DOES MORE PRESERVATIVE MEAN A BETTER PRODUCT?

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ABSTRACT

Does more preservative provide better protection of wood products or does it disproportionately increase the potential for introducing pesticide into the environment? In an era of sensitivity about misuse of pesticides in the environment, it seems prudent to examine the dose-response benefits from wood preservatives for treated-wood products exposed in natural settings. Results from "graveyard tests" of preservative-treated wood stakes exposed in the ground are regarded as reliable models of durability in treated-wood products. In this paper, failure distribution patterns of preservative-treated stakes in long-term field plots are discussed with reference to early failures, to first quartile and median failure times, and to distribution about medians. Evidence supports a hypothesis that for inorganic wood preservatives, retention levels above a certain upper bound do not yield proportionate durability gains. Environmental factors do not appear to extensively change the upper bounds of the dose-response relationship but can significantly affect the lifespan at any retention within that dose-response range. A similar relationship is suspected for metal-organic preservatives. With organic systems such as creosote, there is a direct relationship between dose and increased durability. If this hypothesis about a truncated dose-response relationship proves to be a fundamental performance characteristic of inorganic and organo-metallic wood preservatives, then the upper bounds of the dose-response relationship should be an important benchmark in standards that seek to define that optimum point at which product reliability is maximized with minimal potential environmental impact.

In an era of sensitivity about misuse of pesticides in the environment, it seems prudent to examine the dose-response benefits from wood preservatives. In the traditional thinking wherein more (preservative) is better (durability), an experimentally determined value for the maximum amount of preservative that contributes to increased protection of wood from decay fungi, such as the threshold value in soil-block tests, is often less than the minimum retention required by standards for products in use. Requirements for additional preservative are perceived as a "safety factor." Preservative retention levels for items believed to have critical structural importance are often elevated even further, based on the premise that "more is better." Examples of this are the high levels of retention set for wood foundations and crossarms on utility poles.

Does more preservative provide better protection or does it disproportionately increase the potential for introducing pesticide into the environment? To gain some insight into the relationship between preservative dose and product durability, we examined the failure distribution patterns of stakes in long-term field tests for which data sets are complete or nearly complete.

BACKGROUND

The minimum retention of a preservative (threshold value) that prevents growth of decay fungi is determined in standardized laboratory tests, such as the soil-block procedure (2, 6). This threshold value is an expression of toxicity. As such, it has relevance to a system that remains static or relatively static over time.

However, the natural environment is dynamic. The natural selection of growth tolerant fungi or adaptation of fungi to an active ingredient may be one dynamic component in this environmental setting. Because of the dynamics of natural systems, field tests of treated-wood members, vertically inserted in the ground (stake or graveyard tests) (5) are conducted to provide long-term verification of laboratory results.

Results from a long-term field study in Florida exemplify this dynamic. The distribution patterns of preservative-treated stakes that survived for nearly 30 years in

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TABLE I. -Environmental description of field plots.

Location	Environmental description
USDA Forest Service Harrison Experimental Forest Southern Mississippi 32 km north of Gulf of Mexico	Mean annual precipitation, 1580 mm Average annual temperature, 19.6°C Soil type, poarch sandy loam
Madison, Wis	Mean annual precipitation, 780 mm Average annual temperature, 7.4°C Soil type, clay loam soil
Bogalusa, La.	Mean annual precipitation, 1536 mm Average annual temperature, 19.1 °C Soil type, sandy loam
Jacksonville, Fla.	Mean annual precipitation, 1347 mm Average annual temperature, 20.0°C Soil type, sandy

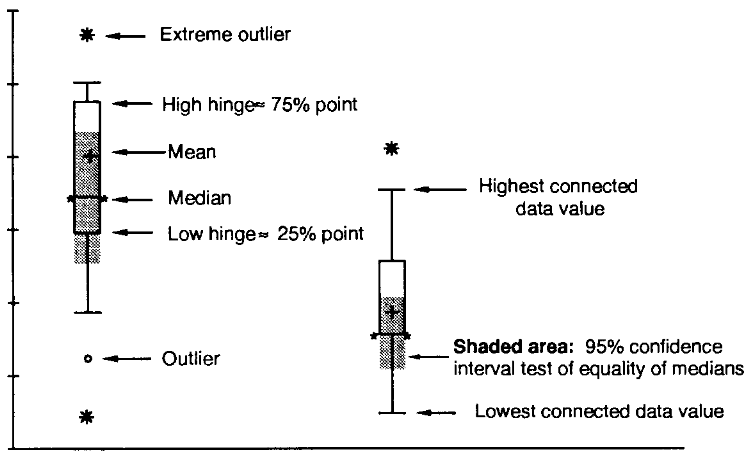

Figure 1. — Components of a box plot.

a Florida field plot evidenced a difference between pentachlorophenol and copper naphthenate in long-term performance at retention levels that were comparable during the first 12 years of exposure (9). We were unable to track the annual performance profile of treated stakes from 12 to 30 years. However, at retention levels that were giving comparable performance at 12 years, more copper-naphthenate-treated stakes than pentachlorophenol-treated stakes had failed at 30 years. These results begged the question as to whether dynamic systems accounted for the difference in long-term performance of the two preservatives that were initially comparable in performance. These results also underscore the need for methods or interpretive concepts that will enable long-term prediction of performance. Treated-wood products are expected to last decades, and significant differences after three decades of exposure from that which were seen during the first decade could have serious economic impacts for users of treated products.

Loss of preservative over time may affect the efficacy of some systems. Wood preservative systems that lose one or more components into the surrounding environment thereby may lose some degree of efficacy; this seems to be an intuitive argument, witness the current interest in monitoring residual preservative in stakes being evaluated in different soils (5). However, if the chemical being released from a treated-woodproduct contributes to apparent efficacy, might items treated with mobile and relatively immobile preservatives have unique service-life distribution patterns?

