LEACHING OF CCA FROM TREATED WOOD

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INTRODUCTION

There is increasing concern about possible environmental contamination from leaching losses of wood preservatives from wood in service and from wood removed from service and placed in landfills. Waterborne chromated copper arsenate (CCA) is of particular interest because of its extensive use in residential construction. While this treatment is considered to be highly resistant to leaching losses, small amounts of contaminants can be measured in the leach water and soil and their potential effects on public health and the environment are being assessed. The considerable confusion in regard to the significance of the losses is evident from the following quotations taken from published technical papers on leaching losses from CCA treated wood:

> "The arsenic introduced into the wood by treatment of this preservative (CCA-B) is by no means stable to extraction. Water at room temperature extracts appreciable amounts ...." (Teichman & Monkman 1966).
>
> "In the highly fixed CCA Type A and C systems, the preservative component ratios remain constant over the service life. There is no significant loss of any component due to leaching or other factors" (Arsenault 1975).
>
> "Substantial quantities of metallic elements were leached from the poles treated with the AWPA type B CCA." (Nurmi 1990).
>
> "There is no evidence to indicate that the chromium and copper components are leached from the outermost 5 mm of sapwood in poles impregnated with K-33 or Tanalith C and stored in running water for ten years." (Evans 1978).

Such inconsistencies have led to considerable confusion and debate among users and producers of treated wood. In this paper I attempt to clarify some of the variables responsible for these inconsistencies and explore the environmental significance of leaching losses from treated wood in service.

THE CCA LEACHING PROCESS

Incompletely fixed wood

Copper, chromium and arsenic are fixed in wood following pressure treatment, by complex chemical reactions that have been described and discussed by others (e.g., Pizzi 1982, Dahlgren 1972). The rate of fixation is highly dependent on many factors, including temperature, RH, wood species and CCA formulation, as discussed by Dr. Anderson

(1989) in his paper to the CWPA last year. While treated wood should not leave the treating facility until the fixation reaction is complete, it is conceivable that some incompletely fixed wood is transported and sold. This is especially the case with winter treated wood, although most of this material is inventoried by the treating plant until the more active spring building season.

The approximate time to complete fixation, as determined by a number of investigators, is plotted in Fig. 1 as a function of temperature. An example of leaching losses, as a function of extent of fixation is shown in Fig. 2.

Fixation studies show that Cr VI is the CCA component that takes the longest time to be immobilized. Cr in this valence state is highly mobile and reactive and is therefore a much greater environmental threat than the Cr III in properly fixed wood.

Properly fixed wood

The active ingredients of CCA are deposited in treated wood as stable, low solubility complexes. The main depletion mechanisms are by leaching and mechanical loss of surface deposits. Leaching of CCA from properly fixed wood (essentially no free Cr VI) depends on a number of physico-chemical processes including wetting of the treated wood by capillary adsorption and diffusion penetration of moisture into the wood, hydrolysis or solution of components of the complexed chemicals, diffusion of the dissolved components to the surface and washing away of the dissolved material.

The extent of leaching depends on the conditions of exposure to the leaching medium and the physical nature of the treated wood, as it affects moisture absorption and diffusion of the dissolved materials away from the wood. Loss of surface deposits is mainly affected by the preservative and processing variables that affect wood surface cleanliness.

It is hypothesized (Hager 1969) that copper and chromium arsenates in treated wood are slowly hydrolysed in service. The resulting copper and chromium components are practically insoluble while the arsenic may be leached out. It has also been suggested that ultra-violet light exposure during weathering may accelerate leaching losses, although the u.v. resistance of the trivalent chromium component of CCA is well known.

FACTORS AFFECTING LEACHING OF CCA FROM TREATED WOOD

Effect of exposure conditions

All of the diffusion and solubilizing processes are highly temperature and moisture dependent. Thus, the service conditions have a great effect on leaching losses. Wood exposed to conditions of high rainfall under moderate annual temperature conditions, as characteristic of some coastal regions of BC will leach more than wood in colder drier climates. Treated wood, continually exposed to water

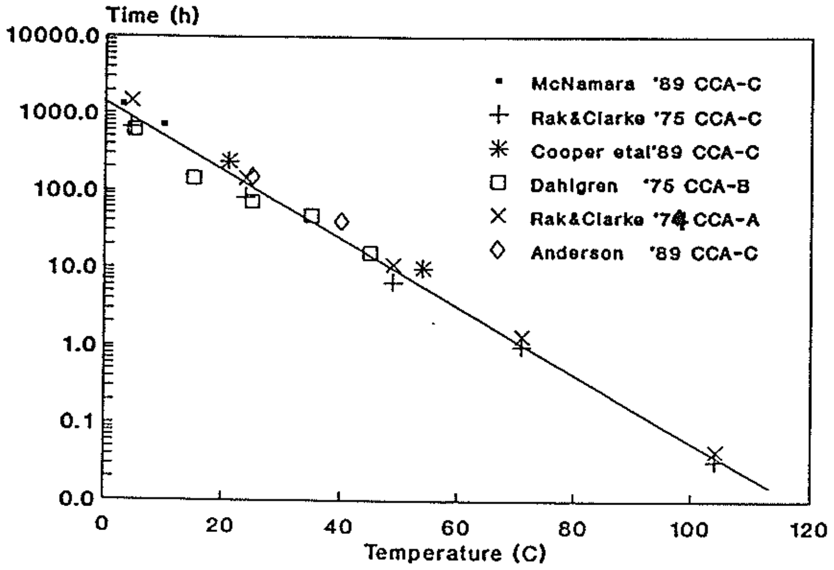


Figure 1. Relationship between temperature and time to fixation for CCA treated wood

