SOIL CONTAMINATION FROM POLES - USA

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Summary

The Electric Power Research Institute (EPRI) has conducted a nationwide field measurements effort involving 190 in-service wood poles used in the transmission and distribution of electricity in the United States. The field work consisted of collecting soil samples as a function of distance and depth at these pole sites. The soil samples from 168 pole sites were analyzed for pentachlorophenol (PCP), other chlorophenols, and total petroleum hydrocarbons (TPH), and 22 pole sites were analyzed for polycyclic aromatic hydrocarbons (PAHs), which are indicative of creosote preservation. Soil samples from each site were also analyzed for selected physical and chemical properties. Subsamples were used to conduct laboratory studies for determining distribution coefficients (K_d) and biodegradation coefficients (K). Examination of different subsets of the data revealed that the general trends in attenuation and migration potential were very similar from pole site to pole site. The chemical data revealed rapid attenuation of PCP, TPH, and PAH soil concentrations with increasing distance from the pole. Transport/fate modeling using EPRI's ROAM™ was performed using the data, and preliminary results showed that the attenuation factors (AFs) for PCP from in-service poles generally exceeded the value of 10,000.

1. Introduction

Electric utilities often use wood poles treated with pentachlorophenol (PCP) or creosote in their transmission and distribution systems. Currently, there are approximately 60 million utility-owned wood poles in service across the United States, of which about 36 million are PCP-treated and 18 million are creosote-treated (Malecki, 1992). About 3 percent of these poles are replaced annually, necessitating the disposal or reuse of used poles in accordance with U.S. Resource Conservation and Recovery Act (RCRA) regulations (EPRI, 1990).

The U.S. RCRA Toxicity Characteristic (TC) rule used the chemical-specific Maximum Contaminant Levels (MCLs) promulgated under the U.S. Safe Drinking Water Act as the basis

for establishing hazardous waste regulatory levels. In 1990, the U.S. Environmental Protection Agency (EPA) promulgated revised TC rules, which included PCP for the first time. In 1991, EPA reclassified PCP as a B-2 carcinogen (probable human carcinogen; sufficient evidence in animals with limited or no human evidence of carcinogenicity) and revised the MCL for PCP from 1 mg/l to 0.001 mg/l, a 1000-fold decrease. A similar decrease in the TC regulatory level for PCP could have an enormous impact on the electrical utility and telecommunications industries in the United States.

The impact of the regulations applies to creosote-treated poles as well. MCLs have been proposed or finalized for all of the higher molecular weight PAHs (four to six rings) at levels from 0.0001 mg/L to 0.0004 mg/L. In addition, in 1992 a new TC rule was proposed which included many of the PAHs found in creosote, such as naphthalene, fluoranthene, benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and indeno(1,2,3-cd)pyrene.

In response to concern about regulatory changes and soil contamination at pole sites, the Electric Power Research Institute (EPRI) undertook research to study the levels of soil contamination resulting from the use of wood pole preservatives. In cooperation with 34 individual utilities and the Utility Solid Waste Activities Group (USWAG), EPRI has completed a nationwide research effort which involved the sampling and analysis of soil samples in close proximity to a broad spectrum of PCP-preserved in-service utility poles. In all, 190 pole sites were sampled in 28 states.

2. Methodology

The pole sites were selected using several criteria, including in-service ages, history, location, and accessibility. First, a set of poles was identified by each participating electric utility for possible inclusion in the sampling program, based on the established criteria. With utility cooperation, each potential site was visited to examine it and its surrounding conditions. Site suitability was confirmed by the manual boring of a test hole.

After the pole sites were selected, a sampling crew collected the representative soil samples using hand augering equipment, and sometimes a power auger. The samples were collected over a range of depths and distances from the pole using a sampling design which consisted of four evenly-spaced radial spokes extending from the center of the pole: north, east, south, west. Samples were collected along the radial spokes from four distances away from the edge of the pole: at approximately 3, 8, 18, and 30 inches. For poles over 55 feet in length, samples were also collected at 48 inches from the pole. Four discrete samples were collected at four depths (at the surface, approximately two feet below the pole butt, and at two intermediate depths) along each radial spoke at the 3-inch and 8-inch distances. The samples collected at the four depths from the 18-, 30-, and 48-inch locations were composited into one sample for each location. Using this sampling scheme, 40 to 44 soil samples were collected from each pole site.

