Chapter 19. Initial Preservative Treatment of Wood in Covered Bridges

Introduction

The chapter provides information on treatment chemicals, pretreatment specifications, and pertinent standards that help specify wood for covered bridges that will resist biodeterioration. Wherever possible, consult the original standards to confirm that the chemicals suggested are suitable for a particular application.

Historic covered bridges were masterpieces of design that allowed untreated wood to survive for many decades. However, in most covered bridges, some members eventually succumb to decay or insect attack. This chapter discusses options for preservative treatment of the replacement members, while considering factors such as appearance, odor, durability, availability, and environmental concerns.

The basic design premise employed in covered bridges is to limit exposure to water, which is one of the essential elements for biodeterioration. All organisms capable of substantial biodegradation have four basic needs: adequate temperature, oxygen, water, and a food source. The temperature ranges for most decay organisms are broad. They survive temperatures well below freezing and above 40°C (104°F) and do best between 16 and 32°C (64.4 and 89.6°F), depending on the organism. Most wood-degrading organisms are aerobic and require oxygen, but many organisms are adapted for low-oxygen environments. As a result, few strategies for preventing decay limit oxygen or temperature.

Water is essential for nearly all fungal action. It swells wood, and at higher levels, it serves as a diffusion medium for fungal enzymes and the breakdown products they produce, and is a reactant in the processes whereby the carbohydrate components of the wood are broken into smaller fragments.

Most wood-degrading agents require that free or liquid water be present in the wood before substantial attack can occur. The point where liquid water is present is called the fiber saturation point, and, for most wood species, falls between 24 and 32 percent (water-to-wood weight ratio). Covered bridges were constructed to limit the potential for the bridge deck and superstructure to become wet enough to allow fungal attack.

Wood is usually the food source for decay (although some agents, notably carpenter ants, do not consume wood as a food source). Bridge designers have poisoned this food source, depending on naturally toxic compounds present in the heartwood of those species, or, when these chemicals are absent, adding supplemental chemicals to preserve the wood.

Decay is therefore most likely to occur on decay-susceptible wood species that are exposed where they are likely to become wet above the fiber saturation point under temperature regimes favorable for growth. One can predict the rate of decay out of direct soil contact by evaluating the number of days per month with measurable rainfall and the average monthly temperature. These data are used to construct a climate index. The Scheffer Climate Index is one example of this approach and produces values from 0 to 400 for low to extremely high decay hazards, respectively. Thus, a bridge in southern Mississippi is at much greater risk for decay than a similar structure in northern Maine. These indices are reasonably predictive for above ground exposures, but are poor predictors of wood performance in direct soil contact.

Evaluating the Need for Preservative Treatment

Preservative treatment of replacement members in covered bridges may not be necessary in bridges where the wood will not become wet or where there is no risk of insect attack, but the wood in most bridge components will last longer if it receives some type of supplemental treatment. In most environments, wood must be exposed to liquid water to accumulate enough moisture to cause decay. Even in humid climates, the moisture content of wood protected from precipitation is typically below 25 percent. Covered bridge designers were aware of this moisture content relationship and effectively used it to protect the bridge components. However, even in a covered bridge, it is difficult to protect wood from liquid water continuously, and several areas of the structure are particularly susceptible to wetting. Perhaps the most important of these are supports such as sole plates members that directly contact the ground, stone, or masonry. Other areas of exposure are the weatherboarding and members near the ends of the bridges where wind-driven precipitation can reach the interior of the structure. The risk of deterioration in a covered bridge depends upon the wood species, amount of rainfall, local temperature, and ability of various design elements to shed or exclude moisture. Thus, the risk of fungal attack on interior members not exposed to wetting will be low, while large timbers exposed to wetting can experience considerable degradation.

Decay risk also can be affected by the presence of water-trapping joints between members, bolts, or connectors that channel water into the interior, and other features that encourage water ingress. While covering a bridge deck reduces the risk of biodeterioration, it cannot completely eliminate that risk.

Perhaps the most reliable indicator of whether a replacement member should be treated with preservatives is the condition of the member being replaced. If the member being replaced had suffered biological attack, and no significant changes were made in the structure to remedy the sources of moisture for that member, then preservative treatment should be strongly considered.

Types of Deterioration

Covered bridges are primarily susceptible to attack by fungi and insects, although birds such as woodpeckers and some mammals (such as voles or porcupines) can physically damage the wood as they seek food, shelter, or nesting sites.

The fungi that attack wood are divided into five broad groups, based on the type of damage they cause. All of these fungi have life cycles that begin with simple spores that land on the wood and geminate to produce hyphae that grow into the wood, where their enzymes degrade specific components of the wood. After it obtains enough energy, the fungus produces more spores, and the cycle is repeated. Fungal spores are almost always present in the air. For example, a single fungus-fruiting structure can produce nearly one billion spores in a single day. As a result, favorable conditions for fungal attack will inevitably lead to decay.

Molds and Stains

These fungi generally grow through the ray cells, which store starches and other compounds in living trees. Stain and mold generally do not attack the structural components of the wood, and their damage is primarily cosmetic. Mold fungi produce prodigious amounts of pigmented spores on the wood surface; these can be removed by brushing. Stain fungi discolor the wood green, blue, or black with brownish pigments produced in the hyphae growing within the wood. This damage penetrates deep into the sapwood and cannot be removed by brushing.

Decay Fungi

Decay fungi all affect cellulose, hemicellulose, or lignin in the wood cell and can cause substantial reductions in material properties. The three types of attack can be distinguished based on the appearance of the decayed wood.

Soft rot fungi cause a gradual degradation from the surface inward and primarily attack cellulose and hemicellulose. These fungi are more prevalent in very wet environments, in agricultural soils, or on certain preservative treatments. In covered bridges, this damage is most likely to occur wherever bridge timbers abut locations where water can collect. Soft rot attack gradually softens the outer surface of both hardwoods and softwoods. Because the attack occurs on the surface, soft rot damage can be particularly important where members are used in bending. Because of the high moisture content, the wood may appear mushy. In general, however, soft rot damage is likely to be less common than other types of damage.

Brown rot fungi also attack both cellulose and hemicellulose, but their damage is primarily internal. These fungi are a serious concern, because they tend to rapidly break down cellulose at considerable distances from where the fungus is growing. As a result, these fungi cause substantial strength losses at very early stages of attack. Brown rot fungi tend to be more prevalent on coniferous wood species. In the early stages of decay, the wood surface lacks luster and appears dull or dead, and as the decay progresses, the wood develops a brown discoloration, with cross grain checking, collapse, or crumbling, and abnormal shrinkage. The appearance is similar to wood that has been charred. Wood that has been brown rotted and subsequently dried is sometimes mistakenly referred to as dry rotted wood. If the decay has developed within a member, it may not be readily visible, but symptoms such as crushing of the wood or excessive shrinking may be apparent.

White rot fungi use all three of the structural polymers that make up wood and, at their extreme, can cause up to 97 percent weight loss. White rot attack tends to become visible as strength effects become apparent. White rot fungi are most common on hardwoods. In the early stages of decay, the wood may have a bleached appearance, and black zone lines may appear in these lighter areas. Hardwoods suffering from white rot attack do not crack across the grain or shrink excessively like brown rotted wood, unless they are severely degraded.

In general, symptoms of fungal decay include the presence of fruiting bodies (mushroom-type growths), sunken faces or localized depressions, staining or discolorations that indicate wetting, or the presence of soil, plant growth, or moss growth.

Wood Boring Inscets

While a variety of insects can attack wood, three groups are responsible for most of the damage: powder post beetles, termites, and carpenter ants.

Powder post beetles are capable of attacking wood that is below the fiber saturation point, allowing them to attack timbers in the bridge superstructure that are protected from direct wetting.

Powder post beetles lay their eggs on the surface of untreated, noncoated sapwood of the desired species. The eggs hatch into larvae that tunnel into the wood, leaving little evidence of their presence inside the wood. The larvae tunnel extensively through the wood over periods extending for 1 to 7 or more years. After the larvae have obtained a sufficient amount of energy, they pupate to become adults. These adults then exit the wood, leaving round exit holes on the wood surface. This is often the first visible sign of an infestation. The inside of powder post-damaged wood tends to be crumbly and powdery. Prevention is easiest by applying paint or other sealing finishes to the wood.

Termites are social insects that live in large colonies organized in a caste system containing workers, soldiers, and reproductives. Three types of termites attack wood products. Dampwood termites are confined to the Pacific Northwest, where they attack very wet wood in a variety of environments. Damage from these termites is most easily controlled by eliminating the source of moisture, although preservative treatments are also effective. Where it is not possible to eliminate the source of moisture, preservative treatment remains the only option.

Subterranean termites are found in most regions of the United States below 50°N latitude and are distinguished by nests in soil contact. Native subterranean termites live in colonies up to one million workers. Although they require moisture for attack to occur, these termites can produce mud tunnels from the soil over nonwood obstacles and into wood that is not in direct soil contact. Workers then carry wet soil up the tubes, providing moisture that allows them to attack the otherwise dry wood. Subterranean termites cause an estimated $1 billion in damage per year, but their importance in some regions is likely to be overshadowed by an imported termite species, the Formosan termite (*Coptotermis farmasanus).* Although the range of this species is largely confined to major ports along the Gulf Coast as well as most of the Hawaiian islands, the voracious nature of this insect has raised concerns among many wood users. Formosan termites nest in colonies as large as five million workers. These termites attack virtually all wood species and have even been known to penetrate wood with low preservative levels. The best method for preventing termite attack in covered bridges is to use wood that has been pressure treated with preservatives.

Dry wood termites, unlike other termites, can attack very dry wood above the ground. Found primarily in the desert Southwest, these insects leave little sign of their attack and are difficult to control. Fortunately, drywood termites are not often found where covered bridges are used extensively.

Carpenter ants are also social insects with castes of workers, soldiers, and reproductives, but differ in a number of important characteristics from termites. While termites are rarely seen outside the nest, carpenters must forage outside the nest for food. Carpenter ant workers are typically dark-colored and have constrictions between the body segments, while termites are cream-colored and lack constrictions on the body. Most importantly, termites use wood as a food source, while carpenter ants do not; they mine the wood to create galleries to rear their young. This sometimes makes it difficult to control carpenter ant attacks. Carpenter ants attack wood in a variety of environments, including pressure-treated wood.

