ENVIRONMENTAL PERSISTENCE AND MIGRATION OF WOOD POLE PRESERVATIVES: PART ONE

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SUMMARY

An investigation into the environmental persistence and migration of pentachlorophenol (PCP) and chromated copper arsenate-polyethylene glycol (CCA-PEG) was undertaken by the Environmental Sciences Section at Ontario Hydro Research in 1987. Co-funding by the Canadian Electrical Association in 1989 permitted the project to expand considerably and to include another proposed alternative treatment, copper naphthenate. The first phase of this study is comprised of investigations of in-service poles and poles installed in a Hydro test site. Previously published work in this area is reviewed and preliminary results from the field tests are presented.

INTRODUCTION

Electrical and telephone utilities throughout Canada use large numbers of wood poles for the support of overhead transmission and distribution lines. To prolong the life of these poles almost all are full-length pressure treated or butt thermally treated with a suitable preservative. Creosote, which had been used as a wood preservative for many years, was replaced by pentachlorophenol in the mid-1950's as the preferred preservative for poles. More recently, the waterborne preservatives, chromated copper arsenate (CCA) and ammoniacal copper arsenate (ACA) have been used for significant quantities of poles. Their tendency to harden the wood, however, has made them unpopular with line maintenance personnel. Chromated copper arsenate (CCA) has recently been modified with polyethylene glycol (PEG) to improve the climbing properties of poles treated with this preservative. CCA-PEG poles are being installed on a regular basis by telephone utilities and on a trial basis by a number of electrical utilities.

Copper naphthenate, which, like pentachlorophenol, is an oil-borne preservative, is considered to be more environmentally acceptable than pentachlorophenol. It is registered as a general wood preservative in Canada and the United States and can be purchased and used by the general public. It has recently been included in the American Wood-Preservers' Association (AWPA) Standard for the pressure treatment of wood poles and it has been recommended for groundline re-treatment of wood poles (1).

Although there is currently no prohibition on the use of pentachlorophenol for treatment of utility poles, the concerns expressed by the public and the regulatory agencies suggest that some regulation regarding the use of pentachlorophenol may be enacted in the future. To ensure an adequate supply of properly treated poles utilities must work with suppliers to develop and evaluate new preservatives and with regulatory agencies to ensure that all preservatives do not pose undue risk to the employees, the general public, or the environment.

With respect to this latter objective, a project was undertaken by the Environmental Science Section of Ontario Hydro Research to examine the routes by which preservatives in treated poles enter the environment and, where possible, predict their fate. The preservatives of interest at this time are pentachlorophenol, CCA-PEG, and copper naphthenate.

Specific questions to be answered include: What is the total amount of preservative lost in the first year following installation, and by what mechanism(s) is it lost? Are these losses environmentally significant? Once it leaves the pole, how does it behave in the soil, ie, is it retained by adsorption, leached by rainwater etc, and how would this behaviour be expected to vary across Canada? What are the actual field distributions of preservatives in poles, surrounding soils and vegetation, and how do these change as the poles age? How do the three treatments (PCP, CCA-PEG and Cu-Nap) compare with regard to their environmental impact?

Answers to these questions are needed for the Canadian utilities to make decisions regarding future wood preservative choices, and to justify these decisions to federal and provincial regulatory authorities.

ENVIRONMENTAL PATHWAYS

The possible routes by which preservatives in treated poles (eg PCP) may enter the environment and their fate are illustrated in Figure 1; not all pathways are applicable to all three preservatives. The routes are numbered to facilitate their description.

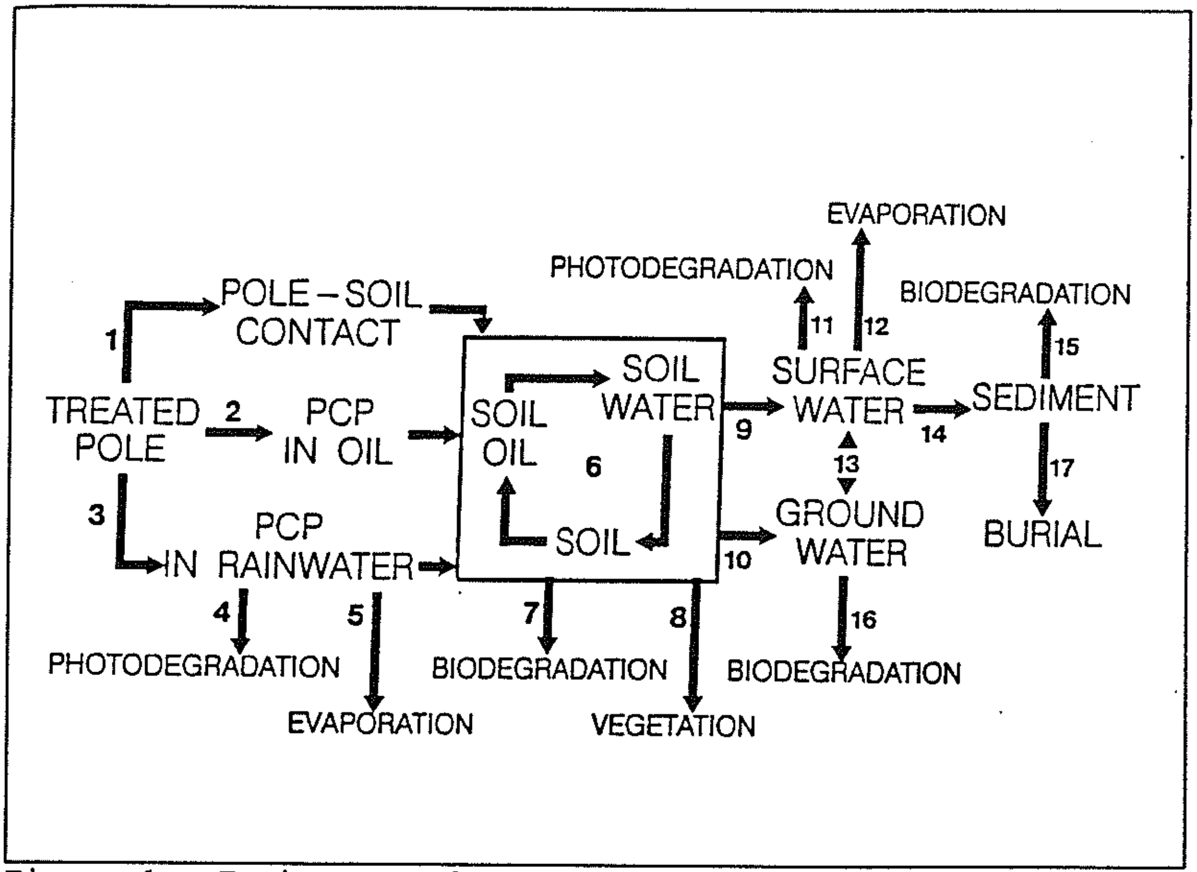

Figure 1. Environmental pathways of pole preservatives.