Regarding laboratory test procedures for preservative efficacy, the American-type soil-block tests (2, 6), in which the preservative-treated assay block is challenged with fungi growing in soil, are regarded as being more severe than the European agar-block tests in which the assay block is challenged with fungi growing on agar (7, 19). In soil-block tests, the type of soil used can affect the amount of decay caused in untreated wood by either brown- or white-rot fungi (1). However, Duncan (11) concluded that there is little evidence that differences in soil nutrient levels will change threshold values in such tests. Protocols for leaching blocks prior to exposing them to decay fungi are included within these standard tests, but those protocols still operate within a fixed time domain. We anticipate that a series of tests conducted at different times, in different laboratories, or with different assay fungi would yield a range of threshold values. This has happened in soil-block tests using copper naphthenate (9).

In the United States, the traditional approach to evaluate data from experimental field plots is to compare averages. The merits of recognizing the variability in the analysis of treated products has been set forth (17). Characterizing durable products on the basis of percentiles of survivability may provide a more sensitive indicator of dose-response effect than does a comparison of averages. To wit, does more preservative have the same relative impact in delaying failure of the lst, 5th, 10th, or 25th percentile as it may have in delaying failure of the first half of the population? Might items treated with mobile and relatively immobile preservatives have unique service-life distribution patterns? An even more fundamental question is whether different failure distribution patterns of products treated with various preservatives can be predicted, modeled, characterized, or even anticipated using accelerated laboratory tests? In the same manner, can relative performance in different edaphic or climatic locations be predicted?

METHODS AND MATERIALS

Data from field plots maintained by the USDA Forest Service, Forest Products Laboratory (FPL) (14) during the past 50 years were utilized. Some plots were located in quite different environments **(Table 1).** In all plots, stakes were vertically inserted into the soil to a depth of half their length. Plots were inspected at intervals, and stakes were recorded as failing when they could be broken, by hand, at time of inspection. A randomized block design was used in all field plots listed in **Table 1.** All stakes included in this report were southern pine sapwood, standard 50- by 100- by 450-mm (nominal 2- by 4- by 18- in.) specimens. All preservative treatments referenced in this discussion were pressure treatments **(Table** 2). We placed emphasis upon plots in which all the stakes had failed or sufficient data were available to at least determine the quartiles of service life (16). Service-life data for preservative-treated stakes were also plotted to show distribution patterns of failures about the respective medians for different retention levels of individual preservatives at one location and among locations. For plots in which all stakes failed, box plots (21) **(Fig. 1)** are used to visually present summary statistics **(Figs. 3** through **6).** Where possible, patterns of field performance are related to outputs of current laboratory methodologies.

The following briefly describes the preservatives included in this report. The coal-tar creosote used to treat the stakes that we documented was slightly different from the creosote that complies with U.S. Environmental Protection Agency (EPA) regulations today. However, the principle that creosote is an organic system, vis-à-vis an inorganic system, remains valid. The threshold value for creosote in laboratory tests varies with both types of creosote tested and tolerance of the assay fungus. Threshold values for a variety of creosotes encompass a range from 48 to 192 kg/m^3 (3 to 12 pcf) (8, 13). Several petroleum solvents were also included to provide some indication of whether petroleum solvents influence patterns of failure in populations of stakes as well as survival times. Sodium pentachlorophenate represents an organic salt.

Metal-organic systems are represented by oxine copper (copper-8-quinolinolate), copper formate, copper naphthenate, and zinc naphthenate. It is recognized that the efficacy of treatments with an organic solvent could reflect biocidal activity of either the metallic component, the organic component, or a combination of the two, as well as the physical effect of the solvent. Where data exist, we show performance of stakes treated with the organic solvent alone to enable the reader to assess the independent contribution of the organic solvent system.

TABLE 2. — Treatments and field sites for stakes included in this report.

Preservative	Exposure site	Plot	Treating process
Acid copper chromate in water	Mississippi	15	Full cell -pressure: 1034.1 × 10^{+3} Pa for 3 hr. -temperature: ambient
Chromated copper arsenate in water	Mississippi	15	Full cell -pressure: 1034.1 × 10^{+3} Pa for 3 hr. -temperature: ambient
Chromated zinc chloride in water	Mississippi Wisconsin Louisiana Florida	2	Full cell -no additional information available
Coal-tar creosote	Mississippi Wisconsin	4	Reuping process -initial air: 310.2 × 10^{+3} Pa -pressure: 1034.1 × 10^{+3} Pa for 1.5 hr. -vacuum: 92.8 × 10^{+3} Pa for 15 min. -treating temperature: 93.3°C
Copper-8-quinolinolate (oxine copper) in Stoddard solvent	Mississippi	54	Reuping process -initial air: 172.3 × 10^{+3} Pa -pressure: 1034.1 × 10^{+3} Pa for 2 hr. -vacuum: 92.8 × 10^{+3} Pa for 20 min. -temperature: ambient
Copper-8-quinolinolate in heavy petroleum oil	Mississippi	62	Reuping process -initial air: 137.9 × 10^{+3} Pa -pressure: 1034.1 × 10^{+3} Pa for 2 hr. -vacuum: 92.8 × 10^{+3} Pa for 1 hr. -treating temperature: 65.5°C -post treatment heating: 93.3°C
Copper formate in water	Mississippi	47	Full cell -pressure: 1034.1 × 10^{+3} Pa for 1 hr. -post treatment steaming at 103.4 × 10^{+3} Pa for 1.5 hr. (121°C)
Copper naphthenate in No. 2 fuel oil	Mississippi Wisconsin	7	Reuping process -initial air: 103.4 × 10^{+3} Pa -pressure: 1034.1 × 10^{+3} Pa for 1 hr. -vacuum: 92.8 × 10^{+3} Pa for 1/2 hr. -treating temperature: 51.7°C -post treatment heating: 79.4°C
Copper naphthenate in catalytic gas-based oil	Mississippi	20	Reuping process -initial air: 517.0 × 10^{+3} Pa -pressure: 1034.1 × 10^{+3} Pa for 2 hr. -vacuum: 92.8 × 10^{+3} Pa for 1/2 hr. -treating temperature: 82.2°C -post treatment heating: none
Copper naphthenate in creosote	Mississippi	20	Reuping process -initial air: 551.5 × 10^{+3} Pa -pressure: 1034.1 × 10^{+3} Pa for 2 hr. -vacuum: 92.8 × 10^{+3} Pa for 1/2 hr. -treating temperature: 93.3°C -post treatment heating: none
Fluor chrome arsenate phenol-type A in water	Mississippi Wisconsin Louisiana Florida	2	Full cell -no additional information available
Nickel-arsenic-chromium	Mississippi	15	Full cell -pressure: 1034.1 × 10^{+3} Pa for 3 hr. -temperature: ambient
Sodium penta-chlorophenate	Mississippi Wisconsin Louisiana Florida	2	Full cell -no additional information available

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TABLE 2. — Continued from previous page.

