INFLUENCE OF PRESERVATIVE TREATMENT ON DURABILITY OF ACA-TREATED WHITE SPRUCE POLES

by

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ABSTRACT

In 1977, sixty-two white spruce pole sections were installed at the Western Forest Products Laboratory's Westham Island test field site. They had been commercially pressure-impregnated with ammoniacal copper arsenate (ACA) or pentachlorophenol (PCP). Twenty-four of the ACA-treated spruce poles were studied to determine the influence of preservative penetration, retention, and nitrogen level on decay resistance of spruce poles after seven years of field testing. Such information was considered of great value in establishing treated spruce as viable pole material in Canada.

Studies using a 0.5% solution of chrome azurol S indicated that for the ACA-treated spruce poles after seven years in test, average preservative penetration of 1.14 in. (2.90 cm) was generally greater than that required by Canadian standards. However, analysis using energy-dispersive X-ray spectrometry showed that the mean retention of 0.50 lb./ft.^{3} (8.06 kg/m^3) was less than the level of 0.6 lb./ft.^{3} (9.6 kg/m^3) for ACA, required by the CSA standard. It was also found that copper was present in greater quantity than arsenic, in spite of their equal presence in the original ACA treating solution.

In microbiological studies, a total of seventy-one fungal isolates belonging to seventeen genera and four taxa were identified to genus, with fifteen of these identified as to species. Unlike the untreated control poles, true wood-decaying Basidiomycetes were not found associated with the ACA-treated spruce poles.

Analysis employing an Orion ammonia-specific electrode coupled to an Orion Microprocessor ionalyser 901 revealed that nitrogen content due to ACA treatment was significantly increased in the treated zone and also beyond the penetration limit of preservative. A linear relationship existed between nitrogen content and chemical retention in the first analytical zone.

Variation in moisture content above the fiber saturation point produced marked changes in electrical resistance as detected by Shigometer measurements. The practical application of the Shigometer for detection of internal decay is limited by such inconsistences.

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1.0 INTRODUCTION

Wood utility poles in transmission and distribution systems represent a large annual capital investment. Canadian electrical and telephone companies have a considerable financial investment in wooden poles in service, amounting to an annual rate in excess of $80 million (Ruddick, 1984b). Every year over $29 million is invested in British Columbia alone through the installation of preservative treated wooden poles.

Canada has an uneven distribution of coniferous species capable of being used as pole material. In particular, the regions between the Pacific Coast and the Rocky Mountains are endowed with several softwoods which produce trees of great quality and height. At the same time the industrial and population pressures on eastern and central Canadian forests have long ago removed almost all the best pole material (Sugden, 1979).

Traditionally, Canada has been a net pole exporter due to its vast forest resource. The province of B.C. is particularly fortunate since it contains commercial quantities of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), western red cedar (*Thuja plicata* Donn) and lodgepole pine (*Pinus contorta* Dougl.), for the supply of the utility poles.

Since the early 1970's, however, there has been a number of comments concerning the shortage of these poles. At the 1974 meeting of the Western Forest Products Laboratory's (WFPL) Research Program Committee on Treated Wood Products, it was revealed that Canada was importing a considerable number of utility poles mainly from the U.S.A. and Finland (Dobie, 1976). As a consequence, a study was conducted to analyze the supply-demand situation, and to identify and understand the various problems plaguing the industry. Possible ways of solving or eliminating some of the problems were suggested. The simple, short-term solution was to import poles from other countries, such as the U.S.A. However, it became obvious that a more appropriate, long-term solution would be to utilize some of the other wood species, currently not used for poles in Canada.

Although western red cedar and lodgepole pine are the two wood species most widely used, the B.C. forests also contain large quantities of western hemlock (<u>Tsuga heterophylla</u> (Raf.) Sarg.), amabilis fir (<u>Abies amabilis</u> (Doug.) Forbes) and white spruce (<u>Picea glauca</u> (Moench) Voss). In 1974, the WFPL proposed to the Research Program Committee on Wood Preservation a study to determine the strength and treatability of three alternative pole species available in B.C. Among these species, there was considerable interest in the potential of spruce for satisfying some of the future demand. Spruce is particularly attractive because it is available in relatively large quantities and the pole produced from this species would meet the requirements of the pole classes in greatest demand.

In 1977, sixty-two white spruce pole sections were installed at the WFPL's Westham Island test field site near Vancouver. They had been commercially incised and pressure-impregnated with ammoniacal copper arsenate (ACA) or pentachlorophenol (PCP) in oil. As a consequence of the treating conditions used for the poles, those treated with ACA were well penetrated but the preservative retentions were low, whereas the PCP-treated poles had poor penetration but a high chemical content in the treated zone (Ruddick, 1978). This material therefore provides an unique opportunity to investigate the influence of the parameters of preservative penetration and retention on the long-term durability of spruce poles. This present study investigated only the ACA-treated poles.

Since it was intended that a number of the spruce pole sections would be installed in a graveyard test to evaluate their service life, one additional factor, kerfing, was included in the design of the original study in 1977. Twenty-two of the forty-one spruce poles to be later installed at Westham Island test field site were therefore full-length kerfed 0.32 in. (0.81 cm) in width extending to the pith of poles, to minimize the formation of deep checks in service and treated with ACA using the Lowry empty-cell process. Installation of representative samples of all treatments in the graveyard test permitted monitoring of fungal colonization, decay, preservative leaching and checking characteristics of the ACA-treated pole sections.

Four main objectives have been identified for this study:

a) To determine the ACA preservative penetration and retention of the poles in test and report on the preservative distribution and possible leaching of ACA;

b) To determine whether decay fungi have become established in the treated and untreated wood;

c) To confirm or deny previous observations of enhanced nitrogen levels in the untreated core of commodities treated with ACA preservative;

d) To evaluate the usefulness of a Shigometer for the detection of decay in poles, by comparing Shigometer data with the results obtained from fungal isolation studies.

Such information is required to establish the viability of ACA-treated spruce as pole material in Canada.

1.1 CHEMICAL DISTRIBUTION STUDY

Preservative systems must perform their functions throughout the service life of the product under a variety of exposure conditions. Thus, wooden poles must be preservative-treated to protect both the above- and below-ground portions for several decades, in a variety of climates and soils.

Because of the relatively high cost of organic solvents, much work has been directed to developing water-soluble rather than oil-soluble formulations (e.g. PCP) for protection of poles. ACA is one waterborne preservative that has become well established for treatment of poles during the past 20 years. This formulation contains, as active ingredients, equal amounts of copper and arsenic, expressed as CuO and As_2O_5. In ACA, the ammonia in the solvent reacts with the copper arsenate to form a soluble complex which, although stable in ammonium hydroxide solution, readily breaks down to form an insoluble copper arsenate when the solvent is removed. Inorganic salts of copper-arsenic-zinc dissolved in ammonium hydroxide have been formulated and tested in wood for toxicity to fungi, water repellency (Rak, 1975), glowing combustion resistance, and leach resistance (Rak and Clarke, 1974). In recent studies (Krzyzewski, 1978a; Rak, 1977a; Ruddick, 1978), the outstanding penetration of ammoniacal preservative solutions into spruce roundwood has been shown.

The fixation of ammoniacal copper compounds depends on the volatilization of ammonia and the insolubilization of the preservative. Copper arsenate-treated wood has proven to be one of the most durable of the preservative treatments used today. It is relatively non-leachable and the preservative is highly effective.

The objective of this part of the study was to determine the preservative penetration and retention of the poles in test for several years and to compare these results with initial values obtained in 1977 prior to graveyard installation.

1.2 BIOLOGICAL STUDY

The service life of wood poles can be drastically reduced by decay, insect attack, and even automobile collisions. The most serious of these is undoubtedly decay.

During recent pole shortages, several wood-treating companies examined the suitability of spruce as a pole material. In various experiments conducted on spruce, however, it has been reported that potential problems existed due to excessive checking and difficulty in obtaining an adequate treatment. It is also known that spruce wood is very low in natural decay resistance, and as such must be preservative-treated for applications involving ground contact. In utility poles fungal attack is favoured in the surface layers just above and below the groundline, and also in the core of these regions. Both of these locations are critical with respect to the serviceable life of the pole, since its strength is dependent on its cantilever beam configuration, where the maximum moment is developed about the groundline.

The identity and the effects on microorganisms colonizing wood have been the subject of many major investigations. Information on the identities, frequencies, and the role of the major fungi associated with degradation in utility poles is essential for control programs. An understanding of the successional relationships among microorganisms in the initiation and development of wood decay, and their effects on preservative stability and pole strength is required to devise the best protection strategies.

This portion of the study was designed to obtain the identity, frequency, and role of the major fungi involved in degradation in the ACA-treated white spruce poles after several years in field testing.

1.3 NITROGEN ENHANCEMENT STUDY

Wood-degrading microorganisms have the same basic growth requirements as do the green plants. These include a source of food, an adequate supply of water, favourable temperature, oxygen, and a suitable pH.

Optimal nutritional needs of wood-damaging microorganisms vary, but all species obviously can exist on what is available in wood itself. Energy and most of the cell-building materials for microorganisms are supplied mainly by the carbohydrate fraction consisting of holocellulose, starches, and sugars, and for some organisms, by the lignin fraction. Nitrogen and minerals are available, though in comparatively small amounts. A trace amount of thiamin, the vitamin B1 of animal nutrition, apparently is needed by most decay fungi.

Cellulose, hemicellulose and lignin comprise more than 90 percent of the dry weight of most woods, so are sufficiently abundant to meet the requirements of microorganisms utilizing them. However, nitrogen is extremely sparse, being present in amounts no greater than about 0.03 to 0.10 percent (Cowling, 1970). Nevertheless, these quantities are adequate for rapid decay of wood, indicating unique nitrogen-utilizing efficiency by the attacking fungi. It has been suggested by Cowling that this efficiency may derive in part from an ability of the fungi to solubilize the nitrogen in the protoplasm of their older hyphae and transport it to new zones of attack, where it supplements the nitrogen existing in the zones.

Several researchers (Cowling, 1970; Cowling and Merrill, 1965; Findlay, 1934; Merrill and Cowling, 1965 and 1966) have shown that increasing the nitrogen content of wood frequently increases the rate of decay by wood-inhabiting fungi. Moderately greater rates of decay have been observed to be correlated with greater amounts of natural nitrogen, but there is still conflicting evidence as to whether decay can be increased appreciably by artificially adding nitrogen to wood (Cowling, 1970).

It is generally assumed that, during the fixation of the ammonia-based wood preservative, such as ACA, the ammonia is lost from the wood. However, it has previously been reported by Ruddick (1979) that the treatment of wood with ammoniacal type preservatives results in certain enhancement of the nitrogen content in the untreated core. Therefore, the question of whether the loss of ammonia from ACA-treated wood is complete could well prove to be important, particularly in spruce when inadequate treatment combined with the easy formation of deep checks is encountered.

Comparison of the ACA- and non-ACA-treated spruce woods would allow conclusions to be made on possible nitrogen enhancement. Thus the objective of this part of the study was to measure the residual nitrogen level in wood treated with ACA and to determine also to what extent, if any, the nitrogen level in wood was enhanced by the treatment. Any possible nitrogen enhancement was correlated with the presence of fungi inhabiting the wood.

1.4 SHIGOMETER STUDY

Early recognition of an attack and the degree of any wood deterioration are important to the pole producers to minimize possible losses. Unfortunately, biological attack is not readily identified in the initial stages. Superficial mycelium and fungal fruit bodies are only produced after fungi have become well established.

Some of the key elements in a long-term decay control program for utilities are proper pole specifications, careful pole selection and handling, effective preservative treatment, reliable inspections, and pole maintenance programs involving ancillary preservative treatment. However, the reliable detection of early decay in poles followed by effective economical remedial treatment has been of particular importance.

Existing methods for internal decay detection, such as boring, sounding, sonic detectors, and X-rays, are either insensitive to incipient decay attack or unreliable. Recently, the Shigometer has been proposed for detection of decay in living hardwood trees. The Shigometer is a resistance meter, which measures changes in the condition of the wood associated with changes in electrical resistance. A pulsed direct current, passing through wood in progressive stages of decay, meets with decreasing resistance. Such changes caused by fungal attack are, for example, specific gravity, pH, moisture and the concentration of cations (Brudermann, 1977).

Despite considerable research conducted on wood utility poles, there is no clear indication of the value of the Shigometer in detecting early decay in poles under field conditions. The objective of this final segment of the study was to determine whether a Shigometer could be used for detection of early decay in poles having been in field test for several years. Shigometer readings were, therefore, taken in wood adjacent to the locations sampled for the fungal studies, and the results interpreted in terms of presence or absence of active decay fungi.

2.0 LITERATURE REVIEW

2.1 SUPPLY AND DEMAND FOR UTILITY POLES IN CANADA

Since the building of the nation's railway and the invention of the telegraph, wood utility poles have been widely used in Canada. With the growing population and industry, the demand for electrification spread through urban and rural areas across the nation. During the period between the late 1950s and the early 1970s, there was a significant increase in the electrical distribution facilities, particularly in the Prairie provinces of Alberta, Saskatchewan and Manitoba. For example, actual purchases of these provinces increased approximately 15% a year from 1970 when 50,800 poles were procured to 1973 when 77,600 poles were obtained (Karaim, 1975). With rising disposable incomes and more automobiles purchased, there have been pressures to improve road transportation networks, often necessitating relocation of existing pole lines. The requirement for pole replacement, at the rate of anywhere from 0.5 to 2.5% depending on the utility reporting (Sugden, 1979), has also been an important factor affecting a constant demand for new poles. There have been some counteracting effects on the demand for wooden poles due to aesthetic reason, development of new technology such as microwave systems in telegraph pole line, and encroachment into the market by concrete and steel poles (Karaim, 1975; Sugden, 1979). Nevertheless, such types of natural, economic and environmental factors have maintained a steady pressure on the electrical, telephone and telegraph utility companies and, by extension, on the suppliers of wooden poles. Thus, natural wooden poles have been a unique product of Canada's forests, since they have been effectively used in the form in which they grew.

Historically, the utility pole industry in Canada was established around western red cedar mainly due to its natural decay resistance, straightness, length and light weight, comparatively thin sapwood, suitability of climbing and finally its abundance relative to demand. Even without treatment, an average western red cedar pole life somewhat less than 20 years can be expected (USDA, 1974). Since the early 1970s, the requirements for utility poles have been gradually increasing across Canada. However, because B.C. contains half of the nation's total softwood growing stock (Table 1), and all its western red cedar, the province traditionally has been a net pole exporter, as well as a steady supplier to the rest of the country.

The trend in utility pole exports from B.C. for the period 1963 to 1978 is shown in Table 2. One significant feature of the data is that exports of poles from B.C. since

TABLE 1. Forest resources comparison (B.C. Ministry of Forests, 1979).

Forest Region	Forest Land (million ha.)	Softwood Growing Stock (million m^3)	Hardwood Growing Stock (million m^3)	Total Growing Stock (million m^3)
British Columbia(1)	52.1	7,871	211	8,082
Canada(2)	342.0	15,202	4,079	19,281
World(3)	2,795.0	107,000	180,000	287,000

Original sources:

(1) British Columbia Ministry of Forests, Inventory Statistics, 1978

(2) Canadian Forestry Service, Canada's Forests, 1978

(3) FAO, World Pulp and Paper Demand, Supply and Trade, 1977; Royal College of Forestry, Stockholm, Sweden, World Forest Resources, 1974

Note: The quality of forest land and growing stock statistics is not uniform amongst regions of the world due to the use of different definitions and measurements standards.

TABLE 2. Trend in utility pole exports from B.C. (Sugden, 1979).

Year	Total Quantity Exported (Lineal Feet)			
	To other Provinces	To U.S.A.	To other Countries	Total
1963	3,894,070	7,797,268	1,014,324	12,705,662
1964	2,909,059	6,566,569	677,201	10,172,829
1965	5,958,518	3,750,672	473,529	10,182,719
1966	3,358,961	8,026,637	1,005,065	12,390,663
1967	2,252,050	6,496,834	3,128,154	11,877,038
1968	1,271,184	5,917,141	4,281,641	11,469,966
1969	815,305	4,700,716	2,088,801	7,604,822
1970	1,407,227	6,059,181	1,583,584	9,049,992
1971	2,073,375	3,699,385	271,502	6,044,262
1972	2,069,189	4,183,636	213,192	6,466,017
1973	2,693,753	2,205,397	638,317	5,537,467
1974	3,912,525	3,483,773	49,784	7,446,082
1975	2,027,878	1,574,975	522,624	4,125,477
1976	1,788,082	1,602,261	67,600	3,457,943
1977	1,018,076	2,352,849	80,225	3,451,150
1978	2,865,669	3,132,550	1,800	6,000,019

Original source: B.C. Ministry of Forests, Annual Reports

Note: 1. Due to the use of different measurement units, i.e. pieces and lineal feet, and no categorization between poles and piles in some B.C. forest districts, the above data until 1976 do not coincide with those available in other literature sources such as B.C. Annual Reports and Dobie (1976).

2. Further data after 1978 are omitted because of their unavailability.

1971 were seldom more than half of those from 1963 to 1968. But log production in B.C. increased from 16.02 million cunits in 1966 to 24.77 million in 1973, and western red cedar output jumped from 2.09 to 3.10 million cunits (Dobie, 1976). Thus the probable situation, as Dobie (1976) points out, was one of a diminishing portion of the harvest being utilized as pole stock. At the same time, demand for B.C. poles from the rest of the country increased substantially since 1969, consequently putting pressure on the available supply.