The oil-borne preservatives, pentachlorophenol and copper naphthenate, may be transferred to the soil by direct movement of the preservative/oil solution from the pole to the soil at or below ground level **1**. In addition there may be movement of the oil carrier due to gravity down the pole and into the soil at ground level **2**. All three preservatives are subject to transfer to the soil by rainwater leaching **3**.

In the soil a dynamic situation exists in which the preservative is partitioned between the various phases which are present, ie, soil, water, and for the oil-borne preservatives, oil. The preservatives may be lost from the soil by uptake by surrounding vegetation **8**, by transfer to surface water **9** or by transfer to groundwater **10**. In the case of pentachlorophenol, and possibly the naphthenic acid component of copper naphthenate, biodegradation in the soil **7** may be significant, at least in the summer months.

Preservatives in the groundwater may be transferred to the surface water **12** or where possible may undergo biodegradation **13**. Preservatives in surface water may be transferred to sediments in

rivers and lakes **15** where they may be buried under successive layers of sediment **17**, thus providing a long term source of contamination, or they may undergo biodegration **16**.
In the particular case of pentachlorophenol it has been shown that this preservative undergoes photodegradation when present in aqueous solutions which are exposed to light (2). This phenomenon is expected to occur in surface water **11** and on the wet surfaces of poles during and after rain **4**. In addition it is possible that a small amount of pentachlorophenol may be transferred directly to the atmosphere by evaporation from surface waters **17** or treated poles **5**.

"FUGACITY" MODELLING

The behaviour of a contaminant in the environment is dependent on its physico-chemical properties and the properties of the environment to which it is released.

An understanding of the environmental behaviour of pole preservatives is necessary to allow predictions to be made regarding the extent of the preservative migration under various environmental conditions. One of the more recently accepted approaches to studying environmental pathways of chemical contaminants is through the use of fugacity models (3,4). Fugacity has units of pressure, and can be viewed as the "escaping tendency" of a chemical. These models are based on the concept that differences in the fugacity of a chemical species between environmental compartments (eg, air, water, soil, sediments, and biota) drives the transport of the chemical from compartments of high fugacity to those of low fugacity. This continues until equilibrium is reached, and fugacities in all compartments are equal. The concentration of the chemical in a given compartment, C, is the product of the fugacity, f, and the fugacity capacity, Z, ie, $C = Zf$. Each compartment has a fugacity capacity for a given chemical, which depends on the chemical's properties of vapour pressure, aqueous solubility and octanol-water partition coefficient (Kow).

For Level I calculations, the conditions are those of equilibrium, steady-state, and no flow. Higher levels of the model include advection, reaction, non-equilibrium conditions, as well as a more detailed environment consisting of many subcompartments, but these will not be described here.

The fugacity model was run for PCP at pH 5.5, 7.0 and 8.5. The results for the Level I calculation are shown in Figure 2. An explanation of the choices of parameter values for the model can be found elsewhere (5). For all pH levels examined, the three most contaminated compartments are water, soil and sediment. For

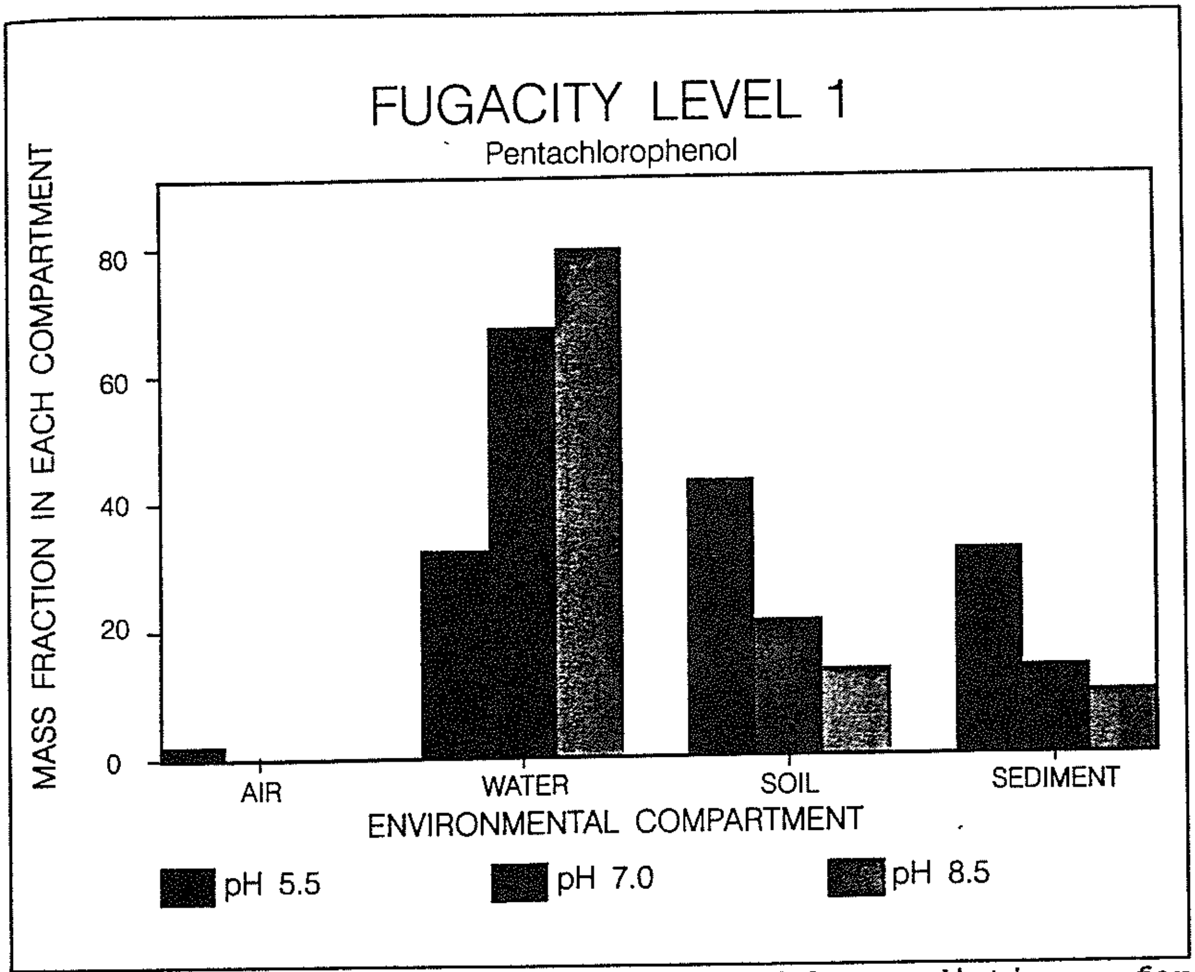

Figure 2. Fugacity Level I model predictions for pentachlorophenol at pH 5.5, 7.0 and 8.5.