Preservative	Exposure site	Plot	Treating process
Zinc chloride	Mississippi Wisconsin Louisiana Florida	2	Full cell -no additional information available
Zinc naphthenate in No. 2 fuel oil	Mississippi Wisconsin	7	Reuping process -initial air: $103.4 \times 10^{+3}$ Pa -pressure: $1034.1 \times 10^{+3}$ Pa for 1 hr. -vacuum: $92.8 \times 10^{+3}$ Pa for 1/2 hr. -treating temperature: 51.7°C -post treatment heating: 79.4°C

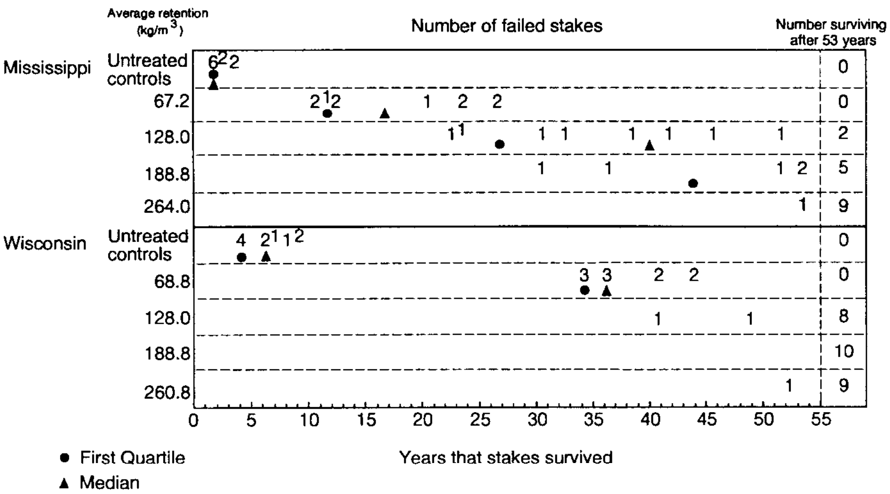

Figure 2. —Number of stakes treated with coal-tar creosote that failed at intervals indicated.

Oxine copper (copper-8-quinolinolate) is currently accepted for treatment of southern pine lumber used above the ground. A minimum retention of 0.32 kg/m^3 (0.02 pcf) is required (4). The minimum retention levels required in the United States (4) for copper naphthenate in southern pine lumber are 0.64 kg/m^3 (0.04 pcf) elemental copper in wood used above the ground and 0.96 kg/m^3 (0.06 pcf) elemental copper in wood used in ground contact. Most of the reported threshold values for copper naphthenate were within 0.5 to 1.0 kg/m^3 (0.03 to 0.065 pcf) elemental copper (9).

Copper formate was not included in American Wood Preservers' Association (AWPA) standards for wood preservatives. No threshold value was established for copper formate in soil-block tests. In soil-block tests with red pine, copper formate did not prevent decay by the copper-tolerant decay fungus, *Poria monticola,* even at retention levels of 4.0 kg/m^3 (0.25 pcf) elemental copper (18). Results of an unpublished study by Duncan (12) showed that copper-tolerant decay fungi could decompose wood treated to a retention of 2.9 kg/m^3 (0.18 pcf) metallic copper. Zinc naphthenate is another metal-organic preservative that has not been accepted to standard by AWPA.

Inorganic treatments include zinc chloride (ZC), chromated zinc chloride (CZC), fluor chrome arsenate phenol (FCAP), chromated copper arsenate (CCA), acid copper chromate (ACC), and nickel-arsenic-chromium. ZC is perhaps the most mobile system included in this review. ZC has been used as a wood preservative extensively in Europe and the United States (10), but information on minimum retention levels that may have been required in the past was not available. Scheffer and Van Kleeck (20) demonstrated in laboratory tests that wood treated to retention levels of 6.9 and 13.0 kg/m^3 (0.43 and 0.81 pcf) ZC lost resistance to decay by *Trametes serialis* under conditions that permitted loss of the fire retardant through leaching. They used a decay test in which small blocks were incubated for two sequential 3.5-month periods over agar in an enclosed vessel. During the first incubation, the treated blocks absorbed so much water that much of the chemical was lost as water dripped from the blocks.

CZC and FCAP were formerly accepted for treatment of southern pine lumber used above the ground (3) but were not recommended for treatment of southern pine lumber exposed in ground contact. Minimum retention levels for CZC and FCAP in aboveground exposure are 7.2 and 4.0 kg/m^3 (0.45 and 0.25 pcf), respectively.

CCA is perhaps the most widely used inorganic wood preservative in the United States. Minimum retention levels for CCA (4) in southern pine are 4.0 kg/m^3 (0.25 pcf) in lumber used above the ground and 6.4 kg/m^3 (0.4 pcf) in lumber used in ground contact. The stakes that we describe in this report were treated with CCA-I, a formulation that is no longer used in the United States. ACC is less widely used in the United States. Retention levels for ACC are 4.0 kg/m^3 (0.25 pcf) for southern pine lumber used above the ground and 8.0 kg/m^3 (0.50 pcf) for southern pine lumber used in ground contact. Nickel-arsenic-chromium is not a wood preservative. It is included as another example of the field performance profile of wood treated with inorganic chemicals.

RESULTS

A clear dose-response effect was seen with creosote, wherein increased retention levels resulted in increased years of survival. Increased retentions increased both first quartile and median failure times **(Fig. 2).** Similarly, evidence of a dose-response relationship was seen with sodium pentachlorophenate in three locations, although it is most obvious in the Wisconsin and Mississippi plots **(Fig. 3).** The impact of increased retention levels of inorganic and metal-organo preservatives in this analysis was less obvious.

