem Holz bei kuenstlicher Wetterbeanspruchung (Weathering behavior of chromium-copper-boron (CCB)-treated wood). *Holz als Roh- und Werkstoff*. 43(12): 518.

CCB treatment improved durability of a semitransparent surface finish.

Sell, J.; Feist, W.C. 1985b. Unterschiede der Oberflächenbehandlung von Holzaußenbauteilen in den USA und in Westeuropa. (Differences in the surface finishing of exterior wood siding in the USA and Western Europe). *Holz-Zentralblatt*. 111(40/41):617-618.

Williams, R.S.; Feist, W.C. 1985. Wood modified by inorganic salts: Mechanism and properties. I. Weathering rate, water repellency, and dimensional stability of wood modified with chromium (III) nitrate versus chromic acid. *Wood and Fiber Science*. 17(2): 184-198.

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Cassens, D.L.; Feist, W.C. 1986a. Finishing wood exteriors. Selection, application, and maintenance. *Agric. Handb. 647*. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 56 p.

Details the characteristics of different kinds of wood, manufacturing and construction practices that affect surfaces to be finished, and different types of finishes that can be used on wood outdoors, including their compatibility with different wood products and proper application and reapplication procedures. (Copies of this publication are available from the Superintendent of Documents, U.S. Government Printing Office, 710 N. Capitol Street, Washington, DC 20402. Stock number: 001-000-044-50-8.)

Cassens, D.L.; Feist, W.C. 1986b. Durability of exterior wood finishes depends on proper selection and application. *Workbench Magazine*. 42(2): 84-89.

Condensed version of the North Central Regional Extension Publication No. 135, "Selection and application of exterior finishes for wood" (Cassens and Feist 1980).

Feist, W.C. 1986. Protective finishes and coatings for wood. In: Bever, M. B., ed. *The Encyclopedia of Materials Science and Engineering*. Oxford, England: Pergamon Press: 3981-2.

Describes wood properties important in finishing, types of finishes, and application considerations.

Hon, D.N.-S.; Feist, W.C. 1986. Weathering characteristics of hardwood surfaces. *Wood Science and Technology*. 20(2): 169-183.

Outdoor and artificial ultraviolet light exposure tests on red oak, white oak, yellow-poplar, and sweetgum.

Sell, J.; Feist, W.C. 1986a. Role of density in the erosion of wood during weathering. *Forest Products Journal*. 36(3): 57-60.

The rate of erosion per unit time depended predominantly on wood density and thus on wood cell wall thickness.

Sell, J.; Feist, W.C. 1986b. U.S. and European finishes for weather-exposed wood—a comparison. *Forest Products Journal*. 36(4): 37-41.

The United States and European countries agree on factors important in wood weathering and basic properties required of wood finishes, but differ on which types of finishes to use and where to use them.

Williams, R.S. 1986. Effects of acid rain on painted wood surfaces: Importance of the substrate. In: Baboian, R., ed. *Materials Degradation Caused By Acid Rain*. Symposium Series 318. Washington, DC: American Chemical Society: 310-331.

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Feist, W.C. 1987a. Pretreatment/primer/finish interactions and their importance in the outdoor weathering of finished wood. In: *Proceedings of the Annual Convention of the Oil Colour Chemist's Association of New Zealand; "Timber, Its Design and Protection;" Rotorua, New Zealand; July 22-26.*

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Feist, W.C. 1987b. Weathering performance of finished yellow-poplar siding. *Forest Products Journal*. 37(3): 15-22.

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Feist, W.C. 1987c. Coatings research at the Forest Products Laboratory. Preprint for a seminar on coatings for wood substrates; Seattle, WA: Federation of Societies for Coatings Technology; May 1-2; 20 p.

Feist, W.C.; Peterson, G. 1987. Protecting wood from humidity. *Fine Woodworking*. (May/June): 59-61.

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U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 1987. Finishing of wood. In: *Wood Handbook: Wood as an engineering material*. Agric. Handb. 72 rev. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. Chapter 16.

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