As indicated above, the utility pole market which had been traditionally stable changed markedly in the early 1970s. As a result, Canada became a net pole importer for the first time in 1974. The trends in total annual Canadian imports and exports of utility poles for the period 1963 to 1983 are presented in Table 3, and are shown graphically in Figure 1. The most striking feature about the figure is that considerable fluctuations in pole imports were apparent, particularly for several years since 1973. On the other hand, it leaves no doubt that the trend in exports has been steadily downward. It is clearly noted that there was a fairly dramatic increase in imports in 1973, so that net pole imports were about 4.4 million lin. ft. in 1974. This had an adverse effect on the balance of payments for poles, which in 1974

TABLE 3. Trend in total annual Canadian imports, exports, payments and receipts of utility poles.

Year	Exports		Imports	
	Value in 1000 of $	Total Quantity (To U.S.A.) in Lin. Ft.	Value in 1000 of $	Total Quantity (From U.S.A.) in Lin. Ft.
1963	5,377	8,126,327 (8,088,705)	-	-
1964	4,866	6,935,318 (6,910,411)	459	1,176,180 (1,176,180)
1965	5,025	6,733,764 (6,687,930)	1,398	2,129,111 (2,129,111)
1966	5,538	6,895,309 (6,890,656)	1,616	3,049,932 (3,049,932)
1967	5,324	6,092,943 (5,979,833)	791	1,388,683 (1,388,683)
1968	6,435	7,520,449 (7,341,056)	504	492,465 (492,465)
1969	6,281	5,897,501 (5,791,219)	399	354,778 (354,778)
1970	6,384	6,357,994 (5,928,918)	932	664,846 (664,846)
1971	5,707	5,632,980 (5,204,439)	811	620,994 (620,994)
1972	6,040	5,217,016 (5,180,081)	900	1,007,187 (1,007,187)
1973	5,892	4,886,554 (4,803,287)	3,629	3,874,716 (3,422,716)
1974	7,230	5,102,732 (4,281,274)	12,105	9,475,269 (8,831,674)
1975	7,644	4,269,435 (2,768,079)	11,980	7,818,437 (7,415,837)
1976	9,262	5,223,450 (2,288,718)	4,030	2,029,880 (1,561,373)
1977	6,859	3,564,042 (2,892,867)	3,031	1,505,536 (1,505,536)
1978	7,618	3,311,452 (2,673,636)	8,076	4,478,659 (3,166,689)
1979	7,802	2,813,173 (2,570,840)	10,459	3,593,119 (3,205,059)
1980	8,587	2,863,510 (2,769,414)	10,530	3,614,124 (3,110,277)

TABLE 3. (cont.)

Year	Exports		Imports	
	Value in 1000 of $	Total Quantity (To U.S.A.) in Lin. Ft.	Value in 1000 of $	Total Quantity (From U.S.A.) in Lin. Ft.
1981	8,890	3,135,880 (2,719,137)	6,668	2,192,383 (1,839,471)
1982	10,853	2,632,950 (1,701,762)	7,032	2,102,410 (1,729,646)
1983	13,876	3,122,047 (2,634,065)	2,629	825,085 (825,085)

Source: Statistics Canada Catalogues 65-202, 65-203

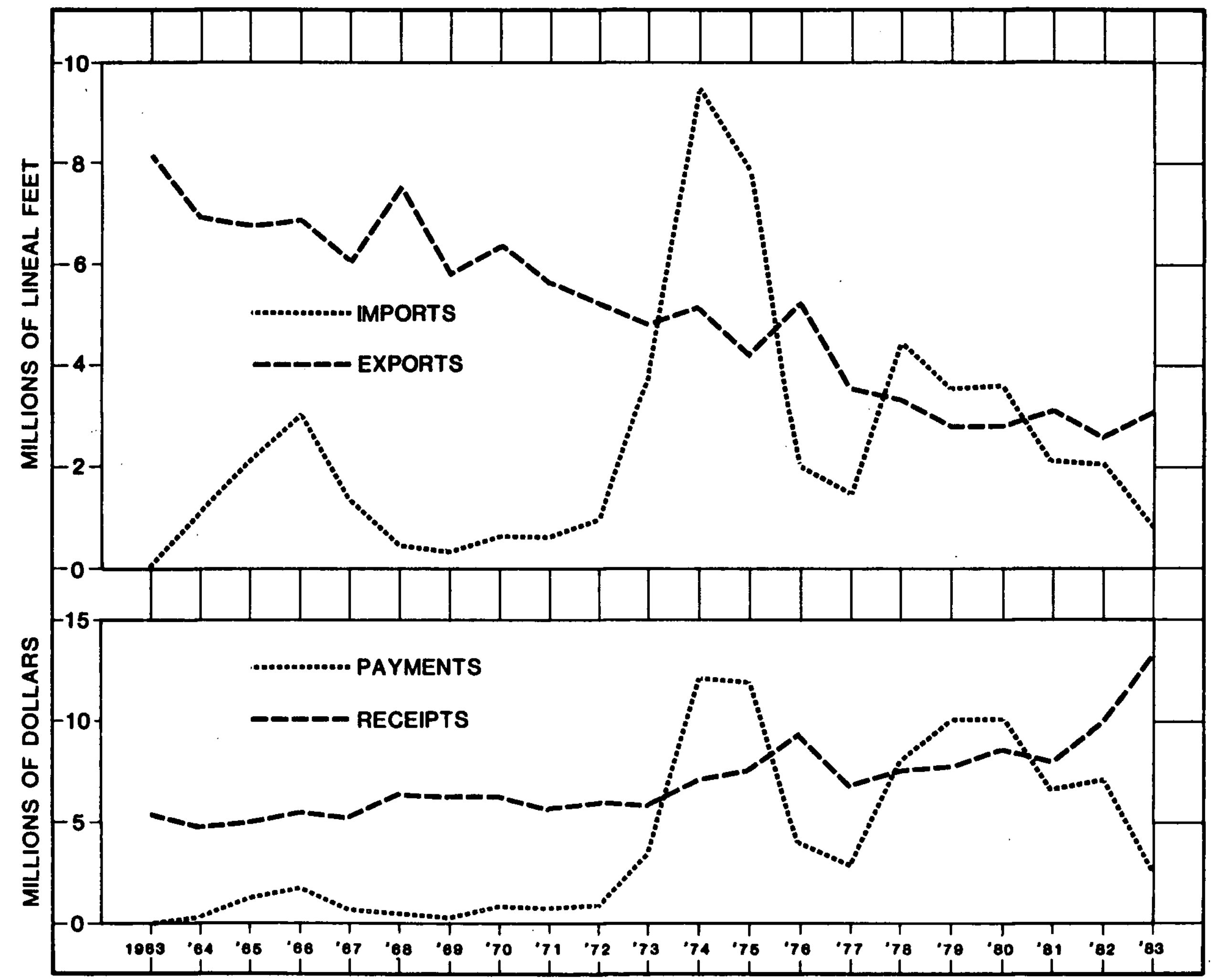

Figure 1. Changes in annual Canadian imports, exports, payments and receipts of utility poles.

was a deficit of $4.9 million compared with a surplus of $2.3 million in the prior year.

The principal reason that Canada became a net importer of poles during the years 1974 and 1975 and again in 1978 - 1980 is that, as noted previously, very high lumber prices resulted in the diversion of some pole stock to sawmills, thus creating a reduction in pole inventories. Another reason was the sudden increase in demand in conjunction with an extremely low supply situation. It should also be noted that this change was a result of heavy forward buying in 1973 for the following years. Further detailed discussion and analysis are available elsewhere (Dobie, 1976; Karaim, 1975; Sugden, 1979).

As most pole suppliers anticipated, Canada returned shortly to its former position as a net pole exporter. Due to a dramatic increase in pole imports from the U.S.A. (Table 3), however, this position was reversed again for the short period between 1978 and 1980. The large proportion of imports was southern yellow pine from southern U.S. destined for central and eastern Canada. As Dobie (1976) indicated, this trend appeared to be mainly because of price advantage and equivalent freight costs for poles from Alabama to southern Ontario compared with those from B.C. In spite of the major fluctuation that occurred from the early 1970s until 1980, it is clearly shown that the trade trend for poles in recent years has been fairly stable, with the increased surplus of receipts commencing in 1981 and persisting to the present.

In a recent study conducted by Sugden (1979), the future demand and supply of wooden utility poles in Canada has been extensively analysed on the basis of calculated pole usage rates and estimated provincial populations. Without considering the eventuality of imports of poles from foreign countries, what his analyses have shown is that projected demands for wooden utility poles to the year 2000 is sufficient to be met by projected domestic supplies.

Since the early 1970s, as noted, there has been the danger that southern yellow pine suppliers could maintain or enlarge their proportion of the pole market. Regardless of the Canadian supply situation, there will always be a likelihood of poles being imported. Therefore, Canada should compete successfully in price to continue to be a net pole exporter, as well as to satisfy its domestic demands. But in order to avoid the necessity of having to import to accommodate increased pole requirements, as Dobie (1976) points out, an obvious need exists for closer liaison between buyer and seller regarding future supply. There are also needs for a greater lead-time allowance on the part of pole buyers, and for manufacturers to check comparative pole and lumber values carefully before consigning pole stock to a sawmill. In agreement with the literature (Dobie, 1976; Karaim, 1975; Ruddick, 1978; Sugden, 1979), it is believed that a more appropriate, long-term solution would be to utilize some of the little-used pole species available in Canada. Therefore, an urgent need exists for research data on the satisfactory treatment of non-traditional species such as white spruce for use as utility poles, with the objective of making pole supply more elastic.

2.2 WHITE SPRUCE AS POTENTIAL POLE SPECIES

White spruce, a characteristic tree of the boreal forest region, can be found almost everywhere in Canada, making up approximately 40% of the coniferous volume and one-third of the total volume of all species grown in this country (Sudgen, 1979). Even in B.C. where the number of conifers are found, a number of species of spruce again predominates, consisting of 25% of the mature volume in the province. This species is widely used for reforestation and planting, and its pole-sized timber is abundant in large quantities. On the average (Hosie, 1975; Isenberg, 1980), white spruce is 80 ft. (24 m) tall and 24 in. (61 cm) in diameter, but some trees attain heights of 120 ft. (36 m) with a diameter of up to 48 in. (122 cm).

The wood is lustrous, nearly white to pale brown coloured with an indistinct heartwood, is usually straight grained, light to moderately light (e.g. a little denser than western red cedar), and very uniform in appearance.

2.2.1 CHEMICAL, PHYSICAL AND MECHANICAL PROPERTIES OF WHITE SPRUCE

The chemical properties of coniferous woods are surprisingly similar with only minor variations occurring among species. Wood of all species is chemically composed of holocellulose (alpha cellulose and hemicellulose), lignin, ash and extractives. The proximate values for the chemical composition of white spruce wood are shown in Table 4. For sake of comparison, the table also includes several coniferous woods which are either dominant or potential species for pole production in Canada. Of the chemical properties of coniferous woods, extractive content is probably the only variable of consequence, and as Panshin and De Zeeuw (1970) point out, the extractives generally constitute a few percent of the oven-dry weight of wood. The heartwood of white spruce contains acetone- and petroleum ether-soluble extractives (Rogers _et al._, 1969), and Swan (1973) reported information on fatty acids and resin acids. For the percent composition of heartwood extractives are available elsewhere (Drew and Pylant, 1966). However, the extractives, such as thujaplicins

TABLE 4. Chemical composition of six common coniferous woods (Isenberg, 1980)

Species	Alpha-cellulose (%)	Hemi-cellulose (%)	Lignin (%)	Total pentosan (%)	Ash (%)	Solubility in: Alcohol benzene (%)	Solubility in: Hot water (%)
White spruce (<u>Picea glauca</u>)	42.6	16.4	29.4	11.8	0.3	2.0	2.6
Amabilis fir (<u>Abies amabilis</u>)	43.8	-	28.2	9.8	0.5	2.6	3.2
Douglas-fir (<u>Pseudotsuga menziesii</u>)	49.6	14.1	27.7	7.9	0.2	4.1	5.0
Lodgepole pine (<u>Pinus contorta</u>)	45.7	-	27.2	12.4	0.2	3.5	2.7
Western hemlock (<u>Tsuga heterophylla</u>)	49.2	15.5	29.4	9.2	0.3	2.6	2.0
Western red cedar (<u>Thuja plicata</u>)	44.0	14.6	30.9	9.0	0.3	14.1	11.0

Note: All percentages based on moisture-free wood.

responsible for the natural decay resistance of western red cedar (Kurth, 1950; Rennerfelt, 1948), are not present in spruce wood.

The physical properties of wood normally include specific gravity, shrinkage, anatomy. These properties closely relate to the mechanical strength properties of the wood and to its ability to be impregnated by preservative solutions. To illustrate the physical properties of white spruce, Table 5 has been prepared to include white spruce and the five other species listed in Table 4. Of these species presented, there is a little difference in most of the physical properties examined, though Douglas-fir has a significantly higher specific gravity value. It could be argued that the presence of resin canals is beneficial for the distribution of preservative solutions both in the transverse and radial directions. Attributes such as tracheid diameter and ray volume would influence the ease of penetration both in vertical and lateral directions. Thus the small average tracheid diameter with the presence of blocked bordered pits of white spruce may account for some of the difficulties in preservative treatment reported for this species. The process of heartwood formation or drying causes the pit membrane to shift thereby blocking the pit aperture by the torus (Stamm, 1970). This situation, which is well known in the interior variety of

TABLE 5. Physical properties of six common coniferous woods.

Species	Specific Gravity[1]		Ray Volume[2] (%)	Tracheid Dimensions[2]		Resin Canals[2] (normal)	Shrinkage[1] Green to Oven-dry (%)			Ave. Ring Width[3] (mm)	Late-wood[3] (%)
	Green Volume	Oven-dry Volume		Length (mm)	Diameter (μm)		Radial	Tangential	Volumetric		
White spruce	0.37	0.42	7.0	3.3	35	present	4.7	8.2	13.7	1.7	21
Amabilis fir	0.35	0.42	7.0	3.3	60	absent	4.6	9.8	13.8	1.7	22
Douglas-fir	0.45	0.51	7.3	3.4	55	present	5.0	7.8	11.8	1.7	35
Lodgepole pine	0.38	0.43	5.7	3.2	55	present	4.5	6.7	11.5	1.0	23
Western hemlock	0.38	0.44	8.0	3.0	50	absent	4.3	7.9	11.9	1.3	31
Western red cedar	0.31	0.34	6.9	3.1	45	absent	2.4	5.0	6.8	1.7	27

Sources:

1. Isenberg (1980)
2. Panshin and De Zeeuw (1970)
3. Jessome (1977)

Douglas-fir, also occurs in white spruce (Sebastian et al., 1965).

The mechanical properties of wood obtained from small clear specimens are extremely useful in determining the relative strength between species. These properties are dependent on a number of factors such as the moisture content and physical properties of the wood, which may vary among species and even within the same species. Table 6 summarizes the mechanical properties of the six species in both green and air-dry conditions. On the basis of the green data given in the table, these species could be ranked in order of increasing fibre stress at proportional limit in static bending as follows: white spruce, lodgepole pine, amabilis fir, western red cedar, western hemlock and Douglas-fir.

Although the results of mechanical tests made on small clear specimens can be used to select wood species for a given end-use, it should be noted that in very few cases is the end-use satisfied exactly by such specimens. Wooden utility poles are normally tested for several purposes, in accordance with established test procedures such as those published by the American Society for Testing and Materials (ASTM) in their standard: ASTM D 1036-83 Standard Methods of Static Tests of Wood Poles (ASTM, 1984). The strength

TABLE 6. Mechanical properties of six common conifers (Jessome, 1977).

Attribute	Test	Species: White spruce	Amabilis fir	Douglas-fir	Lodgepole pine	Western hemlock	Western red cedar
Static Bending	Stress at Proportional	2,780	2,990	4,320	2,970	4,110	3,100
	Limit (psi)	5,320	5,810	7,740	7,050	7,800	4,990
	Modulus of Rupture	5,100	5,480	7,500	5,650	6,960	5,300
	(psi)	9,090	9,990	12,850	11,020	11,760	7,800
	Modulus of Elasticity	1,150	1,350	1,610	1,270	1,480	1,050
	(1000 psi)	1,440	1,650	1,960	1,580	1,790	1,200
Impact Bending	Stress at Proportional	8,350	8,680	10,360	7,760	9,000	7,580
	Limit (psi)	10,920	12,000	14,340	10,780	11,200	9,700
	Modulus of Elasticity	1,370	1,610	2,000	1,370	1,970	1,380
	(1000 psi)	2,000	2,260	2,810	1,830	2,310	1,490
Compression	Crushing Stress at Pro-	1,820	2,140	2,810	2,220	2,980	2,310
Parallel to	portional Limit (psi)	3,710	4,150	4,950	4,450	5,290	3,970
Grain	Maximum Crushing Stress	2,470	2,770	3,610	2,860	3,580	2,780
	(psi)	5,350	5,920	7,270	6,270	6,780	4,920
	Modulus of Elasticity	1,310	1,460	1,670	1,420	1,620	1,170
	(1000 psi)	1,650	1,750	1,970	1,660	1,750	1,320
Compression	Stress at Proportional	245	234	460	276	373	278
Perpendicular	Limit (psi)	500	523	871	529	657	497
to Grain							

TABLE 6. (cont.)