The analytical methods used for the chemical analysis of all samples were microscale solvent extraction (MSE) methods developed for EPRI by META Environmental, Inc. (META). They are all modifications of EPA standard methods, and consist of extracting 2 g of soil with an appropriate solvent.

Samples analyzed for PCP and other chlorophenols were extracted with acetone/methylene chloride using an ultrasonic disrupter. The extract was then cleaned using an acid-base partition, and concentrated in a microscale Kuderna-Danish concentrating apparatus. Following final concentration, the extract was analyzed by capillary gas chromatography with electron capture detector (GC/ECD). The quantitation limit for determining PCP in soil using this method was 100 µg/kg (ppb).

For TPH, samples were extracted with 1,1,2-trichloro-1,2,2-trifluoroethane (Freon-113) using an ultrasonic disruptor. The extract was brought to the final volume of 20.0 mL and cleaned with silica gel. The extract was analyzed by Fourier Transform infrared spectroscopy (FTIR). The quantitation limit for determining TPH in soil was approximately 60 mg/kg.

Samples from creosote-preserved poles sites were analyzed for a range of compounds, including monocyclic aromatic hydrocarbons (MAHs), PAHs, and substituted phenols. The method used consisted of extracting the soil in methylene chloride using rotation and hand-shaking. The extract was concentrated in a microscale Kuderna-Danish concentrating apparatus. Following final concentration, the extract was analyzed by capillary gas chromatography with flame ionization detector (GC/FID). The quantitation limits were 100 µg/kg (ppb) for MAHs and PAHs, and 400 µg/kg (ppb) for the phenols.

The MSE methods used for analysis of soils from pole sites are described in detail in the two-volume EPRI report "Microscale Solvent Extraction Methods for the Analysis of Solids and Liquids" (EPRI, 1995b).

Results from individual pole sites were used with EPRI's ROAM™ model, a model that simulates the transport of organic and inorganic constituents in the unsaturated and saturated zones, and accounts for hydrodynamic dispersion, linear adsorption, and first-order decay. ROAM™ offers multiple solution methods for both unsaturated and saturated zone transport. The one-dimensional unsaturated zone analytical solution and three-dimensional saturated zone analytical solutions were selected for this modeling.

3. Results and Discussion

PCP Results

The PCP results showed much variability in soil concentrations around utility poles, both at a given site and among sites. At some sites, PCP soil concentrations 3 inches from the pole varied by five orders of magnitude. Both the mean and the maximum PCP concentrations from

each pole site varied by four orders of magnitude across all sites. The maximum soil PCP concentration at most pole sites was less than 100 mg/kg; however, a maximum concentration of at least 100 mg/kg was observed at 56 (33 percent) of the pole sites, with a maximum observed PCP concentration in a soil of 5,800 mg/kg. In addition, most pole sites (90 percent) had at least one soil sample with no detectable PCP (at a detection limit of approximately 0.03 mg/kg). The distribution of the maximum PCP concentration at each site is illustrated in Figure 1.

The locations of maximum concentrations at individual pole sites varied in depth and distance from the pole, with no apparent general pattern. The maximum and mean PCP concentrations found at each distance from the pole is presented graphically in Figure 2. As seen in this figure, both average and maximum PCP concentrations in soil samples decreased rapidly with increasing distance from the pole. For the majority of the sites, PCP levels decreased significantly in the interval from the 3-inch ring to the 8-inch ring. For most sites (75 percent), the concentrations of PCP also decreased beyond the 8-inch ring. PCP concentrations in the outer rings (30 or 48 inches) were an average of almost two orders of magnitude lower than those observed at the 3-inch ring. The incidence of non-detected samples increased with increasing distance from the pole: 9.6 percent of the samples were non-detect at the 3-inch ring, 32 percent at the 8-inch ring, 47 percent at the 18-inch ring, and 58 percent at the 30-inch ring.

Although it can be easily seen that soil PCP concentrations decreased rapidly with increasing distance from the pole, no similar phenomenon was observed with respect to sample depth. Figure 3 presents the maximum PCP concentrations and the average of the mean PCP concentrations found at each depth sampled for all 168 pole sites. The average of the mean PCP values did decrease with increasing depth, but not at the same rate as it did with respect to distance from the pole, and the maximum PCP value for the medium interval was actually higher than that for the shallow interval. The highest contamination did not occur consistently at one depth interval. Although the top samples did, in general, have significantly higher maximum PCP values, maximum PCP values occurred at all four depths: at the soil surface at 74 sites, at the shallow interval at 22 sites, at the medium interval (near the butt of the pole) at 46 sites, and at the deep interval (at or below the butt of the pole) at 25 sites.