a system pH of 5.5, most of the PCP is found sorbed to the soil and sediments. At a pH of 7.0 (at which 99% of the PCP is in the dissociated, or phenate form) more than 2/3 of the PCP is in the water, and at a pH of 8.5, more than 80% is in the water. Pentachlorophenol becomes a greater water pollution problem as pH increases because the material has a much higher water solubility, and a correspondingly lower affinity for soil and sediments, at higher pH levels.

Choi and Aomine (6,7) elucidated the effects of pH on PCP adsorption, finding that adsorption occurs to a greater extent on strongly acidic soils than on moderately acidic soils, regardless of clay mineral or organic matter content. They found no adsorption on slightly acidic or neutral soils. They conducted experiments designed to separate the mechanisms of losses from aqueous PCP solution when various amounts of soils are added. The solution concentrations ranged from 12.5 to 500 mg/L. Below pH 5.0, PCP precipitated from soil solution according to the solubility of PCP at the prevailing pH. Above pH 5.4, the solution concentration decreased as clay was added, indicating adsorption to clay particles was occurring. In desorption experiments, the precipitated PCP dissolved readily when saturated soil was washed with deionized water, and the clay-adsorbed PCP was also released, but at a much lower rate.

Banerji et al (8) conducted a number of experiments to assess the potential for pentachlorophenol migration into ground water, at PCP concentrations likely to be found in contaminated aquifer systems (<10 mg/L). They concluded, from their experimental results, that soil organic content and pH were equally important properties governing the extent of adsorption, that adsorption increases significantly with decreasing pH, and that adsorption to soils is largely reversible. For one soil given as an example, about 69% of the PCP in solution was removed at a solution pH 4.2 while about 10% was removed by the same soil at a pH of 6.6. Very little adsorption of PCP would be expected to occur on alkaline soils. The significance of the reversibility is that while PCP will be initially retained on the soil to a large extent, it will slowly be released to ground water when water of a lower concentration passes through the contamination zone.

STUDIES OF THE MIGRATION OF PRESERVATIVES FROM TREATED WOOD POLES

U.S.A. STUDY

The fate of PCP in soils was addressed by Arsenault (9). Soil samples were taken from around the bases of PCP-treated poles in various geographical areas. The samples were collected at distances of 1, 12 and 60 in. from the poles in each cardinal direction, to a depth of six in. from the ground surface. The age of the poles and the soil pH were not reported. Average PCP concentrations at the pole (1 in.) were 658 mg/kg with a maximum of 9500 mg/kg. At 12 in. the average concentration was 3.4 mg/kg with a maximum of 450 mg/kg. At 60 in. the average concentration was 0.26 mg/kg with background concentrations reported to be 0.2-0.4 mg/kg. Jones (10) reported that the background levels found in this study were very high and that some other explanation such as reagent contamination would be more plausible. Arsenault concluded that the results indicate that either degradation of PCP by the soil or a lack of migration into the soil was occurring. He later stated that "...the argument could be made that PCP has percolated through the soil into layers below the six-in. zone sampled and into the ground water and, therefore, was non-detectable in our sampling." He dismissed this argument, claiming that biodegradation of PCP, which has been demonstrated in the laboratory, removed the PCP from the soil sampled.

NOVA SCOTIA POWER STUDY

In 1983, the Nova Scotia Power Corporation began a three-year field study (11) to determine the extent of migration of PCP from poles which had been ground-line retreated with 10% PCP grease, using the spade-injection method. They report that about 0.43 kg of PCP was applied to each pole. The test poles consisted of two poles from each of three retreatment years, 1981, 1982 and 1983. Soil samples were taken at distances up to 6.0 m from the poles at depths of 0.15, 0.30 and 0.45 m. Author T.P. Toner concluded that there was limited migration of PCP from the poles out to a distance of six metres, with the PCP levels being relatively low. The concentration of PCP around the test poles did not show any clear trends with depth of soil and the PCP concentration decreased rapidly with distance from the poles. Toner's overall conclusion was that the pole retreatment program did not endanger any element of the environment.

BRITISH COLUMBIA HYDRO STUDY

A study was conducted by B.C. Hydro (12) to determine whether PCP migrates from poles which had been groundline retreated. B.C. Hydro uses a formulation of 15% sodium borate, 10% PCP, 15% creosote, and the remaining 60% is a grease carrier. This solution is applied to a 60 cm x 120 cm sheet of polyethylene-coated Kraft paper, in a layer 6 mm thick. This bandage is wrapped around a pole which has been excavated to a depth of 60 cm. The bandage extends slightly above ground level (2 cm), and the excavation is backfilled with the original material.

Soil samples were taken around four poles, two of which had been similarly retreated 12 years previous (poles #1 and #2) and two of which had never been retreated (poles #3 and #4). Samples were taken at depths of 10 cm, 50 cm and 100 cm from the soil surface, at distances of 10 cm, 50 cm and 100 cm from the poles. Before treatment with the bandages, PCP was detected in soil samples collected 10 cm from poles 1 and 2, but not from poles 3 and 4 (at the level of 1 mg/kg dry soil). Subsequent samples were taken at 0, 3, 6, 9, 18, 25, 39, and 54 weeks post-treatment. For all the poles tested, significant amounts of PCP were found only within 10 cm of the poles, at depths of 10, 50 and 100 cm, over the entire 54 weeks of the study. The other samples, at 50 and 100 cm from the poles, were outside the zone of soil disturbed during the bandage application. They did not show any PCP contamination, except for a number of highly suspect values for pole 2 and 39 weeks post-treatment, which should probably be disregarded, according to the authors of the report.