The exposure site had a marked effect on the duration and survival of stakes treated with ZC, CZC, FCAP, and sodium pentachlorophenate **(Figs. 3** through **6)** but not on the overall dose-response pattern seen with each preservative. With these four systems, the exposure site at Boglusa, La., was most severe. There, survival times for stakes treated to the respective lowest retention levels were sometimes significantly less than those of comparable retention levels in other locations. With sodium pentachorophenate, the service life of stakes at the highest retention in Louisiana was also significantly less than that of stakes at the highest retention in Wisconsin, Mississippi, or Florida.

Among the four systems (ZC, CZC, FCAP, and sodium pentachlorophenate), the greatest absence of a dose-response relationship between retention and longevity of treated material was with ZC **(Fig. 4).** This was true for all locations.

For stakes treated with CZC **(Fig. 5),** there was no real gain in median life span of the population of stakes treated at greater than 12.2 kg/m^3 (0.76 pcf). At all locations, the median value for stakes treated at 16.3 kg/m^3 (1.02 pcf) was not greater than that of stakes treated to at least one of the lower retention levels. The range of stake failures about the median was somewhat reduced by increased retention. A marked gain in service life was observed in the Mississippi plot, with the increase of retention from the lowest level, 7.8 kg/m^3 (0.49 pcf), to the next level of retention, 12.2 kg/m^3 (0.76 pcf), but this was not evident in the other plots. Overall, for each respective combination of retention by location, the median service life was greater than or equal to the average service life.

For stakes treated with FCAP **(Fig. 6),** a large dose-response relationship between retention and median service life was observed only in the Mississippi plots. The median of stakes treated at the lowest retention was less than that of the higher retention levels at each location. For plots in Wisconsin, Louisiana, and Florida, the dose-response relationship between retention levels of 3.2 and 4.8 kg/m^3 (0.2 and 0.3 pcf) was greater than that between stakes treated with retention levels of 4.8 and 9.6 kg/m^3 (0.3 and 0.6 pcf). At those three plots, a difference of only one to several years separated both average and median population life times at the higher two retention levels.

A unique feature of the service-life distribution patterns for stakes treated with sodium pentachlorophenate was the reduced spread in failure times about the median value that occurs at the highest retention level. The time between first and third quartiles of stake failures was the least at the highest retention of 15.8

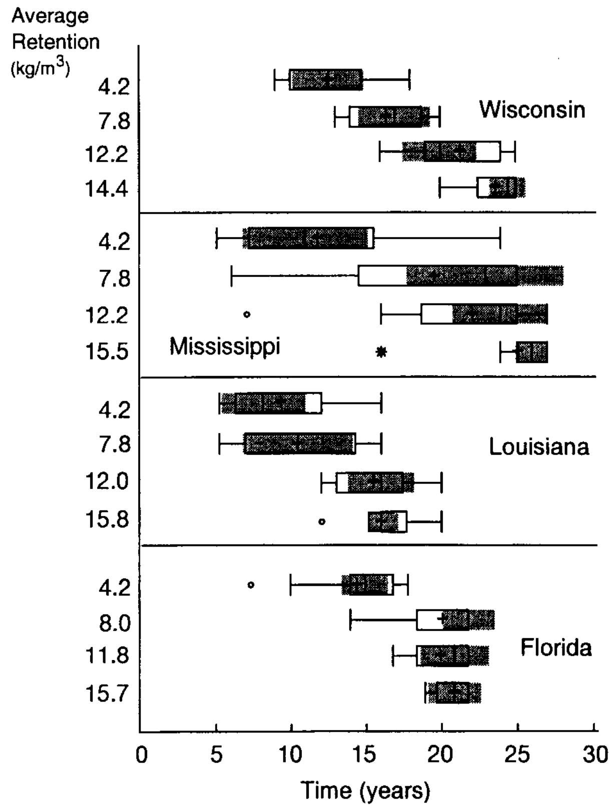

Figure 3.—Distribution of times-to-failure for stakes treated with sodium pentachlorophenate.

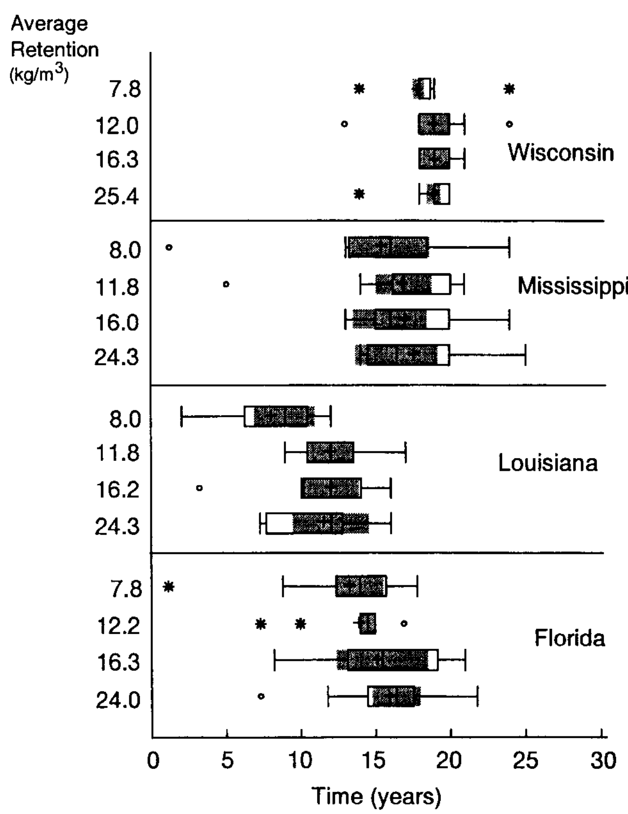

Figure 4.— Distribution of times-to-failure for stakes treated with zinc chloride.