Preventing Fungal and Insect Attack

Although a variety of organisms have evolved to utilize wood for food or habitat, there are numerous strategies for preventing this damage.

Ideally, wood kept below the fiber saturation point should be free of fungal attack, but can be susceptible to powder post beetles, carpenter ants, or termites. The two approaches to limiting deterioration are to use natural durable heartwood or nondurable woods that have been supplementally protected with chemicals.

The heartwood of some native species, such as redwood, western red cedar, eastern white cedar, white oak, osage orange, and black walnut has natural durability that may be sufficient to prevent decay in moderate exposures. As the sapwood of these species dies inside a living tree, it undergoes reactions that produce a series of toxic chemicals. One must stress that it is typically only the heartwood that has enhanced durability, and that the proportion of heartwood that it is practical to achieve in a member must be a consideration. For example, although heartwood of Southern Pine species may be similar in durability to that of Douglas Fir, it is very difficult to obtain large Southern Pine timbers with a high proportion of heartwood. Conversely, larger members cut from Douglas Fir trees typically contain a high proportion of heartwood. While naturally durable heartwoods resist insect and fungal attack, the degree of resistance can vary widely from tree to tree and even within the same tree. As a result, structures of naturally durable woods can exhibit variable performance, particularly in direct soil contact. In general, naturally durable woods perform best when used above ground as decking or sheathing.

While naturally durable heartwoods remain an attractive option for some applications, many of the naturally durable species have lower structural properties that limit their usefulness in highway structures and are more costly than other species. As an alternative, the use of nondurable species supplementally protected with synthetic preservatives typically is recommended.

Methods of Preservative Treatment

Attempts to protect nondurable woods from deterioration date back thousands of years, but effective wood preservation dates to the 1830s, when John Bethell patented creosote as a preservative and the Bethell, or full cell process, for delivering it into the wood. These two patents form the foundation of the current preservation industry.

Preservation seeks to render wood either toxic to the deteriorating organisms or unrecognizable as a substrate. In either case, the goal is to deliver a specific amount of chemical (retention) to a specified depth. The depth to which the treatment penetrates depends on the wood species and its intended use. For example, penetration requirements are greater in thick sapwood species such as Southern Pine than in thin sapwood species like Douglas Fir or White Oak. These differing requirements reflect the difficulty of moving liquids through heartwood as well as the knowledge that sapwood has little decay resistance. As a result, the goal of most treatments is to protect the shell of sapwood surrounding the untreated heartwood core.

There are a variety of methods for delivering chemicals into wood. Brushing is, by far, the simplest method for providing supplemental protection, but it also produces the shallowest depth of treatment. Brush treatments typically are used to provide supplemental protection when treated wood must be cut after treatment, although there is some evidence that it also improves the performance of naturally durable woods.

Dipping in preservative is used for some wood products, including windows, door frames, and pallets. In the former two instances, the shallow protection is adequate because the wood is usually coated and protected from the weather. Pallets are relatively low-value commodities that have limited service lives, making more elaborate treatments uneconomical. Dipping is also used to treat framing lumber with borates in New Zealand. Wood is dipped in a concentrated boron solution, and then stored for 30 to 45 days to allow diffusion. This process is not widely used in North America.

In general, brushing and dipping do not adequately penetrate preservative, and they are largely relegated to supplemental protection of either naturally durable or preservative-treated woods.

The most effective methods for supplemental wood protection involve using combinations of vacuum and pressure to force chemicals into the wood. The two basic approaches to pressure impregnation are the full and empty cell processes. Both are performed in pressure vessels. The goal of these treatments is to deliver a specific weight of chemical per unit area of wood (expressed on a pounds per chemical/cubic foot of wood or kg/m^3 basis) to a specific depth.
The full cell process begins with a vacuum to remove as much air as possible from the wood, then adds solution under vacuum and raises pressure. As the vacuum is released, preservative is drawn into the wood. Increasing pressure then forces more chemical into the wood. Pressure is held until the desired solution is injected. The pressure is then released, and vacuum and heating periods recover excess solution and clean the wood surface. Full cell cycles produce maximum solution uptake in the treated zone. They are typically used to treat wood with creosote to marine retentions (very high loadings) or for water-based systems where water is a cheap solvent and treatment chemical concentrations can be adjusted to produce the desired retention.

The empty cell processes eliminate the initial vacuum and were designed to reduce the amount of treatment solution deposited in the wood (i.e., retention). When pressure is introduced. it traps and compresses a pocket of air. At the end of the process, the compressed air pocket expands, carrying excess preservative from the wood. This reduces the overall chemical loading in comparison with the full cell process. There are a number of variations on the empty cell process, but all are designed to reduce retention. Empty cell processes are widely used for treating wood in timber bridges.

Environmental Considerations for Treatment

For decades, wood users believed that more chemicals were better and that surface appearance was of little concern. Changing societal values and increasing environmental awareness have altered these concepts. It is now recognized that poor treatment practices can lead to surface bleeding of preservative, excessive leaching, and a far greater potential for environmental impact.

It is important to specify standards that allow the treater to produce an environmentally friendly product. The American Wood Preserver Association (AWPA) preservative retention standards (Use Category Standards (UC) 4 and 5) are sufficient for a long-lasting, durable product.[22] Asking the treater to increase the retention beyond these guidelines increases the amount of leachable chemicals in the wood without a noticeable service gain. Similarly, retreating wood that has failed to meet AWPA standards for initial retention increases the leachable material present. Selecting material free of surface residues is another way to assist in minimizing environmental risk. Allowing time for the use of proper treatment practices is also important. A common complaint of treaters is that customers demand the treated product on very short notice. This can cause the treater to rush or delete processing steps that improve the final product. This problem is especially relevant to post-treatment conditioning of water-based preservatives.

Post-treatment conditioning, or fixation, is necessary to reduce leaching from water-type preservatives. The active ingredients of various water-based wood preservatives (copper, chromium, arsenic, and zinc) are initially water soluble in the treating solution, but become resistant to leaching when placed into the wood. This leach resistance is a result of the chemical fixation reactions that render the toxic ingredients insoluble in water. The mechanism and requirements for these fixation reactions differ depending on the type of wood preservative. Some reactions occur very rapidly during pressure treatment, while others may take days or even weeks to reach completion, depending on post-treatment storage and processing conditions. If the treated wood is placed in service before these reactions are completed, the initial release of preservative into the environment may be many times greater than for wood that has been adequately conditioned. The AWPA has recently formed several task forces to consider the development of fixation, or leaching minimization, standards for CCA-C and other wood preservatives; however, there are currently no nationally recognized standards for fixation of waterborne preservatives in the United States.

Oil-type preservatives offer a unique difficulty, in that such preservatives sometimes bleed to the surface of the wood. This problem may be apparent immediately after treatment, but in some cases the problem does not become obvious until after the product is placed in service in a location where it is exposed to direct sunlight. The volume of preservative that bleeds out of the wood and may drip into the environment is typically quite small, but it may appear much larger if it spreads on the surface of standing water. It should be made clear that pieces with oily surfaces (or bleeders) will not be accepted when specifying wood treated with oil-type preservatives. However, bleeding is not always apparent initially, and may occur later when the wood is placed in service. This problem is best addressed by controlling treatment processes. The processes that reduce bleeding vary somewhat, depending on the type of preservative. The treaters also typically use a combination of these processes to obtain a clean surface. Some of the key steps include maintaining clean facilities and working solutions, avoiding over-treatment, and using post-treatment conditioning techniques such as final vacuum, steaming, and expansion baths.

Construction practices can also make a difference in preservative released into the environment. Treated material shipped to the job site should always be stored free from standing water and wet soil, and protected from precipitation. Field fabrication of treated wood that cannot be handled before applying treatment should be done carefully. Construction debris like sawdust has a disproportionately high surface-area-to-volume ratio, leaching more chemicals into water. Taking practical steps to collect such debris can minimize the threat.

In some regions of the country, the industry has responded to environmental concerns by developing a series of best management practices (BMPs) designed to fix or immobilize preservative, produce retentions that are reasonably close to the target, and reduce the risk of bleeding from the finished product. While BMPs are not mandatory, their use is highly recommended for any treated wood used over or in water. Where applicable, descriptions of appropriate BMPs are included for the preservatives discussed in this chapter.

Treatment Specifications

The primary standards for pressure treatment of wood in the United States are promulgated by AWPA, which are widely referenced in the AASHTO standards. Founded in 1904, the AWPA is a consensus standards-writing body consisting of wood treaters, chemical suppliers, and general interest members. The primary objective of the AWPA standards is to protect the consumer or user of treated wood products.

The AWPA standards specify treatments according to the risk of decay and the commodity. Thus, for the same decay hazard, specifications will be far more rigorous for a bridge timber than for a fence post. In addition, the standards recognize regional differences in wood species employed. Covered bridge designers have always experienced difficulties in using the AWPA standards because of requirements to incise some difficult-to-treat species and the lack of nonpigmented preservatives for many applications.

While it may occasionally be necessary to refer beyond the AWPA standards, the goal of these standards is to assist designers in specifying properly protected wood without compromising the aesthetics of the finished product.

AWPA standards are considered to be minimums for chemical loading and penetration. Specifications may be made more rigorous; however, it should be clear that the intended change and the associated costs truly improve reliability. In addition, the AWPA standards are results-oriented; within specific process limitations, the method for achieving the desired retention and penetration is largely left to the treater.

Methods for improving Performance of Treated Wood

The performance of treated wood is largely a function of the initial treatment quality. The primary goal of treatment is to produce an envelope of protection around the untreated core. Any damage to this treated shell opens the interior to possible fungal or insect attack. These openings can be created naturally through the development of seasoning checks that extend beyond the original depth of treatment, or they can originate from damage due to cutting, notching, or drilling a member after treatment.

To limit the risk of these problems, the wood should be seasoned before treatment. This helps ensure that checks have already formed and creates a better treatment envelope. However, seasoning to in-service conditions is generally not practical. Most large timbers are treated while their core moisture contents are above 30 percent, a practice that guarantees the development of some post-treatment checking. Wherever possible, simple practices such as placing the member so that the largest check faces down in a structure can reduce the risk of wetting through checks.

It is nearly impossible to completely eliminate the need for onsite fabrication; however, a majority of cutting and drilling can be done before treatment. In cases where holes must be redrilled because of twisting or slight misalignments, application of preservative to the freshly exposed wood is recommended.