ONTARIO HYDRO PRELIMINARY STUDY

Three poles from Newmarket, ON were chosen for this preliminary study (13). The first pole, full-length PCP-oil treated in 1955, was groundline retreated in 1982. The second pole, installed in 1982, had been full-length treated and had not been groundline re-treated. The third pole, installed new in 1985, had a very black greasy appearance with a pool of black material at the base of the pole (known as "bleeder" pole).

For the first pole (from 1955) soil cores were taken by pounding a 1.5-m long, 5-cm diameter aluminum tube into the ground. The tubes were cut into 25 cm lengths and analysed for PCP. For the other poles, soil samples were taken from the top 30 cm using a stainless steel, Oakfield soil auger tube. For the first pole, soil cores were taken along two perpendicular transects at distances of 0.25, 0.50, 1.0, 2.0 and 5.0 m from the pole in both directions. The soil analysis results are in Table 1. The soil pH was between 8.2 and 8.5.

TABLE 1

PENTACHLOROPHENOL LEVELS IN SOILS NEAR PCP-TREATED POLES IN SOUTHERN ONTARIO

Pole Description	Distance from Pole (m)	Depth (m)	[PCP] (mg/kg)
1955 installed	0.0	0.0 - 0.3	500
1982 retreated	0.25	0.0 - 0.3	0.11
		0.3 - 0.6	trace
		0.6 - 1.5	not detected
	0.5	0.0 - 1.5	nd
	1.0	0.0 - 1.5	nd
	2.0	0.0 - 1.5	nd
	5.0	0.0 - 1.5	nd
1982 installed	0.25	0.0 - 0.3	nd
	0.5	0.0 - 0.3	nd
	1.0	0.0 - 0.3	nd
	2.0	0.0 - 0.3	nd
	5.0	0.0 - 0.3	nd
1985 installed	0.25	0.0 - 0.3	2.3
	0.5	0.0 - 0.3	nd
	1.0	0.0 - 0.3	nd
	2.0	0.0 - 0.3	nd
	5.0	0.0 - 0.3	nd

Pentachlorophenol was not detectable in the soil around treated wood poles at distances greater than 0.25 m from the pole, with a lower detection limit of 0.05 mg/kg. PCP concentrations decrease sharply within this distance (from 500 mg/kg to a few mg/kg).

CCA-PEG POLES

The soil around three 1984 CCA-PEG poles in Holland Landing, ON, was sampled to a depth of 0.25 m, at distances of 0.25, 0.5 1.0 and 2.0 m from the poles, using a soil auger. The samples were analysed for total chromium, copper and arsenic, and the results are shown in Figures 3 and 4.

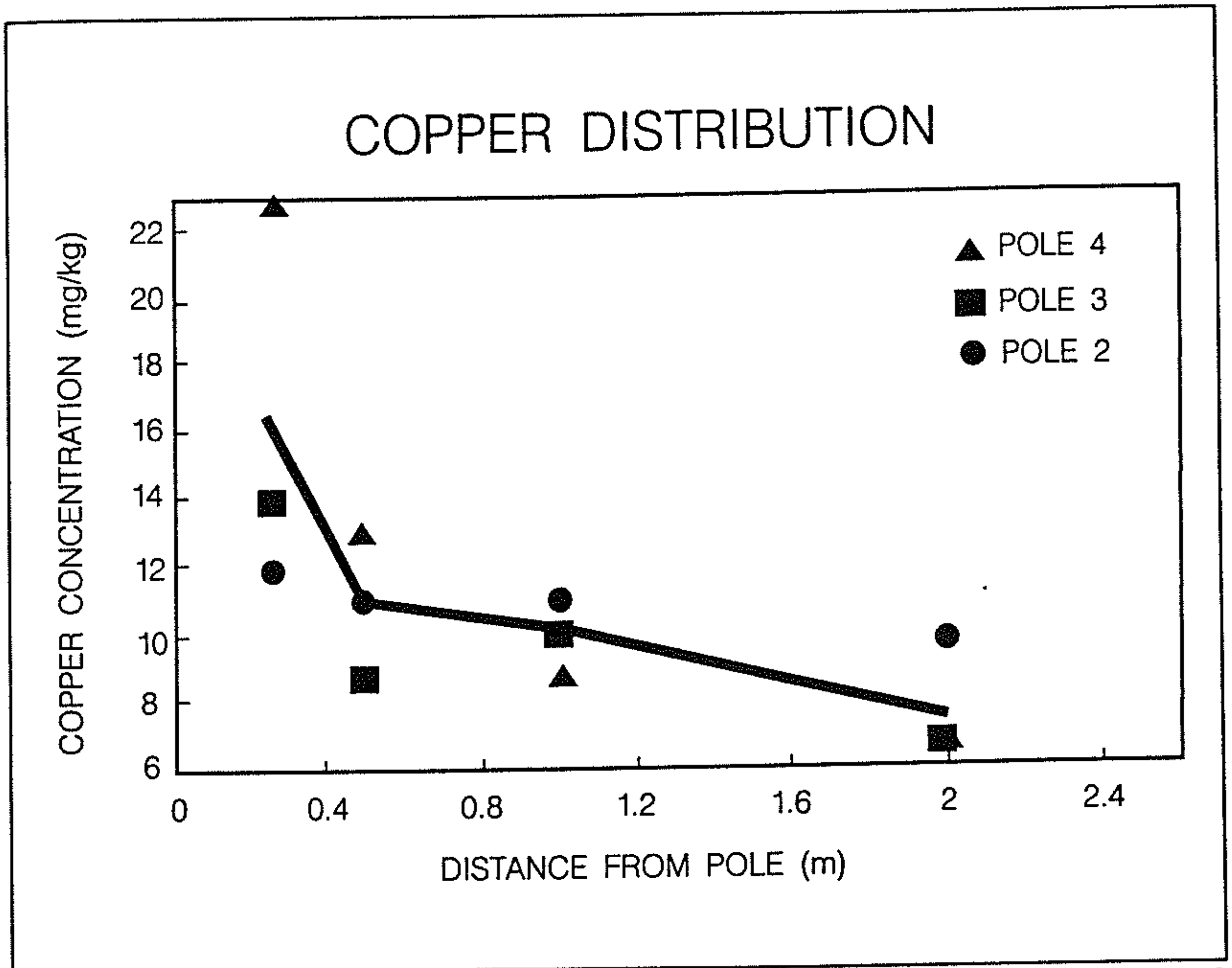

Figure 3. Copper distribution in soils near three 1984 CCA-PEG poles. Solid line average of three poles.