		Species					
Attribute	Test	White spruce	Amabilis fir	Douglas-fir	Lodgepole pine	Western hemlock	Western red cedar
Hardness	Load Required to Imbed 0.444 in. Sphere to Half Diameter (lb) — Side	279	322	481	362	468	265
		423	442	672	492	617	330
	End	320	406	589	339	561	431
		555	835	903	673	992	674
Shear Parallel to Grain	Maximum Stress (psi)	670	714	922	724	752	696
		985	1,093	1,382	1,238	940	809
Cleavage	Splitting Strength (lb./in. width, 3 in. long)	156	168	216	186	202	136
		221	210	222	297	214	145
Tesion Perpendicular to Grain	Maximum Stress (psi)	307	274	407	332	390	238
		475	444	444	548	425	357

Note: Values in the first line for each property are the species means in the unseasoned condition; those in the second line are adjusted to 12 percent moisture condition.

properties of whole pole from white spruce have been obtained from available literature sources (Eggleston, 1952; Sugden, 1979), and are presented in Table 7. For sake of comparison, data from western red cedar, lodgepole pine, amabilis fir and western hemlock poles are also included. On the basis of the data given in the table, it is evident that both amabilis fir and western hemlock are potential candidates as substitutes for western red cedar and lodgepole pine poles, at least in terms of mechanical strength properties. On the other hand, white spruce appears to have lower strength properties than any of the species listed. This might be a cause for concern, particularly when considering this species as a source of longer poles.

2.2.2 PROBLEMS ASSOCIATED WITH WHITE SPRUCE

During the past decade, the Eastern Forest Products Laboratory (EFPL) conducted numerous studies on the treatment of white spruce with waterborne preservatives (Krzyzewski, 1978; Rak, 1977a,b and c; Rak and Clarke, 1975a; Ralph and Shields, 1984a and b). However, because of the difficulty in penetrating this species with preservatives, limited use has been made of it for the production of preserved wood products.

Due to the pole shortage in the early 1970s, several

TABLE 7. Summary of pole strength tests.

Species	Origin	Treatment: Drying	Treatment: Preservation	Pole Length (ft.)	No. of Poles	Modulus of Rupture[a]: Average (psi)	Std. Dev.	Coeff. of Var. (%)	5% Fractile	Source[b]
White spruce	B.C.	Air	Bethel-PCP	35	53	4961	951	19.2	3562	1
	B.C.	Air	Bethel-ACA	35	53	4911	684	13.9	3872	1
Amabilis fir	B.C.	Kiln	Bethel-PCP	35	52	5642	1032	18.3	4118	1
	B.C.	Kiln	Bethel-ACA	35	51	5194	781	15.0	4016	1
Western hemlock	B.C.	None	None	25	52	6135	739	12.0	4999	1
	B.C.	Air	Creosote	25	50	6432	975	15.2	4963	1
	B.C.	Kiln	Bethel-PCP	35	52	7483	1026	13.7	5922	1
	B.C.	Kiln	Bethel-ACA	35	50	6967	1034	14.8	5407	1
Lodgepole pine	U.S.A.	-	CCA	-	9	5836	-	-	-	2
	B.C.	None	None	25	23	5809	627	10.8	4839	1
	B.C.	Air	Rueping-Creosote	25	24	6671	862	12.9	5353	1
	Alta.	None	None	25	23	6604	667	10.1	5567	1
	Alta.	None	None	25	25	6581	527	8.0	5752	1
	U.S.A.	None	None	25	6	4955	542	10.9	4116	1
	U.S.A.	Air	Rueping-Creosote	25	6	5174	492	9.5	4406	1
	U.S.A.	Air	Rueping-Creosote	30	21	5150	684	13.3	4106	1
	U.S.A.	None	None	45	5	4220	648	15.3	3245	1

TABLE 7. (cont.)

Species	Origin	Drying	Preservation	Pole Length (ft.)	No. of Poles	Modulus of Rupture[a] Average (psi)	Std. Dev.	Coeff. of Var. (%)	5% Fractile	Source[b]
		Treatment								
Western red cedar	U.S.A.	-	CCA	-	2	4395	-	-	-	2
	U.S.A.	-	CCA	-	3	5207	-	-	-	2
	U.S.A.	-	CCA	-	5	4882	-	-	-	2
	B.C.	None	None	30	51	5229	763	14.6	4075	1
	B.C.	-	Butt Treated	30	25	4694	885	18.9	3391	1
	B.C.	None	None	30	51	4587	599	13.1	3672	1
	B.C.	None	None	30	40	5787	877	15.2	4466	1
	B.C.	None	None	30	40	5620	827	14.7	4370	1
	U.S.A.	None	None	30	26	5550	514	9.3	4746	1
	U.S.A.	None	None	30	25	5325	505	9.5	4536	1

[a] The groundline MOR values were determined approximately at 6 feet above the butt.

[b] 1) Sugden (1979)
2) Eggleston (1952)

wood-treating companies examined the suitability of spruce as pole material. It has been reported by Rutherford (1977) of Domtar that, in experiments conducted on spruce, potential problems existed due to excessive checking formation and difficulty in obtaining an adequate treatment. This is consistent with the world literature in which the refractory behaviour of several species of spruce is described (Banks, 1973; Dunleavy et al., 1973a and b; Hauffe, 1970; Hackbarth, 1975; Liese and Bauch, 1967; Rak, 1977a; Rak and Clarke, 1975a; Siau and Shaw, 1971; Unligil, 1971). It is generally known that spruce wood is very low in natural decay resistance (MacLean, 1935; Nicholas and Siau, 1973; Panshin and De Zeeuw, 1970; USDA, 1974). For example, untreated fence posts of white spruce have an average service life of only 3.2 years in eastern Canada (Krzyzewski and Sedziak, 1974). Thus any damage by checking after shallow treatment could expose spruce wood with low natural durability to high decay hazard.

Despite extensive studies (Hackbarth, 1975; Hackbarth and Liese, 1975; Liese and Bauch, 1967; Rak, 1977a; Siau, 1970), the reasons for the refractory nature of spruce are not fully understood. Liese and Bauch (1967) have proposed that the low permeability of the ray cells is due to the relatively small proportion of ray tracheids. However, in a more recent study conducted by Hackbarth and Liese (1975) on spruce treated with two waterborne preservatives, copper chrome fluoride and copper chrome borate, they concluded that neither the number nor the area of ray cells influenced the preservative penetration, and rather increasing density and the proportion of latewood both reduced the preservative absorption. Sapwood was found to be more permeable than heartwood and axial penetration in sapwood was thirty-four times greater than that in either the radial or tangential directions. The only chemical factor for which a positive influence was detected was the solution concentration, suggesting that increasing the solution strength caused a reduction in the amount of solution absorbed (Harkbarth and Liese, 1975). Recently Rak (1977a) has also suggested that structural reasons for the low permeability of spruce are fewer bordered pits with smaller margo pores, and less efficient capillary connections between ray parenchyma on cross-fields than in permeable species such as pines.

White spruce heartwood is undoubtedly one of the most difficult woods to treat. Although the range of permeability is thought to be relatively narrow in spruce, exceptions to this may occur depending on the species of spruce, their geographic location and rate of growth (Ralph and Shields, 1984b). In addition permeability may be affected by such factors as the method of log storage, time of year the material is cut, as well as several other variables. Permeability also differs within a single annual ring with earlywood bands often being more permeable than latewood. This phenomenon is frequently observed as a banding effect in some pressure-treated spruce (Ralph and Shields, 1984b).

2.3 FACTORS AFFECTING THE TREATABILITY OF SPRUCE ROUNDWOOD

The Canadian wood preservation industry has relied heavily on specific wood species for pressure treatment. Consequently, more permeable wood species for use in preservative-treated commodities have become depleted in Canada. Thus spruce can be a convenient replacement for them from abundant local resources provided that it can be treated to levels adequate to protect commodities in ground contact.

In general, the problem of treating difficultly penetrable species such as spruce has been attacked by three basic methods. These are: (1) the use of enzymes, molds, or bacteria (microbiological); (2) incising and variation of the treating conditions (physical); and (3) preservative type and formulation (chemical).

2.3.1 MICROBIOLOGICAL STUDIES

A number of researchers have shown that microorganisms and enzymes can increase the permeability of wood. Work in this area was initiated by Lindgren and Harvey (1952) when they found that *Trichoderma* mold improved the permeability of southern pine sapwood sprayed with fluoride solutions. Several subsequent studies (Dunleavy *et al.*, 1973a and b; Ellwood and Ecklund, 1959; Greaves and Barnacle, 1970; Knuth and McCoy, 1962; Schulz, 1968; Unligil, 1971 and 1972a) have reported that bacteria and other fungi also effectively increase the permeability of wood, indicating that the increased permeability is principally due to degradation of the ray cells and pit membranes. For example, steeping spruce poles for two months in stagnant water caused a breakdown of the pit membranes, resulting in an improved permeability of the ray cells (Dunleavy *et al.*, 1973b). The degree of improvement depends upon both the time of year and the duration of ponding, reflecting the effect of water temperature on bacterial activity. Schulz (1968) also observed that penetration of fluor-chrome arsenic phenol (FCAP) preservative increased up to 67% in the sapwood region of ponded spruce poles.

Similarly, when treating ponded white spruce pole sections with CCA preservative, Unligil (1971) reported a 50% greater solution absorption. For creosote treatment, the improvement in permeability was even more marked, with increased retentions up to 179% (Unligil, 1971 and 1972a). According to Unligil, the effects of ponding are limited to the sapwood zone. Although bacteria were detected throughout the sapwood, only the resin canals, epithelial cells and ray parenchyma were particularly affected in the inner region. He also suggested that attack of the surface of the pole section by soft rot fungi may have contributed to the improved permeability.

Since it is known that microorganisms degrade wood by enzymatic action, it is logical to assume that permeability could be increased by treatment with enzymes. This assumption was verified in a study by Nicholas and Thomas (1968) which showed that several enzymes attack the pit membranes in loblolly pine sapwood, resulting in a significant increase in permeability. Unligil and Krzyzewski (1972) attempted to improve the permeability of spruce by enzymatic decomposition of the pectic substances in the liquid-flow-controlling tori. Dunleavy and his co-workers (1973b) have also conducted a similar study on water-stored spruce logs to examined water-stored spruce logs for enzymatic activity, particularly that involving pectate lyase, since degradation products from pectic substances (i.e. pit membranes) would enhance further lyase activity. While the enzymatic pretreatment of pole material may improve the overall permeability, it remains unclear whether any significant improvement in penetration in the radial direction is obtained. Indeed Adolph (1976) has suggested that impregnation radially is much more difficult than in either the tangential or axial direction. Assuming that bordered pit membranes and tori are partially destroyed, this would lead to improved tangential movement because of bordered pits being on the radial faces.

The use of microorganisms and enzymes to improve the permeability of wood is advantageous because they are selective in their attack, thus minimizing strength loss. According to Unligil (1972a), static bending tests on air-dried small, clear specimens of white spruce indicated a slight loss in strength. However, Dunleavy and his co-workers (1973b) have reported that strength tests on full-sized Sitka spruce (Picea sitchensis (Bong.) Carr) poles indicated that any reduction resulting from ponding was negligible. They found that an added benefit of ponding of poles was the clean surface appearance after treatment with oil-borne preservatives. Concerning roundwoods such as utility poles, However, there are certain problems. Water storage of poles leads to extra handling since they must be placed in water and later be stacked for drying. Furthermore the poles are difficult to dry and the risk of decay during the drying process increases.

Experiments with enzyme treatments have so far been carried out mostly on small wood specimens. Therefore, studies on the applicability of enzyme treatments to roundwoods are required. At present, the enzyme preparations are still too expensive to have a practical use. Although use of the mould fungus Trichoderma is a simple method to improve permeability of softwood (Bergman, 1984), it is not used in practice. Presumably this is because a mould attack is still regarded as a gateway to wood decay.

2.3.2 PHYSICAL STUDIES

2.3.2.1 INCISING

While natural seasoning or artificial preconditioning normally improve results of treatment, some refractory species require additional preparation in order to obtain satisfactory treating results. At present, the most commonly imployed method of preparing these species is incising, which is performed on both sawn and round material. Incising has been one of the most effective and least costly methods of improveing the treatability of wood (Nicholas and Siau, 1973). By mechanically rupturing the wood cells at periodic intervals along and across the piece, the structure is rendered sufficiently porous to permit the flow of preservative solutions into the incised zone.

A number of reports indicate that the permeability of spruce to preservatives can be improved by incising (Banks, 1973; Horn et al., 1977; Krzyzewski and Shields, 1977; Möhler, 1969; Ralph and Shields, 1984a). Banks (1973) has reported the development of a close-spaced incising pattern for use on spruce lumber, and in a very recent study (Ralph and Shields, 1984a) incising of spruce lumber proved beneficial by increasing preservative penetration in the heartwood areas of boards, even when treated by the thermal diffusion process. Horn and his co-workers (1977) have shown that incising spruce poles clearly enhances both the penetration and retention of waterborne preservatives applied by pressure impregnation. They also noted that an additional benefit resulting from incising was the dramatic lowering of the concentration gradient over the outer 1.2 in. (3 cm) analytical zone, with the pattern of 1.2 in. (3 cm) deep incisions staggered 0.4 in. (1 cm) and laterally 1.2 in. (3 cm). Thus by choosing a suitable spacing and depth of incisions, it is possible to provide poles with a more uniform preservative treatment. In addition to improving treatment results, a secondary benefit provided by incising is the reduction of deep checks (Krzyzewski and Shields, 1977).

The main disadvantages of incising are that it produces a rough surface and results in some strength loss (Möhler, 1969; Nicholas and Siau, 1973). However, for most products such as pole and timber, these disadvantages are not too serious and incising undoubtedly will continue to be the principal method of improving treatability.

2.3.2.2 VARIATION OF THE TREATING CONDITIONS

To a certain extent, the treatment results can be altered by using different treating cycles. For example, it is generally known that the full-cell process can be used to maximize retention. Furthermore, the Lowry and Rueping processes can be used to reduce retention while obtaining better penetration compared with the full-cell process (Canadian Institute of Timber Construction, 1971). Pressure processes used with oilborne solutions may be either full-cell or empty-cell, while the full-cell process is almost always used with the waterborne solutions (Kennedy, 1981). Although these pressure-treating processes have proven to be effective means of impregnating wood with preservative solutions in most cases, they do not provide adequate treatment of refractory wood. This is mainly the result of insufficient pressure to overcome the air-liquid interfaces in the extremely small pores of this type of wood (Nicholas and Siau, 1973). Thus it is anticipated that significantly better results could be obtained by altering the treating schedule (e.g. pressure and temperature).

The work by MacLean (1935) clearly showed that increasing the pressure from 100 to 250 psi (689 to 1723 kPa) improved the treatment of refractory wood. However, the research by Siau (1970) and Walters and Whittington (1970) has indicated that considerably higher pressures are required to obtain complete impregnation of this type of wood.

Although an increase in pressure appears to be a means of achieving better treatment of refractory wood, increasing the duration of applied pressure rather than its magnitude was found to be more beneficial to improving penetration (Hackbarth, 1975). These results are in agreement with those of an earlier study by Hauffe (1970), who also noted the beneficial effect of increasing the temperature of creosote solution when treating black spruce (Picea mariana (Mill.) B.S.P.). Both Hauffe and Bosshard (1968), who investigated the use of high pressures and temperatures on the impregnation of Norway spruce (Picea abies (L.) Karst.) with coal-tar oil, concluded that pressures greater than 150 psi (1032 kPa) and temperatures in excess of 100°C caused damage to the wood structure. It was also observed during treatment of squared timbers of white spruce that collapse occurred at about 65°C in some timbers, mostly on heartwood faces (Krzyzewski, 1978). This effect has not been observed in the treatment of roundwood, but until such time as the influence of temperature is determined, Krzyzewski has recommended that the temperature should not be higher than that indicated.

A number of pilot plant studies (Krzyzewski, 1978; Rak, 1975 and 1977c) have been conducted on white spruce lumber and roundwood to determine optimum treating conditions. Using a modified treating schedule, i.e. flow in preservative at 57°C with pressures up to 150 psi (1032 kPa), Krzyzewski (1978) obtained good penetrations and retentions in a large number of spruce roundwood treated with ammoniacal salt preservatives. This observation is in agreement with that reported by Rak (1975).

The treating schedule plays an important role in achieving a satisfactory preservative treatment. However, it should be noted that certain factors place restrictions on the pressure and temperature used. As Nicholas and Siau (1973) point out, susceptibility of wood to collapse varies with the pressure, permeability, wood species, size of the specimen, type of preservative, rate of pressure increase, and preservative temperature. Consequently, all these factors must be considered when the use of higher pressure is contemplated.

2.3.3 CHEMICAL STUDIES

The third area of research activity to increase the penetrability of spruce is the proper selection of chemicals and additives for formulations. Since the characteristics of the treating solution have an effect on the treatment of wood, the problem of treating difficultly penetrable species such as spruce has been attacked by using more penetrative preservatives (e.g. ACA) and their modifications. Long experience with aqueous ammonia as a solvent for inorganic preservative salts as originally used in the U.S.A. (Fritz, 1947; Gordon, 1947) for the treatment of a difficult-to-treat white fir (*Abies concolor* (Gord. & Glend.) Lindl.) prompted trials of this solvent for the treatment of Canadian spruce (Rak, 1977a). Since then, ammonia has been used in preservative formulation studies and in the development of a copper-zinc-arsenic (CZA) preservative system for treatment of spruce (Clarke and Rak, 1974; Rak, 1976; Rak and Clarke, 1975a).

