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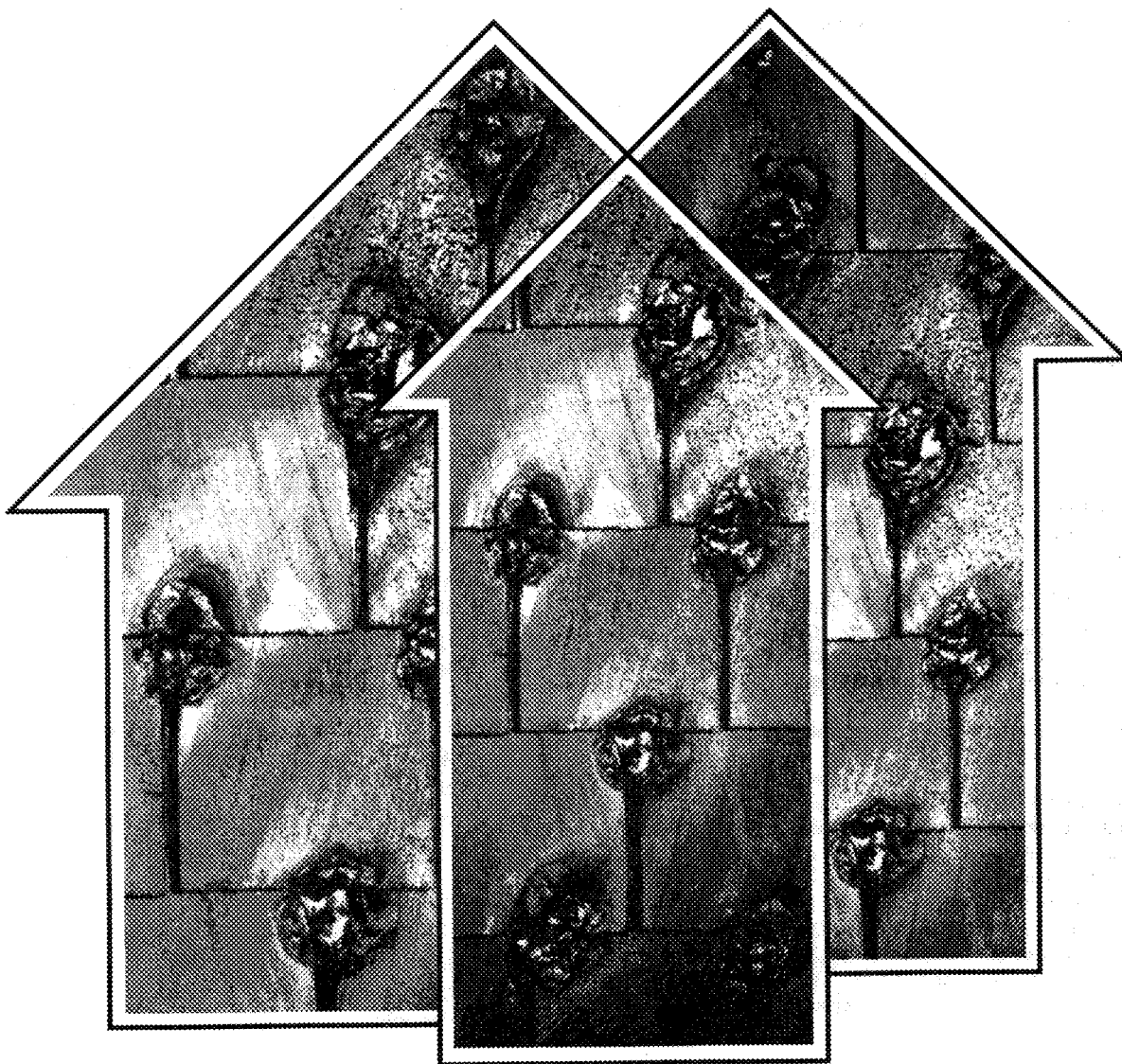
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# Fire Performance of Wood Treated With Combined Fire-Retardant and Preservative Systems

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# Abstract

The availability of western redcedar has decreased in recent years, and other species of wood are being considered as substitute materials for wood shakes and shingles. However, the wood of these alternative species is more susceptible to decay than is western redcedar. The objective of this study was to evaluate the fire performance of combined fire-retardant and preservative treatments using different fire test methods. Several amino resin fire retardants were used in combination with several wood preservative compounds that imparted both fire retardancy and decay resistance to wood. Treated specimens underwent fire tube tests and based on the results of these tests, two fire retardants and two quaternary ammonium preservatives were selected for additional fire testing. These treated materials were subjected to a modified Schlyter test and a burning brand test. The heat release rate was also measured. Both weathered and unweathered specimens were evaluated. The unweathered and weathered treated material exhibited good fire performance.

**Keywords:** Preservative, fire retardant, shingles, Pacific silver fir, western hemlock, western redcedar

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# Fire Performance of Wood Treated With Combined Fire-Retardant and Preservative Systems

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## Introduction

The availability of western redcedar (*Thuja plicata*) logs has decreased in recent years and as a result, other species, such as western hemlock (*Tsuga heterophylla*) and Pacific silver fir (*Abies amabilis*), are being considered as substitute materials for wood shakes and shingles. The wood of these two alternative species is more susceptible to decay than is western redcedar. Also, to better fill the need for wood shakes and shingles, treatment with a fire retardant would enable additional and widespread use. Therefore, these alternative species require a treatment that imparts both fire retardancy and decay resistance.