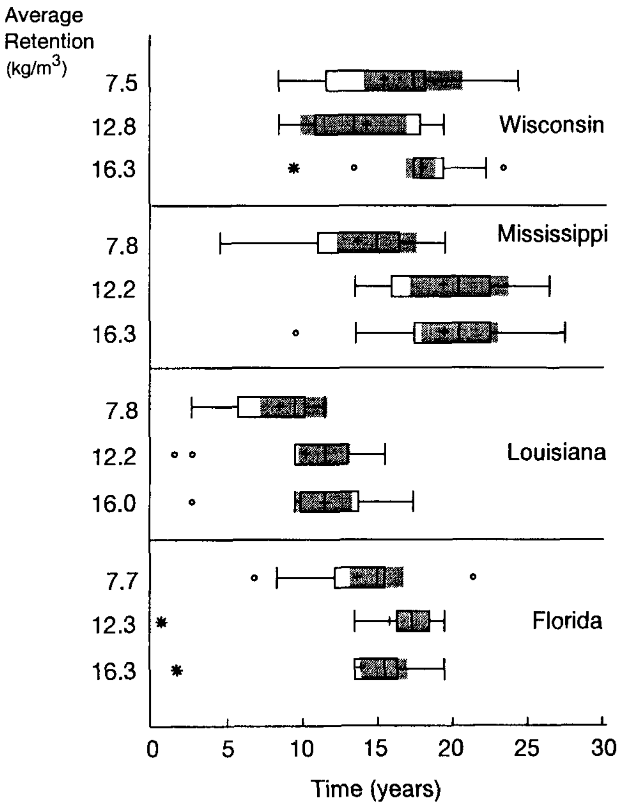

Figure 5. — Distribution of times-to-failure for stakes treated with chromated zinc chloride.

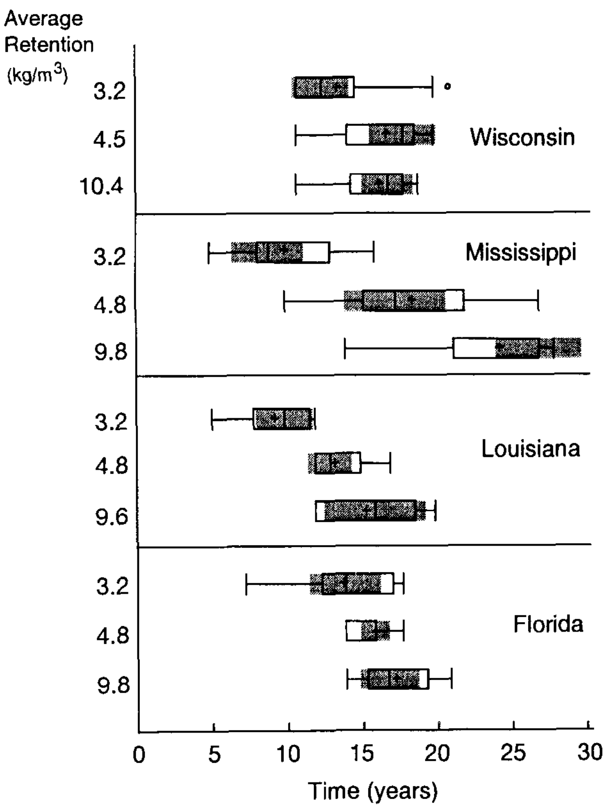

Figure 6. — Distribution of times-to-failure for stakes treated with fluor chrome arsenate phenol-Type A.

kg/m^3 (0.99 pcf) at all locations. This reduction in distribution of failures about the median seemed to be an abrupt change between the last two retention levels rather than a progressive reduction in distribution from lowest retention to highest. A dose-response relationship for the median life of stakes treated with sodium pentachlorophenate was observed in plots in Mississippi, Wisconsin, and Louisiana. Median values tended to approximate the mean or were greater than the mean.

For stakes treated with sodium pentachlorophenate, the range of failure times at the lowest three retention levels was almost twice as great in Mississippi than in other plots. The range in failure times within their respective retention levels for stakes treated with FCAP and ZC was also greater in Mississippi than at the other locations. For stakes treated with ZC and exposed in Wisconsin, the distribution of failure about the median was different from that of stakes in other plots in that the range of failures was small (± 1 to 2 yr.) for all retention levels.

Data on the more recently developed waterborne inorganic treatments were less complete **(Fig.** 7). Still, the relationships between retention and first quartile of failures can be determined for most retention levels. The first quartile of performance of acid copper chromate and nickel-arsenic-chromium increased between the lowest and midrange retention levels, but not between the midrange and highest retention levels. The first quartile of performance cannot be determined for stakes treated with CCA-I at a retention of 7.0 kg/m^3 (0.44 pcf). If that quartile were to be increased in proportion to the increase in retention, the next stake must survive 96 years after installation. Two out of 10 stakes at this retention have already failed; therefore, it seems doubtful that the difference in first quartiles of performance will truly be proportional to the increase in retention from 4.6 to 7.0 kg/m^3 (0.29 to 0.44 pcf).

With copper naphthenate **(Figs. 8** and **9),** there was a marked increase in survival time associated with the presence of a small amount of preservative. Increases in preservative retention beyond that point often do not yield a proportionate gain in quartile or median values. Of these two population parameters, the first quartile values seemed less influenced by additional preservative than did median survival time. The latter sometimes benefits from the increased retention when the quartile does not. For stakes treated with copper naphthenate in No. 2 fuel oil **(Fig. 8)** and exposed in Mississippi, there was little gain in the first quartile with retention levels greater than 0.48 kg/m^3 (0.03 pcf). Quartile values for stakes treated above that retention with copper naphthenate and exposed in Wisconsin were quite variable, with a two-fold gain in service life occurring at a three-fold increase in retention to 21.4 kg/m^3 (1.3 pcf). For those stakes treated with copper naphthenate in different carriers and exposed in Mississippi **(Fig. 9),** there seemed to be little difference in the first quartile and median values for stakes treated to a retention within a range of 0.34 to 0.52 kg/m^3 (0.02 to 0.03 pcf) elemental copper. This retention range falls just below the lower bounds of threshold values reported for copper naphthenate (9).

With zinc naphthenate **(Fig. 10),** there was very little gain in either the quartile or median failure times as retention increased from 0.18 to 0.98 kg/m^3 Zn (0.01 to 0.06 pcf). Only at a retention of 1.41 kg/m^3 Zn (0.09 pcf) was an increase observed in the first quartile and median failure times. In the Mississippi plot, the distribution of failures was not altered by the increased retention.