Rak (1977a) reported that the permeability of spruce roundwood in the radial direction was improved using an aqueous ammoniacal solution of inorganic salts, compared with ordinary aqueous solutions. On the basis of this observation, experimental ammoniacal preservatives, copper-arsenic-additive (CAA) and copper-zinc-arsenic-additive (CZAA), developed by Rak (1976 and 1977c) and Rak and Unligil (1977), have provided high chemical retentions and excellent sapwood penetration in white spruce. These preservatives have improved fixation properties in the wood compared to conventional ACA, are toxic to a wide range of fungi, and at the same time reduce the amount of arsenic necessary for their formulation. CAA is now included in the Canadian Standards Association preservation standard CSA 080 as a modification of ACA, while CZAA has been accepted provisionally as ammoniacal copper zinc arsenate (ACZA).

A commercial schedule for treatment of spruce with the new preservative, copper-ammonia-additive, was prepared by Krzyzewski and Rak (1973) in which a pressure of 150 psi (1032 kPa) and temperatures ranging from 52°C to 75°C were employed. Encouraging results with this treating schedule were reported by Rak (1977c), Ralph and Shields (1984a) and Unligil and Krzyzewski (1978) with both pressure treatments and diffusion treatments of the groundline bandage-type on spruce having moisture contents above the fiber saturation point. Positive economic benefits of ACA or ACZA systems include a wider yet less expensive range of woods (*e.g. Picea* and *Populus* species) that can be treated (Ralph and Shields, 1984a).

2.4 PROTECTION OF POLES WITH WATERBORNE CHEMICALS

With increasing importance of communications and power supply in everyday life, experience has led utility companies to specify preservative treatment to ensure continued strength and eliminate the high cost of replacement. For these reasons, preservative treatment of most species of poles has been employed by means of pressure impregnation for many years.

Although creosote was the first preservative to become established in Canada, a number of other preservatives have since followed and the wood-preserving industry has settled on a few basic materials and formulations which have stood the test of time. Wood preservatives can be arranged into two broad categories: organic-solvent substances (oilborne) and water-soluble inorganic salts (waterborne). Five oilborne preservatives are described in the Canadian Standard for wood preservation using pressure processes (CSA-080 Wood Preservation, 1983a). They are creosote, pentachlorophenol, bis (tributyltin) oxide, copper-8-quinolinolate and copper naphthenate. On the other hand, of the common waterborne preservatives, two systems such as CCA and ACA are most widely used in Canada (Smith, 1977) and provide excellent and long-lasting protection of treated wood against biodegradation (Gjovik and Davidson, 1972).

Three preservatives have been in common use for utility poles pressure-treated in accordance with the CSA 080.4 specifications, namely creosote, PCP and CCA. Although PCP is still the main preservative employed for utility poles, the waterborne preservatives are gaining more acceptance by some utility companies.

Since the early 1970s, considerable effort has been devoted towards the development of new wood preservatives (Butcher et al., 1977; Clarke and Rak, 1974; Johnson and Gutzmer, 1978; Rak and Clarke, 1975a; Sparks, 1978) and, because of the relatively high cost of organic solvents, much of this activity has been directed to developing water-soluble rather than oil-soluble formulations. These waterborne preservatives involve chemicals which are toxic to fungi, and preferably show some ability for fixation in the wood, thereby preventing their subsequent leaching from wood when in contact with water. Approved formulations of preservatives used in Canada are covered by Standard CSA-080 Wood Preservation. Good examples of such formulations are CCA, ACA and CAA, the first two of which form the bulk of waterborne preservatives currently used in Canada. ACA is particularly attractive since the penetration of ammonia into all components of wood substance, and its action on the structure of wood are identified as factors affecting the treatability of spruce.

2.4.1 CHROMATED COPPER ARSENATE (CCA)

The chromated copper arsenates are known in the American Wood-Preservers' Association (AWPA, 1984) and CSA (1983b) as

Type A, B, and C, listed in their order of acceptance as AWPA standards. These formulations differ principally in the proportions of arsenic and chromium present in each formulations differ principally in the proportions of arsenic and chromium present in each formulation. All three, on the oxide basis, contain about 19% CuO. Type A is high in chromium, Type B high in arsenic, while Type C is intermediate. Type C is close in composition to the numerical average of Types A and B, and also close to the two widely used British formulations, Tanalith C and Celcure A. The composition of each type of CCA preservatives is shown in Table 8.

CCA preservatives have been used widely for many years throughout the world for treating permeable species. Although all three types of CCA could be used, only Types B and C have found extensive use since the introduction of CCA preservatives into the Canadian standards. However, the situation has changed such that Type C formulation is now favoured by CCA treaters, mainly due to its adoption by a major chain of Type B users and due in part to a desire by treaters to use a preservative with a lower arsenic content (Ruddick, 1982).

Research in various countries has looked into many aspects of CCA preservative system for treating wood, thus enabling properties such as fixation of toxic chemicals,

TABLE 8. Composition of the CCA preservatives.

	AWPA standards[1]			CSA Standards[2]
	Type A	Type B	Type C	
CrO_3(%)	59.4(65.5)69.3	33.0(35.3)38.0	44.5(47.5)50.5	36 - 65
CuO(%)	16.0(18.1)20.9	18.0(19.6)22.0	17.0(18.5)21.0	19
As_2O_5(%)	14.7(16.4)19.7	42.0(45.1)48.0	30.0(34.0)38.0	16 - 45

Sources:

1. American Wood-Preservers' Association (1984).
2. Canadian Standards Association 080, Wood Preservation (1983b).

Note: Figures in parentheses represent nominal composition on the oxide basis; others represent range.

their resistance to leaching, water repellency, electrical resistivity, paintability, and cost to be controlled (Rak and Clarke, 1975a). This has been possible by varying the nature and the ratio of the copper, chromium and arsenic components. In CCA solution, these three components are all water-soluble. When the solution is impregnated into wood, fixation depends on an oxidation-reduction reaction between chromium components in the preservative and reducing groups in the wood substance, thereby preventing their subsequent leaching from wood (Rak and Clarke, 1975b). Since the rate of the reduction-oxidation reactions is a function of the concentration of the reducing compound and temperature, the stability of the preservative system is limited during both treatments and storage. For this reason, maximum treating temperatures of only 49°C are allowed by the AWPA and CSA standards. A protracted schedule necessary for treating difficult-to-treat species leads to problems with early precipitation of toxic chemicals (Rak and Clarke, 1975a). It has been also reported by Rak and Clarke (1975b) that variation of the chemical components in the preservative solution did not provide sufficient control over the rates of the oxidation-reduction reactions to enable adequate penetration to be achieved.

2.4.2 AMMONIACAL COPPER ARSENATE (ACA)

Information in support of ACA, under the trade name "Chemonite", was submitted to the AWPA Preservatives Committee in 1949 (Baechler, 1949), following the papers presented to the Association in 1947 (Fritz, 1947; Gordon, 1947; Ott, 1947). The original patent was issued to Gordon in 1939.

ACA was originally prepared at the treating plant by mixing a copper chemical with arsenic trioxide in ammonium hydroxide. Because of the components used, the preservative was incorrectly called ammoniacal copper arsenite. However, in the mid-1970s, it was realized that this was erroneous, since during the mixing process, the air oxidized the arsenic to the pentavalent form (Ruddick, 1982). Thus the name was changed to ammoniacal copper arsenate. ACA has been used for many years on the west coast of the United States and is now widely used in Canada.

2.4.2.1 CHEMICAL COMPOSITION AND FORMULATION

The historical development of the specifications for ACA composition is shown in Table 9. According to the original standards (Beachler, 1949; Gordon, 1947), ACA was formulated from copper hydroxide, arsenic trioxide, acetic acid, and ammonia. Although no definite information is available, it is unlikely that copper hydroxide is used in the formulation

TABLE 9. Historical development of ACA composition.

	AWPA Standards				1983 CSA Standards[5]
	1949 Proposal[1]	1953 Acceptance[2]	1969 Oxide Basis[3]	1984 Oxide Basis[4]	
Cu as $Cu(OH)_2$(%)	60 ± 5	55.7(57.7)59.7	-	-	-
As as As_2O_3(%)	40 ± 5	38.7(40.7)42.7	-	-	-
Cu as CuO(%)	-	-	(49.8)47.7 min.	(49.8)47.7 min.	49.8-63.0
As as As_2O_5(%)	-	-	(50.2)47.6 min.	(50.2)47.6 min.	37.0-50.2
NH_3	2.0-3.0% in soln.	1.5-2.0x$Cu(OH)_2$	1.5-2.0xCuO	1.5 min.xCuO	1.5-3.5xCuO
Acetic acid(%)	0.05 in soln.	1.6	1.7 max.	1.7 max.	-
Carbonate as CO_2	-	-	-	-	0.0-0.8xCuO

Sources:

1. Baechler (1949)
2. ________ (1953)
3. American Wood-Preservers' Association (1971)
4. ____________________________________ (1984)
5. Canadian Standards Association 080, Wood Preservation (1983b)

Note: Figures in parentheses represent nominal composition; other figures represent range.

of ACA, because of its higher cost in the preparation rather than the sulfate or basic carbonate (Winter et al., 1965). However, the direct use of copper sulfate may be somewhat undesirable if the resulting ACA solution is to be used in the treatment of utility poles, where residual conductivity is unwanted (Hartford 1973).

Over the past 30 years, the ACA preservative system has become well established, and its formulation presently contains equal weights of cupric and arsenic oxides, plus optional small amounts of ammonium acetate or bicarbonate, all dissolved in 4-6% of aqueous ammonia. Acetate ions enhance copper solubility, and carbonate ions render the surface of the treated wood more water repellent (Kennedy, 1981). Unlike CCA, the ammoniacal preservative is not marketed as a prepared formulation.

With the oxidation of As_2O_3 to As_2O_5, the ammonia in the solvent reacts with the copper arsenate to form a soluble complex:

$$3CuO + As_2O_3 + 12NH_3 + 4H_2O \xrightarrow{O_2} 3Cu(NH_3)_4^{2+} + 2H_2AsO_4^- + 4OH^- \qquad (1)$$

This soluble complex is stable in ammonium hydroxide solution.

2.4.2.2 MECHANISM OF FIXATION

The fixation of ammoniacal copper systems in wood has been reported by Eadie and Wallace (1962), Rak and Clarke (1974) and Sundman (1984). While the CCA preservative depends on a reaction between the preservative components and the wood, the fixation of ammoniacal copper compounds depends on the volatilization of ammonia and the insolubilization of the preservative.

Following impregnation of the ACA into the wood, the ammonia in the solvent evaporates. Although the soluble complex in ammonium hydroxide solution is stable as shown in reaction (1), it readily breaks down to form insoluble copper arsenate when the solvent is removed:

$$3Cu(NH_3)_4^{2+} + 2H_2AsO_4^- + 4OH^- \xrightarrow{\nearrow 12NH_3} Cu_3(AsO_4)_2 \cdot 4H_2O \qquad (2)$$

For this reason, the ACA system is relatively resistant to leaching when the treated wood is placed in service and the formulation enables time and temperature to be varied without danger of premature precipitation of toxic chemicals, provided that loss of ammonia from the treating solution is prevented (Rak and Clarke, 1974). However, Wilson and his co-workers (1955) reported that the ACA-treated wood has lower arsenic fixation.

Copper arsenate-treated wood has proven to be one of the most durable of the preservative treatments used today. Although it is relatively non-leachable and the ACA preservative is highly effective, considerable effort has been devoted towards the development of several ammonia-based preservatives that make use of the method of fixation applied in ACA (Butcher et al., 1977; Clarke and Rak, 1974; Rak and Clarke, 1975a). In accelerated laboratory and field tests, it has been shown that these modified preservatives are more resistant to leaching compared with ACA. Ammoniacal copper borate (ACB) is another similarly precipitated preservative (Johnson and Gutzmer, 1978; Vinden and McQuire, 1984).

2.5 FACTORS INFLUENCING THE EFFECTIVENESS OF PRESERVATIVE SYSTEMS

Preservative systems must perform their function throughout the service life of the product under a variety of exposure conditions. Thus, utility poles must be treated with systems that protect both the aerial and below-ground portions for several decades in a variety of climates, soils and leaching conditions.

In general, the effectiveness of a wood-preservative treatment in preventing deterioration is dependent on the treatment results, as well as the preservative system. The two main criteria used to establish the effectiveness of a preservative treatment are depth of penetration and level of chemical retention. Almost all wood products purchased today are inspected for conformance with a results-type specification, because an accurate measure of both penetration and retention would indicate whether the wood was properly treated.

2.5.1 PENETRATION

It has been recognized that there are a number of factors affecting penetration other than treating techniques. These are species, pit aspiration, sapwood depth, sap stain, incising technique, dryness, and season of the year. Regardless of what causes lack of penetration, it affects service life. For example, poles which do not receive adequate penetration are subject to decay in the untreated sapwood and low-retention zones near the point of termination of seasoning checks. These checks normally close at or near the groundline, and rain water running down the inside of checks accumulates dust, spores and moisture. Therefore, the wood should be adequately treated well beyond the point of penetration of these checks to prevent it from decay hazard.

While it is often observed that the depth of penetration is approximately uniform on all sides of the material, not infrequently the penetration is much deeper at some points than others, showing an untreated core of wood of irregular or star-shaped cross section (Best, 1974; Bramhall, 1966). The causes of this naturally vary, but are known to include factors such as off-center pith, thickness of the growth rings, density, sap stain, moisture content differences, and checking pattern (Arsenault, 1973).

Since sapwood is perishable, it is important that it should be thoroughly treated to prevent early failures. In general, the depth of sapwood controls the depth of penetration (Arsenault, 1966; Hearn, 1951). In species where the sapwood is thin, as well as in large poles and timbers, incising procedures have been practised for more thorough penetration (Banks, 1973; Best and Martin, 1969; Graham and Estep, 1966; Ruddick, 1978). Although incising may encourage formation of several shallow checks rather than one major check, it is insufficient in preventing formation of checks that extend beyond the zone of treated wood. This is particularly true when the depth of penetration is shallow, as in difficult-to-treat species having a narrow sapwood (Graham and Estep, 1966). Thus the use of saw kerfs has been employed to reduce deep checking through the thin sapwood (Graham, 1973; Graham and Estep, 1966; Helsing and Graham, 1976; Ruddick, 1981; Ruddick and Ross, 1979). It has been concluded that kerfing is much more effective than incising in controlling checking in roundwood, particularly when treated with waterborne preservatives.

Some aspects of variability in penetration are described above, namely, species, off-center pith, and sapwood depth.

Other factors affecting penetration, especially lack of penetration in the inner sapwood, may include water pockets or areas of saturation due to the presence of mold fungi or bacteria, or incipient decay (Arsenault, 1973). However, more importantly, causes of variability related to treatment practices include treating poles and lumber of widely different moisture contents, following various periods and methods of air drying. Several researchers (Coetzee and Laar, 1976; Krzyzewski, 1978; Rak, 1977a; Ruddick, 1978) have shown that when material is impregnated with a waterborne preservative, increasing the moisture expedites the spread of preservative and results in deeper preservative penetration. According to Krzyzewski (1978), the optimum practical condition is the medium range of 28 to 35% moisture content. However, since the worst checks in a pole frequently extend more than two inches into the pole, Ruddick (1978) recommended to conduct the treatment of roundwood at moisture contents not exceeding 25%. Indeed, there is even concern that the current commercial practice of drying the material to just less than 25% moisture content does not establish adequate checking patterns prior to treatment. To a certain extent, this may be alleviated by pretreatments such as incising and/or kerfing.

Complete penetration of the sapwood should be the ideal in all pressure treatments. Although long experience has shown that even slight penetrations have some value, deeper penetrations are highly desirable to avoid exposing untreated wood when checks occurs in service, particularly for important members of high replacement cost. Whatever the cause, if wood is not adequately penetrated, early failures would result.

2.5.2 RETENTION

The second criterion used in establishing the efficacy of preservative treatment is the amount of chemical retained in wood. The retention of preservative is an equally important factor influencing the effectiveness of preservative systems in extending the service life of treated wood products. However, it should be noted that net retention of preservative by the treated wood alone is not an adequate index of the efficiency of treatment. As mentioned previously, this is because the preservative can be concentrated in certain areas of the wood, leaving wide variations in depth of penetration.

In general, the frequency distribution of retention in a group of treated poles shows a normal distribution. Thus it is obvious that many of the treated poles will have below-average retentions. Also, it is obvious that some of them will be in the risk retention level category specified in the appropriate standards. These low-retention poles are candidates for early failure.

Not only are poles different from each other, but retentions within a pole are as variable as those among poles. Mills and his co-workers (1965) have suggested that while 30 to 40% of the variation in retention can be explained by measured physical characteristics, 60 to 70% of pole-to-pole variation is normal due to other factors. A study conducted by Arsenault (1966) on the penta retention variation in standard pole species reported that percentage variation is less near the surface of the wood than at greater depths, where permeability differences add to the variation. The more refractory species such as Douglas-fir and lodgepole pine have greater variation between poles compared with red and southern pines.

As described earlier, the retention of preservative in wood is influenced by several factors, including permeability and surface-to-volume ratio. These two factors account for the large differences in absorption between small-diameter and large-diameter poles (Arsenault, 1973). Varying surface-to-volume ratios explain the fact that the top of poles receive considerably more treatment than the butts, and small-diameter poles in a cylinder charge tend to be overtreated when the large poles are adequately treated.

In a study of the causes of variation in retentions, Mills et al.(1965) found that the retentions on a weight per cubic foot basis were not significantly affected by either density or ring count. Also, it has been reported by Cserjesi et al.(1967) that there is apparently no correlation between specific gravity and absorption of preservative on a weight per surface area basis from waterborne solutions of antistain chemicals (e.g. copper sulfate or sodium pentachlorophenate) applied to western hemlock and Douglas-fir lumber. Therefore, as a practical matter, a uniform method of assigning weight per unit volume retentions to species and products should be used (Arsenault, 1966), avoiding any consideration of density differences between species.