TPH Results

The TPH results also showed much variability in soil concentrations around the poles. Maximum TPH results from each site ranged over three orders of magnitude. Thirty-two sites had maximum TPH concentrations of at least 10,000 mg/kg, and 25 sites had no detectable amounts of TPH greater than the detection limit. The distribution of the maximum TPH concentration at each site is shown in Figure 4.

Similar to PCP, the concentration of TPH decreased rapidly with increasing distance from the pole and decreased less so with depth.

Overall, the TPH results did not correlate well with the PCP results for all samples from all pole sites. Although several poles had fewer than three samples with detectable values for both TPH and PCP, some sites did show a strong correlation between the results of the two parameters. However, no general conclusion could be made about the relationship between PCP and TPH contamination levels. The identification of a relationship between PCP and TPH was confounded by the fact that TPH contamination can originate from sources other than the utility pole, especially in urban, suburban, and industrial areas, as well as along roadways where many of the poles were located.

Creosote Results

Creosote is a complex mixture of hydrocarbons, including MAHs and PAHs. Because of their stability and relative abundance at the pole sites, PAHs were the focus of study to determine the general behavior of creosote constituents around wood poles. However, because of their presence in raw creosote and their relatively high mobility in the environment, MAHs were also measured. Finally, chlorophenols were tested for as an indication of cross-contamination by other wood preservatives.

Similar to the PCP and TPH results, the PAH results showed much variability in soil concentrations around utility poles, both at a given site and among sites. The mean and maximum PAH concentrations from each site varied by three orders of magnitude across all sites. Maximum PAH concentrations from the pole sites ranged from 79 mg/kg to 24,000 mg/kg.

The locations of maximum PAH concentrations at individual pole sites varied by depth and distance from the pole. There was no apparent pattern, except that the maximum concentration occurred most often in the 3-inch ring (18 of 22 sites). The maximum and mean PAH concentrations found at each distance from the pole are presented graphically in Figure 5. As seen in this figure, PAH attenuation was similar to PCP and TPH attenuation; concentrations decreased rapidly with increasing distance from the pole. At the 22 pole sites, average PAH concentrations decreased by as much as two orders of magnitude from the 3-inch ring to the 8-inch ring. The average attenuation overall was slightly less than one order of magnitude. Although the decrease of PAHs occurred rapidly with increasing distance from the pole, no similar phenomenon was observed at the 22 creosote pole sites with respect to sample depth.

Because creosote consists of many compounds, the behavior of the individual PAH compounds was also examined. In particular, the changes in PAH abundances with depth were studied. Figure 6 shows the distributions of PAHs in pure creosote and the average PAH distributions in soil samples from each sampling depth. Naphthalene was the most abundant compound in the pure creosote. However, in the soil samples, the compounds phenanthrene, fluoranthene, and pyrene were the most abundant PAHs. This change in PAH patterns is likely a result of "weathering", and the release and migration of PAHs from the buried pole. For example, naphthalene and other lower molecular weight

compounds are more soluble, volatile, and biodegradable than the higher molecular weight PAHs. Thus, soils near the surface that are exposed to natural "weathering" processes are more likely to have lower relative concentrations of the lower molecular weight PAHs, as was observed at pole sites in this study. In addition, the deeper samples were likely located below the water table and at or below the pole butt. As a result, both dissolved creosote constituents leaching from the near surface soils and from the pole itself could have resulted in an increasing abundance of the lower molecular weight PAHs observed at the two deeper sample locations.

Modeling Results

PCP partitioning coefficient and biodegradation data were used in models simulating PCP migration through the vadose and saturated zones. The modeling was intended to develop a site-specific attenuation factor (AF) that would apply to PCP migration from a single in-service pole. An AF is a measure of the reduction in concentration of a constituent due to chemical and physical processes as it migrates from a source to a receptor well: large AFs indicate large reductions in concentrations.

Using EPA methodology, and K_d and K values determined in this study, AFs were computed for in-service poles using the model predicted 85th percentile concentration at a receptor well. The AFs calculated for individual in-service poles were quite high, ranging from about 12,000 at a distance of 10 meters from the pole to more than 300,000 at 50 meters from the pole.