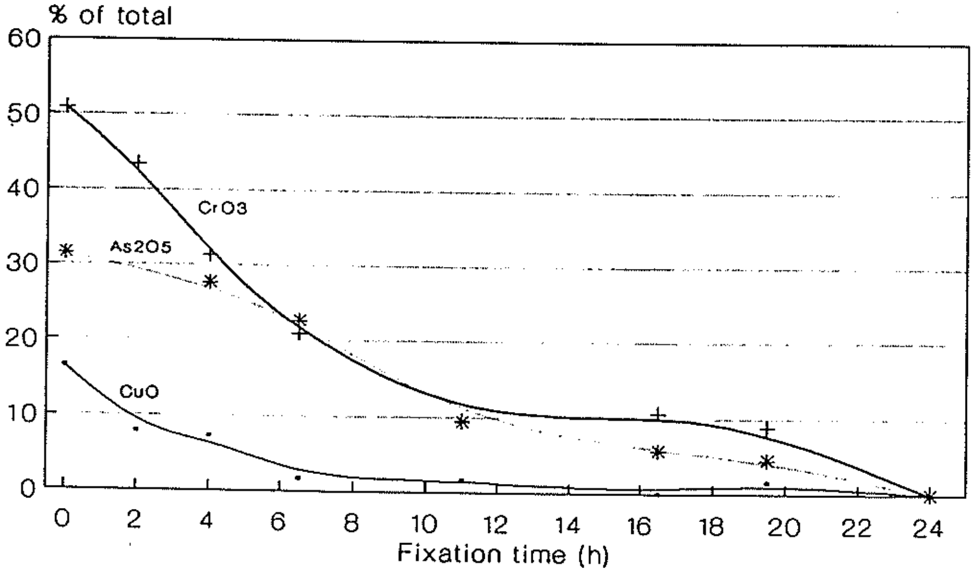


Figure 2. Leaching lossses from treated wood blocks as affected by fixation time (+5°C) (based on 120 hours soaking test)

or damp soil, will lose more preservative than that exposed to occasional rainfall. A continuous light rainfall has a greater leaching effect than the equivalent rainfall by a short heavy shower (Cockroft and Laidlaw 1978). Wood exposed to intermittant rainfall in above ground applications such as in fence boards and decks is less likely to lose chemical compared to wood continually submerged in water. Vertically exposed wood is subjected mainly to driving rain from only one direction at a time and is less exposed than horizontally applied decking. Decking is primarily extracted from the top surface.

Also, we have observed in laboratory leaching tests (Cooper 1989), that under intermittent exposure to acidified water, wood can buffer the leaching solution, reducing the acidity of the water. We have found in field tests, that the pH of water dripping off treated wood products is consistently 0.8 - 1.2 pH units higher than the pH of the rain, indicating that this effect is operative in wood exposed to rainfall also. This buffering effect will not occur in acidic lakes or other bodies of water.

Wood in soil contact is subject to leaching most of the time and also may be affected by the soil solution as discussed later; however, the soil tends to buffer acidic solutions and helps negate effects of acidic precipitation (Murphy and Dickinson 1990).

We can create a hierarchy of relative severity of exposure conditions to help determine if leaching losses are a concern (Table 1).

Table 1: Hierarchy of Severity of Leaching Exposure Conditions

Exposure Conditions	Typical Applications
Protected from rain etc.	Covered patios, gazibos, siding, substructure of decks and bridges.
Occasional or partial exposure to rain water.	Fence boards.
Complete exposure to rain water.	Cedar roofing, decking, railing, stairs and steps.
Exposure to soil.	Fence posts, poles, land piling, retaining walls, preserved wood foundations.
Exposure to fresh water.	Cribs, lock gates, fresh water piling.
Exposure to sea water, acidified water, warm water.	Marine piling, piers, cribs, cooling towers, acid lakes.
Exposure to metal complexing compounds.	Silos, bog water (hypothesized) wood stave pipes and tanks for chemicals.

The above ranking is based on the author's interpretation of available literature. Some of the contributing factors will be discussed in more detail later. Of course, there will be considerable variation within each of the above categories as a result of different climatic conditions and other variables as discussed below.

Effect of Wood Sample or Product Size

Most published leaching studies have been based on evaluations on small samples, since these are easier to control and give much faster results in the laboratory. This is a valid approach where relative performance is of interest. Such a leaching test is incorporated in the standard soil block test procedure for evaluating decay resistance (AWPA M10-77).

HOWEVER, SUCH RESULTS SHOULD NEVER BE EXTRAPOLATED TO PREDICT PERFORMANCE OF PRODUCTS IN SERVICE.

The potential for losses increases with increasing relative surface area of the exposed wood. In small samples, the rate of wetting and the relative area exposed directly to the leaching environment are increased, and the diffusion distances decreased. Of particular significance with wood, the relative amount of exposed end grain is higher in small dimension samples. Since the diffusion and permeation coefficients along the grain are several orders of magnitude higher than for the transverse directions, leaching losses are further biased. The ratios of end grain to side grain in various standard and non-standard lab test blocks and commercial products are compared with some relative leaching rates in Table 2.

Table 2: Relative Surface Area to Volume and Proportion of End Grain of Typical Treated Wood Samples

Sample or Product	Surface Area / Volume (cm^{-1})	Percent End grain	Leaching Losses (%)			Time frame
			Cu	Cr	As	
Sawdust (Dahlgren 1967)	~60	~33	21	—	15	6 hours
Microtome samples (Rak & Clarke 1974)	402	0.20	27	0.7	18	1 day
Standard AWPA Blocks (2.5 cm cube)	2.4	33.3	—	—	—	
1cmX1cmX5cm (Cooper, 1989)	4.4	9.1	6.4	1.1	5.7	13 days
5cmX5cmX1.9cm (Warner, 1990)	1.85	21.6	5.2	1.0	18	40 days
2"X6"X12' deck board	0.67	0.81		?		
2m Pole section (Evans 1978)	0.21	4.8	n.m.	n.m.	20*	10 years
40' pole	0.12	1.36		?		

* Most As loss occurred in the first few months
n.m. Not measurable

Effect of Wood Species

The chemical nature of wood affects the mode and quality of fixation. Hardwoods, which have higher hemicellulose content, lower lignin content and a different type of lignin than softwoods generally have greater leaching losses than softwoods under identical treatment and exposure conditions (Wallace 1968).