In addition to drying and precutting/boring, preservative penetration can be improved in many species by incising, a process that drives metal teeth 15.2 to 19 mm (0.6 to 0.75 inches) into the wood. Incising opens the wood to flow and improves treatment to the depth of the incisions. Incising is required to effective treat many thin sapwood conifers as well as many hardwoods. While it reduces strength (up to 15-20 percent on 2 by 4s), the effect is reduced as timber size increases, and any losses are more than offset by the improved performance of the treated wood.

In some instances, even for historic structures, it may be more advantageous to substitute engineered wood products or smaller sizes of timber that are either less likely to check or be treated evenly. A large timber is aesthetically pleasing, but it is far more prone to checking and has a proportionally smaller treated area than several smaller timbers bolted together. The smaller timbers will be better treated and are less likely to develop deep checks. Similarly, substituting glue-laminated beams or laminated veneer lumber can produce products that are less likely to check in-service because they are thoroughly dried before treatment. Clearly, these products must be used carefully to retain the historic character of the bridge, but they offer considerable advantages with regard to treatment characteristics.

Preservative Chemicals

Wood preservatives are generally classified or grouped by the type of application or exposure environment in which they are expected to provide long-term protection. Some preservatives have sufficient leach resistance and broad spectrum efficacy to protect wood that is exposed directly to soil and water. These preservatives also will protect wood exposed above ground, and may be used in those applications at lower retentions (concentrations in the wood). Other preservatives have intermediate toxicity or leach resistance that allows them to protect wood fully exposed to the weather, but not in contact with the ground. Still other preservatives lack the permanence or toxicity to withstand continued exposure to precipitation, but may be effective with occasional wetting. Finally, there are formulations that are readily leachable to the extent that they can only withstand very occasional, superficial wetting. It is not possible to evaluate a preservative's long-term efficacy in all types of exposure environments, and there is no set formula for predicting exactly how long a wood preservative will perform in a specific application. This is especially true for above-ground applications, because preservatives are tested most extensively in ground contact. To compensate for this uncertainty, the tendency is to be conservative in selecting a preservative for a particular application.

Preservatives are also classified by their solubility in either water- or oil-type solvents. This classification is not always absolute, because some preservatives can be formulated to be used with either type of solvent. Water-based preservatives often include some type of cosolvent, such as amine or ammonia, to keep one or more of the active ingredients in solution. Each solvent has advantages and disadvantages depending on the application.

Oil-type systems are among our oldest and most effective preservatives. These systems are usually used in medium to heavy oils that leave the wood surface a dark brown color, although some lighter solvents can minimize color changes. Oil-based systems are widely believed to experience reduced checking and splitting, although this is often difficult to document. Oil-based systems have provided excellent protection in a number of highway applications and are compatible with most wood species. These systems can be very difficult to paint or stain because the initial oil preservative can migrate through or discolor the coating. The use of more volatile solvents can reduce this problem.

Water-based preservatives are often used when cleanliness and paintability of the treated wood are required. Wood treated with water-based preservatives also typically has less odor than wood treated with some types of oil-based preservatives. However, unless supplemented with a water repellent, the water-based systems do not confer dimensional stability to the treated wood. In addition, water-based preservatives that use copper as a fungicide may not adequately protect hardwood species under conditions that favor soft rot attack. (As mentioned above, the high moisture levels needed to promote soft rot attack are unlikely to occur in covered bridge components.) Some water-based preservatives may increase the rate of corrosion of mild steel fasteners. The most widely used waterborne treatment is a mixture of chromic acid, cupric oxide, and arsenic pentaoxide, called chromated copper arsenate (CCA). Developed in India in the 1930s, CCA is used to impregnate 60 percent of the wood treated in the United States. CCA is strongly fixed to the wood and has provided excellent protection in a variety of environments. The primary drawbacks to CCA are those associated with any heavy metal preservatives. While CCA is fixed, small amounts of copper and arsenic are continually solubilized, and those losses have raised environmental concerns. Over the past 10 years, a variety of alternative chromium and/or arsenic-free systems have been developed, but none has had the cost and performance advantages of CCA. As a result, alternatives such as ammoniacal copper quat, ammoniacal copper zinc arsenate, and copper azole have relatively small U.S. markets. It is also notable that all of the recently standardized CCA alternatives contain, and appear to leach, much higher levels of copper than does CCA. Thus, it is probably advisable to use available aquatic models to assess the risk of copper leaching where invertebrate fish may be sensitive to copper concentrations in water and sediment. However, these alternative treatments are available commercially and may be appropriate where CCA is not considered to be suitable.

Each preservative also has many unique characteristics that might affect its suitability for a particular application. These include factors such as appearance, odor, toxicity, wood species compatibility, and availability. All of the preservatives mentioned in the sections below are registered with the U.S. Environmental Protection Agency (EPA) for use as wood preservatives.

In some instances, the preservative may be classified as a restricted-use pesticide, meaning that the applicator must be licensed by the appropriate State agency to apply chemicals. The use of preservative treated wood, however, does not require a license, even if the treatment chemical is classified as a restricted-use pesticide.

Preservatives That Are Effective in High-Decay Hazard Applications

These preservatives exhibit sufficient toxicity and leach resistance to protect wood in contact with the ground or in other high-moisture, high-deterioration hazard applications. In bridges, these types of applications may include sole plates resting on piers or wooden members that directly contact footings in abutments or approaches. Preservatives listed in this section are also effective in preventing decay in other, less severe exposures.

Water-Based Preservatives

Acid Copper Chromate (ACC)-Acid copper chromate (ACC) has been used as a wood preservative in Europe and the United States since the 1920s. ACC contains 31.8 percent copper oxide and 68.2 percent chromium trioxide. The treated wood has a light greenish-brown color, and little noticeable odor. Tests on stakes and posts exposed to decay and termite attack indicate that wood impregnated with ACC gives acceptable service, although it may be susceptible to attack by some species of copper tolerant fungi. It is listed in AWPA standards for a wide range of softwood and hardwood species, with a minimum retention of 4.0 or 8.0 kg/m^3 (0.25 lbs/ft^3 or 0.5 lbs/ft^3) for wood used above ground or in ground contact, respectively. However, in critical structural applications such as highway construction, its AWPA listings are limited to sign posts, handrails, guardrails, and glulam beams used above ground. It may be difficult to obtain adequate penetration of ACC in some of the more refractory wood species such as White Oak or Douglas Fir. This is because ACC must be used at relatively low treating temperatures (38°C to 66°C (100°F to 150°F)), and because rapid reactions of chromium in the wood can hinder further penetration during longer pressure periods. The high chromium content of ACC, however, has the benefit of preventing much of the corrosion that might otherwise occur with an acidic copper preservative. Only a limited number of treatment facilities use ACC, primarily for treating wood used in cooling towers.

ACC does not contain arsenic and thus may offer environmental and handling advantages in some applications. The treatment solution does utilize hexavalent chromium, but the chromium is converted to the more benign trivalent state during treatment and subsequent storage of the wood. This process of chromium reduction is the basis for fixation in ACC, and is dependent on time, temperature, and moisture. Fixation standards or BMPs have not yet been developed for ACC, because of its relatively low usage. As a general guide, the fixation considerations discussed for CCA (see below) can be applied to ACC.

Ammoniacal Copper Citrate (CC)-Ammoniacal copper citrate (CC) is a wood preservative that uses copper oxide (62 percent) as the fungicide and insecticide, and citric acid (38 percent) to help distribute copper within the wood structure. The color of the treated wood vanes from light green to dark brown. The wood may have a slight ammonia odor until it is thoroughly dried after treatment. Exposure tests with stakes and posts placed in ground contact indicate that the treated wood resists attack by both fungi and insects. However, it is possible that the lack of a cobiocide may render the wood vulnerable to attack by certain species of copper-tolerant fungi. CC is listed in AWPA standards for treating a range of softwood species and wood products. The minimum CC retention is 4.0 and 8.0 kg/m^3 (0.25 and 0.4 lb/ft^3) for wood used above ground or in ground contact, respectively. CC is not listed in AWPA standards for use in highway construction or other structurally critical applications (the AWPA standards typically employ higher preservative loadings for highway construction in consideration of the need for a higher level of reliability than might be required for fence). As with other preservatives containing ammonia, CC has an increased ability to penetrate into difficult-to-treat wood species such as Douglas Fir. The CC treatment can accelerate corrosion in comparison to untreated wood, necessitating the use of hot-dipped galvanized or stainless steel fasteners. Few treating plants currently use CC, and wood treated with this product may not be readily available in most areas.

CC does not contain arsenic or chromium, and thus may offer environmental or safety advantages in some situations. The copper is solubilized by the ammonia in the treating solution, and becomes insoluble (fixed) as the ammonia volatilizes from the wood. Wood treated with CC should not be exposed to precipitation or other sources of environmental moisture until this fixation process is complete. This time period varies with temperature. If the wood arrives at the job site appearing heavy, wet, and with a strong ammonia odor, it may not be thoroughly fixed. Fixation can be ensured by placing sticks between courses of the wood (stickering) and placing it in an area with good air flow to facilitate drying. Although the wood should be covered to protect it from precipitation, it should not be covered in a way that impedes air circulation until after it has dried and the ammonia odor has dissipated. There currently are no fixation standards or BMPs to ensure fixation in CC-treated wood. However, the BMPs developed by the Western Wood Preservers Institute (WWPI) for ammoniacal copper zinc arsenate (ACZA)-treated wood are applicable (see below).[25]

Alkaline Copper Quat (ACQ) – Alkalinecopper quat (ACQ) is one of several wood preservatives that has been developed in recent years because of environmental or safety concerns with CCA. The fungicides and insecticides in ACQ are copper oxide (67 percent) and a quaternary ammonium compound (quat). Multiple variations of ACQ have been standardized or are in the process of standardization. ACQ type B (ACQ-B) is an ammoniacal copper formulation, ACQ type D (ACQ-D) is an amine copper formulation, and ACQ type C (ACQ-C) is a combined ammoniacal-amine formulation with a slightly different quat compound. ACQ-B-treated wood has a dark greenish-brown color that fades to a lighter brown, and may have a slight ammonia odor until the wood dries. Wood treated with ACQ-D has a light brown color and little noticeable odor, while wood treated with ACQ-C varies in appearance between that of ACQ-B and ACQ-D, depending on the formulation. Stakes treated with these three formulations have demonstrated efficacy against decay fungi and insects when exposed in ground contact. The ACQ formulations are listed in AWPA standards for a range of applications and many softwood species, although the ACQ-C listings are limited because it is the most recently standardized. Minimum retentions of 4.0, 6.4, or 9.6 kg/m^3 (0.25, 0.4 or 0.6 lbs/ft^3) are specified for wood used above ground, in ground contact, or for highway construction, respectively. The multiple formulations of ACQ allow some flexibility in achieving compatibility with a specific wood species and application. When ammonia is used as the carrier, ACQ has improved ability to penetrate into difficult-to-treat wood species. However, if the wood species is readily treated, such as Southern Pine, an amine carrier can be used to provide a more uniform surface appearance. All of the ACQ treatments accelerate corrosion of metal fasteners relative to untreated wood, and hot-dipped galvanized or stainless steel fasteners are a necessity. The number of pressure treatment facilities using ACQ is increasing. In the western United States, the ACQ-B formulation is used because it allows better penetration in difficult-to-treat western species. Treating plants in the rest of the country generally use the ACQ-D formulation. Researchers are currently evaluating the performance of a secondary highway bridge constructed from ACQ-D-treated Southern Pine lumber.[26] Use of the more recently standardized ACQ-C formulation is expected to increase in both parts of the country.