The results of the model simulations indicated that biodegradation is a very effective attenuating agent for PCP in the soil and groundwater, particularly with distance from the pole or in environments where low groundwater flow rates or high retardation results in slow migration. Slow migration rates result in more attenuation than fast migration rates because they allow more time for microorganisms to degrade PCP. It is important to note that these rates of attenuation were achieved even with biodegradation rates that were reduced by two and three orders of magnitude from laboratory-derived values. Actual biodegradation in field settings will be even more significant if true biodegradation rates are closer to laboratory rates than assumed here.

4. Conclusions

PCP and TPH Results

An important trend in the data was the rapid decrease of both PCP and TPH concentrations in soils with increasing distance from the utility pole. For 111 of the 168 pole sites (66 percent), PCP levels dropped by as much as three orders of magnitude from the 3-inch ring to the 8-inch ring. The average PCP attenuation overall was slightly less than three orders of magnitude. Maximum PCP values were found only in 3-inch and 8-inch samples, except at one site. These observations clearly indicate that the soils with the highest preservative concentrations were

contained in the near vicinity of the pole. However, although the TPH contamination showed a pattern similar to PCP, there was generally not a good correlation between the two contaminants.

No general pattern was identified for either PCP or TPH with respect to sample depth. Maximum PCP and TPH values occurred at all sampling intervals, and it could not be concluded that leaching from the soil surface was the sole mechanism causing contamination below the surface. Several pathways can exist for the movement of preservative contamination from the pole. For example, preservatives can leach from the pole surface exposed above ground and run down to the ground surface, migrate from the soil surface to deeper depths because of dissolution from rain water, and leach from the portion of the pole buried in the ground. In addition, for those poles which have the pole butt near the water table, fluctuations in the water table can result in intermittent migration of contaminants at the interface.

Creosote Results

The contamination at creosote pole sites was very similar to that at PCP pole sites: the contamination remained in the near vicinity of the pole, and no general pattern could be identified with respect to depth. At the 22 pole sites, average PAH concentrations dropped off by as much as two orders of magnitude from the 3-inch ring to the 8-inch ring. The PAH concentration of greatest frequency was less than 1 mg/kg, and only samples from the 3- and 8-inch rings, with one exception from the 18-inch ring, had concentrations greater than 500 mg/kg.

The affects of the release, migration, and transformation of individual components were illustrated in the PAH distributions from the different sample depths. The relative concentrations of the PAHs varied from depth to depth. This illustrates the importance of collecting samples at various depths and analyzing samples for the full range of PAHs. Even if total PAH concentrations do not vary greatly by depth at a given site, the distribution of PAHs may be substantially different at each depth. The higher molecular weight compounds, which are generally more toxic and resistant to degradation, tend to remain near the ground surface while the lower molecular weight, more mobile, and less toxic compounds are found in greater abundance in the deeper depths.

Attenuation Factors (AFs)

Attenuation of PCP is highly dependent on local hydrogeologic and soil chemistry conditions. Modeling of PCP migration in soil and groundwater showed that biodegradation can cause large reductions in PCP concentration, particularly in environments where slow migration rates allow ample time for microorganisms to degrade the chemical. Calculated AFs ranged from approximately 12,000 to more than 300,000 as the observation distance increased from 10 m to 50 m from the pole.

5. Literature

Electric Power Research Institute, 1990. Pentachlorohenol (PCP)-Treated Wood Poles and Crossarms: Toxicity Characteristic Leaching Procedure (TCLP) Results. Prepared by Environmental Management Services, EPRI EN-7062, Interim Report.

Electric Power Research Institute, 1995a. Interim Report on the Fate of Wood Preservatives in Soils Adjacent to In-Service Utility Poles in the United States. Prepared by META Environmental, Inc., Atlantic Environmental Services, Inc., Utah State University, and Science & Technology Management, Inc., EPRI TR-104968.

Electric Power Research Institute, 1995b. Microscale Solvent Extraction Methods for the Analysis of Soils and Liquids. Prepared by META Environmental, Inc., EPRI TR-105317-V1&2.

Malecki, R., 1992. Regulations Regarding the Disposal of Treated Wood. In the Proceedings of Wood Pole Seminar, Sept. 17-18, 1992, Syracuse, NY.