Some conventional fire retardants, which are mainly waterborne inorganic salts, provide a certain degree of decay resistance. These chemicals are not suitable for exterior use because they leach out of the wood. A simple one-step process that gives both resistance to fire and microbial decay and may be used for exterior applications is currently not available for the treatment of wood products. This study evaluated various wood preservative and fire-retardant mixtures that could be used as a combined treatment for wood products. Related investigations on improving the decay resistance alone can be found in De Groot (1994a,b).

A preliminary investigation to determine which combinations of fire retardants and preservatives are compatible was conducted by placing a quantity of fire-retardant solution (4 to 10 g) in a 35-mL vial. To each vial was added sufficient preservative to yield a solution with concentration of 1×, 2×,

and 5× the commercial application levels. The vials were agitated, and the solutions that did not exhibit phase separation or precipitation were judged to be compatible.

The following fire retardants were included:<sup>1</sup>

- UDPF (urea, dicyandiamide, phosphoric acid and formaldehyde)
- MDPF (melamine, dicyandiamide, phosphoric acid and formaldehyde)
- Irotherm 909–200 (commercial version of UDPF)
- Irotherm 909–300 (commercial version of MDPF)
- Fyrol-6 (diethyl N,N-bis (2-hydroxyethyl) aminomethyl phosphonate)
- Fyrol-51 (proprietary oligomeric phosphorus esters)
- Dricon (guanylurea phosphate and boric acid)
- NCX (undisclosed proprietary formulation)
- DPF (dicyandiamide, phosphoric acid and formaldehyde)
- DP (dicyandiamide and phosphoric acid)
- Amgard TR (ammonium polyphosphate)
- Retardol S (THPS) (tetrakis(hydroxymethyl)phosphonium sulfate)

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<sup>1</sup>The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

The following commercial-use wood preservatives were also included:

- CCA (chromated copper arsenate)
- ACQ (ammoniacal copper quaternary)
- DDAC (didecyl dimethyl ammonium chloride)
- NP-1 (DDAC with 3-iodo-2-propynyl butyl carbamate)
- ACA (ammoniacal copper arsenate)
- ACZA (ammoniacal copper zinc arsenate)
- ACB (ammoniacal copper borate)
- CuOct-macro (copper octoate, macro emulsion)
- CuOct-micro (copper octoate, micro emulsion)
- CuNaph-macro (copper naphthenate, macro emulsion)
- CuNaph-micro (copper naphthenate, micro emulsion)
- CuNaph-wr (copper naphthenate, with water repellent)
- CuNaph-wb (copper naphthenate, waterborne emulsion)
- ZnNaph-wr (zinc naphthenate, with water repellent)
- ZnNaph-wb (zinc naphthenate, waterborne emulsion)
- CuNaph-ob (copper naphthenate, oilborne)
- ZnNaph-wb (zinc naphthenate, aqueous solution)
- CuZnNaph-wr (copper zinc naphthenate, with water repellent)
- CuNapSol (copper naphthenate, with solubilizing agent)

Based on the results of the compatibility tests and because a leach-resistant exterior use fire retardant was desired, three fire retardants were chosen for further evaluation: DP, DPF, and UDPF. Six preservatives were selected for combination with each of the three fire retardants: CCA, NP-1, ACQ, ZnNaph-wb, ACA, and DDAC. Initially, some combinations (in particular, UDPF with DDAC or NP-1) were not compatible at higher fire-retardant concentration levels. However, it was discovered that the addition of isopropanol to the UDPF/DDAC or UDPF/NP-1 mixtures would act as a co-solvent and solubilize the preservative. A treating solution containing 30 percent UDPF required approximately 10-percent isopropanol to bring about a homogeneous solution.

The UDPF fire retardant was developed by researchers at the Eastern Forest Products Laboratory (EFPL) in Canada (Juneja 1972). Additional work was performed by EFPL scientists to better understand the UDPF system (Fung and others 1973, 1976; Juneja and Richardson 1974).

This paper discusses the fire tests conducted on selected combinations of fire retardants and preservatives.

## Experimental Methods

This study consisted of two stages. The first part consisted of selecting several compatible combinations from the first stage and testing fire tube specimens. The fire tube test served to give a rough idea of the fire performance of each combination. The second stage of the study involved treating test decks with a limited number of combinations of fire retardants and preservatives. These decks were evaluated for fire performance by several fire test methods.

## Materials

To ensure a uniform and consistent treatment, southern yellow pine was used for the fire tube specimens, which were 1.02 m long by 19 mm wide by 9.5 mm thick (40 by 0.75 by 0.37 in.). Western hemlock and Pacific silver fir shakes were used for the modified Schlyter and the burning brand tests. The shakes were quartersawn with no knots, slash grain, or other visible defects. The dimensions of the shakes were 10 mm (0.375 in.) at butt, 460 mm (18 in.) long, and 100 to 200 mm (4 to 8 in.) wide, with a 140-mm (5.5-in.) exposure when assembled in a deck. For the Ohio State University (OSU) heat release rate test, Pacific silver fir shakes were cut to dimensions of 150 by 150 by 13 mm (6 by 6 by 0.5 in.).