With the wood preservative copper formate **(Fig. 11),** the median survival time, but probably not the first quartile, of stakes treated with 0.48 kg/m^3 (0.03 pcf) elemental copper was significantly greater than that of the untreated controls. Doubling the retention of copper from 0.48 to 0.90 kg/m^3 (0.03 to 0.06 pcf) quadrupled the first quartile and median survival times. The increment in first quartile values between 0.90 and 1.92 kg/m^3 (0.06 and 0.12 pcf) copper as metal, however, was not proportionate to the two-fold increase in retention.

With copper-8-quinolinolate **(Fig. 12),** the pattern of relatively little response being associated with an increase in retention from 0.16 to 0.96 kg/m^3 appears in both a light oil (Stoddard solvent) and a heavy petroleum solvent. The addition of copper-8-quinolinolate to Stoddard solvent produced no significant gain in quartile or median values within this range of retention. At a retention of 1.92 to 1.98 kg/m^3, a marked, possibly significant, increase in both quartile and median failure times occurred.

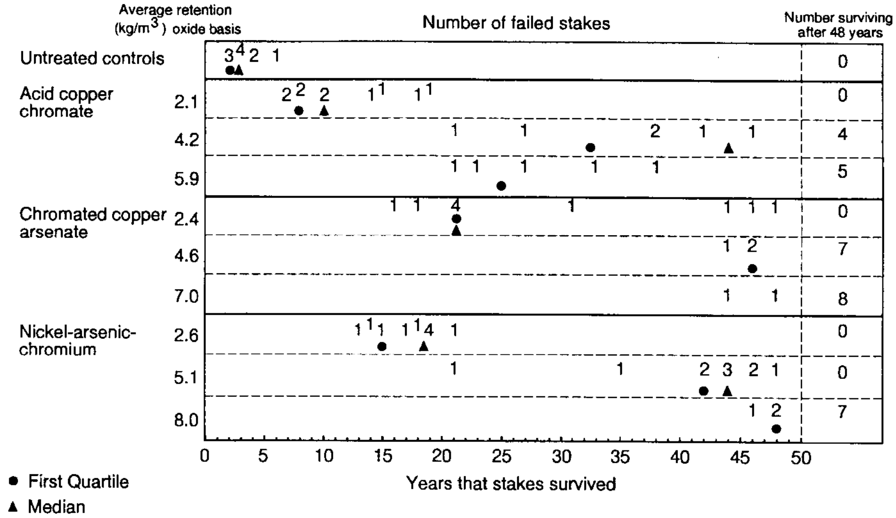

Figure 7. — Number of stakes treated with inorganic systems that failed at intervals indicated.

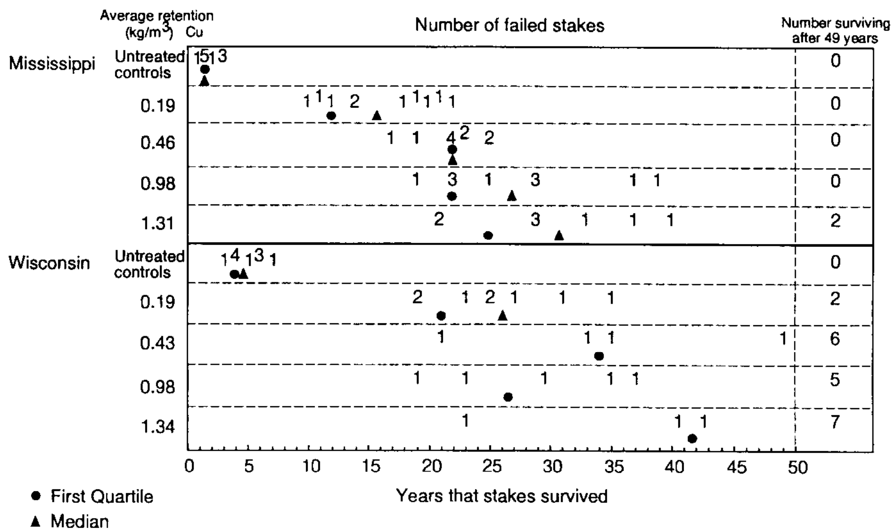

Figure 8. — Number of stakes treated with copper naphthenate in No. 2 fuel oil that failed at intervals indicated.

Discussion

Dose-response relationships in terms of increased longevity per unit increment of chemical treatment (retention) seem to be more directly linked in organic systems than in inorganic or metal-organic systems represented in our data set. This was especially true for creosote. It is this type of linkage that permitted the development of performance-based preservative specifications from test data (15).

For the inorganic systems and some metal-organic preservatives, there appears to be an upper bound to a proportionate dose-response effect in the field. Retention levels greater than those values do not yield proportionate gains in median survival time and have even less, if any, effect on increasing the longevity of the first quartile of treated members to fail.

If this ultimately proves to be an underlying principle of wood protection by these systems, then a key objective of accelerated laboratory investigations should be to define the upper limit of the dose-response curve for candidate systems.

There seems to be a pattern of minimal

effect of increased preservative retention (dose) upon increased survival time (response) of stakes treated with mobile, inorganic systems. This was most pronounced with ZC. With CZC and FCAP, this minimal dose-response effect was tempered, but not masked by differences between locations for the four preservatives that were tested in three neotropical sites and one temperate site.

The lack of a distinctive dose-response relationship with the more mobile treatments indicates that the governing factors are time or rate limited rather than dose limited. The absence of a marked difference between the temperate, drier site in Wisconsin from results in the warmer, wetter southern sites of Louisiana, Mississippi, and Florida and the fact that differences between locations in the southern United States are sometimes greater than those between the southern states and Wisconsin implies that site-specific, edaphic factors are perhaps more important than general climatic parameters. It is these factors that contribute to binding of the eluted material near the stake or govern rate of movement of leached chemical components away from the stake. Gross climatic differences would seemingly govern the rate reactions of microorganisms that degrade the wood.

If there is a relationship between performance in ground contact and performance of materials treated to comparable retention and exposed above the ground, we may infer that those past minimum retention levels for CZC and FCAP did not provide comparable protection of treated-wood products in service. Materials treated with FCAP to a minimum retention of 4.0 kg/m^3 would likely perform in ground contact for at least 10 years, with only occasional failures at some locations. In contrast, southern pine materials treated with CZC to a minimum retention of 7.2 kg/m^3 and exposed in ground contact could be expected to show some failure within 10 years (some within 2 yr.) at all locations and loss of nearly half the population in environments equivalent to that in Louisiana.