Thus, products such as CCA treated hardwood railway ties (rarely used), poplar "mini-ties", hardwood cooling tower slats, etc. are expected to be greater risks of contamination than softwoods under the same conditions.

High density, lower permeability species tend to be more resistant to leaching (Cockcroft et al. 1978, Wilson 1971). Wood permeability may vary by many orders of magnitude among species. This permeability is important for the initial treating of the wood, and also affects the rate of absorption of moisture and rates of diffusion of moisture and dissolved salts. However, low permeability woods have CCA concentrated near the surface where it is more easily leached and eroded.

These species effects are evident from the results of a study by Cherian et al (1979) on the condition of CCA-A treated coupons exposed to marine borer attack in Cochin Harbour, India. Shorea robusta panels, which accepted very little treatment (5.1 kg/m^3), lost virtually all of their treatment over the 6 - 9 year service life. Bombax insigne samples, treated to about 29 kg/m^3 lost 17 - 27% of the treatment over their 8-9 year service life. Other hardwood species were intermediate in their losses. It should be noted that the retention level was much below recommended levels to protect against marine animals and the panels were heavily infested with marine borers when removed from service. Much of the chemical losses were likely due to erosion and destruction of the wood by the marine organisms.

There have not been many comparisons of leaching losses of different species under controlled conditions. McNamara (1982) found that leaching losses were higher in HEM-FIR than in Southern pine blocks subjected to the EPA "Leachate Toxicity Extraction Procedure". Pasek (1990), using the same procedure with sawdust from treated boards found a large interaction effect between species and pH of the leach water. At low pH's (3-4), jack pine was leached to a much greater extent than Southern pine or lodgepole pine. At more neutral conditions, the Southern pine leached slightly more than the other species.

In a comparison of the leaching from small specimens cut from the surface zone of commercially treated poles, we found rates of CCA leaching from red pine were about double those from lodgepole pine, Douglas-fir and western redcedar (Cooper 1989).

Effects of age or time in service on leaching

With all preservatives, losses are highest soon after installation and attenuate with time. This results from one-time losses of surface deposits and immediate losses of unfixed or mobile portions of the preservative. Also, surface concentrations are highest at this point, resulting in a steep concentration gradient across the boundary between the wood and the leaching environment. It has been suggested (Cockroft and Laidlaw 1978) that the rate of preservative depletion varies with the square root of time. Unfortunately, there have been few studies where losses from a single structure have been followed sequentially over time. Fig. 3 shows one example of the levelling off of elemental loss with time under laboratory leaching conditions.

The following examples demonstrate this further. Fahlstrom _et al_ (1967) found that the rate of leaching was highest in the first 6 hours of exposure of small blocks to water; it dropped to 1/5 - 1/10 of the initial rate after 18h and to 1/100 of the initial rate after an additional 24h. Teichman and Monkman (1966), using thin wafers of maple and birch, found the arsenic leached was approximately halved on each successive day over a 3 day leach period.

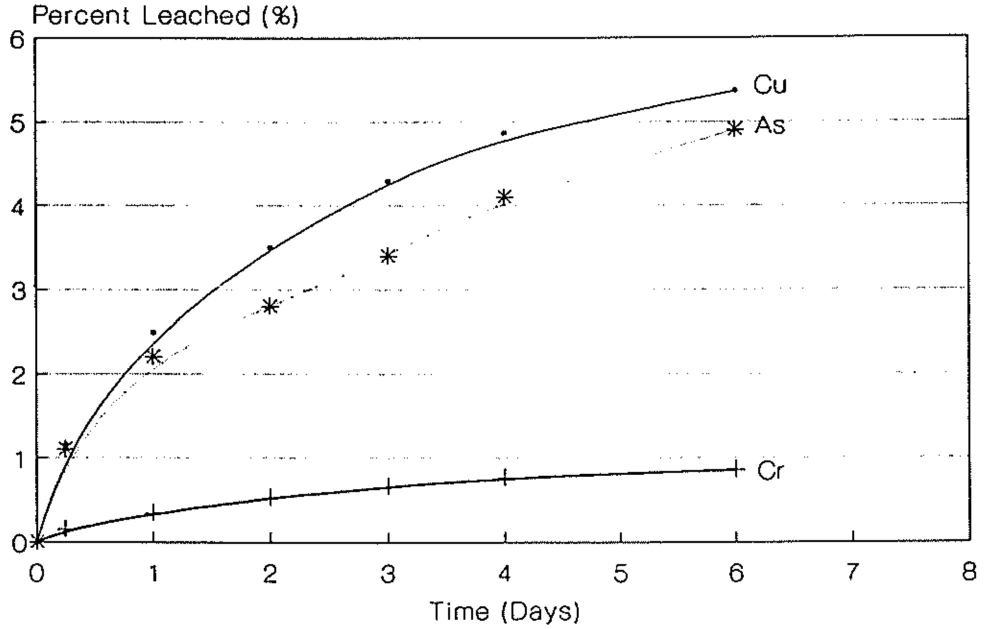


Figure 3. Levelling of elemental losses
with time of exposure to leaching

Evans (1978) evaluated leaching from CCA-B and CCA-C treated Scots pine pole sections in running water for ten years by periodically analysing the outer 5 mm zone. Both treatments lost about 20% of their arsenic component over the first few months. Additional losses over the 10 year test period were not measureable within the variation in retention estimates in the sampling zone. Copper and chromium losses over the entire exposure period were not detectable.

Cserjesi (1976), in a study of preservative depletion from treated western redcedar shakes, found that initial levels of As in collected rain water of 7 -10 ppm dropped to levels of 2 - 3 ppm after 6-8 months. Evans (1987) analysed the runoff from CCA treated "board-on-board" roof coverings over a two year period. Copper levels dropped exponentially over the period from about 5 ppm to less than 1 ppm. Similarily, the arsenic level dropped from about 7 ppm to 1-2 ppm. Chromium levels were uniformly low (< 1ppm).