## Procedures

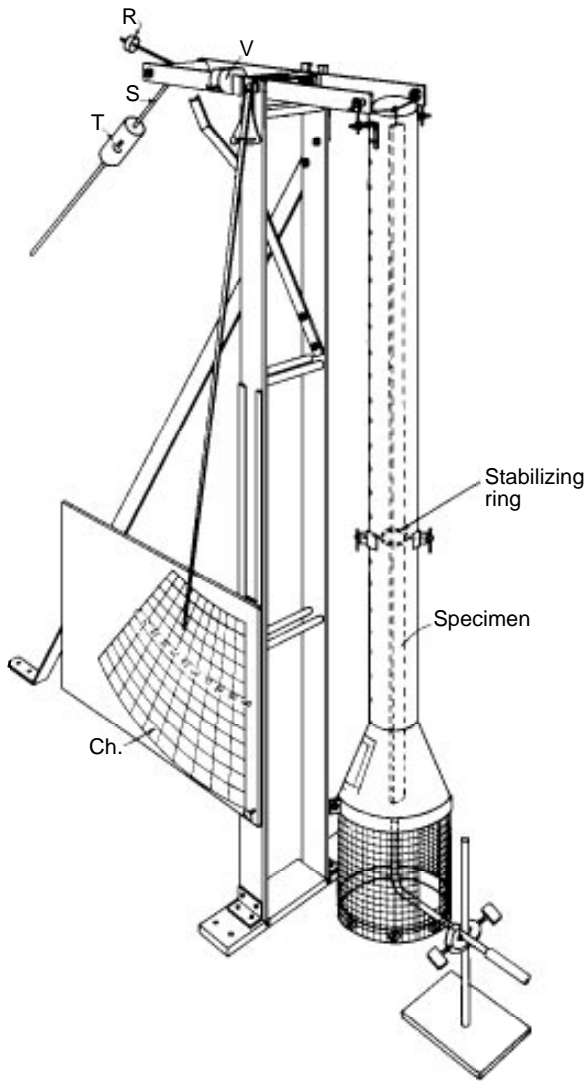
### Treatments

All treated wood specimens were pressure impregnated with mixtures of a fire retardant and a preservative using a full-cell pressure process. A vacuum of 0.1 MPa (15 lb/in<sup>2</sup>) was pulled for 30 min, the treating solution was added, and pressure of 1.0 MPa (150 lb/in<sup>2</sup>) was applied for 2 h. The pressure was then released, the treated specimens were removed from the tank, and the excess treating solution was blotted from the specimens. The dry chemical retention was calculated from the weight of treating solution each specimen had absorbed during the treating process by weighing specimens before and after treatment.

### Drying

The southern yellow pine fire tube sticks were dried after treatment in an oven at 65°C (150°F) for 5 days. The specimens were then equilibrated to a constant moisture content at 23°C (73°F), 50-percent relative humidity.

The shakes were kiln dried after treatment. The kiln schedule used a dry bulb of 49°C (120°F) and a wet bulb of 45°C (113°F) for 6 days. This equates to a relative humidity of 80 percent or an equilibrium moisture content of 14 percent.



**Figure 1—Fire tube test apparatus.**

After that, both the dry- and wet-bulb temperatures were increased by 6°C (10°F) on each of the following days until the dry-bulb temperature reached 82°C (180°F). The shakes were allowed to cure at 82°C (180°F) for 48 h and then equilibrated to a constant moisture content at 27°C (80°F) and 30-percent relative humidity.

The OSU heat release rate specimens were oven dried at 49°C (120°F) for 2 days, then at 71°C (160°F) for 2 days. These specimens were then cured at 82°C (180°F) for 2 days.

### Fire Tube Test

The ASTM Test Method E 69–80 (ASTM 1980) apparatus was used to measure percentage weight loss caused by combustion. Specimens were exposed to the flame for 3 min. Each treated specimen was placed in the fire tube (Fig. 1),



**Figure 2—Modified Schlyter test apparatus.**

and the flame from a gas burner was placed directly beneath the vertically oriented specimen. Weight loss was recorded for an additional 7 min after the burner was removed. The percentage weight loss at the end of the 10 min was reported.

### Modified Schlyter Test

The modified Schlyter test was used to measure the vertical flamespread of the hemlock and fir shakes. Two decks were constructed out of the treated and untreated material following the procedure in LeVan and Holmes (1986). Two matched decks were held parallel in a vertical position, with the test surfaces facing each other 50-mm (2-in.) apart (Fig. 2). The bottom of one deck was supported 100 mm (4 in.) higher than the bottom of the other. Behind the testing rack was a ruler for recording flame height. The arrangement of the decks promoted combustion, because each panel radiated heat to the other. At the start of the test, the burner was placed between the decks and the gas ignited. The initial height of the flame was recorded immediately and at every 15 s thereafter for 10 min. At the end of 5 min of exposure, the gas flame was shut off. The maximum flame height was reported.