These observations lead to the question, What should be the objective of minimum standards, particularly when the growing environmental concerns are emphasizing less use of pesticides and more specific tailoring of treatments to environmental challenge?

If environmental considerations enter into the establishment of minimum standards, then the upper bounds of the dose-response relationship should weigh heavily in establishing a minimum retention. With inorganic systems, the added durability of the treated product that results from retention levels above the upper bounds of the dose-response curve is not proportionate to additional dose (retention) of preservative. Indeed, there may be little or no gain in longevity of the first percentiles of the population to fail.

Stated differently, at what retention is enough, enough? These data sets indicated that the "more is better" theory does not apply as well with inorganic or metal-organic systems as it does with organic systems. With some organic systems, increased retention may reduce variability about the median performance. However, with some metal-organic or inorganic systems, it may not be technically possible to improve the reaches of durability, expressed as duration of years in service, significantly beyond that

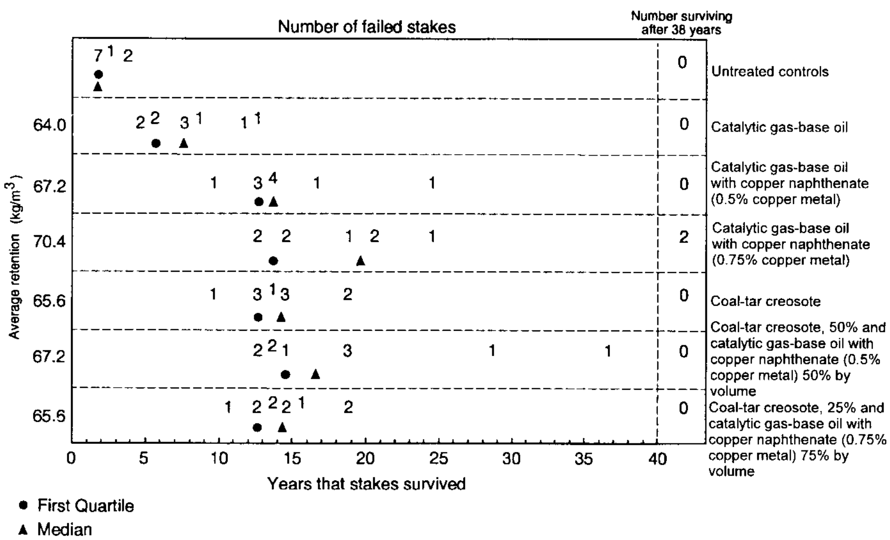

Figure 9. — Number of stakes treated with copper naphthenate in either catalytic gas-based oil or creosote that failed at intervals indicated.

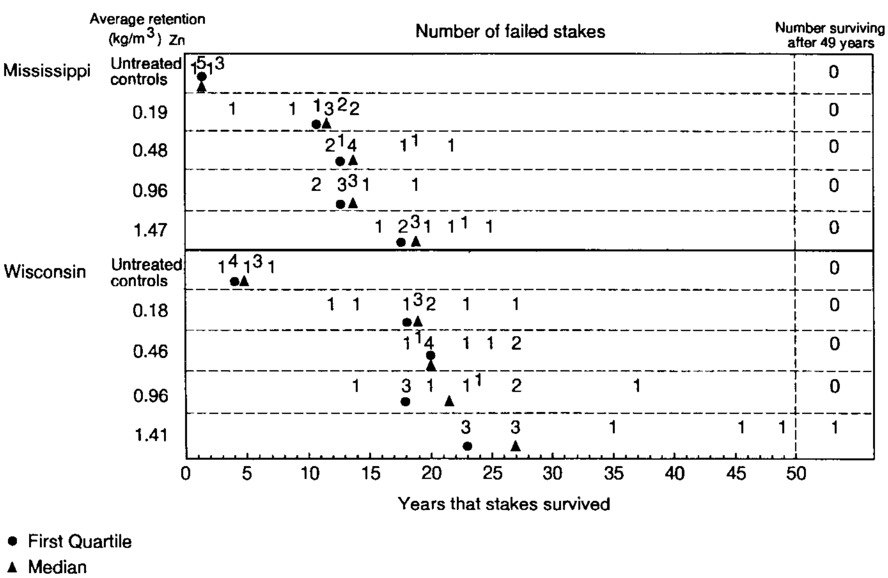

Figure 10. — Number of stakes treated with zinc naphthenate that failed at intervals indicated.

which is achieved at the upper bounds of the linear dose-response curve. To increase the retention would introduce additional chemical into the environment without increased gain in service life. This principle may explain the difference in performance of pentachlorophenol-treated stakes from copper-naphthenate-treated stakes in Florida (9). If added protection is needed, a blend of technologies may be required.

Results with stakes treated with copper-8-quinolinolate and copper formate suggest that both laboratory and field evaluations were conducted at retention levels below the range at which dose-response effects may exist. The survival times of stakes treated with copper formate were surprising, given the absence of a threshold value as determined in laboratory soil-block studies. Whether this reflects lack of exposure of the treated stakes to copper-tolerant decay fungi, over-emphasis of copper-tolerant fungi in laboratory studies, inadequate design for field evaluations, or a real effect was not determined. Nonetheless, it underscores the difficulties in predicting field performance for all types of preservative formulations from results of laboratory trials. The appearance of some dose effect in the field at a retention close to the maximum dose used in laboratory studies also raises the question whether a dose effect could have been detected in laboratory tests had the range of retention levels gone higher. Results with copper-8-quinolinolate indicated that the type of petroleum carrier can alter the absolute life span of treated stakes, but again not affect the dose-response pattern that is fundamental to this preservative system. It would seem that laboratory experimentation should be extensive enough to technically characterize dose-response relationships. Then, that characterization should shape the design of field experimentation.

These results also question whether or not field experimentation should be designed to test for differences among the initial 5 or 10 percent of the treated items that fail. Similarly, criteria that are keyed to acceptance of a candidate system that performs equivalent to some level of a "reference" treatment when the "reference" is showing some percentile of failure assumes a direct relationship between increased retention (dose) and response (longevity of treated product). That relationship should be demonstrated in laboratory testing before the assumption of its existence is implemented. If that relationship does not exist (that is, there is an upper bound to field efficacy regardless of retention), accepting a candidate preservative on the hypothesis that increased retention ensures increased performance could be fallacious.