Figure 1: Distribution of Maximum PCP Concentrations from 168 PCP Pole Sites

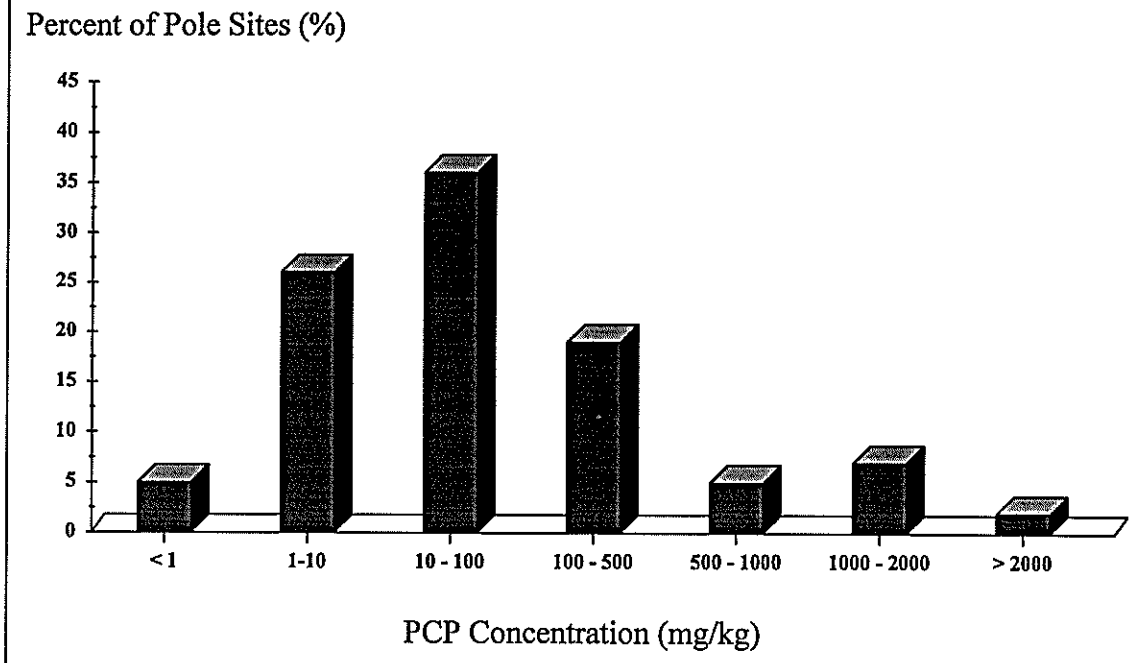

Figure 2: Maximum and Mean Soil PCP Concentrations by Distance (168 Pole Sites)