ACQ-treated wood does not contain arsenic or chromium, and thus may offer handling and environmental advantages in some applications. ACQ-treated wood contains copper, which can be of concern in aquatic environments. The release and environmental impact of copper from ACQ-B-treated wood was recently evaluated in a wetland boardwalk study.[23] Soil and sediment samples removed from within a few feet of the boardwalk did contain elevated levels of copper, but there was no measurable impact on either the number or diversity of aquatic invertebrates adjacent to the structure. Specific standards or BMPs for fixation of ACQ are not yet available, although it is likely that the BMPs developed for ACZA (see below) could be applied to wood treated with ACQ-B.

Ammoniacal Copperzinc Arsenate (ACZA) – Ammoniacalcopper zinc arsenate (ACZA) contains copper oxide (50 percent), zinc oxide (25 percent), and arsenic pentoxide (25 percent). ACZA is a refinement of an earlier formulation, ACA, that is no longer available in the United States. The color of the treated wood varies from olive to bluish green. The wood may have a slight ammonia odor until it is thoroughly dried after treatment. ACZA is an established preservative that protects wood from decay and insect attack in a wide range of exposures and applications. It has also protected stakes and posts placed in ground contact in exposure tests. ACZA is listed in AWPA standards for treating a range of softwood and hardwood species and wood products. The minimum ACZA retention is 4.0 or 6.4 kg/m^3 (0.25 and 0.4 lb/ft^3) for wood used above ground or in ground contact, respectively. A slightly higher retention (9.6 kg/m^3 or 0.6 lb/ft^3) is required for wood used in highway construction and for critical structural components used in high decay hazard exposures. The ammonia in the treating solution, in combination with processing techniques such as steaming and extended pressure periods, allow ACZA to obtain better penetration of difficult-to-treat wood species than many other water-based wood preservatives. ACZA is frequently used in the western United States for treating the Douglas Fir lumber and timbers used in construction of secondary highway bridges, trail bridges, and boardwalks. The ACZA treatment can accelerate corrosion in comparison to untreated wood, requiring the use of hot-dipped galvanized or stainless steel fasteners. Treatment facilities using ACZA are currently located in western States, where many of the native tree species are difficult to treat with CCA.

ACZA does contain inorganic arsenic, and is classified as a restricted-use pesticide by the EPA. Producers of treated wood, in cooperation with the EPA, have created Consumer Information Sheets (CIS) that give guidance on appropriate handling and use site precautions for wood treated with inorganic arsenic. These CIS should be made available to all personnel involved in handling ACZA-treated wood. The CIS limitations on the uses of ACZA-treated wood do not affect covered bridges. The environmental impact of ACZA-treated wood in sensitive environments has been evaluated. One study found that soil and sediment samples removed from directly under a large ACZA-treated elevated walkway had elevated levels of copper, zinc, and arsenic.[23] However, samples removed at greater distances were not elevated, and there was no detectable impact on either the number or diversity of aquatic invertebrates adjacent to the structure. Another study found only occasional elevated samples, even immediately under the dripline of a wetland boardwalk.[26]

As with all water-based preservatives, the safety and environmental compatibility of the treated wood depends on completion of fixation reactions to reduce the solubility of preservative components. In ACZA, the copper and zinc are solubilized by the ammonia in the treating solution, and become insoluble as the ammonia volatilizes from the wood. As the copper and zinc precipitate, they form insoluble zinc arsenates or copper arsenates within the wood, Wood treated with ACZA should not be exposed to precipitation or other sources of environmental moisture until this fixation process is complete. The WWPI has developed BMP processing guidelines to help ensure that ACZA-treated wood is fixed before it leaves the treating plant. These BMPs specify that the treated wood either be air dried for three weeks at a temperature above 16°C (60°F) or kiln dried to below 30 percent moisture content. The air drying time may be shortened if an in-cylinder ammonia removal step is incorporated into the treatment cycle. If the wood arrives at the job site appearing heavy, wet, and with a strong ammonia odor, it may not be thoroughly fixed. Fixation can be ensured by stickering the material and placing it in an area with good air flow. Although the wood should be covered to protect it from precipitation, it should not be covered in a way that impedes air circulation until after it has dried and the ammonia odor has dissipated.

Chromated Copper Arsenate (CCA) – Chromated copper arsenate (CCA) is the most commonly used of all wood preservatives, and until very recently represented more than 90 percent of the sales of waterborne wood preservatives. CCA-treated wood is commonly sold at retail lumber yards as green-treated wood, although most residential applications were withdrawn from the market at the end of 2003. However, it will still be allowed in nonresidential applications such as highway construction. CCA-treated wood has no odor, and as suggested by its common name, a light green color. However, it is often sold with commercially applied dyes or stains to give the wood more of a brown appearance. There are three standardized formulations of CCA: CCA Type A, CCA Type B, and CCA Type C. However, CCA Type C (CCA-C) is the formulation used by nearly all treating facilities because of its leach resistance and demonstrated efficacy. CCA-C is comprised of 47.5 percent chromium trioxide, 18.5 percent copper oxide, and 34.0 percent arsenic pentoxide dissolved in water. CCA-C has decades of proven performance in field trials and in-service applications. In accelerated testing, it is the reference preservative used to evaluate the performance of other waterborne wood preservatives. Because it has been so widely used for many years, CCA-C is listed in AWPA standards for a wide range of wood products and applications. The minimum retention of CCA-C in the wood is 4.0, 6.4, or 9.6 kg/m^3 (0.25, 0.40, or 0.60 lbs/ft^3) for above ground, ground contact, and critical structural applications, respectively. As with ACC, it may be difficult to obtain adequate penetration of CCA in some difficult-to-treat wood species. Temperature limitations during treatment and rapid reaction of chromium within the wood structure can hinder penetration during longer pressure periods. However, the chromium does serve as a corrosion inhibitor, and corrosion of fasteners in CCA-treated wood is not as much a concern as it can be with some of the chromium-free alternative preservatives. Treating facilities that use CCA are widespread within the United States, making it the most readily available of all preservatives.

CCA does contain inorganic arsenic, and is classified as a restricted-use pesticide by the EPA. Producers of treated wood, in cooperation with the EPA, have created CIS that give guidance on appropriate handling and use site precautions for wood treated with inorganic arsenic. These CIS should be made available to all personnel involved in handling CCA-treated wood. The CIS limitations placed on the uses of CCA-treated wood do not impact covered bridges. The environmental impact of CCA-treated wood has been evaluated in two timber bridges in Florida.[25] In some cases, samples removed from under the bridge did have evaluated levels of copper or chromium or arsenic, but there was no detectable effect on aquatic invertebrate populations. Similar results were found in an evaluation of the environmental impact of CCA-treated wood used in construction of a wetland boardwalk.[23] CCA may offer an advantage over the newer alternative preservatives for use in aquatic environments, because the treated wood contains and leaches less copper. Although arsenic raises concerns as a toxin for mammals, copper may be more of a concern for fish and aquatic invertebrates.[23]

As with other water-based preservatives, the risk of chemical exposure from CCA-treated wood is minimized after chemical fixation reactions to lock the chemical in the wood. The CCA treating solution contains hexavalent chromium, but the chromium reduces to the less toxic trivalent state within the wood. This process of chromium reduction is also critical in fixing the arsenic and copper in the wood, and CCA-treated wood should not be exposed to precipitation or other sources of environmental moisture until this fixation process is complete or nearly complete. The rate of fixation of CCA is highly temperature-dependent, requiring only a few hours at 66°C (150°F), but weeks or even months at temperatures below 16°C (60°F). Because of this temperature relationship, some treating facilities use kilns, steam, or hot water baths to accelerate fixation. An AWPA test method, the chromotropic acid test, can be used to determine if fixation in CCA-treated wood is complete.[20] There is some concern that the chromotropic acid test may be overly conservative because it requires more than 99.5 percent of the chromium to be reduced to the trivalent form. However, it is currently the only standardized test available, and is specified in the BMPs developed by the WWPI.[21]

Copper Azole (CBA and CA-B)-Copper azole is another recently developed preservative formulation that relies primarily on amine copper, but with cobiocides, to protect wood from decay and insect attack. The first copper azole formulation developed was copper azole-Type A (CBA-A), which contains 49 percent copper, 49 percent boric acid, and 2 percent tebuconazole. More recently, the copper azole-Type B (CA-B) formulation was standardized. CA-B does not contain boric acid, and is comprised of 96 percent copper and 4 percent Tebuconazole. Wood treated with either copper azole formulation has a greenish-brown color and little or no odor. The copper azole formulations have been evaluated with in-ground stake tests and found to protect wood against attack by decay fungi and insects. The formulations are listed in AWPA standards for treatment of a range of softwood species. Minimum retentions of CBA-A in the wood are 5.28, 6.56, or 9.76 kg/m^3 (3.3, 0.41, or 0.61 lb/ft^3) for wood used above ground, in ground contact, or in critical structural components, respectively. Minimum retentions of CA-B in the wood are 1.6, 3.2, or 4.96 kg/m^3 (0.10, 0.21, or 0.31 lb/ft^3) for wood used above ground, in ground contact, or in critical structural components, respectively. Although listed as an amine formulation, copper azole may also be formulated with an amine-ammonia formulation. The ammonia may be included when the copper azole formulations are used to treat refractory species, and the ability of such a formulation to adequately treat Douglas Fir has been demonstrated. The inclusion of the ammonia, however, is likely to have slight effects on the surface appearance and initial odor of the treated wood. The copper azole treatments do increase the rate of corrosion of metal fasteners relative to untreated wood, and hot-dipped galvanized or stainless steel fasteners are recommended. Because copper azole has been developed only recently, relatively few treating facilities are currently using this preservative.