Figure 3—Burning brand test apparatus.

### Modified Class C Burning Brand Test

A modified version of the ASTM Test Method E 108–91a (ASTM 1991a) for the Class C burning brand test of roof coverings was used. This test measured the resistance of the treated shakes to fire penetration and the capability of the fire-retardant/preservative system to control glowing combustion. A roof-section assembly was constructed, measuring 0.30 m (12 in.) wide by 0.79 m (31 in.) long. After conditioning, the assembly was positioned in the deck with a large fan placed 1.5 m (5 ft) from the front edge of the deck in such a manner as to generate a 5.4 m/s (12 mph) wind directed over the surface of the specimen (Fig. 3). A Class C brand was ignited and placed over the joint between two shakes in the same course and just below the butt end of the shake in the course above. The test was continued until the brand was consumed and all evidence of flame, glowing, and smoke disappeared or failure occurred. A failure was defined as burn through to the underside of the deck. In cases where the first brand did not result in a failure, a second brand was placed in the same location as the first successful test. This procedure was repeated for seven additional brands placed at other joints as specified in ASTM E 108. Results were reported as the number of failures out of the number of first tests, then the number of failures out of the number of second tests.

### Heat Release Rate Test

An Ohio State University (OSU) heat release rate calorimeter (Fig. 4) was used to determine the fire performance of leached specimens relative to that of unleached specimens. A large

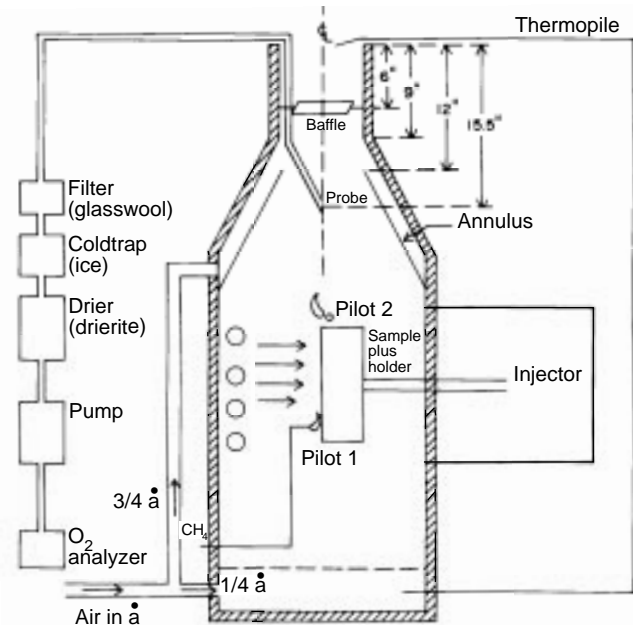


Figure 4—OSU heat release rate apparatus.

heat release rate generally means a rapid flame spread. ASTM E 906–83 (1983) was followed except that the oxygen consumption method, rather than the sensible heat method, was used to measure the heat release rate (Tran 1990). The vertically mounted test specimens were exposed to a radiant heat flux of 40 kW/m<sup>2</sup>. Results were reported as the 5-min average heat release rate for each specimen.

### Leaching

For the modified Schlyter test and the Class C burning brand tests, the leachability of each treatment was determined by method B of ASTM D 2898–81 (1981). After drying and conditioning at 27°C (80°F) and 30-percent relative humidity, test decks were positioned in the accelerated weathering chamber as described in the test method. The decks were then subjected to a 24-h exposure cycle consisting of 4 h each of wetting, drying, wetting, drying, and 8 h of rest. This cycle was repeated for 6 weeks for a total of 1,000 h. The water was applied in a fine spray uniformly distributed over the exposed specimen surface, with the temperature remaining below 32°C (90°F) during the wetting cycle. During the drying cycle, air at 65°C (150°F) was obtained by using ultraviolet lamps and circulating air at a temperature necessary to maintain a constant temperature of 65°C. After completing the accelerated weathering, the specimens were equilibrated at 23°C (73°F) and 50-percent relative humidity.

The OSU heat release rate specimens were leached by placing half the specimens in containers and covering them with distilled water for 13 days. The other half of the specimens were unleached. The water was replaced 6, 30, 78, 126, 174, 222, 270, and 318 h after initiation of the leaching cycle. Upon completion of the leaching, the specimens were dried at

49°C (120°F) for 2 days, then at 60°C (140°F) for 2 days. Finally, both the leached and unleached specimens were equilibrated at 23°C (73°F) and 50-percent relative humidity.

## Results

### Fire Tube Tests

Fifteen of the 18 possible combinations of fire retardants and preservatives were evaluated for fire performance using the fire tube test. The mean weight loss for each combination, number of replicates evaluated in each group, and coefficient of variation (COV) are found in Table 1. The distributions of individual and mean values for each treatment are found in Figure 5. A statistical analysis shows little difference between treatments. One group of treatments (DP/ACA, DP/ACQ, UDPF/DDAC, and UDPF/ACQ) had slightly less fire-retardant performance, and a second group, comprising all the other treatments, had somewhat greater fire-retardant performance with no statistical difference among those 11 treatments (Table 1). Essentially, no particular treatment stood out as better than the rest.