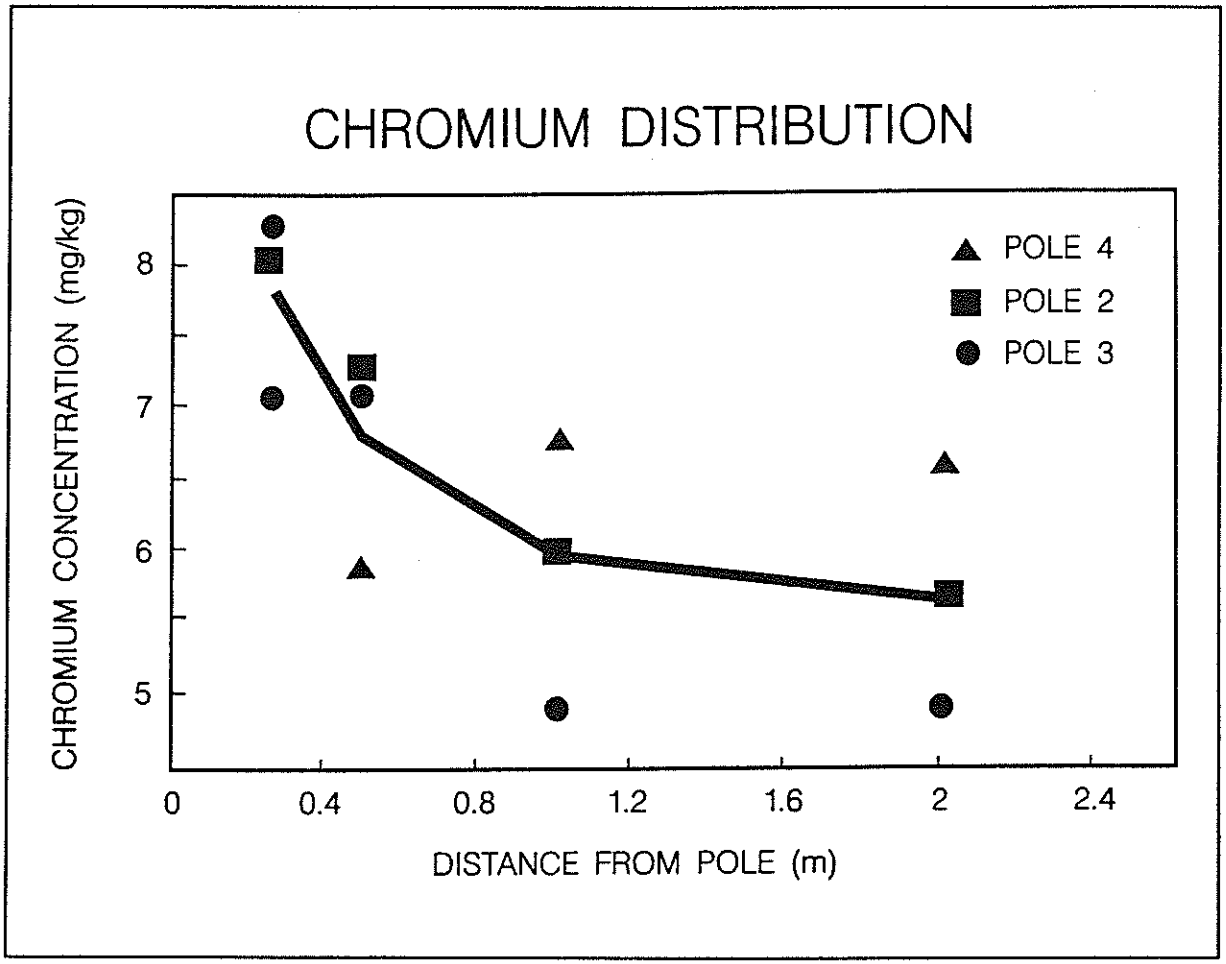

Figure 4. Chromium distribution in soils near three 1984 CCA-PEG poles. Solid line average of three poles.

Background samples were not taken due to the presence of many obstructions such as fences, driveways, fire hydrants, etc. The purpose of taking samples in a transect from these poles was to see if any decline in soil concentrations with distance from the poles could be detected.

Arsenic levels were below the detection limit of 1 ppm at all locations. As shown in Figures 3 and 4, soil concentrations of copper and chromium decreased with increasing distance from the CCA-PEG poles. The levels of these metals found in the soil are not considered to be significant from a health or environmental risk perspective, but the results do indicate that the poles may be a "source" of copper and chromium in this area.

PCP-OIL vs PCP-LPG POLES

In 1975, a number of Southern Yellow Pine poles were installed near Alliston, ON (14). Most of these had received the usual PCP-oil full-length pressure treatment, consisting of about 5% pentachlorophenol in P-9 oil. Some poles, however, had been treated with pentachlorophenol in a liquified petroleum gas carrier - the Cellon treatment. The advantage of this treatment was that the carrier gas volatilized after application, leaving a clean, dry PCP-treated pole.

By 1988, it was clear that the PCP-LPG poles were no longer sound, and it was necessary to replace them. In one line scheduled for change-out, 1975 Southern Yellow Pine PCP-LPG poles had been installed alternately with 1975 Southern Yellow Pine PCP-oil poles. This provided an excellent opportunity to compare pole and soil pentachlorophenol concentrations between the two treatments after 13 years exposure to the same environmental conditions.

Soil samples were collected immediately adjacent to the poles, to a depth of about 20 cm, from opposite sides of each pole. To collect pole cores the soil was removed from each of the sampled sites, exposing the pole to a depth of about 20 cm. An electric rotary corer was used to take two samples from each pole. These were cut into 6 mm slices and analysed by Neutron Activation.

The calculated pentachlorophenol concentrations in the pole cores are shown in Figure 5 and the soil core results are in Table 2.

The pentachlorophenol concentration in the cores decreased from the outer 6 mm toward the centre of the pole, from 13.3 to 9.1 kg/m^3 for the PCP-oil treatment, and from 7.6 to 5.8 kg/m^3 for the PCP-LPG treatment. On average, the ratio of the pentachlorophenol concentrations in PCP-oil poles to those in PCP-LPG poles was 1.66/1. Parker (15) reported that the pentachlorophenol retentions in the sapwood of PCP-LPG Red and Jack Pine poles were 5.4 kg/m^3 and 9.5 kg/m^3 respectively, in the outer 18 mm, after 15 years. The pentachlorophenol retention found here in the outer 18 mm of PCP-LPG Southern Yellow Pine poles after 13 years was 6.8 kg/m^3. In both studies, the preservative retention exceeded the accepted toximetric threshold for pentachlorophenol of 2.4 kg/m^3 yet the PCP-LPG treated poles were decayed. This anomaly has been studied in considerable detail and it is widely recognized that the "carrier" solvent plays a significant role in the efficacy of the preservative and, in general, the "heavier" the oil carrier the greater the efficacy of the pentachlorophenol.