With some of these systems, the location seemed to have more importance than did dose-response. Whether those location effects were predominantly due to differences in physical/chemical properties in the soil or unique populations of wood-destroying microflora was not determined. The soil-block, referenced in this paper, and similar laboratory tests do not give clues about potential location-dependent differences in long-term viability of the treated product. Other approaches need to be taken to gain some predictive capacity for long-term performance in different environments.

In this study, we analyzed failure times. In evaluating the performance of treated products, you should also look at patterns of change in products prior to

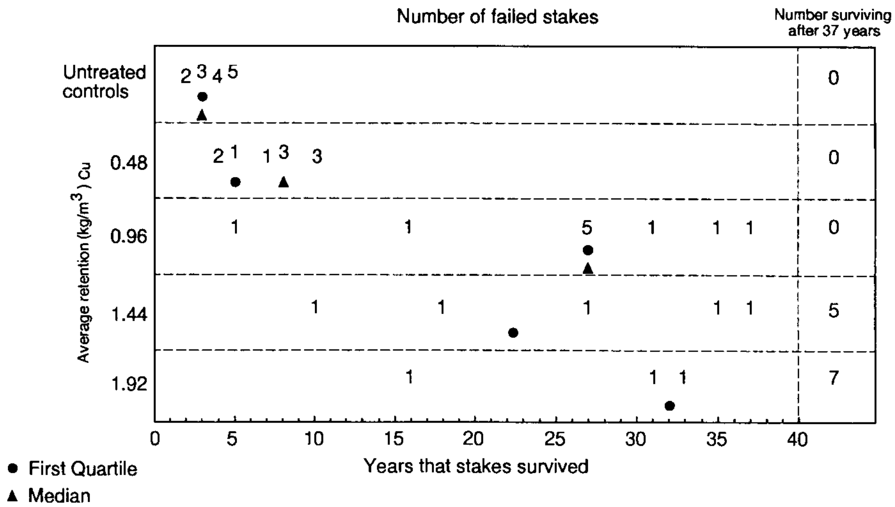

Figure 11. — Number of stakes treated with copper formate that failed at intervals indicated.

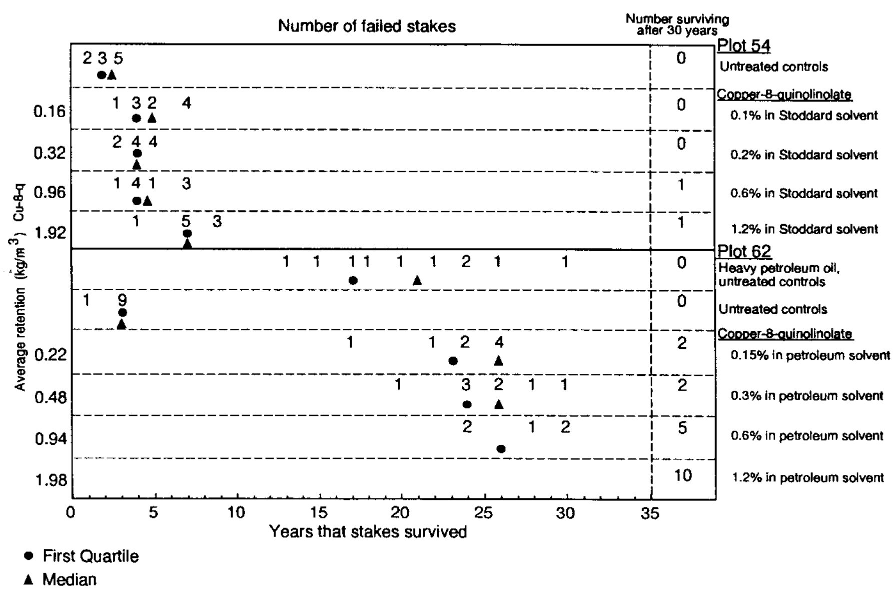

Figure 12. — Number of stakes treated with copper-8-quinolinolate that failed at intervals indicated.

absolute failure. The question as to whether products treated with similar failure distributions have similar or different degradation patterns prior to failure should also be addressed.

Conclusions

Dose-response relationships in terms of increased longevity in the field per unit increment of chemical treatment (retention) seem to be more directly linked in organic systems, especially creosote, than in inorganic systems or in organometal systems included in the data set that we analyzed. With creosote, increased retention levels increased product longevity in the field. With inorganic systems included in this analysis, we hypothesized that retention levels above a certain upper bound do not yield proportionate gains in increased durability as measured by survival times of 50- by 100- by 450-mm stakes. Retention levels greater than those values do not seem to yield proportionate gains in median survival time and have even less, if any, effect on increasing the longevity of the first quartile of treated members to fail. If this hypothesis is ultimately recognized as an underlying principle of wood protection by inorganic systems, then performance-based standards must key to the upper bounds of the dose-response relationship in developing standards that encompass both environmental and structural performance. The concept that more preservative yields more product durability will not prevail. There seems to be a pattern of minimal dose-response effect (retention-increased longevity) with mobile, inorganic preservatives.

For the metal-organic preservatives that we examined, dose-response effects in the field did not seem to follow a consistent pattern. With some, such as copper naphthenate, an upper bound of response that is little affected by increased dose seems apparent. The actual performance life of products treated with copper naphthenate seems strongly influenced by location and type of carrier used. Stakes treated with copper formate had a similar performance profile in the field. The durability of stakes treated with copper formate that was demonstrated in the field was not anticipated on the basis of soil-block tests that failed to determine a threshold value for that preservative.

We conclude that there is a need for accelerated tests that accurately predict field performance profiles of metal-organic preservatives. We also submit that an additional emphasis area of accelerated testing should be in the prediction of location effects. Location-dependent factors can have a major impact on the longevity of treated products. Singular, dose-response laboratory tests do not provide information on location effects.

We encourage others to examine their long-term data sets on field trials with treated-wood products to learn whether our observations reflect a general principle or are unique to the few data sets to which we had access.

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