When each fire retardant was examined, independent of which preservative it was combined with, subtle differences in fire performance emerged. Each of the three groups contained an equivalent level of fire retardant ( $235 \pm 2 \text{ kg/m}^3$  ( $14.7 \pm 0.1 \text{ lb/ft}^3$ )). DPF-1 gave the best fire performance, indicated by the least weight loss (Fig. 6). The DP retardant had the next best fire performance, followed by UDPF. Although the differences between groups are statistically significant, from a practical standpoint, the differences are small enough to be negligible (Table 2).

Taking a similar approach in examining the fire performance of each preservative treatment, independent of the type of fire retardant used, subtle differences were also found. The fire performance of ACQ and DDAC were equivalent. Likewise, the fire performance of DDAC and ACA was comparable to each other. The four preservatives that exhibited the best fire performance and were not significantly different from each other were ACA, NP-1, CCA, and ZnNaph (Fig. 7 and Table 3).

Based on the results of the fire tube tests alone, we can conclude that a combination of DPF fire retardant and ACA, or NP-1, or CCA, or ZnNaph would likely give the slightly better fire performance per given treatment level. Although these combinations had somewhat lower weight losses, all combinations had satisfactory results and for all intents and purposes were the same. Because of other concerns, such as decay resistance, UDPF was chosen to be combined with DDAC (De Groot and others 1992, LeVan and De Groot 1993).

### Modified Schlyter Tests

Four test decks of western hemlock and Pacific silver fir were treated with each combination of fire retardant and preservative level. Two decks were weathered and two were not. Results of the modified Schlyter test (Table 4) generally indicated an increasing level of fire performance with increasing level of fire-retardant retention. Chemical loading of fire retardant greater than  $105 \text{ kg/m}^3$  ( $6.6 \text{ lb/ft}^3$ ) had little or no effect on the fire performance of both the weathered and unweathered specimens. The retention level of preservative did not appear to affect the fire performance of the decks when used in combination with the fire retardant.

**Table 1—Honest significant difference (HSD) between mean percentage weight loss by treatment<sup>a</sup>**

Fire retardant	DPF	DPF	DPF	DPF	DP	DP	DPF	UDPF	UDPF	DPF	DP	DP	DP	UDPF	UDPF
Preservative	ACA	CCA	ZnNaph	DDAC	CCA	ZnNaph	NP-1	ACA	CCA	ACQ	DDAC	ACA	ACQ	DDAC	ACQ
Mean weight loss	11.71	11.88	12.05	12.45	12.83	12.83	12.85	13.00	13.03	14.03	14.09	15.44	16.47	16.75	17.26
Samples/group	(15)	(45)	(15)	(45)	(46)	(9)	(45)	(15)	(29)	(15)	(29)	(13)	(5)	(45)	(15)
COV (%)	13.4	16.8	18.2	21.7	20.8	19.3	25.5	8.8	14.2	19.4	18.5	19.1	8.9	8.0	8.9

<sup>a</sup>Horizontal lines signify treatment groups that showed no statistical difference.