The copper azole formulations do not contain arsenic or chromium, and thus may offer environmental or safety advantages in some applications. Copper azole-treated wood does contain copper, which can be of concern in aquatic environments. Proper handling and post-treatment conditioning of copper azole-treated wood is important to ensure that leaching and potential environmental impacts are minimized. The copper is solubilized in the treating solution by the presence of the amine (and in some cases ammonia). The mechanism of copper fixation in the wood is not completely understood, but appears to be strongly influenced by time, temperature, and retention. Copper fixation in the CBA-A formulation is extremely rapid (within 24 hours) at the lowest retention 3.36 kg/m^3 (0.21 lb/ft^3), but slows considerably at the higher retentions unless heat is used to accelerate the fixation. As with other waterborne preservative formulations, the treated wood should not be exposed to precipitation or other sources of water until these fixation reactions are complete. Specific standards or BMPs for fixation of copper azole are not yet available.

Oil-Type Preservatives

Coal-Tar Creosote–Coal-tar creosote is the oldest wood preservative still in commercial use in the United States. It is made by distilling the coal tar that is obtained after high-temperature carbonization of coal. Unlike the other oil-type preservatives, creosote is not usually dissolved in oil, but it does have properties that make it look and feel oily. Creosote contains a chemically complex mixture of organic molecules, most of which are polycyclic aromatic hydrocarbons (PAHs). The composition of creosote depends on the method of distillation and is somewhat variable. However, the small differences in composition within modern creosotes do not affect its performance as a wood preservative. Creosote-treated wood has a dark brown to black color and a noticeable odor, which some people consider unpleasant. It is very difficult to paint creosote- treated wood. Workers sometimes object to creosote-treated wood because it soils their clothes and photosensitizes the skin on contact. The treated wood sometimes also has an oily surface, and patches of creosote sometimes accumulate, creating a skin contact hazard. Because of these concerns, creosote-treated wood is often not the first choice for applications such as handrails, where there is a high probability of human contact. This is a serious consideration for members in covered bridges that are readily accessible to the public.

However, creosote-treated wood has advantages to offset concerns about its appearance and odor. It has a lengthy record of satisfactory use in a wide range of applications, and a relatively low cost. Creosote is also effective in protecting both hardwoods and softwoods, and is often thought to improve the dimensional stability of the treated wood. Creosote is listed in AWPA standards for a wide range of wood products and wood species. Minimum creosote retentions are in the range of 80 to 128 kg/m^3 (5 to 8 lb/ft^3) for above-ground applications, 160 kg/m^3 (10 lb/ft^3) for wood used in ground contact, and 192 kg/m^3 (12 lb/ft^3) for wood used in critical structural applications such as highway construction. With the use of heated solutions and lengthy pressure periods, creosote can be fairly effective at penetrating even fairly difficult-to-treat wood species. Like other oil-type systems, creosote is suitable for treatment of glue-laminated members. Creosote treatment also does not accelerate, and may even inhibit, the rate of corrosion of metal fasteners relative to untreated wood. Treating facilities using creosote are widely distributed in the United States, making it one of the more readily available preservative treatments.

Creosote is classified as a restricted-use pesticide by the EPA. Producers of treated wood, in cooperation with the EPA, have created CIS that give guidance on appropriate handling and use site precautions for wood treated with creosote. These CIS should be made available to all personnel involved in handling creosote-treated wood. People are sometimes concerned that creosote-treated wood used in aquatic applications, such as bridges, may harm the environment. This concern recently was evaluated in a study of the environmental impact of two creosote-treated wooden bridges in Indiana[27] In each case, elevated levels of PAH were detected in sediments 1.8 to 3 m (6 to 10 ft) downstream from the bridges, and these levels approached levels of concern for one bridge. However, no significant effect on aquatic invertebrate populations was noted for that bridge. There did appear to be a reduction in the population and diversity of aquatic insects within 6 m (20 ft) downstream for the other bridge, but the author postulated that this trend was caused by the deposition of maple leaves in this area.

As with other preservatives, the environmental impact of creosote-treated wood is a function of treatment practices. Creosote in treated wood may sometimes bleed or ooze to the surface and drip to surfaces or the water below. This problem may be apparent immediately after treatment, and such members should not be used in bridges or other aquatic applications. However, in other cases, the problem does not become obvious until after the product is placed in service in a location where it is exposed to direct sunlight. This problem is best addressed through the control of treatment processes and BMPs. The WWPI's BMPs for creosote-treated wood call for the use of either an expansion bath or final steaming at the end of the pressure period:

- Expansion Bath: Following the pressure period, the creosote should be heated -12.2 to 46°C (10-20°F) above press temperatures for a minimum of 1 hour. Pump creosote back to storage and apply a minimum vacuum of 609 mm (24 inches) for a minimum of 2 hours.

- Steaming: Following the pressure period and after the creosote has been pumped back to the storage tank, a vacuum shall be applied for a minimum of 2 hours at not less than 559 mm (22 inches) of vacuum to recover excess preservative. Release vacuum back to atmospheric pressure and steam for a 2-hour period for lumber and timbers, and 3 hours for piling. Maximum temperature during this process shall not exceed 11.55°C (240°F). Apply a second vacuum for a minimum of 4 hours at 559 mm (22 inches) of vacuum.

Pentachlorophenolin Heavy Oil-Pentachchlorophenol has been widely used as a pressure treatment preservative in the United States since the 1940s. The active ingredients, chlorinated phenols, are crystalline solids that can be dissolved in different types of organic solvents. The performance of pentachlorophenol and the properties of the treated wood are influenced by the properties of the solvent. The heavy oil solvent, as specified in AWPA Standard P9, Type A, is preferable when the treated wood is to be used in ground contact, as wood treated with lighter solvents may not be as durable. Wood treated with pentachlorphenol in heavy oil typically has a brown color, and may have a slightly oily surface that is difficult to paint. It also has some odor, which is associated with the solvent. Like creosote, pentachlorophenol in heavy oil should not be used in applications where there is likely to be frequent contact with skin (i.e., handrails). Pentachlorophenol in heavy oil has long been a popular choice for treatment of utility poles, bridge timbers, and glue-laminated beams and foundation piling, and has established its efficacy as a wood preservative. Like creosote, it is effective in protecting both hardwoods and softwoods, and is often thought to improve the dimensional stability of the treated wood. Pentachlorophenol is listed in AWPA standards for a wide range of wood products and wood species. The minimum softwood retentions are 6.4 kg/m^3 (0.4 Ib/ft^3) for wood used above ground or in ground contact, and 8.0 kg/m^3 (0.5 Ib/ft^3) for wood used in severe decay hazard exposures or critical structural applications. Slightly lower minimum retentions 4.0 or 4.8 kg/m^3 (0.25 to 0.3 Ib/ft^3) are specified for treatment of red oak. With the use of heated solutions and extended pressure periods, pentachlorphenol is fairly effective at penetrating difficult-to-treat species. It does not accelerate corrosion of metal fasteners relative to untreated wood, and the heavy oil solvent helps to impart some water repellence to the treated wood. Treating facilities in many areas of the United States use pentachlorphenol in heavy oil, making it one of the most readily available wood preservatives.

Pentachlorophenol is classified as a restricted-use pesticide by the EPA. Producers of treated wood, in cooperation with the EPA, have created CIS that give guidance on appropriate handling and use-site precautions for wood treated with pentachlorphenol. These CIS should be made available to all personnel involved in handling pentachlorophenol-treated wood. People are sometimes concerned that pentachlorophenol-treated wood used in aquatic applications, such as bridges, may harm the environment. To evaluate this concern, Brooks evaluated the environmental impact of two pentachlorophenol-treated bridges in Washington and Oregon.[25] Sediment concentrations of pentachlorophenol were near or below detection limits at the bridge in Washington State, and well below levels of concern. Slightly elevated levels of pentachlorophenol were detected in four sediment samples removed under or downstream from the Oregon bridge, and a small decrease in several biological indices was also noted. However, these changes appeared to be caused by differences in the stream bottom habitat relative to the upstream control.

As with other preservatives, the environmental impact of pentachlorophenol-treated wood is a function of treatment practices. When used with a heavy oil solvent, pentachlorophenol-treated wood may have bleeding or surface oil problems similar to that described for creosote. Any member that has an excessively oily surface or is bleeding pentachlorophenol should not be used. Treatment procedures that are likely to minimize bleeding after the member is placed in service should also be specified. The BMPs developed by WWPI for pentachlorophenol treatment stress thorough drying of the wood before treatment and the use of an empty cell treatment process. In an empty cell process, the air pressure is applied to the wood before the preservative is introduced to the treatment cylinder. Following the pressure period, a final vacuum should be incorporated, as well as either a final steaming or expansion bath similar to that described for creosote treatments.

Copper Naphthenate-The preservative efficacy of copper naphthenate has been known since the early 1900s, and various formulations have been used commercially since the 1940s. It is an organometallic compound formed as a reaction product of copper salts and petroleum-derived naphthenic acids. Copper naphthenate is somewhat unique among commercially applied wood preservatives in that preservative solution can be purchased in small quantities at retail hardware stores and lumberyards. It is often recommended for field treatment of cut ends and drill holes made during construction with pressure-treated wood. Copper naphthenate-treated wood initially has a distinctive bright green color that weathers to light brown. The treated wood also has an odor that dissipates somewhat over time. Depending on the solvent used and treatment procedures, it may be possible to paint copper naphthenate-treated wood after it has been allowed to weather for a few weeks. Like pentachlorophenol, copper naphthenate can be dissolved in a variety of solvents. The heavy oil solvent, as specified in AWPA Standard P9, Type A, or the lighter solvent AWPA Standard P9, Type C are the most commonly used solvents. Although not as widely standardized as creosote and pentachlorophenol treatments, copper naphthenate is listed in AWPA standards for treating major softwood species used for a variety of wood products. It is not listed for treatment of any hardwood species. The minimum copper naphthenate retentions (as elemental copper) range from 0.64 kg/m^3 (0.04 lb/ft^3) for wood used above ground, to 0.96 kg/m^3 (0.06 lb/ft^3) for wood used in ground contact, and 1.2 kg/m^3 (0.075 lb/ft^3) for wood used in critical structural applications. When dissolved in #2 fuel oil, copper naphthenate is able to adequately penetrate many difficult-to-treat wood species. Some of this penetration ability is lost when dissolved in heavier oils. Copper napthentate treatments do not significantly increase corrosion of metal fasteners relative to untreated wood. Copper naphthenate is most commonly used in the treatment of utility poles, although facilities utilizing copper naphthenate are not as widely distributed as those producing wood treated with creosote or pentachlorophenol.