Effect of CCA formulation

Historically, a number of CCA formulations have been developed and used. The most common formulations that have been used are shown in Table 3.

Table 3: CCA Formulations (Oxides basis)

	% Constituents		
Type	CuO	CrO_3	As_2O_5
CCA-A	18.1	65.5	16.4
CCA-B	19.6	35.3	45.1
CCA-C	18.5	47.5	34.0

Systematic laboratory studies, e.g., Henry and Jeroski (1967), Fahlstrom et al (1967) showed that formulations with intermediate chromium and arsenic levels (CCA-C),
provided the best leach resistance and overall effectiveness. For the past 10 years, CCA-C has been used almost exclusively by Canadian treaters.

The relatively high arsenic content CCA-B was used extensively in the 1970's and large amounts of wood treated by this formulation are still in service. Most leaching studies show that this formulation has a higher rate of arsenic leaching and As accumulation in soil near treated wood compared to the other formulations (Cockcroft et al 1978, Richardson 1978, Henry and Jeroski 1967, Pizzi 1982). High chromium, low arsenic CCA-A treated poles installed in Canada for 37 years had high surface loadings (11.1 kg/m^3) indicating relatively little depletion over this long service Ruddick 1990). The element balance in the wood suggests slight preferential leaching of chromium in these poles. Wallace (1968) found slightly higher chromium losses but lower copper and arsenic losses from small blocks of CCA-A treated Scots pine compared to CCA-B and CCA-C treatments.

In a comparison of element distributions around CCA-A, CCA-B and ACA treated Southern pine stakes after 25-31 years in service, DeGroot et al (1979) found greater amounts of arsenic below and adjacent to CCA-B and ACA treated stakes, compared to CCA-A stakes. In all cases, the soil level of all three elements approached background levels at depths greater than 305mm (12") below the stakes. Also, the lateral distribution of arsenic was greater for CCA-B and ACA but approached background levels within 305mm (12") of the stake surfaces.

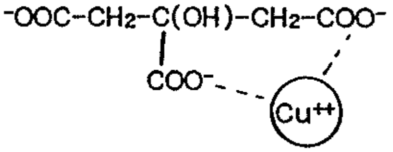
CCA preservatives may be formulated with a number of Cu Cr and As chemicals including $CuSO_4$, CuO, $Na_2Cr_2O_7$, $K_2Cr_2O_7$, Na_2CrO_4, CrO_3, As_2O_5 and H_3AsO_4. Most leaching studies that involve comparison of the above formulations show that there is little difference between oxides and salts based formulations with the same ratios of active elements. However, Rak and Clarke (1974) using an accelerated leaching procedure, found that CCA-C formulated with $CuSO_4$ lost significantly more of all elements compared to CuO based CCA-C.

Effect of pH, Salts, Organic Acids etc.

As with most metal complexes, the solubility of the fixed CCA components increase with increased acidity (decreased pH) of the leach water. However, there is some controversy about the seriousness of the problem, especially in relation to the effects of acidic precipitation or acidic lakes. At pH's of less than 3, the wood itself is degraded and extensive Cu, Cr and As losses will occur. Under less acidic conditions (pH 3.5 - 6) leaching is progressively increased with decreasing pH (Table 4).

However, the effect is much less serious than suggested in a series of newspaper articles deriving from a news release on a study at the University of Guelph. In response to this study which indicated excessive losses of CCA by acidified water (Warner 1989) several studies were undertaken to evaluate the effect of citric acid on leaching of CCA.

These are summarized in Table 5. Citric acid acts as a bidentate ligand capable of sequestering multivalent cations such as copper ion into highly soluble complexes:



$$^{-}OOC{-}CH_2{-}\underset{\substack{|\\ COO^{-}}}{C}(OH){-}CH_2{-}COO^{-} \cdots Cu^{++}$$

Citric acid can also chelate chromium to form water soluble complexes (NRCC 1976).

Table 4: Effect of pH on Leaching of CCA - Small block Laboratory Tests

Sample	pH	% Leached Cu	Cr	As	Reference
CCA-C	2.5	145	29	40	Warner 1989
Jack pine	3.5	75	6	23	"
	4.5	21	3	17	"
CCA-B	3.0	41	<5	24	Murphy & Dickinson 1990
Scots pine	5.6	<5	<5	<5	
CCA-C	3.0	38	<5	<5	Murphy & Dickinson 1990
Scots pine	5.6	<5	<5	<5	
CCA-C	3.0	44	38	42	O'Rourke 1989
Ponderosa pine	5.0	20	10	15	"
CCA-C	3.0	68	8	20	Pasek 1990
Jack pine	4.0	18	2	10	"
(EP Tox.)	5.0	3	-	2	"
CCA-C	3.5*	10	1.4	7	Cooper 1989
Red pine	4.5*	5	1	5	"
	5.5*	6	1	6	"

* pH not continually adjusted

Strong alkaline solutions e.g., 0.1N NaOH, also increase the extraction of CCA components (Teichman and Monkman 1966).

It has been suggested that other organic acids, some of which may be present in rain and surface water in significant quantities, may also show anomalous leaching effects. This is unlikely in the case of the most common organic acids such as formic and acetic acids. However, it is possible that other complex organic acids will accelerate leaching of CCA components.

Two cases in point are peaty organic soils and surface water containing humic or fulvic acids and wood silos containing corn and other grains that can yield silage acids such as formic, lactic and acetic acids.

Humic substances found in surface waters draining sphagnum bogs contain polyaromatic and aliphatic acids with 10 or more carboxylic acid groups per molecule (Hayes and Swift 1978). Becher et al (1983) showed that Cu complexes with humic acids and that dissolved organic materials could extract copper from sediments by formation of these complexes. It is also possible to reduce the leachable arsenic content of ore refining sludges by extracting them with humic acids. Trivalent chromium can be mobilized by complexing with components of composting organic matter in poorly drained soils (NRCC 1976).