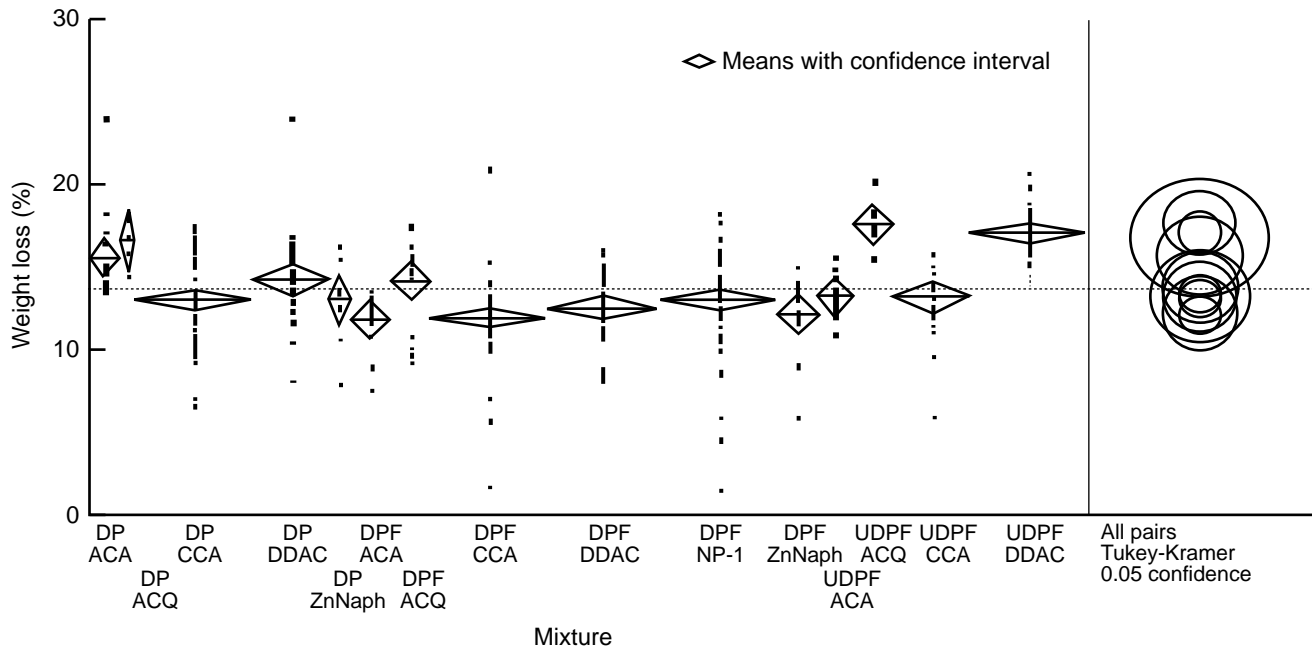


Figure 5—Distribution of percentage weight loss by fire-retardant/preservative mixture.

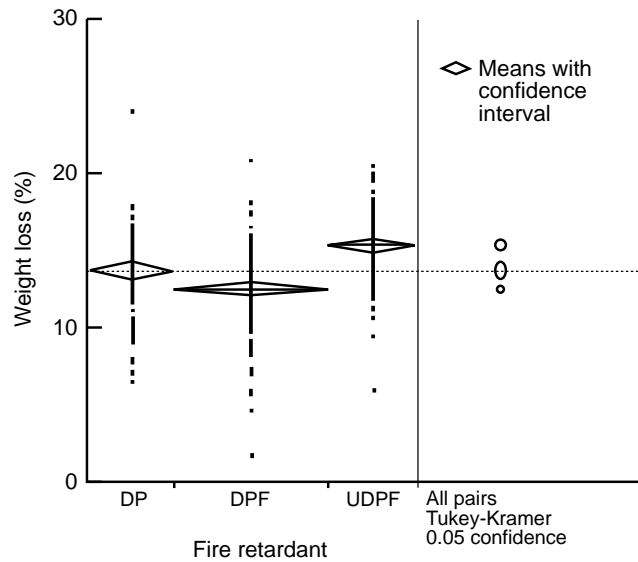
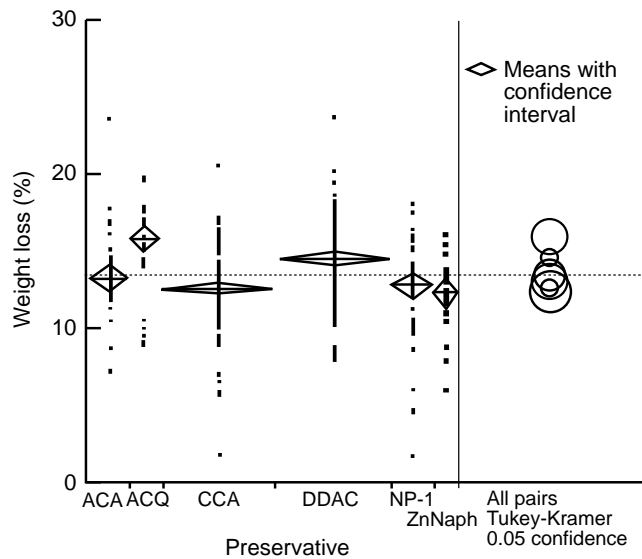


Figure 6—Distribution of percentage weight loss by fire retardant only.

Table 2—Honest significant difference between mean percentage weight loss from fire retardant only

Fire retardant	DPF	DP	UDPF
Mean weight loss (%)	12.44	13.70	15.24
Samples/group	180	102	104
COV (%)	21.1	20.5	15.9





**Figure 7—Distribution of percentage weight loss by preservative only.**

**Table 3—Honest significant difference between mean percentage weight loss from preservative only**

Preservative	ZnNaph	CCA	NP-1	ACA	DDAC	ACQ
Mean weight loss (%)	12.34	12.52	12.85	13.29	14.48	15.76
Samples/group	24	120	45	43	119	35
COV (%)	18.5	19.9	25.5	18.6	18.9	16.4

**Table 4—Results of modified Schlyter tests**

Retention level of UDPF (kg/m <sup>3</sup> (lb/ft <sup>3</sup> ))	Retention level of DDAC (kg/m <sup>3</sup> (lb/ft <sup>3</sup> ))	Hemlock (m (in.))		Pacific silver fir (m(in.))	
		Un-weathered	Weathered	Un-weathered	Weathered
				2.25 (88)	
	5 (0.3)	2.15 (84)	2.05 (80)	2.15 (84)	1.90 (74)
150 (9.4)		0.65 (26)	1.05 (42)	0.75 (30)	1.20 (48)
	5 (9.4)	0.80 (32)	0.80 (32)	0.85 (34)	0.75 (30)
	10 (9.4)	0.80 (32)	0.80 (32)	0.90 (36)	0.80 (32)
105 (6.6)		0.80 (32)	1.15 (46)	0.75 (30)	1.30 (52)
	5 (9.4)	0.95 (38)	0.90 (36)	0.70 (28)	0.80 (32)
	10 (9.4)	1.00 (40)	1.20 (48)	0.90 (36)	0.95 (38)
45 (2.8)		1.20 (48)	1.40 (56)	1.00 (40)	1.35 (54)
	5 (0.3)	1.10 (44)	1.70 (66)	0.95 (38)	1.75 (68)
	10 (0.6)	1.20 (48)	1.65 (64)	1.10 (44)	1.85 (72)