Copper naphthenate, unlike creosote and pentachlorophenol, is not listed as a restricted-use pesticide by the EPA. The lesser human health concerns associated with copper naphthenate are also evidenced by the availability of the preservative solution for retail purchase. However, precautions such as the use of dust masks and gloves should still be used when working with copper naphthenate-treated wood. Because of its more limited use and relatively lower toxicity when compared to creosote or pentachlorophenol treatments, there has been relatively little study of copper naphthenate's potential environmental impacts, especially in aquatic environments. Some leaching may occur, as evidenced by the detection of elevated copper levels in soil samples removed from within 0.3 m (12 inches) of Douglas Fir utility poles in northern California.[28] However, much less copper was detected in soil adjacent to Southern Pine utility poles in Alabama, suggesting that species differences, treatment practices, or site differences influenced leaching. It is known that treatment practices can influence leaching in a manner similar to other oil-type preservatives. In their study, Harp and Grove noted that several of the Douglas Fir utility poles had been repeatedly returned to the treater for surface treatments after complaints about the oily surface. However, those treatments used a heavy oil solvent, and surface oils appear to be less of a problem when #2 fuel oil is used as the solvent. The importance of using treatment practices to minimize environmental concerns associated with copper naphthenate-treated wood is also recognized by the WWPI, which has developed BMPs for production of copper naphthenate-treated wood used in aquatic environments. The recommended treatment practices for treatment in heavy oil include using an expansion bath and/or final steaming similar to that described above for creosote. When #2 fuel oil is used as the solvent, the BMPs recommend using a final vacuum for a minimum of 1 hour.

Chlorothalonil (CTL) in Heavy Oil-Chlorothalonil (CTL) has been used for decades as a broad-spectrum agricultural fungicide. More recently, it has been proposed for use as an oil-based wood preservative comprised of approximately 96 percent tetrachloroisophthalonitrile. CTL is colorless, but the appearance of the treated wood will be dependent on the solvent used. When used in heavy oil solvent, as described in AWPA Standard P9, Type A, the treated wood will have a brown color and may have a slightly oily surface that is difficult to paint. CTL was included in AWPA standards fairly recently as a potential alternative to treatment with pentachlorophenol. However, it has not yet been standardized for use with any wood product or type of exposure, and no minimum retentions are listed. However, based on exposure of field stakes, it appears that chlorothalonil is effective at protecting wood in ground contact when used at a retention of 4.48 kg/m^3 (0.28 lb/ft^3) or greater. CTL has primarily been evaluated for use in protection of softwood species. Availability of CTL is limited. At this time, there are no commercial treatment facilities using CTL.

One of the characteristics of chlorothalonil that has made it attractive as an agricultural pesticide is its relatively low acute toxicity to humans and other mammals. However, precautions such as the use of dust masks and gloves should still be used when working with chlorothalonil-treated wood. The environmental impact of chlorothalonil-treated wood in service has not been evaluated. CTL is relatively nontoxic for birds, but is toxic to fish and aquatic invertebrates. It is moderately persistent in the environment, with a soil half-life of 1 to 3 months. CTL has very low water solubility, which helps to reduce leaching from the treated wood. However, when treated in heavy oil, there is potential for loss of CTL into the environment if the oil moves out of the wood. Best-management treatment practices similar to those described for pentachlorophenol should be used to reduce or minimize bleeding of the oil to the wood surface.

Preservatives That are Effective Above Ground, Fully Exposed to the Weather

The preservatives listed in this section generally do not provide long-term protection for wood exposed in direct contact with soil or standing water, but are effective in preventing attack in wood exposed above the ground, even if it is directly exposed to rainfall, Examples of these applications in covered bridges include weatherboarding and any above-ground portion of the bridge that extends beyond the protective cover of the roof. The preservatives listed in the previous section also perform well in these applications, and can be used at their lower, above-ground retentions. Some above-ground applications that retain moisture and/or collect organic debris may present a deterioration hazard similar to ground contact. Preservatives discussed above may be more appropriate for such applications, especially in critical structural members.

Oilborne Preservatives

Oxine Copper (Copper-8-quinolinolate)-Oxine copper is an organometallic preservative comprised of 10 percent copper-8-quinolinolate and 10 percent nickel-2-ethylhexoate. It is characterized by its low mammalian toxicity, and is permitted by the U.S. Food and Drug Administration for treatment of wood used in direct contact with food. The treated wood has a greenish brown color, and little or no odor. It can be dissolved in a range of hydrocarbon solvents, but provides much longer protection when delivered in heavy oil. Oxine copper is listed in AWPA standards for treatment of several softwood species used in exposed, above-ground applications. The minimum specified retention for these applications is 0.32 kg/m^3 (0.02 lb/ft^3) (as elemental copper). Oxine copper solutions are somewhat heat sensitive, which limits the use of heat to increase preservative penetration. However, adequate penetration of difficult-to-treat species can still be achieved, and oxine copper is sometimes used for treatment of the above-ground portions of Douglas Fir used in wooden bridges and deck railings. Oilborne oxine copper does not accelerate corrosion of metal fasteners relative to untreated wood. Oxine copper is not widely used by pressure-treatment facilities, but is currently available from at least one plant on the West Coast.

Oxine copper-treated wood presents fewer toxicity or safety and handling concerns than the oilborne preservatives that can be used in ground contact. It is also sometimes used as an anti-sapstain preservative or incorporated into retail stains for siding, shingles, and log cabins. However, precautions such as wearing gloves and dust masks should be used when working with the treated wood. Because of its somewhat limited use and low mammalian toxicity, there has been little research to assess the environmental impact of oxine copper-treated wood used in sensitive environments. However, it is an oilborne preservative, and can be susceptible to bleeding or oozing from the treated wood under certain conditions. There are no specific standards or BMPs for oxine copper-treated wood, but some of the same treatment practices used for other oilborne preservatives could apply. Although heating concerns may limit the use of expansion baths, other techniques such as empty cell treatments and final vacuum can be employed.

Pentachlorophenol in Light Solvent-As discussed above, the performance of pentachlorophenol and the properties of the treated wood are influenced by the properties of the solvent. Pentachlorophenol is most effective when applied with a heavy solvent, but it performs very well in lighter solvents for above-ground applications. Lighter solvents also provide the advantage of a less oily surface appearance, lighter color, and improved paintability. Above-ground minimum retentions for pentachlorophenol vary from 4.0-4.8 kg/m^3 (0.25-0.3 lb/ft^3) for treatment of red oak to 6.4 kg/m^3 (0.4 lb/ft^3) for softwood species. Pentachlorophenol in light oil has some similarities to heavy oil. It can be used to treat relatively refractory wood species, and it does not accelerate corrosion. However, one disadvantage of the lighter oil is that less water repellence is imparted to the wood. Treatment facilities using pentachlorphenol in light oil are also not as numerous as those using light oil.

Although pentachlorophenol in light oil provides a clean, dry surface, the same active ingredient is present, and it is still classified as a restricted-use pesticide by the EPA. Precautions on the CIS still apply, and these CIS should be made available to all personnel involved in handling pentachlorophenol-treated wood. However, bleeding of preservative to the surface of the wood is less likely to occur with the lighter oil, reducing concerns about environmental or human exposure.

Preservatives That are Effective Above Ground with Partial Exposure and Occasional Wetting

The preservatives listed in this section have not demonstrated the ability to provide long-term protection against a broad range of decay organisms in high-decay hazard applications. However, they do adequately protect wood that is above ground and occasionally exposed to wetting. Examples of these applications in a covered bridge include members near the ends of the bridge that may be subjected to wetting from wind-blown rain or from splashing during heavy rainfall. Some above-ground applications that retain moisture and/or collect organic debris may present a more severe deterioration hazard, and a preservative from one of the previously discussed sections would then be more appropriate.

Water-Based Preservatives

Didecyldimethylammonium Chloride (DDAC)-Didecyldimethylammonium chloride (DDAC) is one of several quaternary ammonium compounds that are widely used as bactericides, antiseptics, and fungicides. DDAC is the quat component of the wood preservatives ACQ-D and ACQ-B, and is also a component of antisapstain formulations. It is colorless, nearly odorless, and can be formulated for use with either water- or oil-based carriers, although solvency is diminished in lighter aliphatic hydrocarbons such as mineral spirits. DDAC is listed as a preservative in AWPA standards, but has not been standardized for pressure treatment with any specific wood product or exposure environment. Its current pressure treatment use is as a cobiocide to protect wood treated with copper-based preservatives against attack by copper tolerant fungi. Soil block tests indicate that a DDAC retention of 6.4 kg/m^3 (0.4 lb/ft^3) is sufficient to protect wood from attack by brown and white rot fungi. Slightly higher retentions may be needed to protect hardwoods from attack by soft-rot fungi, but most covered bridge applications do not have sufficient moisture to sustain soft-rot attack. Lower retentions would probably be sufficient to protect wood used in above-ground, partially protected applications. There are currently no pressure treatment facilities using DDAC as a stand-alone preservative.

DDAC has low mammalian toxicity, as evidenced by its use as a preservative or disinfectant in various consumer products. However, workers handling wood treated with DDAC should use standard precautions such as wearing dust masks and gloves, The environmental impacts of DDAC in treated wood have been investigated to some extent. Although environmental levels of DDAC were not quantified, an evaluation of the environmental impact of wetland boardwalk treated with ACQ-B found no impact on aquatic invertebrates at the site. The DDAC appears to react, or fix, with wood during and within a few days after treatment, becoming resistant to leaching. However, some leaching of DDAC from treated wood does occur. One study found that 12-25 percent of DDAC was lost from the outer 12.7 mm (0.5 inches) of Southern Pine posts exposed in Florida for 18 months.[29] However, lower leaching rates would be expected from wood exposed above ground and partially protected from precipitation. DDAC is moderately to very toxic to fish and other aquatic organisms. After it is released into the environment, it appears to be relatively resistant to degradation in water, but is readily decomposed by bacteria in soil and sediments. Because it reacts readily with organic matter in soil and sediment. its environmental mobility is limited. There are currently no standards or BMPs for methods of minimizing leaching of DDAC from treated wood, but allowing the wood to dry may increase leach resistance.