Evans (1987) showed that small CCA treated wood blocks placed in silage juices had high leaching losses compared to leaching in water. CCA treated boards, placed in active silos, lost 20 - 50% of the Cu, 50 - 60% of the Cr and 70 - 80% of the arsenic over a two year period. In both of the above cases, the low pH of the system (pH 4 or less) also contributed to the high rate of leaching.

It has also been shown that water of high ionic strength I (where I = SUM of molar concentrations of all ionic species in the water) results in greater leaching of CCA components (Plackett 1984, Irvine and Dahlgren 1976, Table 5).

Table 5: Effect of Citric Acid and Dissolved Salts on Leaching of CCA

Additive	pH	Ratio of elemental loss with *vs* without additive Cu	Cr	As	Reference
Citric acid	3.5	1.5	8	3	Warner 1989
/NaOH JP	4.5	5	10	3	"
Citric acid	5.5	12	10	7	Cooper1989
/NaOH RP					
Citric acid	3.5	2	9	3	Anderson 1989
/NaCitrate	4.5	3	4.5	2	"
SYP	5.5	6	7	2	"
	6.5	0.5	2	0.9	"
Citric acid	3.0	1	2	1.2	Pasek 1990
/Borax	4.0	4	8	2	"
JP	5.0	>50	-	>30	"
$CaCl_2$	--	7.1	--	--	Plackett 1984
$Ca(NO_3)_2$	--	7.9	--	--	Plackett 1984
$Mg(NO_3)_2$	--	2.6	--	--	Plackett 1984
KH_2PO_4/ K_2HPO_4	--	7.9	--	--	Plackett 1984
NaCl	large increase in losses of all elements				Irvine and Dahlgren 1976
0.1N NaOH	13	--	--	5-6	Teichman & Monkman 1966

Irvine and Dahlgren (ibid.) discuss the mechanism of this effect in their paper. At low salinities, copper leaching is reduced due to a postulated coagulation effect. At higher salt contents, Cr and As losses increase due to a shifting of the equilibrium to increased dissolved ion content with increased ionic strength. Also, the portion of copper ion exchanged onto the wood acid groups can be replaced by other cations such as Na^+, Ca^{++} or Mg^{++} in the solution.

Thus, when treated wood is in contact with water with a high salt content, such as sea water, cooling tower water, water contaminated with road salt or fertilizers, we should expect higher leaching losses.

Other Factors

The CCA retention level affects both the absolute amounts of elements leached and the percent of total leached. Fahlstrom et al (1967) found the percent loss of arsenic from small Southern pine blocks decreased with increased CCA-B retention but the reverse was true for CCA-A formulations. Leaching from CCA-C treated blocks was more-or-less independent of retention. Hagar (1969) generally found higher leaching rates with higher CCA loadings.

The preservative treating process may also have an effect on leaching. To a limited extent, preservative penetration and retention can be increased by extending the pressure treating period. This results in a lower proportion of total treatment on the surface and should provide lower percent leaching losses, but may increase absolute emissions. The length and extent of the final vacuum affects the amount of more readily leached surface chemical (Cockcroft et al. 1978).

There is some evidence that high temperature exposure of treated wood increases the tendency of the elements to leach from wood. Conradie and Pizzi (1987) found an increase in Cu, Cr and As leaching and loss of efficacy in small samples exposed to high temperatures either during or after fixation.

This effect may be related to impairment of the fixation process by drying of the samples before fixation. It is generally recognised that wood should not be seasoned during fixation (e.g., Avramidis and Ruddick 1989), as full moisture saturation of the wood cell walls promotes better mass transfer of the chemicals involved in the process.

It is possible that additives such as water repellents can reduce the amount of leaching from CCA treated wood (Fowlie et al 1990). Similarily paint or other coatings should retard the rate of leaching.

ENVIRONMENTAL SIGNIFICANCE OF CCA LEACHING FROM TREATED WOOD IN SERVICE

The toxicity of these preservatives is particularly important because treated wood is used extensively in general residential use, in playground equipment and in preserved wood foundations.

Arsenic and chromium may be highly toxic in certain forms. Thus the treating solutions have high mammalian toxicities. However, treated wood is not considered a toxic or hazardous material because the chemical components are so well fixed in wood.

Concentration of CCA components in the leachate

The environmental significance of arsenic leached from wood depends on the valence state of the extracted As. Trivalent As binds more readily to biological tissues and is more acutely toxic than pentavalent As. Trivalent arsenic is readily oxidized to the pentavalent form and under anaerobic conditions, the reverse transformation may occur. Arsenic in preservative treating solutions is in the pentavalent state. However, speciation studies on treated wood (Woolsen and Gjovik 1981) show that both valence states may be present in treated wood. There is apparently an increase in trivalent arsenic with exposure in service. Similar tests on leached arsenic are required to better assess its environmental significance.

As with arsenic, the environmental and health significance of chromium is strongly dependent on its valence state. CrVI can easily cross biological membranes. As a strong oxidizing agent, it can result in considerable health problems, including respiratory problems, cancer, skin ulcerations and dermatitis. CrIII is considerably less toxic because of its non-corrosive nature and poor membrane permeability. The CCA fixation reaction requires and is essentially defined by reduction of CrVI to CrIII. Studies indicate that virtually all of the chromium in treatd wood is in the trivalent state (Wright 1989) although it has been hypothesized by Pizzi (1981) that some of the fixed chromium is in the hexavalent state.

The significance of chromium in leachate from treated wood will depend on whether it is totally trivalent or not. CrVI reacts very slowly with soil constituents and so is very mobile, moving at the same rate as the ground water (Rouse 1988). Trivalent chromium, on the other hand is highly partitioned to the soil particles. There do not appear to have been any studies to determine the proportion of CrIII in leachate from treated wood in service.

Actual studies on CCA concentrations in leach water are relatively rare. Several examples are shown in Table 6.