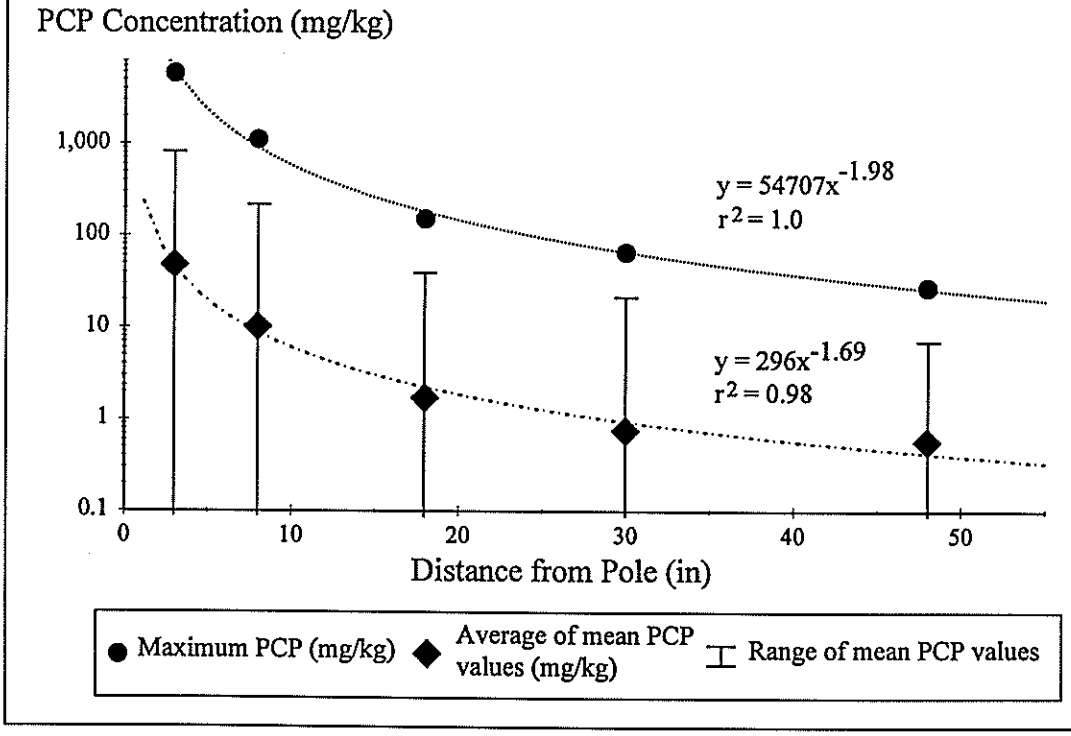

Figure 3: Maximum and Mean Soil PCP Concentrations by Depth (168 Pole Sites)