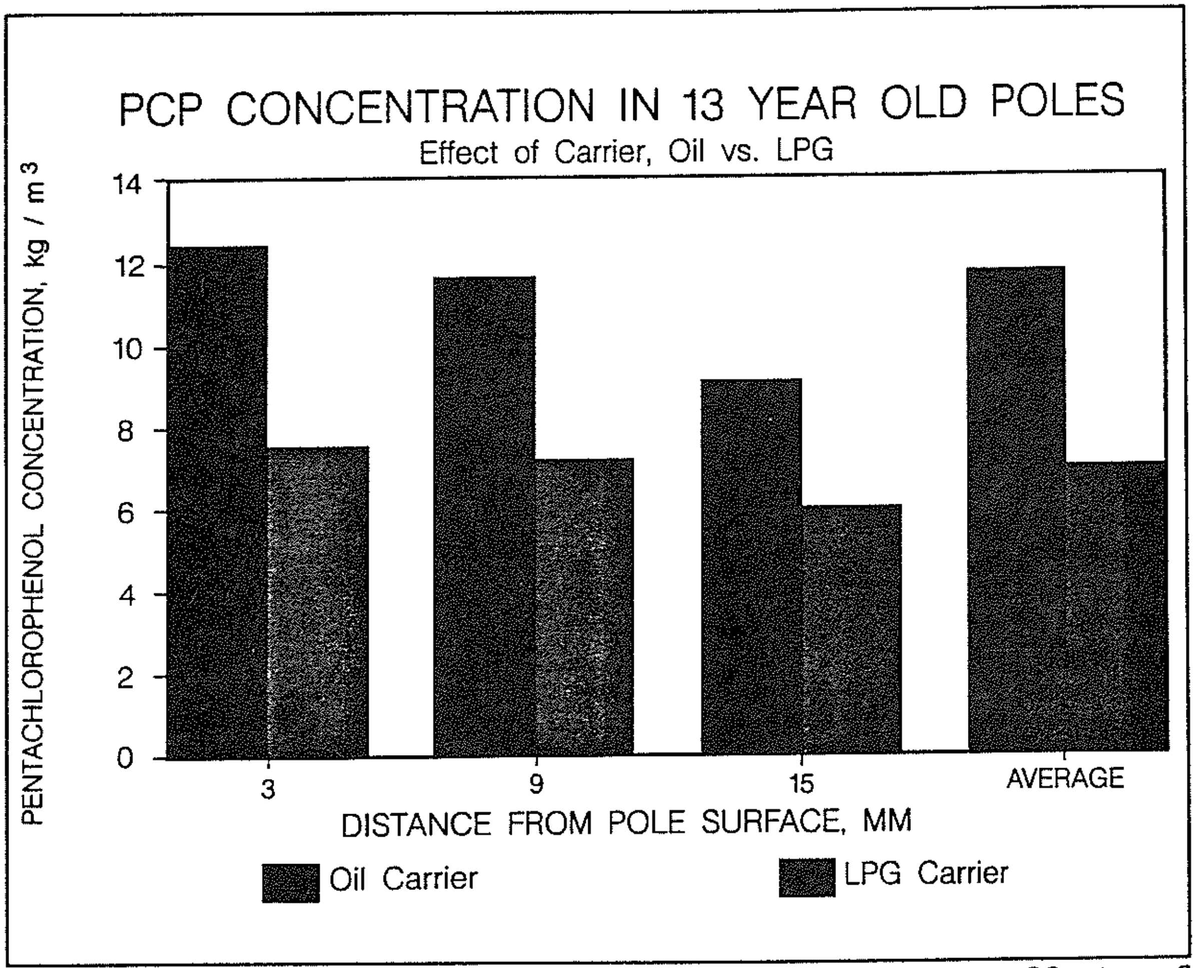

Figure 5. PCP Concentrations in 1975 Poles, effect of carrier, oil vs. LPG

TABLE 2

PENTACHLOROPHENOL CONCENTRATIONS IN SOILS ADJACENT TO 1975 POLES

	Average	Range
PCP-Oil (N=4)	116 mg/kg	11-270
PCP-LPG (N=4)	0.038 mg/kg	<0.01-0.13
Background (N=1)	0.021 mg/kg	

The soil around PCP-LPG-treated poles had consistently low levels of pentachlorophenol, corresponding to soil background levels measured several metres, and across the road, from any poles. The PCP-oil poles were surrounded by soils containing much higher levels of pentachlorophenol, about 3000 times that found, on average, around the PCP-LPG poles. PCP-oil treated poles add much greater quantities of pentachlorophenol to the soil than do PCP-LPG treated poles. This undoubtedly prevents the presence of wood decaying fungi in the soil adjacent to the pole thus providing additional protection against decay. Depletion of pentachlorophenol in the soil is known to occur but it is apparent that even as long as 13 years after installation the pentachlorophenol levels in the soil are being replenished by migration of pentachlorophenol-containing oil from the pole.

CURRENT INVESTIGATIONS INTO THE ENVIRONMENTAL SIGNIFICANCE OF THE USE OF PRESERVED WOOD POLES

The objectives of this study are to determine the factors affecting the migration and persistence of wood pole preservatives in the environment, to quantify their sources and to predict the distribution and fate of these preservatives. The preservatives of interest at this time are pentachlorophenol, CCA-PEG and copper naphthenate.

The approach taken is multi-faceted. Laboratory studies of soil adsorption, modelling and leaching are just getting underway and will not be described here. Field studies began in this past summer, and hundreds of soil and pole cores have been taken from poles of different treatments and ages.

BARRIE TEST PLOT

An Ontario Hydro test plot at Barrie, Ontario, was weeded and graded prior to the installation of the test poles. Six 40 foot (13 m) poles of each of the three treatments were acquired, Red Pine-Penta, Red Pine-CCA-PEG, and Lodgepole Pine-Cu-Nap. Each pole was sectioned into three portions. The top 1 m and the bottom 10 m were installed at the Barrie test plot, while the middle 2 m section was reserved for laboratory leaching experiments. Of each treatment, three 10 m sections and two 1 m sections were selected for installation. The holes were backfilled with a mixed soil of known composition.