Typically, concentrations are in the 0 - 10 ppm range, depending on the exposure conditions, CCA type, etc.

Clearly, the levels are higher than the drinking water standards (1, .05 and .05 ppm for copper, chromium and arsenic respectively) and water quality objectives for aquatic environments (.005, 0.1 and 0.1 ppm for Cu, Cr and As). Water collected from treated wood should not be drunk or used for cooking. On contact with soil, or with dilution with surface and ground waters, these levels will drop by several orders of magnitude.

Table 6: Typical Levels of CCA Components in Leachate from Wood in Service.

Solution	Product	Exposure	Concentration			Reference
			Cu	Cr (ppm)	As	
CCA-B	Cedar shakes	Natural rain Langley, B.C. (first year)	1-7	--	2-12	Cserjesi (1976)
CCA-B	Cedar shakes	Natural rain Langley, B.C. (second year)	.5-2.5	--	1-5	Cserjesi (1976)
CCA-C	Cedar shakes	Natural rain Langley, B.C. (first year)	1-5	--	1-4	Cserjesi (1976)
CCA-B	Roof boards (prewashed)	Natural rain (Norway) after 2y	0.29	0.076	1.11	Evans (1987)
CCA-B	Roof boards (not prewashed)	Natural rain (Norway) after 2y	0.76	0.094	1.21	Evans (1987)
CCA-B	Roof boards	Natural rain (Norway) Max. levels (first rain)	4-5	0.5-0.9	7.3	Evans (1987)
CCA-C	LPP pole section (new)	Natural rain Toronto pH 6	1.8	0.4	0.3	Cooper (1990)
CCA-C	SPF fence 1 Year	Natural rain Toronto pH 6	4-5	7	6.5	Cooper (1990)
CCA-C	39X140X900mm new JP board	Natural rain Toronto pH 5.1	2.8	1.0	--	Hruby (1990)
CCA-C	39X140X900mm Aged JP board (1 month)	Natural rain Toronto pH 5.1	2.7	0.9	--	Hruby (1990)
CCA-C	39X185mm new JP board	Natural rain Toronto pH 5.1	1.8	2.7	--	Hruby (1990)
CCA-C	39X140 decking 10y in service	Natural rain Toronto pH 5.1	<0.1	<0.1	--	Hruby (1990)
CCA-C	19X140X610mm SPF boards	Simulated rain (1 week)	14.5	12.1	7.3	O'Rourke (1990)
CCA-C	19X140X610mm SPF boards	Simulated rain (4 week)	3.0	1.5	5.0	O'Rourke (1990)

Contamination of ground and surface water

The author is not aware of any field studies to monitor the contaminant levels of ground water near CCA treated products. However, several laboratory studies have looked at the Cu, Cr and As content of water passed through treated wood in soil systems. In these cases, the ratio of treated wood to soil is relatively large and the treated wood is quite finely divided. Murphy and Dickinson (1990) found that the leachate concentrations were essentially independent of initial rain pH, presumably due to buffering or neutralization of the water by the soil (Table 7).

Arsenic concentrations were much higher for CCA-B than for CCA-C systems. The amounts of chemicals leached through the soil system were much higher for sand soils than for clay or peat soils.

Table 7. Soil Water Contamination from Leached Treated Wood

Treatment	Sample setup	Soil type	Concentration Cu	Cr	As	Reference
CCA-B	Small stakes in soil Simulated rain pH 5.6	Sand Clay Peat	0.2 0.2 0.1	<.1 0.3 <.1	22.1 4.3 3.4	Murphy & Dickinson (1990)
CCA-B	Small stakes in soil Simulated rain pH 4.1	Sand Clay Peat	0.2 0.2 0.1	<.1 0.2 <.1	22.4 1.9 2.3	Murphy & Dickinson (1990)
CCA-B	Small stakes in soil Simulated rain pH 3.0	Sand Clay Peat	0.2 0.2 0.2	<.1 <.1 <.1	22.4 2.3 2.5	Murphy & Dickinson (1990)
CCA-C	Small stakes in soil Simulated rain pH 5.6	Sand Clay Peat	0.1 0.1 0.1	<.1 <.1 <.1	0.3 0.2 0.2	Murphy & Dickinson (1990)
CCA-C	Small stakes in soil Simulated rain pH 4.1	Sand Clay Peat	0.2 0.1 0.2	<.1 <.1 <.1	0.3 0.2 0.2	Murphy & Dickinson (1990)
CCA-C	Small stakes in soil Simulated rain pH 3.0	Sand Clay Peat	0.3 0.1 0.2	<.1 <.1 <.1	0.5 0.3 0.2	Murphy & Dickinson (1990)
CCA-B	Chips buried in soil exposed to natural rain over a 4y period	Sand Clay Peat	0-.4 <.2 0-.7	.01-.7 <.05 <.05	.1-1.5 .1-2.2 0-1.8	Bergholm (1985)

From these limited tests, it is evident that the As content of ground water close to treated wood may considerably exceed current allowable ground water levels (e.g., MENVIQ 1989, Table 8). Studies on the attenuation of groundwater levels of CCA contaminants with distance from treated products are required.

Table 8. Criteria for Ground Water Contamination by CCA Components (MENVIQ 1989)

Criterion considered	Concentration (ppm) Cu	Cr	As
Ground water contamination			
- Criterion A, background levels	.025	.015	.005
- Criterion B, slight/mod. contaminated	.50	.04	.05
- Criterion C, contaminated, remediation required	1.00	.50	.10

Contamination of soil near treated wood

Because of the strong interaction of arsenic with soil constituents (particularly iron (K_{sp} $FeAsO_4 = 5.7X10^{-21}$), aluminum and calcium (K_{sp} $Ca_3(AsO_4)_2 = 6.8X10^{-19}$)) it is generally considered to have a negligible potential to leach through soil to contaminate the ground water, even under former agricultural practices that resulted in high applications to plants and soil (Sandberg and Allen 1975).