2.5.3 TREATMENT RESULTS OF SPRUCE WITH AMMONIACAL WOOD PRESERVATIVES

Extensive experimentation and industrial trials with ammoniacal preservative solutions have yielded favourable results indicating that spruce roundwood, lumber and plywood can be treated successfully by pressure process (Krzyzewski, 1978; Krzyzewski and Rak, 1973; Krzyzewski et al., 1978; Krzyzewski and Shields, 1977; Rak, 1977a, b, and c; Rak and Clarke, 1975a). Encouraging results were also reported by Ralph and Shields (1984a and b) with non-pressure treatments (e.g. thermal diffusion process) of spruce with moisture contents above the fiber saturation point. Cserjesi (1984) has reported improvements in pole resistance to certain types of decay organisms when treated with ammoniacal wood preservatives.

The CSA (1983c) presently allows for the use of spruce poles treated with ACA at 0.6 lb./ft.^{3} (9.6 kg/m^3) oxide retention with a minimum penetration of 0.5 in. (13 mm) and 100% sapwood up to a depth of 0.75 in. (19 mm). However, even these minimum requirements, particularly for retention, are often not achieved with spruce roundwood, in spite of pretreatments to improve preservative uptake. In a study of preservative treatment of white spruce poles with ACA, Ruddick (1978) found that they showed excellent penetration of preservative, but the chemicals retained were not sufficient to satisfy the level established by the CSA standard. These observations correlate closely with those reported by several investigators (Coetzee and Laar, 1976; Gohre, 1958; Krzyzewski, 1978; Rak, 1977a), in that excellent preservative-penetration values were obtained, while the chemical retentions were much lower than anticipated.

As mentioned previously, the problem of treating difficultly penetrable species such as spruce has been solved in two ways: by increasing the permeability of the wood, and by using more penetrable preservatives.

Several researchers (Banks, 1973; Horn et al., 1977) have shown that incising spruce wood clearly enhances the permeability of waterborne preservatives applied by pressure impregnation, thus improving the penetration of preservatives. It has also been reported by numerous investigators (Dunleavy et al., 1973a and b; Krzyzewski, 1973; Schulz, 1968; Unligil, 1971 and 1972a) that the improvement in the permeability was significantly marked when treating ponded spruce material with preservatives.

Considerable effort has also been made to study the effect of ammonia on various components of the wood substance and some physico-chemical properties of ammonia-treated wood (Bariska and Popper, 1971 and 1975; Bariska et al., 1969; Davidson and Baumgardt, 1970; Rak, 1977a). These studies can be summarized by saying that penetration of ammonia into all components of wood substance, and its action on the substance of wood are identified as factors affecting the treatability. Indeed Rak (1977a) has indicated, in his permeability studies of spruce using a method previously developed (Rak, 1964), that an ammoniacal solution of copper arsenate is an excellent candidate for the treatment of spruce. Studies of the permeability of spruce sapwood microsections to ACA and CCA preservatives proved that the ammoniacal system penetrates 1.7 to 1.8 times faster in the radial direction than the CCA system. The permeability in the tangential direction was 3.8 times better on the average (Rak and Clarke, 1975a). These results were confirmed by pressure treatments of spruce lumber (Rak, 1975) and spruce roundwood (Rak, 1977c) with both preservatives. Supporting evidence for these observations is also provided by the fact described by Rak (1977a) that the permeability of spruce sapwood to an aqueous ammoniacal solution of inorganic salts was found to be better than a plain water solution. He also found that this improved rate of penetration was independent of the nature of the salts in ammoniacal solution.

The effect of ammonia on various components of the wood substance has been investigated on model systems with anhydrous liquid ammonia by many researchers (Bariska and Popper, 1975; Bariska et al., 1969; Fukada, 1968; Marrinan and Mann, 1956; Rak, 1964; Schuerch, 1964; Wellard, 1954). It was often compared with the interaction of water with wood substance. Marrinan and Mann (1956) suggested that anhydrous liquid ammonia converts cellulose I (native cellulose) at about 55°C into cellulose III (ammonium cellulose) which may be reverted back to cellulose I by water at room temperature. It is generally known that the crystallographic unit of cellulose III is geometrically different from that of cellulose I. Of the reported effects of ammonia on wood, Rak (1977a) concluded that only two appeared to be closely related to spruce treatability. First, anhydrous liquid ammonia can penetrate all components of the wood substance including crystalline cellulose, in the better and faster absorption of aqueous ammonia than of water by spruce sapwood. Secondly, ammonia changes the microstructure, reducing the cell wall dimensions and forming a new system of capillaries made up of intertracheal separations in the compound middle lamella of cell walls and also separations between ray cells and longitudinal tracheids. The other properties of ammonia and its effects on wood, such as its plasticizing effect, chemical changes in hemicelluloses affecting the fiber saturation point, sorption and equilibrium moisture content, and densification of wood, are rather related to the properties of treated wood itself (Rak, 1977a). However, it is believed that they illustrate the nature of the treatment with ammoniacal solutions.

Since the structure of wood is obviously a very important factor in its impregnation with preservative, it would seem that its relationship to wood preservation would have been investigated very intensively. However, this is not the case. The literature contains many more references to specifications, practice and technique than to the critical factor of wood anatomy. In the reports on the effect of wood structure, more deal with the bordered pit pairs, since these pits are the most critical, single feature influencing liquid movement in the relatively simple organization of tissues in coniferous woods. Spruce is particularly difficult to treat with waterborne preservatives if the moisture content in the wood is allowed to fall below the fiber saturation point. Under these conditions, it is generally known that continuity of the capillary system is impaired by aspirated tori in bordered pits, and the secondary wall of tracheids has rather higher affinity to hydrophobic liquids than to the water (Rak and Clarke, 1975). Thus it is possible that the anatomical features of spruce, forming the pathways by which a chemical penetrates radially in the sapwood, contain constrictions which cause premature precipitation of the preservative, resulting in an enhanced chemical retention and less chemical penetration. Using a scanning electron microscope coupled to an X-ray energy analyzer, however, Ruddick (1978) failed to locate any consistent high concentrations of copper arsenate in a regular pattern which would have confirmed this hypothesis. Gross cellular inclusions, in the form of crystalline deposits of copper arsenate , were located in several vertical epithelial cells of samples of the ACA-treated spruce, although the adjoining longitudinal resin canals were devoid of copper arsenate. However, the neighboring horizontal resin canals and associated epithelial cells contained no large deposits. Thus he concluded that it is not possible to interpret the poor retention as being mainly due to a blockage of the pathways by which the preservative permeates the wood.

As mentioned earlier, the empty-cell process is known to produce an enhanced chemical penetration and less retention. While there may be other possible interpretations, at the present time high moisture content appears to be the most plausible explanation for the observations of ACA-treated spruce material with satisfactory penetrations but low retentions.

Rak (1977a) has suggested that the initial moisture content of spruce roundwood affects the gross absorptions and depth of penetration of ammoniacal solutions, in that increasing the moisture expedites the spread of preservative and results in deeper chemical penetration while decreasing the chemical retention. Indeed Krzyzewski (1978) reported that in his study of the treatment of white spruce poles with ammoniacal salt preservative, high retentions were obtained at low moisture content (20 to 30%) while deep penetrations were secured at high moisture content (above 75%). These general observations correlate closely with those reported by other investigators (Coetzee and Laar, 1976; Gohre, 1958; Ruddick, 1978), in that an increase in moisture content causes a reduction in chemical retention. This may easily be accounted for by the diluting influence of the water already present in the wood. On the other hand, the chemical would be able to diffuse readily from the preservative solution to the water present in the cell lumens, resulting in better penetration at high moisture content. Indeed Ruddick (1978) has used moisture variation present inside the poles to explain the results from his spruce pole study. The short air-drying period of about five months, while allowing the outer sapwood to dry to less than 25% moisture content, would have a smaller effect on the moisture level of both the transition zone and the heartwood, which were indeed in excess of 30% moisture content for 86% of all pole tests.

The effectiveness of a wood-preservative treatment may also depend on the uniform distribution of all chemical components, particularly in waterborne preservative systems. Good performance of the salt treatments is partially attributed to the fact that they are absorbed into the cell wall and uniformly distributed in the wood. Very recently, however, Ruddick and his co-workers (1981, 1984a) have reported a disproportionate uptake of chemical components, such as copper and arsenic, in ACA-treated woods. This can be explained as being due to the adaptability of these components to the fixation process. The importance of these observations lies in the fact that the arsenic content in the wood should not be allowed to fall to unacceptably low levels (Ruddick, 1984a) which might permit decay by any copper-tolerant fungi such as Phialophora spp.

Although spruce can be treated with preservative to satisfactory levels by using aqueous ammonia solutions, studies of pressure treatments of spruce roundwood have showed an influence of initial moisture content on preservative penetration and retention. With the observations of excellent penetrations but low retentions, this is a fundamental, first-order problem to overcome. It should be also noted that beyond the question of treatability to conventional levels of penetration and retention is the question of service life, since the principal factor involved in deciding the longevity of service life of a pole is the degree and severity of checking in service.

2.6 BIODETERIORATION OF CHEMICALLY TREATED WOOD

Various species of wood have certain unique characteristics that allow one species to be differenciated from another, and the same is true of an abundance of microorganisms which inhabit and degrade both untreated and preservative-treated wood. Microscopical patterns of such degradation are a resultant of the combination of these two participating components, as well as the effectiveness of preservative systems in the treated wood products.

Differences in decay susceptibility between untreated and chemically treated wood have long been studied. In addition to substandard treatment of wood, however, it has been recognized that there are the two other basic reasons for the premature failure of chemically treated wood, namely detoxification or removal of preservative chemicals by wood-inhabiting and wood-destroying microorganisms, and preservative tolerance by certain fungi.

2.6.1 DETOXIFICATION OR REMOVAL OF PRESERVATIVE CHEMICALS BY MICROORGANISMS

Laboratory tests have shown that *Fusarium* sp. is able to break down the dinitrophenol component of FCAP preservative, allowing treated wood to be attacked by non-tolerant fungi such as *Coprinus* sp. (Madhosingh, 1961a and b). Drisko and O'Niell (1966) reported that some microorganisms found on creosoted piles metabolized naphthalene, phenanthrene and neutral fractions of creosote. Losses of arsenic from FCAP-treated wood and of PCP have been noted when the treated wood was exposed to non-wood-destroying fungi (Duncan and Deverall, 1964). Similar results have been obtained on exposure of PCP-treated wood to *Trichoderma viride* (Unligil, 1972b).

Numerous laboratory tests have also shown the effects of wood-destroying fungi on preservatives. DaCosta and Osborne (1968) reported that *Lenzites* sp. affected the water solubility and/or toxicity of CCA preservative in treated wood without causing any decay. Coniophora sp. caused considerable loss of PCP from pine blocks treated with subtoxic amounts of the preservative (Unligil, 1968). It has been reported by Levi (1976) that several wood-decaying fungi such as Poria spp. solubilized and absorbed copper, chromium and arsenic components from the wood treated with CCA preservative, suggesting that the presence of even small amounts of mycelium in wood may result in the solubilization of CCA components.

Bacteria have long been known to be associated with wood in service (Levy, 1975; Smith, 1975). In recent years several researchers (Drysdale and Hedley, 1984; Leightley, 1982; Nilsson, 1982) have intensively studied the effect of bacteria on treated wood products such as posts and poles, and as the third major type of decay, bacterial degrade has been frequently observed in such products. It is believed that the colonization by bacteria in association with fungi is the initial part of the process of decay, and this initial colonization of wood by bacteria is established partly by random action on the surface zones of the samples, but mostly by invasion through the ray parenchyma cells (Liese and Greaves, 1975). Detailed discussions on bacterial degrade have been offered in several works (Drysdale and Hedley, 1984;

Leightley, 1982; Nilsson and Holt, 1983; Schmidt and Liese, 1982).

In the absence of good preservation practice, there can be little doubt that the major cause of wood degradation in service is due to organisms. Even where biodegradation is adequately controlled by the careful application of known wood preservation technology, it is now recognized that other forms of degradation may play a significant role in damaging wood in service. In very recent studies (Banks and Evans, 1984; Carey, 1982; Voulgaridis and Banks, 1981), it has been observed that surface layers of wood were degraded by the action of water. As Carey (1982) points out, the increased moisture contents may play another role in encouraging subsequent colonization by wood destroying organisms.

Despite these numerous studies, very limited data is available on the practical significance of such observations. In fact, the relevance of some of the laboratory results to the field situation has been questioned (Leutritz, 1965). Field evaluations of preservative performance, particularly in utility poles, have been concerned solely with the length of time the treated material remains serviceable. A number of studies (Duncan and Lombard, 1965; Eslyn, 1970; Zabel _et al._, 1980 and 1982) have simply examined the fungi associated with decay in such treated poles. It is now recognized that field tests of wood preservatives should determine not only the performance life of treated wood products but also the fate of the preservative in the wood. The identity and the effects of organisms colonizing wood, both untreated and treated, have also been the vital subject of many investigations (Clubbe and Levy, 1982). Effective studies of field performance should incorporate all the elements, i.e. service life, attacking organisms and biodegradation of preservatives. In this way, it would be possible to determine the importance of detoxification or removal of preservative and thus predict more accurately the performance of the preservative system.

2.6.2 PRESERVATIVE TOLERANCE BY WOOD_DECAYING FUNGI

In the same manner as fungi exert selective influences on various types of media, i.e. acidified, benomyl and/or tetracycline, or phenol-added malt agar, due to their tolerance to such substances (Clubbe and Levy, 1977; Hale and Savory, 1976; Hunt and Cobb, 1971; Smith, 1983), service experience and laboratory tests have shown that preservative tolerance varies with fungal species and strain. It has also been found that within-species differences are often greater than between-species differences (Levi, 1973). The frequency with which tolerant fungi occur in the field, and the economic feasibility of impregnating sufficient preservative into wood to protect against tolerant fungi may determine the likelihood of fungal decay of chemically treated wood.

It has been thought that soft rot fungi may be the ultimate cause of failure of preservative-treated softwoods (Hulme and Butcher, 1977a and b; Smith, 1977). Certainly many species have the ability to tolerate quite high levels of commonly used wood preservatives, which results in premature failure of treated wood products in service (Dale, 1976). The dominant soft rot fungi belong to the genus Phialophora. Members of this genus have shown very active soft rot ability (Nilsson, 1973) and prominent tolerances to copper (Leightley, 1979 and 1980; Nilsson and Henningsson, 1978). Very recently, Leightley and his co-workers (Francis and Leightley, 1983; Leightley and Armstrong, 1980) reported that transmission electron microscopy of the copper-tolerant Phialophora species revealed a distinctive extracellular layer around hyphae. The presence of extracellular polysaccharides on the hyphae of wood decay fungi suggests some physiological role. As Green (1980) suggested, it is believed that these layers act as matrices for hyphal substrate contact and subsequent enzymic activity.

Some of the Basidiomycetes, true wood-destroying fungi, have also shown high tolerance to certain preservatives. For example, Lentinus lepideus is known to be tolerant to creosote and the fungus is widespread in nature. Thus it is necessary to treat wood products, such as railroad ties and utility poles, treated with sufficient creosote to control this fungal species, even though considerably smaller quantities would control other wood-destroying fungi. Duncan and Lombard (1965) reported that failure to do this had led to premature failure to many creosote-treated ties and poles. It has also been known that some Poria spp. are highly tolerant to CCA preservative (DaCosta and Kerruish, 1964; Levi, 1975). Using electron microscopy, Levi (1975) found that copper, chromium and arsenic in CCA-treated pine wood were absorbed from the S2 layers of tracheids in and/or onto the hyphae of P. monticola, but the concentration of these three components varied greatly from hypha to hypha. He explained that this variation may have been due to differences in the binding capacities of the various cell sites for copper, chromium and arsenic.

It is generally known that laboratory tests are essential to avoid the problem of decay susceptibility of chemically treated wood in service by tolerant fungi (Unligil, 1972b). Laboratory tolerance tests are not always feasible. Therefore, field tests on preservatives should identify tolerant decay fungi so that laboratory test data can be related to service experience.

2.7 NITROGEN ENHANCEMENT DUE TO ACA TREATMENT

Nitrogen is present in wood in relatively small amounts, comprising more than about 0.03% but usually less than 0.1% of the dry weight of wood (Allison et al., 1963; Cowling, 1970; Heck, 1929; Merrill and Cowling, 1966; Rennie, 1965; Young and Guinn, 1966). Little is known concerning the nitrogenous materials in wood, largely because the small amounts present are commercially unimportant. But to wood-inhabiting microorganisms and insects that derive their nourishment primarily from the wood itself, these small amounts of nitrogen are of paramount importance. Numerous researchers (Cowling, 1970; Cowling and Merrill, 1966; Findlay, 1934; Henningsson, 1976; King et al., 1980; Merrill and Cowling, 1965 and 1966) have shown that the rate of decay of wood by fungi is related directly to its nitrogen content.

As mentioned previously, it is generally assumed that, during the fixation of the ammonia-based wood preservative, the ammonia is lost from the wood. However, this has not been verified yet. Therefore, the question of whether loss of ammonia from the ACA-treated wood is complete or not, could well prove important, particularly when inadequate treatment of difficult-to-treat and non-durable woods, such as spruce, is encountered.