Pentachlorophenol and copper naphthenate may enter the environment via the oil phase in which they are applied, or they may be leached out by rainwater (aqueous phase) from both the above and below grade portions of the pole. For the chromated copper arsenate--polyethylene glycol, only the aqueous phase leaching needs to be considered in determining the amount of copper, chromium and arsenic lost from the above-ground portion of the pole.

To quantify the total amount of oil-borne preservative lost from the above-ground portion of the pole, the 10 m sections had activated carbon-containing stainless steel mesh collars placed just above ground level. Preservative material passing down the pole in both the oil and aqueous phases should sorb onto this material. Periodic sampling and analysis of the sorbent material will give the total amount of preservative lost from the above-ground portion of the pole to the surrounding soil, as a function of time. The amount of preservative lost from new poles by rainwater leaching will be determined as a function of time in the laboratory.

Samples of the soil adjacent to the poles have been taken to a depth of approximately four feet, on opposite sides of the pole. After each sample was taken, the holes were filled with clean soil. Subsequent samples were taken from different locations around the pole, at intervals of 7, 19, 49 and 136 days since installation. The carbon was removed from the mesh collars and replaced with fresh carbon at the same time as the soil samples were taken. The next sampling will occur at approximately one year since installation, in June, 1990.

IN-SERVICE POLES

Soil, wood and vegetation samples have been collected from the poles listed below. In each case, the poles were of length 40 feet, and three poles from the same area were sampled, except as noted.

Pentachlorophenol-Red Pine: 1989 (45′ poles); 1986; 1981; 1973.
CCA-PEG-Red Pine: 1989; 1986 (two only).
Cu-Nap-Lodgepole Pine: 1989

RESULTS

Preliminary findings of copper concentrations in wood cores taken from CCA-PEG and Cu-Nap poles are the only results available at this time. Figure 6 contains the "raw" data from one CCA-PEG 1986 pole, showing the copper concentration as a function of distance, both up the pole and in from the pole surface. Figure 7 shows the averages from the two cores from opposite sides of the pole.

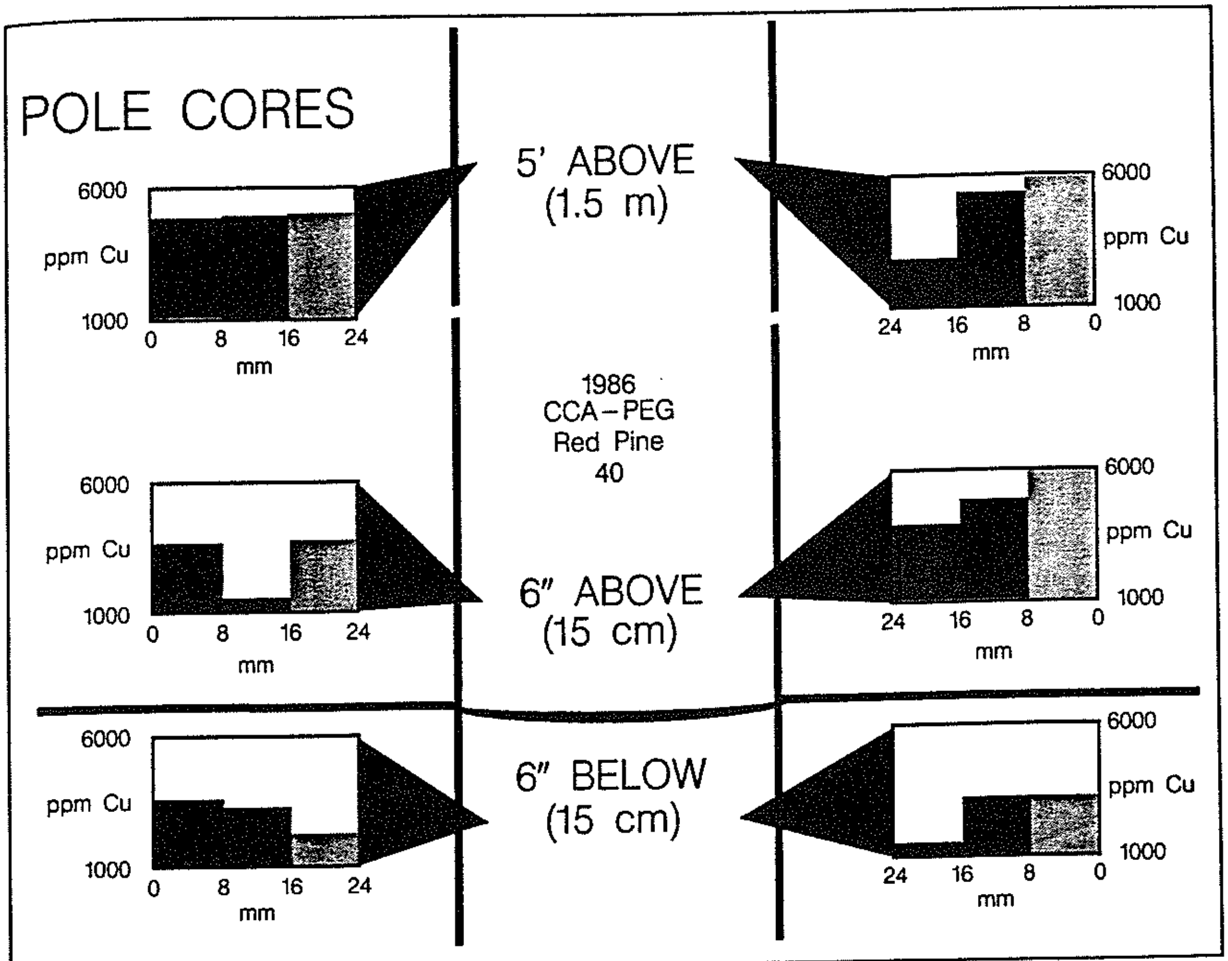

Figure 6. Copper concentration as a function of location on the pole, CCA-PEG, 1986, one pole.

On average, the cores from the two above ground locations (1.5 m and 0.15 m) are not significantly different, with similar decreases in copper concentration with radial depth. The below ground cores (0.15 m) are significantly lower in copper concentration than the two above ground cores. As these results are from only one pole, it is not possible to draw any general conclusions at this time.