In this modified Schlyter test, weathering did not have an observable effect on fire performance at the two higher fire-retardant levels (105 and 150 kg/m<sup>3</sup> (6.6 and 9.4 lb/ft<sup>3</sup>)), but a decrease in fire performance was observed for the lowest level (45 kg/m<sup>3</sup> (2.8 lb/ft<sup>3</sup>)). This effect was more pronounced for the Pacific silver fir than for the western hemlock.

## Modified Class C Burning Brand Tests

Because the results of the modified Schlyter test looked promising with UDPF as the fire retardant, we decided that a closely related fire retardant, MDPF, would also be used to treat test decks for the modified Class C burning brand test. Two test decks of western hemlock and Pacific silver fir were treated at each combination of fire retardant and preservative level. One deck was weathered and the other was not. The results of the Class C burning brand test (Table 5) show that the untreated test decks and the decks treated only with a preservative suffered many failures. Again, the decks treated at the higher fire-retardant levels (105 and 150 kg/m<sup>3</sup> (6.6 and 9.4 lb/ft<sup>3</sup>)) did not exhibit failure, nor did the unweathered decks treated at the lowest fire-retardant level (45 kg/m<sup>3</sup> (2.8 lb/ft<sup>3</sup>)). The only failures of treated decks occurred on the weathered decks with the lowest fire-retardant level. These results confirm that a loading level of 100 to 150 kg/m<sup>3</sup> of fire retardant would likely lessen the negative effect of leaching on fire performance.

## Heat Release Rate

The DDAC treatment had a minimal effect on the results of the burning brand tests; therefore, a similar preservative, NP-1, was also used for the heat release rate tests. The heat release rate of the leached and unleached specimens was measured, and the results are shown in Figures 8 and 9. The three zones (I, II, III) represent heat release rate values that seem to correspond with ASTM E 84 flame spread values that fall into the Class I, II, or III classification of the building codes (ASTM 1991b; LeVan and Tran 1990). The heat release rate of the leached specimens, for both the UDPF and MDPF treated material, was greater than for the unleached specimens. Unleached specimens, at retentions of 7 lb/ft<sup>3</sup> and greater, exhibited heat release rates less than 40 kW/m<sup>2</sup>. This level of fire performance could also be achieved with the leached specimens, although a fire-retardant retention of 9 lb/ft<sup>3</sup> or greater is required.

## Discussion

The ASTM E 108 standard is typically cited by building officials as the test method for evaluating the fire performance of roof coverings, including wood shakes and shingles. Within this test method, there are actually five separate tests

(intermittent flame exposure test, spread of flame test, burning brand test, flying brand test, and rain test) with three levels of classification within each test. These classification levels are A, B, and C, with A being the most severe testing and C the least severe. The burning brand tests performed at the USDA Forest Service, Forest Products Laboratory (FPL), were not meant to exactly follow the methodology of ASTM E 108, but were done with the equipment available at FPL to get an approximation of how treated material would perform in a similar test. It is believed that based on the results of our testing, the combined fire-retardant and preservative treatments would likely pass a full-scale ASTM E 108 test series.

Similarly, the heat release rate tests performed as part of this study are not mandated by the building codes, but help provide an understanding of the level of fire retardancy in the treated shakes. For building materials that have exposed surfaces, the surface flame spread can be quantified by ASTM E 84. The numeric results of this test method are also broken down into classifications I, II, and III, which are not in any way related to the classifications of ASTM E 108. The Class I rating derived from ASTM E 84 is the strictest classification and usually only noncombustible material and wood products that have been well treated with a fire retardant are able to attain a Class I rating. Researchers have found a correlation between the results of the ASTM E 84 test and the rate of heat release. By measuring the heat release rate, we can approximate the surface flame spread of the treated material. Material that has a heat release rate of less than 40 kW/m<sup>2</sup> corresponds to a Class I flame spread rating and indicates that the material is well treated with a fire retardant.

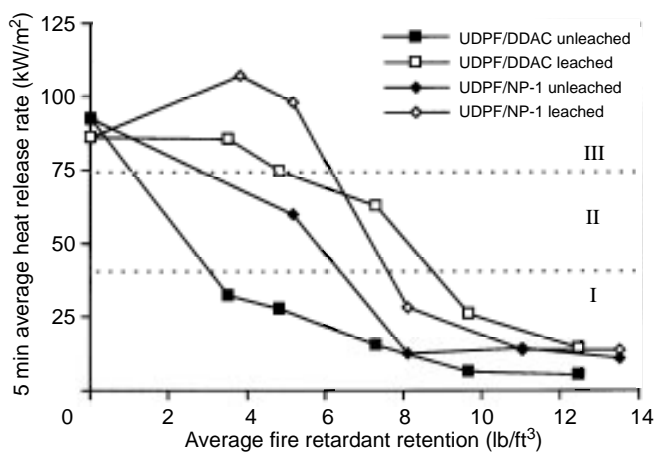
The fixation of UDPF was explored by EFPL scientists in the mid-1970s to determine the necessary curing time and temperature (Juneja and Calve 1977). The UDPF treated wood was cured for 3 to 6 h at 110°C to 150°C. The researchers found that there was some loss of fire retardant through leaching and the problem of strength loss was also a concern.