Very little work has been conducted on the nitrogen enhancement of ACA-treated wood. Based on the method developed by Rennie (1955), Ruddick (1979) determined the nitrogen content of wood with ACA treatment, using an Orion Microprocessor ionalyser, as described in the Orion operating manuals (1977 and 1978). In his study of the nitrogen content of ACA-treated wood, the enhancement of nitrogen was easily detectable after nine months of storage of treated ponderosa pine (Pinus ponderosa Laws.) sapwood stakes indoors, and after two years of storage outdoors of discs cut from treated spruce pole material. However, the nitrogen content of the spruce samples was much less (< 50%) than that of the pine stakes, possibly indicating loss of chemical due to leaching. From the spruce samples, he concluded that the ammonia penetration was significantly greater than that of the preservative solution in some of the wood where no copper or arsenic could be detected.

There are also indications from the ACA pressure treatment of certain wood species, which darken in colour during treatment, that the ammonia may penetrate farther into the wood than the preservative. For example, when Douglas-fir wood is pressure-treated with ACA, it darkens in colour. The cause of this darkening is presumably related to the use of ammonium hydroxide in the preservative, since the treatment with other waterborne preservatives (e.g. CCA) which also contain copper and arsenic does not give this reaction.

Because ammonia is readily liberated from ammonium hydroxide. Ruddick (1979) has suggested that, during the pressure treatment of wood with ACA, the ammonia penetrates the wood cells prior to the preservative solution. Indeed Rak (1977a) has used this fact to explain the improved permeability of spruce to ACA compared with CCA. It has been also suggested by Ruddick (1979) that, during the fixation process, some of the ammonia diffuses further into the wood. Based on these two suggestions, which have not been verified, he has concluded that an enhancement of the nitrogen level could result in non-preservative-treated wood.

2.8 FUNGAL METABOLISM OF NITROGEN

Although the previous study (Ruddick, 1979) has proven that the wood treated with ACA preservative is enhanced in its nitrogen level, it is still questionable in which chemical form this enhanced nitrogen is present in the wood, and also whether fungi are capable of metabolizing this source of nitrogen to promote their growth. Increasing the nitrogen content of wood frequently increases the rate of decay by wood-destroying fungi. However, there is conflicting evidence as to whether decay can be increased appriciably by artificially adding nitrogen to wood. To date, little or no work has been performed on these questions. Nevertheless, answers may be inferred partly on the basis of more recent knowledge of fungal metabolism of nitrogen, derived from combined biochemical and genetical studies.

Fungal nitrogen sources are quite varied and may be organic or inorganic in nature. In the same manner as the degree of specialization depends partly on whether the fungus possesses enzymes to degrade insoluble carbon sources (e.g. starch, cellulose, lignin), or whether it can utilize only soluble carbon compounds, the nitrogen can exert a selective influence. For example, the ability to assimilate nitrate confers a higher degree of nutritional independence (autotropy) than does the need for ammonia or ammonia-compounds, and an even stronger dependence (heterotropy) exists when specific nitrogen compounds, i.e. a particular amino acid, are required (Müller and Loeffler, 1976). In general, not all fungi use nitrogen sources with equal facility, and a fungus may have a requirement for nitrogen in a specific form. Fungi may utilize inorganic nitrogen in the form of nitrates, nitrites or ammonia, or organic nitrogen in the form of amino acids. A few fungi may be able to obtain nitrogen via the direct utilization of molecular nitrogen (Smith, 1970). However, It is questionable whether the fixation of atmospheric nitrogen, which is so well-known among bacteria (Seidler *et al.*, 1972), occurs with fungi. Interestingly, Henningson and Nilsson (1976) reported that nitrogen compounds had migrated to treated transmission poles from surrounding soil. Having shown that during drying of wood, soluble nitrogenous and carbohydrate materials accumulate at evaporative faces of wood. King and his co-workers (1974, 1976, 1979 and 1980) also showed that such soluble materials not only enhanced decay rate of wood in soil by soft rot, but stimulated considerable movement of nitrogen to wood which was attributed to microbial biomass.

Most fungi can use nitrates as a sole or significant source of nitrogen, but as Moore-Landecker (1972) points out, inabilities to utilize nitrates are common among the higher Basidiomycetes to which most wood-decaying fungi belong. As presented in Table 10, it has been postulated by several researchers (Nason, 1962; Nason and Takahashi, 1958; Nicholas, 1963) that nitrate is reduced *via* nitrite and hydroxylamine to ammonia in a series of steps which are essentially electron transfer reactions. The enzymes involved contain a number of cofactors and metals, and utilize NADH or NADPH (see Table 10) as a hydrogen donor. There is still some doubt about the possible existence of an organic reductive route from

TABLE 10. Summary of Nitrate Reduction (Nason, 1962; Nason and Takahashi, 1958; Nicholas, 1963).

Possible pathway	Oxidation/ reduction state of N	Hydrogen donor	Co-factors	Enzyme
NO_3^-	+5	NADH[1] or NADPH[2]	FAD[3] Fe Mo	Nitrate reductase
↓ +2e				
NO_2^-	+3	NADH or NADPH	FAD Cu Fe	Nitrite reductase
↓ +2e				
(HNO) nitroxyl group or (N_2O) nitrous oxide group or NO_2NH_2 nitramide or $H_2N_2O_2$ hyponitrous acid	+1			Hypo-nitrite reductase
↓ +2e				
NH_2OH hydroxylamine	-1	NADH or NADPH	FAD Mg Mn	Hydroxyl-amine reductase
↓				
NH_3				

[1] Reduced nicotinamide adenine dinucleotide

[2] Reduced nicotinamide adenine dinucleotide phosphate

[3] Flavin adenine dinucleotide

nitrite to ammonia, but it is generally accepted that the inorganic reductive pathway is the important one in fungi (Pateman and Kinghorn, 1976). From the equation shown in Table 10, it is probable that one or more intermediate compounds are formed between nitrite and hydroxylamine at the +1 oxidation state for the nitrogen atom. The nature of the postulated intermediates is uncertain; nitroxyl, hyponitrite (N_2O_2), nitrogen dioxide (NO_2) and nitrous oxide have all been considered as possibilities (Nason, 1962; Nicholas, 1963; Pateman and Kinghorn, 1976). The nitrate ion may be incorporated into the wood cells as ammonium, potassium, or calcium nitrate (Cochrane, 1958), and then must be reduced to the oxidation level of ammonia before the nitrogen can be assimilated into organic compounds.

Nitrite is formed from nitrate, and thus in one sense is utilized by all fungi which can use nitrate. Although nitrite is known to be toxic to many fungi and bacteria, it can be used as a nitrogen source by some fungi, i.e. *Aspergillus* spp., *Fusarium* sp. *Neurospora* spp. *Penicillium* spp. and *Ustilago* sp. (Pateman and Kinghorn, 1976). On the other hand, as with nitrate, it is likely that the great majority of fungi can use ammonia as a sole nitrogen source. This has been observed in numerous fungi, such as *Alternaria* sp., *Aspergillus* spp., *Botrytis* sp., *Cladosporium* sp., Coprinus sp., Diplodia sp., Mucor sp., Neurospora spp., Penicillium spp. and Ustilago sp. (Lewis and Fincham, 1970; Morton and Macmillan, 1954; Pateman et al., 1967). It is generally recognized that the form in which the ammonia is supplied is important. The fungi may use nitrogen in the form of ammonium ion (NH_4^+) which can be supplied as ammonium hydroxide or ammonium salts. Although the fungi are capable of metabolizing both nitrate or nitrite and ammonium ion, ammonium ion is known to be preferred because it requires less energy expenditure by the fungus to use this reduced form of nitrogen.

It is interesting to note that some nitrogen sources function as a toxic substance in the form of ammonium hydroxide solution. Because treating wood with alkali (e.g. NaOH and NH_4OH) increases decay resistance in both the laboratory and the field (Amburgey and Johnson, 1978; Baechler, 1959; Highley, 1970 and 1973), alkali treatments have been proposed as an alternative method of wood protection. It has been assumed that the alkali treatment may destroy thiamine (Dwivedi and Arnold, 1973), which is essential for treatment may also increase decay resistance in wood by reducing the availability of other micronutrients essential for fungal growth (Baechler, 1959), or by increasing the pH or ammoniacal nitrogen content (Highley, 1973). If ammonium salts, i.e. ammonium nitrate, are favoured over ammonium hydroxide, as Moore-Landecker (1972) points out, these salts are utilized poorly or possibly not at all by some fungi (e.g. the Blastocladiales, Saprolegniaceae, yeasts, and the higher Basidiomycetes). It was shown by Morton and MacMillan (1954) that this inability is due to the pH effect in the medium. When these salts were used, they found that the pH of the medium rapidly dropped due to the preferential use of ammonium ion which occurs in many fungi, and consequently fungal growth was retarded.

Although much is known about the physiology of wood-inhabiting microorganisms, many areas in the fundamentals of their nitrogen metabolism remain to be questionable. The previous study (Ruddick, 1979) has proven that the treatment of wood with ACA increases its nitrogen content. However, comparatively little is known about the effect of treatment with ammoniacal wood preservatives on the capability of metabolizing enhanced nitrogenous materials to promote fungal growth. Therefore, more extensive and precise information is needed about the nature of fungal nitrogen metabolism in the wood treated with ammoniacal preservatives, under various laboratory and field tests.

2.9 FUNCTION OF THE SHIGOMETER IN RELATION TO ELECTRICAL PROPERTIES OF INFECTED WOOD

The electrical properties of wood are measured by its resistivity or specific resistance or by its reciprocal conductivity. The conductivity of a material determines the current that will flow when the material is placed under a given voltage gradient. Very dry wood is an excellent electrical insulator, with direct-current resistivity in the order of 3×10^{17} to 3×10^{18} ohm-centimeters at room temperature (Bannan, 1967). It is generally known that the electrical resistance of wood is lowered by increasing moisture content. Especially below the fiber saturation point, the direct-current electrical resistance of wood decrease rapidly as the moisture content increases. Even traces of water increase the conductivity considerably. The mechanism of electrical conduction depends on the presence of ions in the wood. A model for ionic conduction was proposed by Lin (1965) to explain the electrical conduction through the cell wall of wood. He pointed out that the number of charges-carriers in wood is the major factor affecting the conduction mechanism over the moisture content range from 0 to 20%. At higher moisture contents, the degree of dissociation of absorbed ions is sufficiently high so that the mobility of ions may become the major factor in determining the electrical conductivity. Therefore, any change in ion concentration, distribution, or both, will also change the electrical conductivity of the wood.

Research on the electrical properties of wood (Brown *et al.*, 1963; Lin, 1965 and 1967; Skaar, 1964), and of trees (Fensom, 1959, 1960 and 1963; Levengood, 1970) provided the basic information for the development of a number of relatively new techniques to detect the internal condition, *i.e.* heartrot, of living trees (McGinnes and Shigo, 1975; Shigo and Berry, 1975; Tattar, 1974; Tattar *et al.*, 1972 and 1974; Tattar and Saufley, 1973). One such technique involves the measurement of the electrical resistance of wood to a pulsed current. The original equipment described by Skutt *et al.* (1972) has been refined substantially. After further development of the meter and the electrodes, the Shigometer (registered trade mark Northeast Electronics Corporation) Model 7950 (Fig.2), described by Shigo and Shigo (1974) and Shigo *et al.* (1977), has been widely investigated for use in utility poles (Brudermann, 1977; Inwards and Graham, 1980; Morris *et al.*, 1984; Perrin, 1978 and 1979; Shortle *et al.*, 1978).

The Shigometer is a meter which measures changes in the condition of the wood, associated with a change in electrical resistance. The method involves the insertion of a twisted

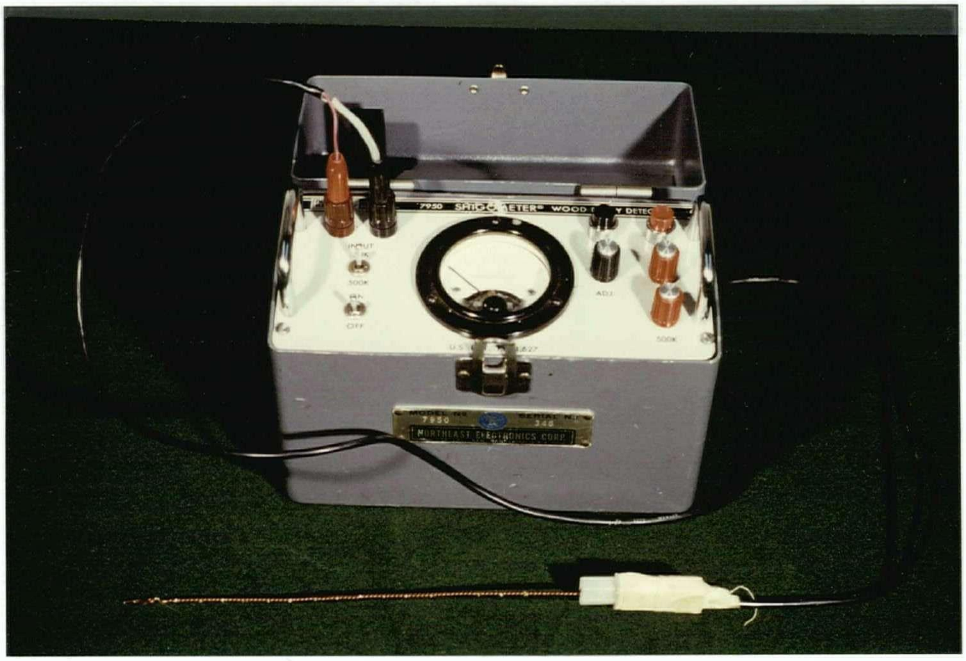

Figure 2. Battery-powered pulsed-current meter, Shigometer Model 7950, and twisted wire probe.

wire probe with bared kinks at the tips into a radially drilled hole. The degree of resistance to a pulsed electric current is closely governed by the concentration of cations, particularly in many deciduous woods (Safford *et al.*, 1974; Shigo and Sharon, 1970; Shigo and Shigo, 1974; Shortle and Shigo, 1973; Tattar *et al.*, 1972). As wood discolors and decays, the cations (primarily potassium, calcium, manganese, and magnesium) increase and resistance decreases. McGinnes and Shigo (1975) stated more specifically that the Shigometer measures mobile ion concentration within the tree. Tattar and his co-workers (1972 and 1974) have recognized that interpretation of Shigometer resistance involves many other factors such as concentration of hydrogen ions (pH), moisture content, specific gravity, and wood structure. In agreement with their studies, Wilkes and Heather (1982a) found that there was a relatively weak correlation of pulse resistance with pH and with moisture content above the fiber saturation point for several hardwood species. However, it has been reported that the weak positive correlation with moisture content is apparently not consistent among species, since a negative correlation was observed for *Abies* and *Sequoia* (Piirto and Wilcox, 1978) and for *Pinus* and *Dyera* spp. (Thornton, 1979a and b). The effects of density and wood structure on pulse resistance have been discussed elsewhere (Skutt *et al.*, 1972;

Wilkes and Heather, 1982a and b), suggesting that above the fiber saturation point, an increase in density could be expected to result in a decrease in conductivity. Shigometer resistance may also vary with cell wall resistivity, drill hole characteristics, probe geometry, and some aspects of measurement procedure such as the pressure, surface area, and quality of electrode contact (Wilson et al., 1982).

Shigo and his co-workers (McGinnes and Shigo, 1975; Shigo and Berry, 1975; Shigo and Shigo, 1974) have stressed the importance of patterns of resistance rather than absolute values for predictive purposes. It has been emphasized by Shortle et al.(1978) that the pattern of readings at intervals along one hole and not individual readings should be taken to indicate the condition of the wood, with a drop of 75% in the reading indicating decay. Readings of over 500 KΩ were taken as 500 KΩ because the original analogue displays were pegged at 500 KΩ. They also stated that where the highest reading was over 500 KΩ, a reading of less than 250 KΩ would indicate decay. However, the Shigometer manual (Osmose Wood Preserving Co., 1980) only states the first (75% drop) of these two criteria for predicting decay.

Since the introduction of the Shigometer, a number of investigators (Brudermann, 1977; Inwards and Graham, 1980; McGinnes and Shigo, 1975; Morris et al., 1984; Perrin, 1978 and 1979; Piirto and Wilcox, 1978; Shigo and Berry, 1975; Shortle, 1982; Shortle et al., 1978; Thornton, 1979a and b; Thornton et al., 1981; Wilkes and Heather, 1982a and b; Wilson et al., 1982; Zabel et al., 1982) have critically examined this instrument as a decay-detecting devise. Not all of them adhered to the principles of two criteria given above, for predicting decay. The literature contains conflicting views as to the effectiveness of the Shigometer for detecting discoloration and decay in both standing trees and converted timber.

McGinnes and Shigo (1975) claimed that the technique is capable of detecting ring shake and discoloured heartwood in black walnut (*Juglans nigra* L.). Shigo and Berry (1975) concluded that the Shigometer detects decay in *Pinus resinosa* Ait. Shortle et al.(1978) reportedly worked out predictive criteria which indicated internal in telegraph poles with 93% accuracy. In agreement with their study, it has been shown by Inwards and Graham (1980) that the Shigometer could detect the condition of pole interiors at a reliability of 76% compared to increment borings. Recently Thornton et al. (1981) and Zabel et al.(1982) also placed a certain amount of confidence in Shigometer methods for detection of internal decay in poles, but not for soft rot. Despite these positive responses, further assessments of the Shigometer in both living trees (Piirto and Wilcox, 1978; Thornton, 1979a and b; Wilkes and Heather, 1982; Wilson _et al._, 1982) and converted timber (Brudermann, 1977; Morris _et al._, 1984; Perrin, 1978 and 1979) have all been critical. Piirto and Wilcox (1978) reported low readings in both sound and decayed heartwood of _Sequoia gigantea_ Lindl. with great variability, especially in sound wood. From soil-block tests with white- and brown-rot fungi on hardwoods and softwoods, Thornton (1979a and b) concluded that the Shigometer detected the presence but not the severity of decay. As a tool for identifying stain and early decay in utility poles, it has been reported by Brudermann (1977) and Perrin (1978 and 1979) that the results of Shigometer measurements are not consistent enough to judge conclusively the effectiveness of this instrument. More recently several researchers (Morris _et al._, 1984; Shortle, 1982; Wilkes and Heather, 1982a; Wilson _et al._, 1982) have also demonstrated no predictive ability for patterns of resistance, and suggested that the previously published evidence should be regarded as inconclusive. They all found great natural variation in electrical resistance without decay, thus suggesting that the method is unreliable.