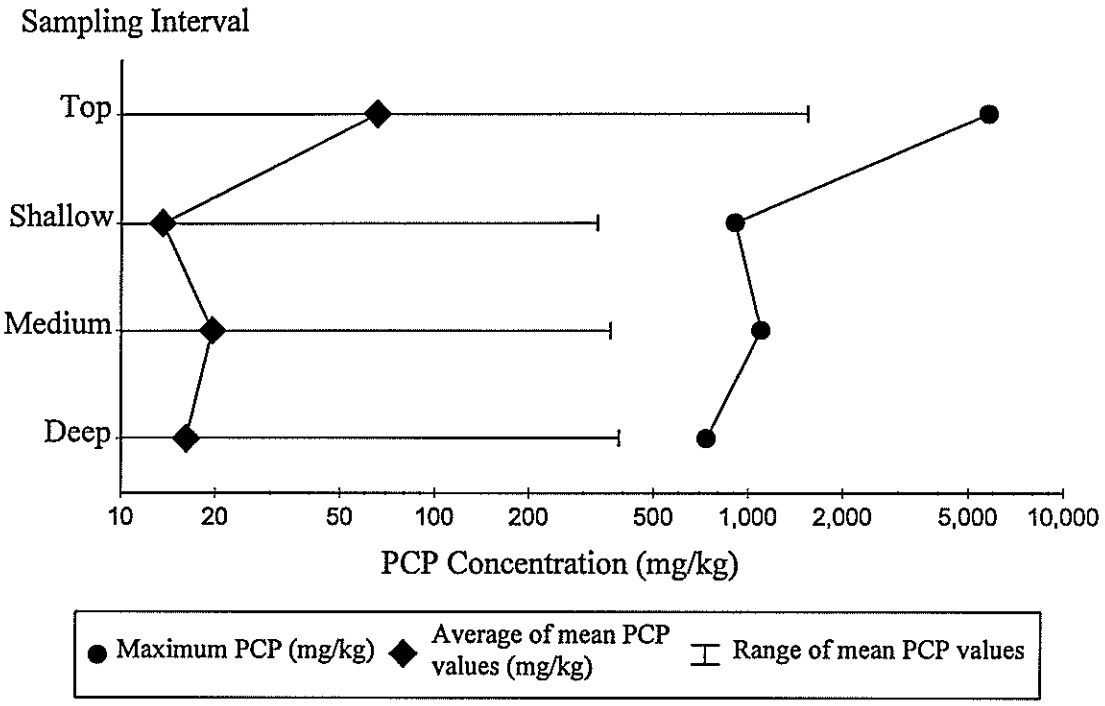

Figure 4: Distribution of Maximum TPH Concentrations from 168 PCP Pole Sites

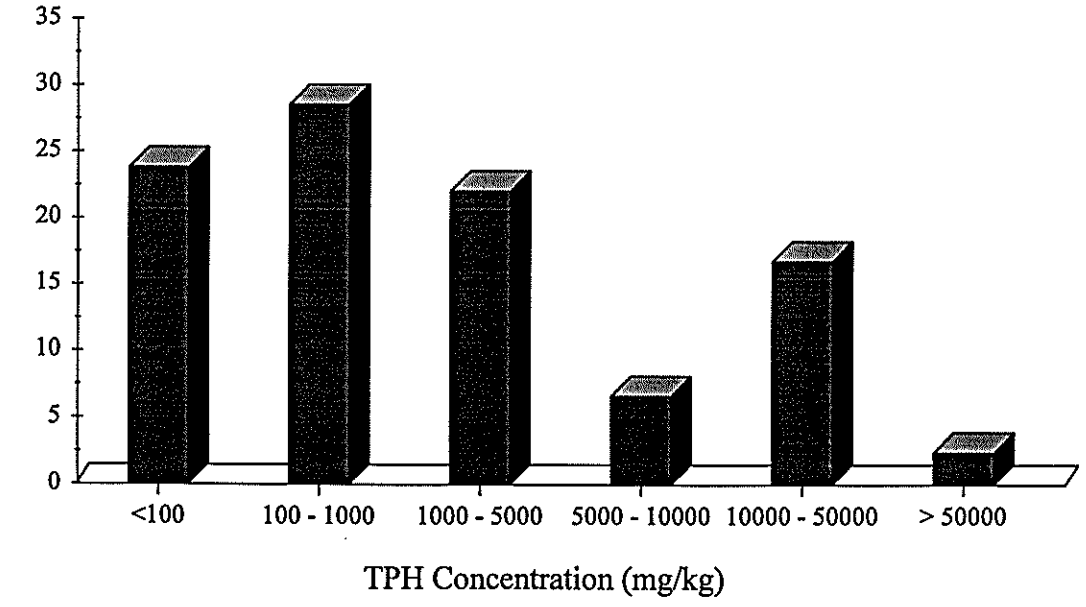

Figure 6: Distribution of PAHs in Creosote and

Figure 5: Maximum and Mean Soil PAH Concentrations

Figure 5: Maximum and Mean Soil PAH Concentrations by Distance (22 Creosote Pole Sites)

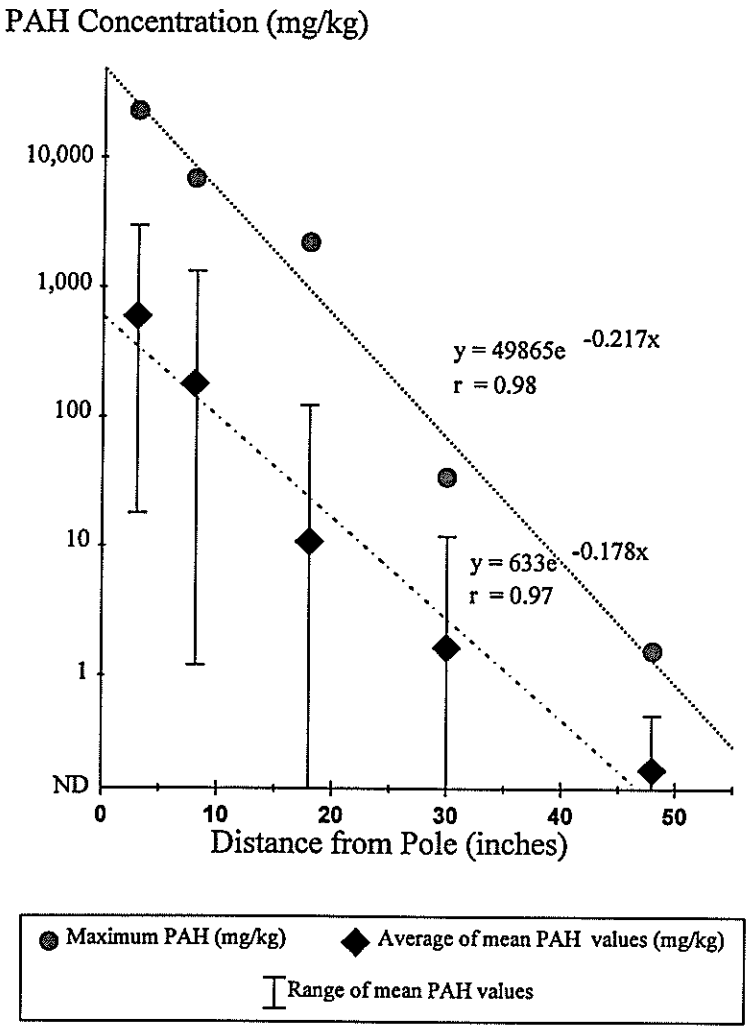

Figure 6: Distribution of PAHs in Creosote and Soil Samples