A study on the distribution of As in the vicinity of CCA-A treated SYP poles in service 32 years (Arsenault, 1975) showed a rapid drop in As soil concentration with distance from the poles. Arsenic concentrations were 53, 36, 23 and 16 ppm in the 0-50mm, 50-100mm, 100-150mm and the 400mm zones compared to a background level of 14 ppm. Similarly, CCA-A treated SYP posts in service 26 years, had As concentrations in the surrounding soil of 14, 10 and 7 ppm in the 0-50mm, 50-100mm and 100-150mm zones compared to a background of 7-12 ppm (ibid, 1975).

One approach in considering soil contamination is to look at levels of CCA components that inhibit plant growth, or result in unacceptable contaminant absorption by food plants. The toxicity of CCA to plants depends on the soil type and the extent of reaction of the elements with the soil. Hexavalent chromium is toxic to plants at 1 - 5 ppm in solution cultures or sand, but at 500 ppm in compost soils. Trivalent Cr is less toxic by a factor of about 10.
The worse case is with acidic sandy soils (NRCC 1976) because of its low affinity for the contaminants.

Grant and Dobbs (1977) found some reduction in growth rates of several plants at CCA levels of 170 ppm and complete inhibition of growth at 7000 ppm. Plants absorbed all elements, but mainly in the root tips. Arsenic at soil levels of 200 ppm resulted in above recommended As levels in carrots grown on the soil. The concentration of **soluble** arsenic in soil necessary to cause injury to plants ranges from 1 ppm to 9 ppm, depending on the plant. Plant growth in arsenic contaminated soil is greatly affected by the soil chemistry. Plants are tolerant of arsenic (as high as 670 ppm) applied to agricultural soils high in reactive aluminum (Woolsen et al 1971). Levi et al (1974) could not detect arsenic absorption into grape plants supported on CCA treated stakes.

Available results on soil contaminant levels, (Table 9) show that the soil in direct contact with CCA treated structures in service for long periods, may have relatively high concentrations of arsenic, but the soil reaches background conditions a short distance from the structures.

Table 9: Summary of Published Data on the Preservative Content of Soil near Treated Wood Under Laboratory and Field Exposure Conditions

Sample or product	Location	Description of Exposure conditions	Soil Conc. (ppm)	References
CCA-B Sand boxes 2-4 y in service	Uppsala Sweden	Fine sand, at surface near wood	Cu 10-13 Cr 5-7 As 1-9	Henninsson & Carlsson 1984
CCA-B Sand boxes 2-4 y in service	Uppsala Sweden	Fine sand, 0.2 m down near wood	Cu 8-12 Cr 3-9 As 1-13	Henninsson & Carlsson 1984
CCA-B Sand boxes 2-4 y in service	Uppsala Sweden	Fine sand, at surface 0.5 m from wood	Cu 9-11 Cr 3-6 As .1-2	Henninsson & Carlsson 1984
CCA-B Sand boxes 2-4 y in service	Uppsala Sweden	Fine sand, 0.2 m down 0.5 m from wood	Cu 1-11 Cr 4-7 As .3-.9	Henninsson & Carlsson 1984
CCA-B Playground supports, 2-4 y.	Uppsala Sweden	Coarse sand, at surface near wood	Cu 7-18 Cr 4-9 As 1-10	Henninsson & Carlsson 1984
CCA-B Playground supports, 2-4y.	Uppsala Sweden	Coarse sand, 0.2 m down near wood	Cu 7-13 Cr 4-12 As .5-8	Henninsson & Carlsson 1984
CCA-B Playground supports, 2-4 y.	Uppsala Sweden	Fine sand, at surface 0.5 m from wood	Cu 6-10 Cr 4-6 As .4-.8	Henninsson & Carlsson 1984
CCA-B Playground supports, 2-4y.	Uppsala Sweden	Fine sand, 0.2 m down 0.5 m from wood	Cu 5-12 Cr 3-6 As .2-.6	Henninsson & Carlsson 1984
CCA-C/PEG Red pine, installed 4y	S. Ontario near pole		Cu 12-23 Cr 7-8 As <0.5	Mortimer (1988)
	2m from pole		Cu 5-10 Cr 5-7 As <1.0	
CCA-B Scots pine Installed 10y	S. Finland *		Cu 8-65 Cr 8-65 As 20-210	Nurmi (1990)
Background Conditions	Saucier MI	Annual rainfall: 160cm subtropical climate pH= 4.9, acidic sandy loam	Cu: 4.0-6.6 Cr: 3.8-9.2 As: 0.6-1.4	DeGroot et al (1979)
50 X 101 mm stakes CCA-A, 10.6 kg/m^3 installed 30y	Saucier MI 0-152 mm zone, 0mm from stake	Annual rainfall: 160cm subtropical climate pH= 4.9, acidic sandy loam	Cu: 75.8 Cr: 45.9 As: 73.2	
50 X 101 mm stakes CCA-B, 8.8 kg/m^3 installed 26y	Saucier MI 0-152 mm zone. 0 mm from stake	Annual rainfall: 160cm subtropical climate pH= 4.9, acidic sandy loam	Cu: 47.9 Cr: 24.2 As: 73.2	

* Assumes a soil density of $2kg/dm^3$

Based on assumed impacts of contaminants in soil on the environment and on human health, the governments of both Ontario (OMOE 1989) and Quebec (MENVIQ 1989) have defined criteria for soil contamination by Cu, Cr and As (Table 10).

Table 10: Criteria for soil contamination by CCA components

Criteria	Concentration (ppm)				Ref.
	Cu	CrVI	Cr	As	
Background	60-100	---	50	10-20	OMOE (1989)
	50	---	75	10	MENVIQ (1989)
Clean-up Guidelines					
Agr./Res./Park	150-200	8-10	750-1000	20-25	OMOE (1989)
Commercial/Ind.	225-300	8-10	750-1000	40-50	OMOE (1989)
Slightly Contam.	100	---	250	30	MENVIQ (1989)
Contaminated*	500	---	800	50	MENVIQ (1989)

* Remediation required

Dislodgeability of CCA from Treated Wood

An additional health and safety concern with waterborne treated wood is the possible transfer of chemical from the wood to humans in contact with it and the ingestion or adsorption through the skin of toxic chemicals. This is of particular concern with children's playground equipment, picnic tables and residential decks. Several investigators have measured the amounts of CCA components available from the surfaces of treated wood (Table 11).