In a very recent study of the effect of moisture content on electrical resistance, Morris and his co-workers (1984) have concluded that there is a large difference between the reading of timbers below 38% and above 45% moisture content. These observations correlate closely with those reported by Piirto and Wilcox (1978), and Thornton (1979a and b), in that moisture content alone could result in a marked lowering of resistance. However, some groups of investigators (Inwards and Graham, 1980; Shortle, 1982) have repeatedly asserted that variations in moisture content above the fiber saturation point do not affect the electrical resistance.

Another interesting area of concern with regard to the effectiveness of the meter for wood in service is the possible effect of the presence of ionized material in the wood on variability in meter readings. Although the Shigometer has been shown to be effective in detecting decay in creosote-treated utility poles (Shigo and Shigo, 1974), it is expected that inorganic materials present in wood treated with fire retardants or waterborne preservative salts could substantially affect resistance readings in the same manner as the increasing ash content of decaying wood appears to affect the readings. In this regard, where very little work has been done, James (1965) reported that water-soluble, salt-type wood preservatives had a substantial effect on the accuracy of electric moisture meters.

3.0 MATERIALS AND METHODS

3.1 MATERIALS

Twelve kerfed and twelve unkerfed ACA-treated poles were selected from those installed at Westham Island field test site in 1977. Based on retention data obtained on each pole prior to installation, these kerfed and unkerfed poles were categorized into four equal groups: retention greater than or equal to 0.60 lb/ft^3 (9.6 kg/m^3); greater than or equal to 0.45 (7.2) and less than 0.60 (9.6); greater than or equal to 0.30 (4.8) and less than 0.45 (7.2); and retention less than 0.30 (4.8). In the selection of each pole, relatively uniform penetration was considered based upon the data available.

3.2 METHODS

3.2.1 SAMPLING METHODS

3.2.1.1 BIOASSAY

The soil around the pole was excavated to facilitate groundline inspection and core sampling. The pole surfaces were examined and probed around the groundline zone. Observations were recorded on the external wood condition, such as major checks, their width and depth, any detectable decay pockets,etc.

Three increment cores, approximately 5 mm in diameter, were removed from the pole in the region of the groundline for biological investigation. The first cores were sampled at about 3.0 cm away from the largest major check developed in non-kerfed poles, or from the kerf of kerfed poles. The second and third cores were taken at positions of 120^{o} and 240^{o} clockwise apart from the first, respectively (Figure 3). The cores extended from the surface of the pole to the pith.

The core borer and extractor were dipped in 70% alcohol, flamed and allowed to cool down. Using flamed forceps, each sampled core was immediately put into a sterlized glass tube with cork caps at both ends (Figures 4a and b). The tube was then wrapped tightly in a plastic bag and kept out of direct sunlight. When sampling was completed, the drilled holes were filled with copper naphthenate preservative, and then sealed with treated plugs to prevent subsequent infection.

After returning to the laboratory, the cores were stored in a cool chamber. Isolations were made within 24 hours of sampling. The details of subdivision for isolation are given in Section 3,2.3.1. Sampling and examination of removed cores for fungal attack were carried out in parallel in order to prevent contamination of the cores.

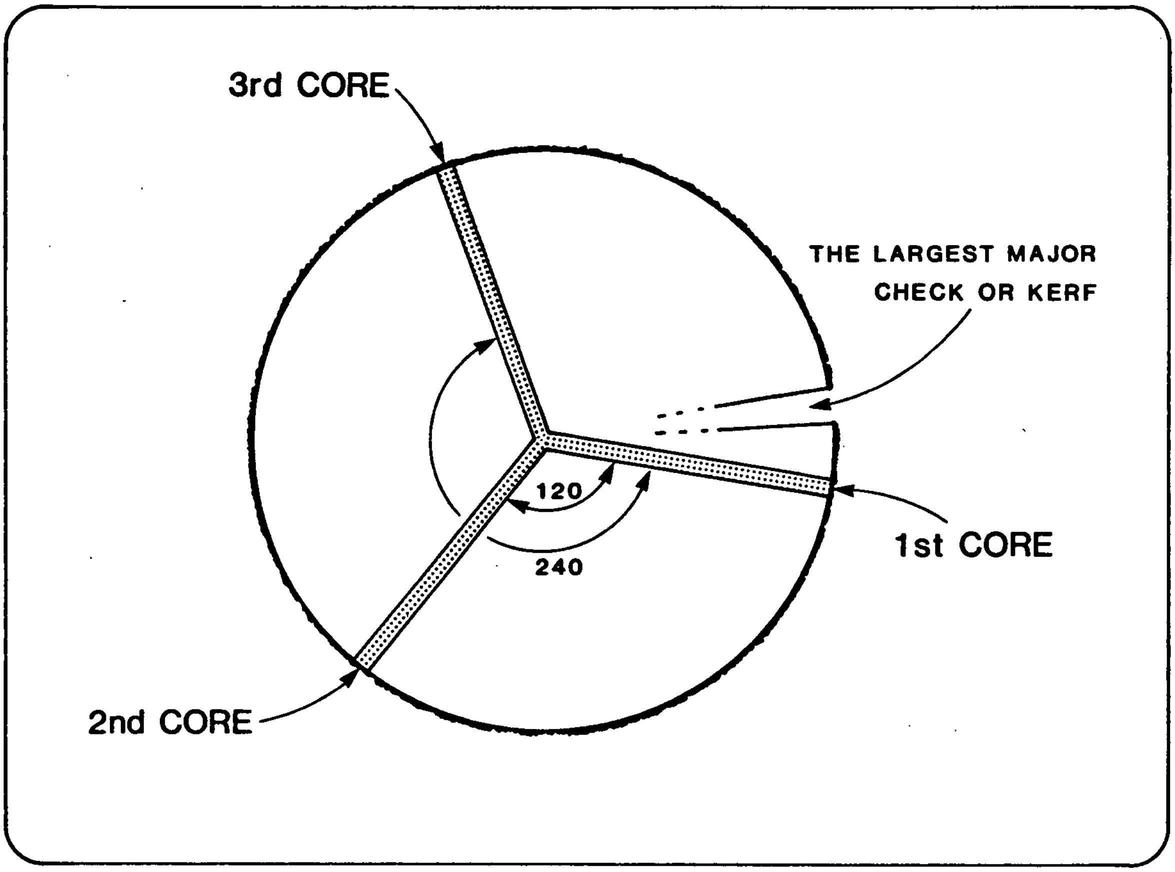

Figure 3. Cross-sectional view of the pole at the groundline, showing the position of three biological cores.

Figure 4a. Using flamed forceps, sampled core is inserted in a sterilized glass tube.

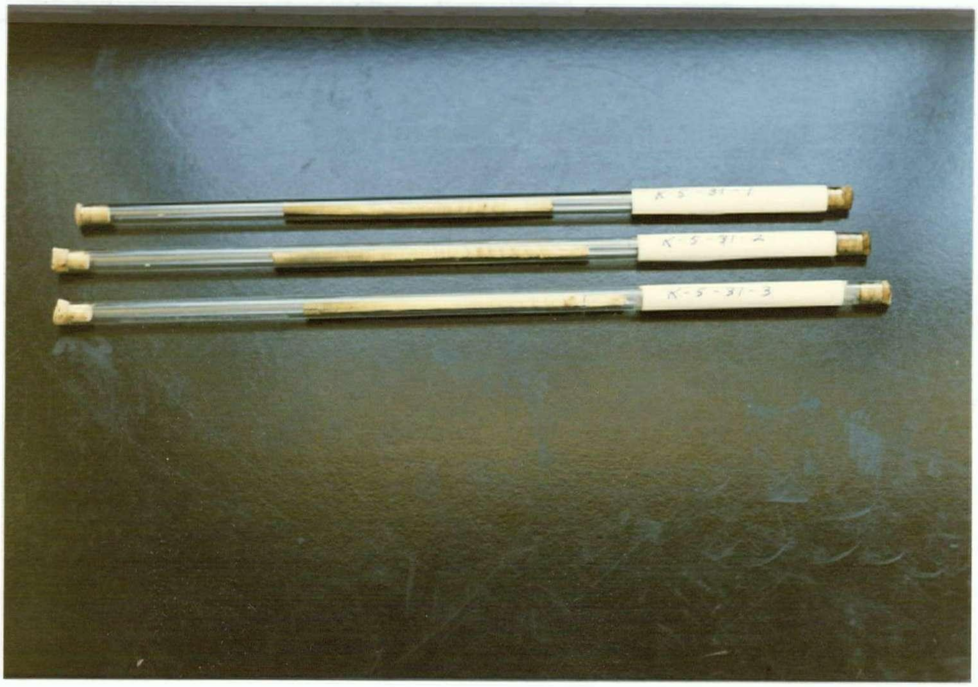

Figure 4b. Sample cores in the sterilized glass tubes with cork caps at both ends.

3.2.1.2 CHEMICAL ASSAY AND NITROGEN

Following the removal of cores for the biological investigation, a second set of cores, each approximately 1.3 cm in diameter was removed adjacent to the site of the second biological core from each of the selected poles (Figure 5), for determination of the ACA preservative retention and penetration, and also for measurement of the nitrogen content. The core extended from the surface of the pole to the pith.

The sampled core was cut into four equal pieces for determination of the moisture content of the pole, and each piece was stored in a glass tube with rubber cap (Figure 6) and returned to the laboratory where it was weighed and oven-dried at 103 $\pm$ 2^{o} for 24 hours. After weighing the oven-dried sample, each piece was sealed within a plastic bag and stored under refrigeration for later determination of the retention and penetration, and for measurement of the nitrogen content.

Upon completion of the core sampling, all holes were injected with copper naphthenate, and carefully sealed with a treated plug to prevent subsequent infection of the pole.

3.2.1.3 SHIGOMETER

The experimental work for the evaluation of the Shigo-

Figure 5. Sampling of cores for the study of chemical distribution and nitrogen content.

Figure 6. Storing a piece of the core for moisture measurement.

meter was conducted using the same poles as those studied during the fungal isolation and chemical assay.

After the initial fungal isolation had been completed, each of the poles was examined using the Shigometer. Based on the information obtained from preliminary isolation of fungi, i.e. the number of fungi present, the Shigometer readings were made near the site of one of the three cores sampled for biological assay.

3.2.2 ANALYSIS OF CHEMICAL PENETRATION AND RETENTION

To determine preservative penetration, the twenty-four cores collected from the poles were stained with a 0.5% solution (weight/volume) of chrome azurol S prepared according to the AWPA Standard A3-77 (AWPA, 1977), by applying a few narrow streaks along the length of each core. The ACA-treated wood stained blue due to a reaction with the copper, and the radial depth of treatment in each core was measured.

After the measurement of preservative penetration, the stained portion was removed with a sharp knife, thereby eliminating any influence from the chrome azurol S. The remainder of each core was then trimmed to length (the wood between 2 mm and 16 mm from the surface of the pole) as specified in the CSA Standard 080.4-M (CSA, 1983c) for the measurement of chemical retention. In addition, two additional portions of each core, adjacent to the first sampled and immediately beyond the treated zone, were cut to a length identical to the CSA standard. They were then ground to 20 mesh sawdust. Three-tenths gram of the ground sawdust was thoroughly mixed with 0.2 g of cellulose powder which acted as a binding agent and the mixture carefully placed in a die. The sawdust in the die was then compressed for 3 minutes at 300 MPa, to produce a pellet 19 mm in diameter and approximately 1.5 mm thick.

The pellets were analysed using a Tracor Northern energy-dispersive X-ray spectrometer with an americium-241 source, a molybdenum target and a lithium-drifted germanium detector. Each pellet was analysed on both sides to check that they were similar, as it had been observed that the cellulose powder tended to settle out in preparing the pellet. The X-ray spectrometer was controlled by an Apple III microcomputer. A computerized standard calibration graph had previously been prepared for various combinations of chromium, copper and arsenic, and included corrections due to inter-element interferences and matrix effects. The results were converted from a weight/weight basis to weight/volume basis by multiplying by a conversion factor that includes the sample specific gravity. The specific gravity determined for each pole prior to installation was taken approximately 1 m below the present sampling site. This was deemed more accurate than using a mean species specific gravity. The preservative retentions were expressed on an oxide basis, i.e. CuO and As_2O_5, from X-ray spectrometer output. Since 0.3 g of sawdust was used to make a pellet instead of the usual 0.4 g, the result was multiplied by 4/3 to obtain the actual retention.

3.2.3 MICROBIOLOGICAL STUDIES

3.2.3.1 ISOLATION PROCEDURES

The fungi responsible for decay and staining in ACA-treated western white spruce have not been previously studied. In general, it is known that fast-growing microfungi or bacteria often overgrow and obscure the decay and staining fungi. Thus a preliminary review of the literature (Clubbe and Levy, 1977; Hale and Savory, 1976; Hunt and Cobb, 1971; Smith, 1983) was done to select media favourable towards the growth and isolation of decay fungi. The two selective media chosen were:

1) malt agar acidified by the addition of 0.5% malic acid (mainly for inhibiting bacterial growth);
2) benomyl/tetracycline malt agar (for suppressing most microfungi such as *Trichoderma* and *Penicillium* spp.).

Media formulation and preparations are presented in Appendix A.

Each core provided four zones for the isolation of fungi. The zones selected for investigation were: i) the outer zone of the treated wood (defined as the wood between 2 mm and 7 mm from the surface of the pole); ii) the untreated wood immediately adjacent to the outer treated shell; iii) the heartwood region; iv) the pith. From each of these selected regions, a 5 mm-long section was taken for culturing and identification of the fungi. Before sectioning for isolation, a whole core was briefly surface-flamed, and before every cut a knife and forceps were dipped in alcohol, flamed and allowed to cool down. All materials needed to make sections, i.e., glass petri dishes, filter papers and wood cutting boards, were sterilized. After a 5 mm-long section of the treated wood was cut and placed on sterilized filter paper in a sterile glass petri dish, a small cutting from the remainder of the treated zone was made and dipped in a 0.5% solution of chrome azurol S. The penetration of the copper component of the ACA was defined by the dark blue color produced. This procedure was used to determine the limit of the ACA penetration. After the second 5 mm section was cut, the third was removed from the heartwood at the midpoint between the second and the pith, and the last section was made as near as possible to the pith. The core was cut up as shown in Figure 7.

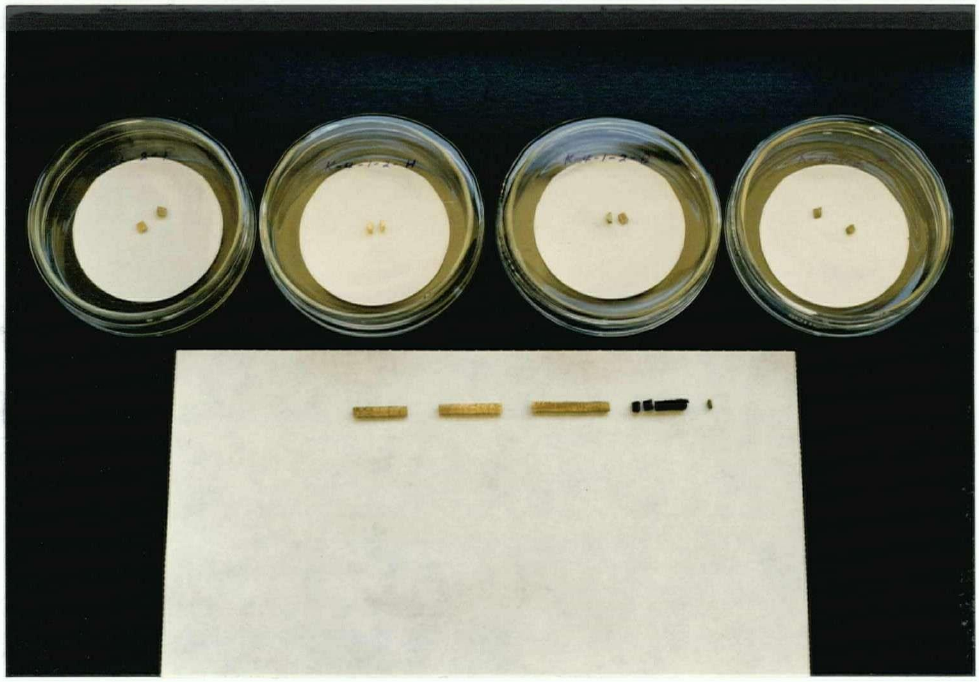

Figure 7. Sectioning procedures of a biological core, providing four zones for the isolation of fungi.

Each 5 mm section prepared for fungal isolation was then cut into four quarters. Two replications of two different media were prepared for the culturing of fungi (Figure 8). Each quarter was positioned in the medium so about 3/4 the piece was above the surface (Figure 9). A coding system was developed to relate all isolates obtained to a pole type (kerfed or non-kerfed), pole number, core location, radial position in a core, and isolate number of media.