The weathering of the test decks for burning brand and modified Schlyter tests and the leaching of the heat release rate specimens show that some fire retardancy is lost due to leaching. What is unknown is the extent of the leaching and why the loss of fire retardant occurs. It may be that a fixed amount or percentage of fire retardant never cures into the wood structure and can be easily washed back out. If that is the case, then it would be possible to simply treat the wood with enough fire retardant to compensate for the loss as a result of leaching. It is also possible that there will be a constant loss of fire retardant during the exposure of the wood, and fire retardancy will continue to diminish. We do not know which scenario is correct. This area of weathering of fire-retardant-treated wood, both natural and artificial, clearly needs further investigation.

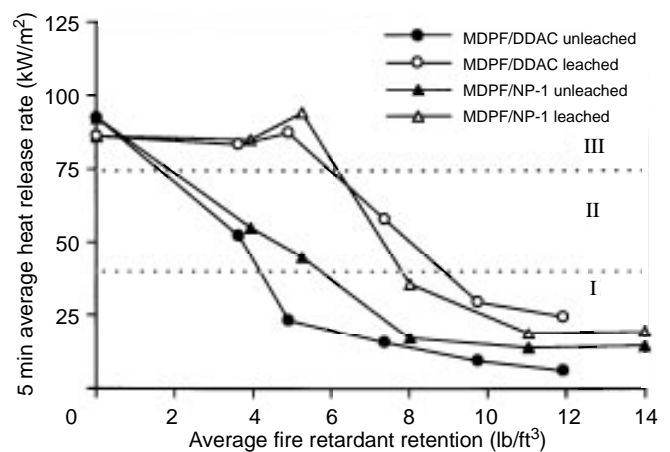
**Table 5—Results of Class C burning brand tests<sup>a</sup>**

Fire retardant	Retention (kg/m <sup>3</sup> (lb/ft <sup>3</sup> ))	Retention DDAC (kg/m <sup>3</sup> (lb/ft <sup>3</sup> ))	Hemlock		Pacific silver fir	
			Un-weathered	Weathered	Un-weathered	Weathered
			8/8	6/8 – 2/2	6/8 – 1/1	7/8 – 1/1
		5 (0.3)	7/8	5/8 – 2/2	4/8	5/7 – 2/2
UDPF	150 (9.4)		No failure	No failure	No failure	No failure
		5 (0.3)	No failure	No failure	No failure	No failure
		10 (0.6)	No failure	No failure	No failure	No failure
UDPF	105 (6.6)		No failure	No failure	No failure	No failure
		5 (0.3)	No failure	No failure	No failure	No failure
		10 (0.6)	No failure	No failure	No failure	No failure
UDPF	45 (2.8)		No failure	No failure	No failure	No failure
		5 (0.3)	No failure	0/8 – 2/8	No failure	1/8 – 2/7
		10 (0.6)	No failure	No failure	No failure	0/8 – 3/8
MDPF	150 (9.4))		No failure	No failure	No failure	No failure
		5 (0.3)	No failure	No failure	No failure	No failure
		10 (0.6)	No failure	No failure	No failure	No failure
MDPF	150 (6.6)		No failure	No failure	No failure	No failure
		5 (0.3)	No failure	No failure	No failure	No failure
		10 (0.6)	No failure	No failure	No failure	No failure
MDPF	45 (2.8)		No failure	No failure	No failure	No failure
		5 (0.3)	No failure	No failure	No failure	No failure
		10 (0.6)	No failure	No failure	No failure	No failure

<sup>a</sup> Results are listed in the format of failures/trials. Passes on the first test were given a second test, which is listed after the first. For example, 1/8 – 2/7 means one failure out of eight brands on the first test, and two failures out of seven possible brands on the second test. No failure means no failure out of eight brands on the first test, and no failure out of eight possible brands on the second test.



**Figure 8—Heat release rate of leached and unleached UDPF-treated southern yellow pine. 1 lb/ft<sup>3</sup> = 16 kg/m<sup>3</sup>.**



**Figure 9—Heat release rate of leached and unleached MDPF-treated southern yellow pine.**

## Conclusions

In this study, the fire tube tests showed that the fire performance of all the fire-retardant and preservative combinations used was fairly similar, allowing us to choose which combinations held the most promise, specifically UDPF and DDAC. Further testing showed that the closely related MDPF and NP-1 could also be successfully used to provide fire retardancy to wood. Material treated with each of these fire retardant/preservative combinations was subjected to accelerated weathering procedures, and fire tests indicated that good fire performance could be achieved with weathered and unweathered specimens.

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