Three copper naphthenate poles, installed in May, 1989, were similarly sampled for copper concentration. The results are shown in Figure 8. After three months installation, the copper concentration appears to be uniform along the length of the pole. These poles will be sampled again after one year's service to monitor changes in copper concentration.

The current study is scheduled to be completed by December, 1990.

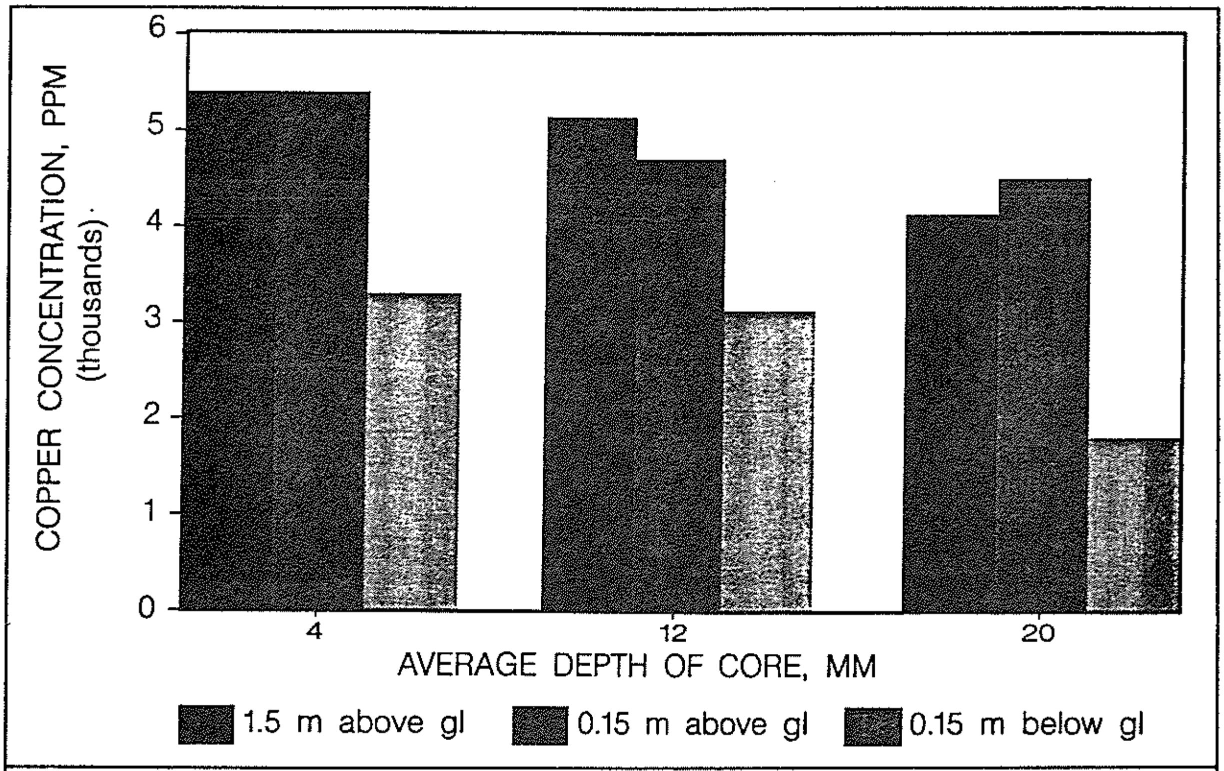

Figure 7. Copper concentration as a function of location on pole shown in Fig. 6, results averaged for each height.

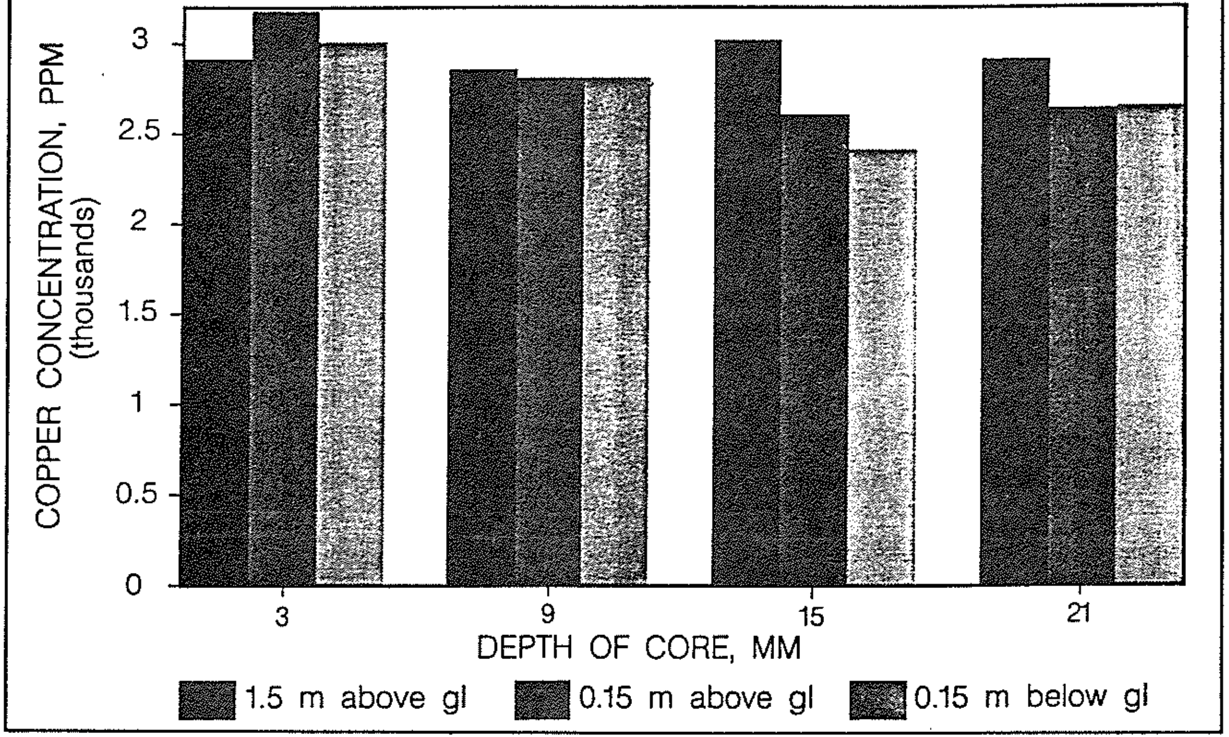

Figure 8. Copper concentration as a function of position on the pole, 1989 Cu-Nap poles, average of three.

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