Oil-Type Preservatives

Isothiazolone (DCOI) – Isothiazolones are a class of organic compounds that have shown some promise for use in wood preservatives. One of these compounds, 4,5-dichloro-2-N-octyl-4-isothiazolin-3-one (DCOI), has been evaluated fairly extensively. DCOI is currently used as a marine antifouling agent in paint films.[30] DCOI has demonstrated sufficient potential as a wood preservative to be listed in AWPA standards, but has not yet been standardized for use with any wood product or exposure environment. Thus, there are no minimum retentions given for this preservative. However, research indicates that it is quite effective in protecting wood used above ground when treated to a retention of 1.6 kg/m^3 (0.1 lb/ft^3) or greater. As with other oil-soluble preservatives, the properties of wood treated with DCOI will somewhat depend on the type of solvent used. Current standards call for the use of light oil solvent (AWPA Standard P9, Type C), which should leave the wood with a relatively dry surface, and may allow subsequent finishing. The treatment may impart a light brown color to the wood. DCOI does have a noticeable odor, and the treated wood may have some odor, depending on the concentration of the treating solution. Availability is a limitation of DCOI, as no treatment facilities are currently using this preservative.

DCOI is not listed as an EPA restricted-use pesticide, and has lower acute toxicity than the restricted-use pesticide preservatives. However, DCOI-treated wood should still be handled carefully, and gloves and dust masks should be used when working with the treated wood. The environmental impact of DCOI-treated wood has not been evaluated, but the molecule does decompose rapidly in sediments or water. The rate of leaching of DCOI from treated wood appears to be somewhat greater than for other preservatives, including pentachlorophenol dissolved in a similar solvent. There currently are no best management practices or similar guidelines for treatment practices to minimize leaching from wood treated with DCOI.

3-Iodo-2-proponyl carbamate (IPBC)-3-Iodo-2-proponyl carbamate (IPBC) is commonly used as an ingredient in antisapstain formulations, or as a fungicide in water-repellent finishes for decks or siding. It is also used to treat millwork. Although described here as an oil-soluble preservative, water-based formulations may also be used. IPBC is colorless, and depending on the solvent and formulation, the treated wood may be paintable. Some formulations may have noticeable odor, but formulations with little or no odor are also possible. IPBC is not an effective insecticide, and is not used as a stand-alone treatment for critical structural members. In above-ground, weather-protected applications, it is used in pressure treatment when combined with an insecticide such as chlorpyrifos. IPBC is listed as a preservative in AWPA standards, but has not been standardized for pressure treatment of any exposure condition or wood product. However, it was recently standardized for dip treatment of ponderosa pine millwork at a minimum retention of 950 ppm (approximately 0.368 kg/m^3 (0.023 lb/ft^3)), and soil block tests indicate that IPBC is effective in preventing fungal attack of both hardwoods and softwoods when used at a retention of 0.352 kg/m^3 (0.022 lb/ft^3) or higher. After nine years, above-ground exposure tests with pressure-treated Douglas Fir, Ponderosa Pine, and Western Hemlock indicate that mixtures of IPBC and chlorpyrifos can protect wood from decay at IPBC retentions as low as 0.8 kg/m^3 (0.05 lb/ft^3). Although not a standardized treatment, some pressure-treating facilities use a mixture of IPBC and chlorpyrifos to treat structural members that are to be used above ground, and that are largely protected from the weather. These facilities are using IPBC retentions of 0.56 kg/m^3 (0.035 lb/ft^3) or higher, with mineral spirits as the solvent. The advantage of this treatment is that it is colorless and allows the wood to maintain its natural appearance. This treatment is being used on relatively refractory western species. In general however, the number of facilities conducting pressure treatments with IPBC is very limited.

IPBC has relatively low acute toxicity for mammals, and is not classified as an EPA restricted-use pesticide. However, standard precautions such as wearing gloves and dust masks should still be followed when working with wood treated with IPBC. Because it typically has not been used for pressure treatment, there has been little evaluation of the environmental impact of wood treated with IPBC. However. it appears that IPBC is nonpersistent in the environment, degrading rapidly in soil and aquatic environments. It has low toxicity for birds, but is highly toxic to fish and aquatic invertebrates. The relatively low IPBC concentrations used in the wood and its rapid degradation in the environment would be expected to limit any environmental accumulations caused by leaching. Because IPBC usually is used with a light solvent, bleeding or oozing of the preservative out of the wood is unlikely.

Tributyltin oxide (TBTO™) – Bis(tri-n-butyltin)oxide (TBTO) is a colorless to slightly yellow liquid preservative that is soluble in organic solvents, but not soluble in water. It has been used extensively as an antifouling agent in marine paints, as a preservative in finishes, and in dip treatments for wood used in millwork. It is listed as a wood preservative in AWPA standards, where it is specified for use with a light hydrocarbon solvent (AWPA Standard P9, Type C). When used in a light solvent, wood treated with TBTO is paintable and has little odor. At this time, TBTO is not listed in AWPA standards for pressure treatment of any wood product for any exposure environment. Used alone, TBTO is not effective in protecting wood that is placed in ground contact, but data indicate that it may be effective in protecting wood products that are used above ground, and partially exposed to the weather. For softwoods, minimum retentions of 0.96 kg/m^3 (0.06 lb/ft^3) have been proposed for control of decay fungi, while at least 0.120 kg/m^3 (0.075 lb/ft^3) of TBTO IS needed to impart insect resistance. Most evaluations have been conducted with softwood species, and it is less certain that these retentions will be effective in protecting hardwood species.

Although less toxic than some wood preservative ingredients, TBTO is moderately to acutely toxic to mammals, and can depress the immune system. Workers handling wood treated with TBTO should use precautions such as wearing gloves and dust masks. TBTO has not been used as a stand-alone pressure treatment wood preservative, and there are no studies of the environmental effects of using TBTO-treated wood in sensitive environments. TBTO can be highly toxic to some aquatic organisms, and these concerns have let to limitations on its use in marine antifouling paints. It has low water solubility, and is readily adsorbed on particles, so it tends to be removed from the water column relatively quickly. However, it may persist in sediments for several years. The amount of TBTO leached from treated wood in a covered bridge application would probably be low because of the partial protection from precipitation, and because relatively low retentions are used in treatment. There are currently no standards or best management practices for minimizing TBTO leaching, but bleeding or oozing of the preservative should not be a problem when the wood is treated using a light solvent.

Propiconazole (PPZ) – Propiconazole (PPZ) is a light-to-dark yellow, clear liquid that contains a fungicidal triazole compound. PPZ is not soluble in water, but is soluble in light organic solvent. Wood treated in this manner has little color and is paintable. PPZ is commonly used as a systemic fungicide to combat plant diseases, and sometimes as a component of antisapstain formulations. It is not very effective at preventing attack by wood-destroying insects, and may need to be used in combination with an insecticide, such as chlorpyrifos. Propiconazole is listed as a wood preservative in AWPA standards, but is not standardized for pressure treatment of any wood product or exposure application. PPZ is not effective in protecting wood placed in ground contact, but it has been proposed as a dip treatment for wood used in partially protected above-ground exposures. The minimum retention proposed for dip treatments is approximately 4.96 kg/m^3 (0.31 lb/ft^3). Most of the efficacy data for PPZ was obtained using softwoods, and the retentions needed to protect hardwoods are less clear. Currently there are no pressure treatment facilities utilizing PPZ as a stand-alone preservative treatment.

PPZ has relatively low mammalian toxicity, but workers handling wood treated with PPZ should still follow precautions such as wearing gloves and dust masks. The environmental impact of PPZ-treated wood used in sensitive environments has not been evaluated. Because of its low water solubility, PPZ is not highly leachable, and it is only slightly to moderately toxic to fish. It breaks down fairly rapidly in water and soil, and has limited mobility in soil. The USFS uses it as a fungicide, although care must be taken to avoid spraying PPZ near water.

Tebuconazole (TEB) – Tebuconazole is a triazole-based fungicide that is commonly used to control plant diseases, and is also incorporated into wood preservative formulations. Although included here as an oil-based preservative, it can also be formulated to be compatible with waterborne preservatives. For example, tebuconazole is added to the waterborne preservative copper azole (see above) to improve the formulation's performance against copper-tolerant fungi. Tebuconazole is listed as a wood preservative in AWPA standards, but is not specified as a stand-alone pressure treatment preservative for any wood product or exposure application. It is specified for use with light organic solvent, which should render the treated wood colorless and paintable. Although not standardized as a stand-alone preservative, it appears that Tebuconazole has potential to protect wood that is exposed above ground and partially protected from weathering. When incorporated with a water repellent, it appears to work effectively above ground in preventing attack by brown rot fungi, even at retentions as low as 0.16 to 0.48 kg/m^3 (0.01 to 0.03 lb/ft^3), but there is insufficient long-term data to confirm this efficacy. Retentions needed to protect against soft-rot attack would probably be greater, and an insecticide such as chlorpyrifos would be needed in areas where insect attack may be a concern. There currently are no pressure treatment facilities in the United States that use tebuconazole as a stand-alone wood preservative.

Tebuconazole has relatively low mammalian toxicity, but workers handling wood treated with this preservative should use standard precautions such as wearing gloves and dust masks. The environmental impact of wood pressure treated with tebuconazole has not been evaluated, but it appears that tebuconazole is fairly leach-resistant. At the low retentions used, and when partially protected from precipitation, the amounts of tebuconazole entering the environment are expected to be quite low.