Because of the widely different procedures used to asses dislodgeability, valid comparisons of the findings cannot be made. However, dislodgeability appears to be greater with ACA than CCA, unless specific efforts are made to produce a clean ACA product (Woolsen and Gjovik 1981). Generally, the availability of components decreases with age of the treated wood. Higher amounts are dislodged from the end grain than the sides of treated wood (Johanson and Dale 1973). The amount dislodged consists of both water soluble components and insoluble particles. Some of the above investigations include both water soluble and insoluble (particulates) in the analysis (e.g., Warner 1989, USDA 1980, Coggins and Hiscocks 1978). The soluble component is of most concern, and tends to be low compared to the insoluble component (Johanson and Dale (1973).

Table 11. Dislodgeability of CCA from Treated Wood

Treatment	Loading kg/m³	Dislodging Method*	Age in Service (y)	Approximate Dislodgeability (ug/100cm²)			Reference
				Cu	Cr	As	
CCA-A	7	A	36	--	--	17	Woolsen & Gjovik (1981)
CCA-A	10.6	A	23	--	--	7	
CCA-A	12.2	A	13	--	--	4.4	
CCA-B	8.3	A	32	--	--	12	"
CCA-B	6.7	A	13	--	--	28	"
CCA-C	6.4	A	10	--	--	28	"
CCA-C	7.5	A	6	--	--	18	"
CCA-C	6.4	A	0	--	--	34-144	"
CCA-C	3.2	B dry	1	20	20	15	Warner (1989)
CCA-C	3.2	B wet pH7	1	75	110	150	
CCA-C	3.2	B dry	0	45	35	30	
CCA-C	3.2	B wet pH7	0	175	130	350	"
CCA-C	15.	C	0	670-3100	--	60-80[@]	Johanson & Dale (1971)
CCA-C	15.	C	0	1330-3070	-	60-160[@]	
CCA-C	--	D	0	--	--	46	USDA (1980)
CCA-C	9.6	E	0	--	--	26	"
CCA	--	F	0	--	--	32	Arsenault (1975)
CCA-C	--	G	variable	.1-91	.1-25	.1-32	Galarneau et al (1989)
CCA-C	15.9	H	0	--	300	--	Coggins & Hiscocks (1978)

* A - Wet with distilled water, scrub with a brush (3X)
B - Mechanical rubbing of wetted cheese-cloth over the surface for 1 min.
C- Wash and gently scrub with soft brush with 300ml water for 2 min. Repeat 4 more times.
D - Pads of water-soaked filter paper placed on surface for 48h.
E - Hand wipe, damp sponge.
F - Wet hand wipe.
G - Wipe 2m length with damp gauze sponge.
H - Swab with wet cotton wool

[@] soluble component only

Interpretation of dislodgeability results varies greatly from investigator to investigator. Warner (1989) used a "worse case" scenario of assuming that the entire body is exposed at the measured rates and that complete absorbance of the contaminants through the skin occurred. Under these assumptions, toxic limit values for arsenic and chromium were exceeded by factors of 70 and 32 on new wood (wetted) and 30 and 21 on weathered wood. However, Warner (ibid.) suggests that under more reasonable assumptions, it is unlikely that exposure to CCA treated wood will result in human health risks. Coggins and Hiscocks (1978) confirmed that the chromium component of CCA dislodged from wood after fixation is trivalent and therefore unable to pass through unbroken skin easily (NRCC 1976). A more realistic absorbance factor for arsenic is 0.1 % (Woolsen and Gjovik 1981). In fact, the US Environmental Protection Agengy (EPA 1984) considers dermal absorbance from dry arsenic treated wood to be negligible, based on absence of As in urine samples of dogs with dermally applied wet treated sawdust.

Based on a recent evaluation of As dislodgeability, the U.S. Consumer Products Safety Commission Health Services Directorate has characterised the risk of cancer posed by arsenically treated wood in playgrounds as "negligible" (less than 1 in one million, AWPI 1990).

RECOMMENDATIONS TO MINIMIZE ADVERSE EFFECTS OF CCA ON PUBLIC HEALTH AND THE ENVIRONMENT

(i) Avoid use of CCA and ACA treated wood for applications where there is evidence that unacceptable leaching could result. For example: Water storage tanks, reservoir covers, water troughs, silos, compost bins.

(ii) Consider the end use requirements carefully before specifying treatment. For example, wood that is always below the water table or submerged in water (e.g., lower tiers of dock cribs), does not require any preservative treatment, because of the lack of oxygen required by decay fungi and insects.

(iii) Adverse effects of handling and using waterborne treated wood can be minimized by following the recommendations of the US EPA approved Consumer Information Sheets distributed to users of treated wood in the USA:

- If used in residential construction, all sawdust and construction debris must be cleaned up and disposed of.
- Do not use where it may contaminate human or animal food or water (except for incidental contact such as docks and bridges).
- Wear a dust mask and eye protection when cutting or machining treated wood. Where possible, do this work out-of-doors to avoid contaminating the interior air with airborne sawdust.
- After working with the wood, wash prior to eating, drinking or smoking.

FURTHER STUDY NEEDS

(i) Expand the existing database on CCA leaching to include more information on total losses from products in service, concentration of components in leach water and nearby ground and surface water and adjacent soil concentrations.

(ii) Evaluate the effects of humic acids, fertilizers, and road salt on CCA leaching.

(iii) Evaluate the effects of high temperatures (before, during and after fixation) on leaching of CCA.

(iv) Determine the proportion, if any, of CrVI and AsIII in leachate from properly fixed wood.

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