Zinc Naphthenate-Zinc naphthenate is used extensively as a component in over-the-counter wood preservative products. It can be formulated as either a solvent-borne or waterborne preservative. Unlike copper naphthenate, zinc napthenate imparts little color to the wood, and thus is more compatible with finishes. When formulated in light solvent, the treated wood may also be paintable. However, wood treated with zinc naphthenate may have a noticeable odor. Zinc is not nearly as effective a fungicide as copper, and zinc naphthenate is not used as a stand-alone preservative for exposed structural members. Zinc naphthenate is not listed as a wood preservative in AWPA standards. However, zinc naphthenate does have some preservative efficacy, and may be sufficient to protect wood used above ground and partially protected from the weather. Zinc naphthenate pressure treatments have been shown to extend the life of treated stakes exposed in Mississippi, and brush treatments of a waterborne zinc naphthenate significantly improved the performance of pine fully exposed to the weather (above ground) in Mississippi. However, zinc naphthenate was less effective in protecting hardwoods in that study. Adding a water-repellent component to the treating solution appears to increase the efficacy of zinc naphthenate treatments.

Zinc naphthenate has only low to moderate mammalian toxicity. However, workers handling zinc naphthenate treated wood should use standard precautions such as wearing gloves and dust masks. There have not been any studies of the environmental effects of zinc naphthenate treated wood used in aquatic environments. Zinc naphthenate has relatively low environmental toxicity and has not been the subject of as much review as many other pesticides.

Preservatives That are Effective Above Ground, Occasionally Damp, But Protected from Liquid Water

The preservatives listed in this section are waterborne preservatives that do not fix in the wood, and thus are readily leachable. They provide adequate protection as long as the wood is not subjected to liquid water that could wash the active ingredients out of the wood. Examples of these types of applications in covered bridges are internal members that are well-protected from the weather, but may be subject to insect attack or occasionally dampened due to humidity or condensation.

Borates–Borate compounds are the most commonly used unfixed waterborne preservatives. They are used to pressure treat framing lumber used in areas of high termite hazard, and as surface treatments for a wide range of wood products such as log cabins and the interiors of wood structures. They are also applied as internal treatments via rods or pastes. At higher retentions, borates are also used as fire-retardant treatments for wood. Boron has some exceptional performance characteristics, including low mammalian toxicity and activity against fungi and insects. and it is inexpensive. Another advantage of boron is its ability to move and diffuse with water into wood that normally resists traditional pressure treatment. In addition, wood treated with borates has no color, no odor, and can be finished. While boron has many potential applications in framing, it is probably not suitable for most components of a covered bridge, because the chemical will leach from the wood under wet conditions. It may, however, be a useful treatment for insect protection in areas continually protected from wetting. Inorganic boron is listed as a wood preservative in AWPA standards, and includes formulations prepared from sodium octaborate, sodium tetraborate, sodium pentaborate, and boric acid. Inorganic boron is also standardized as a pressure treatment for a variety of species of softwood lumber used out of contact with the ground and continuously protected from liquid water. The minimum retention (as B_2O_3) is 2.72 kg/m^3 (0.17 Ib/ft^3), except that 4.48 kg/m^3 (0.28 Ib/ft^3) is specified for areas with Formosan subterranean termites.

Borate preservatives are available in several forms, but the most common is disodium octaborate tetrahydrate (DOT). DOT has higher water solubility than many other forms of borate, allowing the use of higher solution concentrations and increasing the mobility of the borate through the wood. With the use of heated solutions, extended pressure periods, and diffusion periods after treatment, DOT is able to penetrate relatively refractory species such as spruce. There are several pressure treatment facilities in the United States that use borate solutions to treat wood.

Although borates have low mammalian toxicity, workers handling borate-treated wood should use standard precautions such as wearing gloves and dust masks. The impact of the use of borate-treated wood for construction projects in environmentally sensitive areas has not been evaluated. Because borate-treated wood is used in areas where it is protected from precipitation or liquid water, little or no losses into the environment should occur. In addition, borates have low toxicity to birds, aquatic invertebrates, and fish, and boron salts occur naturally in the environment at relatively high levels. However, because borates are readily leachable, extra care should be taken to ensure that borate-treated wood stored at the job site is well-protected from precipitation. Exposure to precipitation could cause depletion of boron in the wood to below effective levels, and cause harm to vegetation directly below the stored wood.

Conclusions

There is a wide array of methods for limiting the risk of biodeterioration in covered bridges. Careful design to exclude water, coupled with the use of properly specified preservative-treated wood where necessary, and a regular program of maintenance and inspection can help sharply reduce losses associated with decay.

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16. Abstract
This manual provides guidance to those involved with all aspects of the work, from initial inspection and evaluation, through the engineering of rehabilitation, to construction issues. Broadly speaking, this manual covers general terminology and historic development of covered bridges. The manual also addresses loads, structural analysis, connections, and design issues. The last six chapters contain discussions of evaluation, maintenance, strengthening, and preservation of existing covered bridges; historic considerations of existing structures; and provide a state-of-the-art guide on wood preservatives for covered bridges. Historic preservation requirements as they relate to the U.S. Department of Interior standards for these important and unusual structures also are provided. The appendices include an extensive series of case studies.

The manual focuses on the nuances of the engineering aspects of covered bridges, including some issues not addressed currently by national bridge specifications. The chapter on timber connections provides a comprehensive discussion of covered bridge joinery and represents an important contribution to covered bridge engineering.

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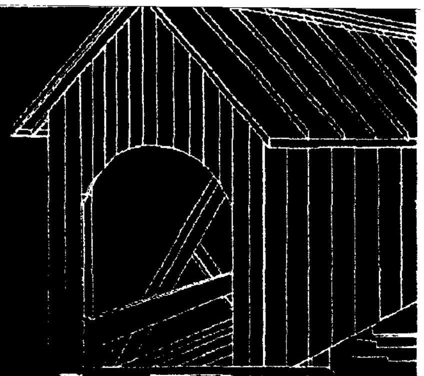

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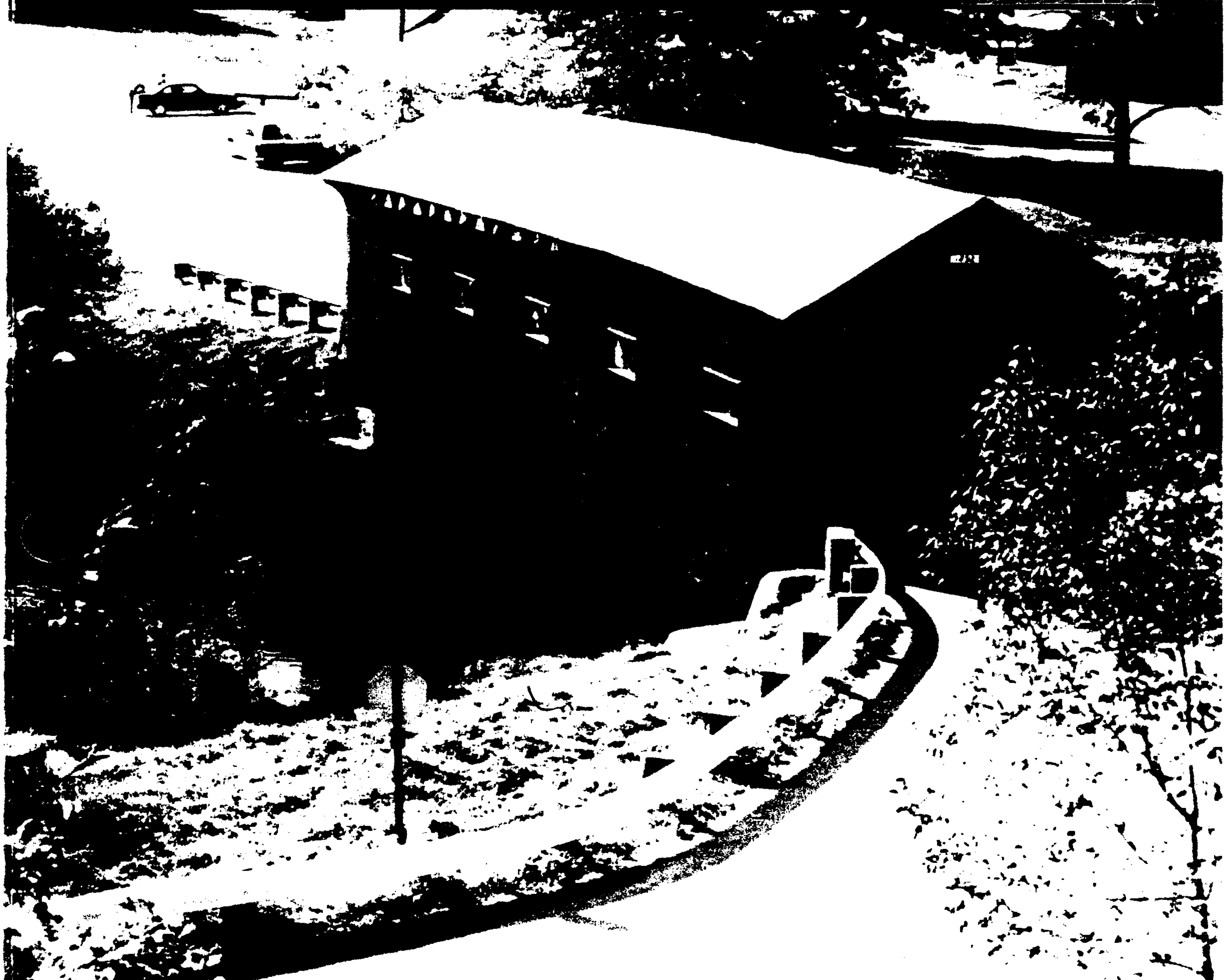

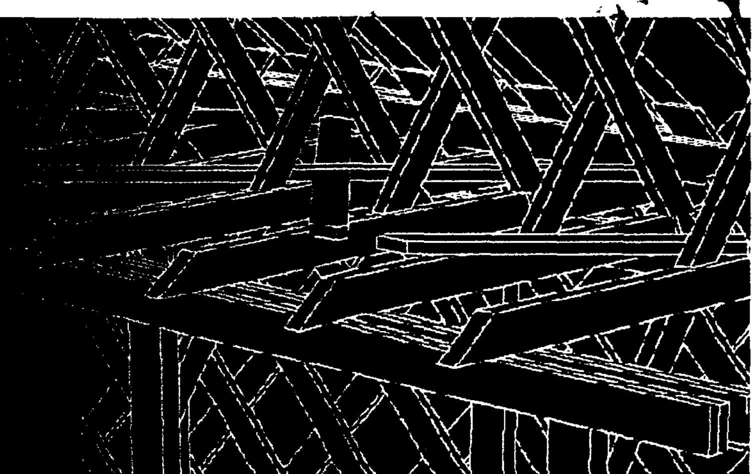

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