The plates were incubated at about 22°C and monitored for several weeks. When fungal growth appeared from the wood samples, they were examined daily, both macroscopically and microscopically. Frequent subculturing onto pure malt agar plates was necessary for the isolation of a single fungus from the frequently occuring bacterial contamination or from other fungi. In some cases, as many as five fungi were obtained from the same core position. Cores from which no fungi could be isolated initially, were sometimes reisolated to confirm absence of fungal infection. The average observation period for a plate was about eight weeks. The numbers and kinds of colonies were recorded on core data sheets. Isolations of selected fungi were first made onto pure malt agar plates, and subcultured repetitively, as necessary from mycelial margins or streaking to establish pure cultures. Pure isolations of selected fungi were then

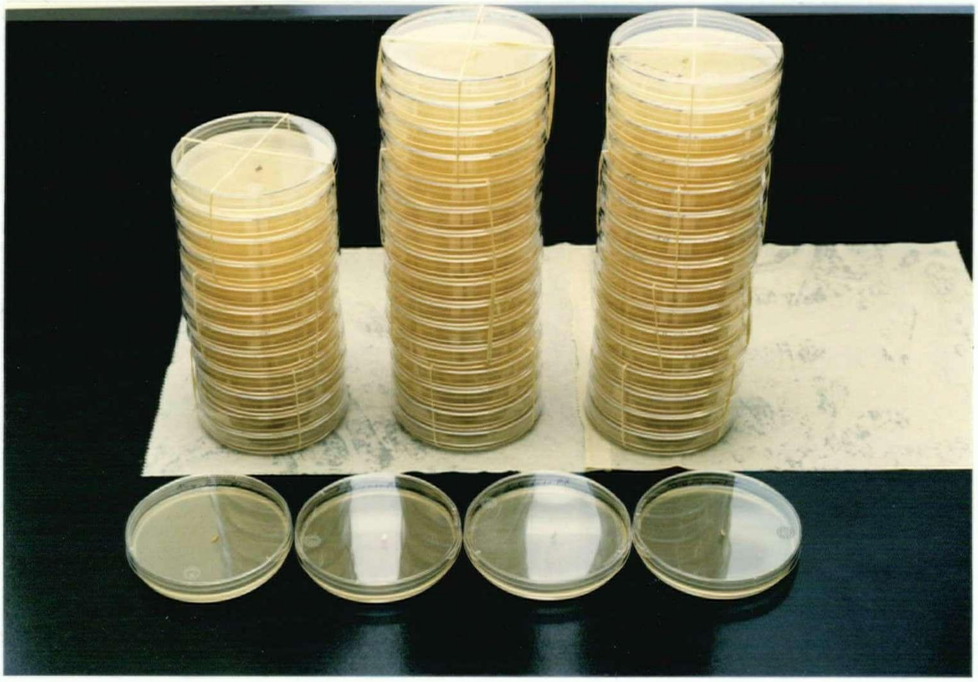

Figure 8. Two replications of two different types of media, representing each section of four selected zones.

Figure 9. Positioning about 3/4 of each piece above the medium surface.

made into malt agar test tubes and maintained in a culture bank for later identification and study.

Approximately one thousand fungi were isolated from the twenty-four poles. When the same fungus appeared in a core position on the two selective media or replicate plates, it was recorded alphabetically as one isolate (e.g. Fungus A, B, etc.). Because there was sometimes variation in the growth pattern observed on the media (e.g. *Phoma* sp.), the tentative name of the fungus was modified by a series of numbers (e.g. Fungus A1, A2, etc.). Fungi readily indentifiable from cultural and microscopic characteristics, were recorded only after several isolates had been studied and included in the culture collection.

By this method approximately ninety isolates were selected for further study as being representative of the principal fungal population inhabiting the twenty-four ACA-treated white spruce poles.

3.2.3.2 IDENTIFICATION AND GROUPING OF THE ISOLATES

Pure isolation of selected fungi were stored in a culture bank for subsequent identification and study. After several months, malt agar plates were prepared to transfer those fungi maintained in test tubes. Because of their ability to exhibit different forms on different media, all fungi were sub-cultured onto uniform medium of 1.5% malt extract, 2% agar and distilled water.

Sub-cultured petri dishes were put in plastic bags and kept at a temperature of 22^{o}C in a dark growth chamber for approximately two weeks depending on their growth rates. Heavily sporulating cultures were kept separately to avoid cross-contamination.

Macroscopic cultural and microscopic characteristics were determined for each isolate. Using dichotomous keys, some of the fungi were identified readily and the others sorted into taxa of similar unknowns. For those unknown fungi, semi-permanent microscope slides were prepared for each isolate, using lactophenol as the mounting medium.

Some isolates of the known and unknown fungi were sent to Biosystematics Research Institute of Agriculture Canada (Ottawa), Centraalbureau Voor Schimmelcultures (Baarn, Netherlands), or Commonwealth Mycological Institute (Kew, England), for confirmation or identification. The identities of the named fungi were also confirmed by Dr. E.C. Setliff of the Western Laboratory of Forintek Canada Corp. All isolates were then categorized into three major groups of pole-inhabiting fungi as follows: Basidiomycetes; soft-rot fungi; and microfungi.

3.2.4 DETERMINATION OF NITROGEN

Following analysis of a portion of the wood sawdust for chemical retention, the remainder of the treated zone near the pole surface and the untreated zone immediately adjacent to the treated shell were analyzed for their nitrogen contents. In addition, two other 1 cm portions from the heartwood and pith of each core were cut and ground to 20 mesh sawdust.

The method used was based on that described by Rennie (1965) for the determination of nitrogen in woody tissue. Approximately 300 mg of oven-dried wood, depending on the availability of sawdust sample, was weighed into a 100 ml Kjeldahl flask, followed by 40 mg of mercuric oxide and 4 g of potassium sulphate. Five ml of analytical-grade concentrated sulphuric acid was added and the mixture gently swirled.

It was then left to stand for 10 minutes prior to heating to boiling. The heating schedule depended upon the sample, but in general heating on an electric rack was maintained for a half hour after the solution was clear. Care was taken to minimize foaming during the initial heating. During heating, the flask was rotated several times to speed clearing and to wash down any particles spattered onto the side of the flask. When the heating was completed, the solution was allowed to cool slightly before transferring to a 100 ml volumetric flask. This transfer took place while the solution was still warm, because otherwise it could solidify readily. 5 ml of 2M sodium iodide solution was then added to the digestate which was finally diluted with distilled water up to 100 ml of diluted solution.

The diluted solution in a volumetric flask was placed in cool area overnight after which the nitrogen content was measured using an Orion ammonia-specific electrode (Orion 95-10) coupled to an Orion Microprocessor ionalyser 901. This instrument was operated in the analate-addition mode, as described in the Orion operating manuals (1977 and 1978) and the nitrogen concentration in percentage was read directly from the analyzer display. In summary, the method involved pipetting 1 ml of the ammonia standard into a 0.4M sodium hydroxide solution and after allowing the reading to stabilize, adding 10 ml of the diluted digestate to the solution and recording the results. Two replicated readings on each solution were made to provide an average nitrogen content.

3.2.5 SHIGOMETER MEASUREMENTS

Measurements for internal decay were made with a special twisted-wire probe; an abrupt drop in electrical resistance supposedly indicates decay. Resistance measurements with the Shigometer on each pole involved drilling, from surface to pith, a radially oriented hole, 3/32 in. (2.4 mm) in diameter, at groundline. The hole was made with 8 in. (20.3 cm) long drill bit mounted in a lightweight battery powered drill. The time taken to drill the hole was usually 40 to 60 seconds with frequent removal of the bit from the hole to eliminate sawdust. The measurement of resistance was begun a couple of minutes after drilling had been completed.

Meter readings were made at 1 cm intervals, as indicated by painted marks on the probe, to progressively deeper positions inside the pole. These measurements established the internal profile of the electrical resistance. When inserting the twisted-wired probe into a hole, it was kept horizontal. The procedure followed was based on that described in the Shigometer method manual.

The electrical resistance readings in kilo ohms (kΩ) were plotted on scaled sketches of the cores. Deflection percentages were calculated for the lowest each reading from the highest value for a core. The core positions where a deflection percentage was 75 or greater were recorded being possibly decayed.

When the inspection was completed, all drilled holes were filled with copper naphthenate preservative from a plastic squeeze bottle, and then carefully sealed with a treated plug to prevent subsequent infection of the pole.

4.0 RESULTS AND DISCUSSION

4.1 CHEMICAL DISTRIBUTION STUDY

The effectiveness of a wood-preservative treatment in preventing deterioration is dependent on the degree of treatment, as well as the effectiveness of the preservative system itself. Treatment variables include depth of penetration, level of chemical retention, and preservative distribution.

4.1.1 PENETRATION

Table 11 represents the results of preservative penetration determined for the ACA-treated spruce poles after seven years in test. The histogram of the average penetration values (Figure 10) depicts a slight right-skewed distribution with the 50 percent of the observed penetrations falling within the range of 1.0 (2.5) to 1.2 in. (3.0 cm). The significance of this large penetration is evident when comparing the data obtained in this study with the current ACA-penetration requirements for spruce poles described in the CSA 080 Wood Preservation Standard, section 080.4. The current standard requires a minimum preservative penetration of 0.50 in. (13 mm) and 100% sapwood up to a depth of 0.75 in. (19 mm). Results from this study clearly indicate that all the test poles achieved the CSA-required penetration. These observations correlate closely with those reported by Ruddick

TABLE 11. Preservative penetration values determined for the ACA-treated spruce poles after seven years in test.

	Penetration (in.)		
Pole Number	Min.	Max.	Ave.
K-3-24	1.14	1.17	1.16
K-3-25	1.26	1.39	1.33
K-3-29	1.02	1.20	1.11
N-3-49	0.79	1.03	0.91
K-4- 1	1.33	1.42	1.38
N-4- 2	0.96	1.09	1.03
K-4- 5	1.06	1.12	1.09
K-4- 8	1.27	1.34	1.31
N-4-10	1.45	1.54	1.50
K-4-20	1.14	1.19	1.17
N-4-23	0.91	0.98	0.95
K-4-25	1.04	1.07	1.06
N-4-29	1.17	1.33	1.25
N-4-41	1.05	1.15	1.10
N-5-11	0.97	1.56	1.27
N-5-16	0.88	0.92	0.90
K-5-21	0.93	0.99	0.96
N-5-23	1.08	1.12	1.10
K-5-26	1.01	1.03	1.02
N-5-29	1.34	1.51	1.43
K-5-31	1.04	1.08	1.06
K-5-39	0.99	1.14	1.07
N-5-50	1.04	1.15	1.10
N-5-51	1.06	1.10	1.08
Mean			1.14
Std. Dev.			0.19

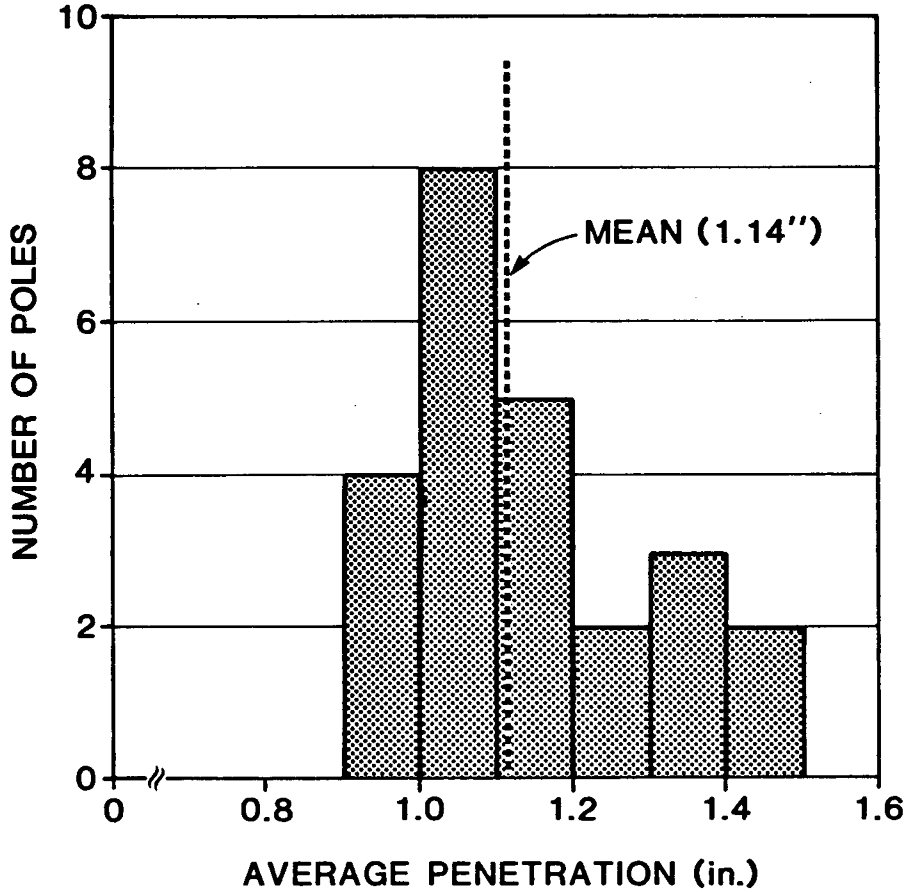

Figure 10. Histogram of average ACA penetration.

(1978), in that excellent penetration were obtained in a large number of treatments of spruce roundwood. Ruddick attributed the satisfactory penetration values to the combination of incising and ACA treatment.

Indeed, Horn and his co-workers (1977) have shown that incising spruce poles clearly enhances the penetration of waterborne preservatives applied by pressure impregnation. Banks (1973) has also reported the development of a close-spaced incising pattern for use on spruce lumber to improve the penetration of preservatives.

Considerable effort has been made to study the effect of ammonia on various components of the wood substance and some physico-chemical properties of ammonia-treated wood (Bariska and Popper, 1971 and 1975; Bariska _et al._, 1969; Davidson and Bangardt, 1970; Rak, 1977a). From these studies, it can be concluded that penetration of ammonia into all components of wood substance, and its action on the structure of wood are identified as factors affecting the treatability. Thus, treatments of spruce poles with Cu-As preservatives dissolved in aqueous ammonia provided excellent sapwood penetration. Supporting evidence for these observations is provided by a comparison of the results of the ACA-treated poles with those recorded for a similar group of the PCP-treated poles (Ruddick, 1978).

The inferior penetration of the latter was obvious. Rak (1977a) has also shown that the permeability of spruce sapwood in the radial direction to an aqueous ammoniacal solution of inorganic salts was found to be better than that of water. Thus, it may be concluded from these observations that the use of ACA solutions with the application of incising have both contributed towards the excellent penetrations observed for the ACA-treated spruce poles.

4.1.2 RETENTION

The retention of preservative is one of the most important factors influencing the extension of the service life of preservative-treated poles. Thus, in this study, the chemical retention was determined in three different assay zones for each pole, by analyzing the boring that had been used to assess the penetration. The analytical results are presented in Table 12. This table also shows the total chemical content and the relative percentage of the two components, Cu and As, in the three analytical zones, and for comparison the retention values measured prior to installation for the first zone only. The present values determined for zone 1 according to the CSA standard method may be compared with those described in the CSA 080.4 standard of 0.6 lb./ft.^{3}(9.6 kg/m^3) for ACA, on an element oxide basis.

TABLE 12. Analysis of ACA chemical retention.

Pole number	Zone of analysis[a]	Retention				Relative percentage		Retention prior to installation[b] ($lb./ft.^3$)
		Cu (kg/m^3)	As (kg/m^3)	Total (kg/m^3)	Total ($lb./ft.^3$)	Cu	As	
K-3-24	1	5.00	3.67	8.67	0.53	58	42	0.27
	2	0.80	0.27	1.07	0.07	75	25	
	3	0.27	0.13	0.40	0.03	67	33	
K-3-25	1	6.27	6.00	12.27	0.77	51	49	0.62
	2	1.60	1.33	2.93	0.18	55	45	
	3	0.40	0.27	0.67	0.04	60	40	
K-3-29	1	3.47	2.13	5.60	0.35	62	38	0.39
	2	0.80	0.27	1.07	0.07	75	25	
	3	0.13	0.13	0.26	0.01	50	50	
N-3-49	1	4.13	2.67	6.80	0.43	61	39	0.28
	2	0.80	0.40	1.20	0.08	67	33	
	3	0.27	0.13	0.40	0.03	67	33	
K-4- 1	1	5.87	4.93	10.80	0.68	54	46	0.67
	2	2.13	1.87	4.00	0.25	53	47	
	3	0.27	0.40	0.67	0.04	40	60	
K-4- 2	1	2.40	1.60	4.00	0.25	60	40	0.39
	2	0.53	0.27	0.80	0.05	67	33	
	3	0.13	0.13	0.26	0.01	50	50	

TABLE 12. (cont.)

Pole number	Zone of analysis[a]	Retention: Cu (kg/m^3)	As (kg/m^3)	Total (kg/m^3)	Total (lb./ft.^{3})	Relative percentage: Cu	As	Retention prior to installation[b] (lb./ft.^{3})
K-4- 5	1	4.67	3.33	8.00	0.49	58	42	0.26
	2	1.73	1.07	2.80	0.17	62	38	
	3	0.27	0.27	0.54	0.03	50	50	
K-4- 8	1	2.40	1.73	4.13	0.25	58	42	0.54
	2	1.13	0.87	2.00	0.12	57	43	
	3	0.27	0.27	0.54	0.03	50	50	
K-4-10	1	5.33	4.40	9.73	0.61	55	45	0.62
	2	1.73	1.07	2.80	0.17	62	38	
	3	0.40	0.13	0.53	0.03	75	25	
K-4-20	1	4.67	2.40	6.93	0.43	65	35	0.55
	2	1.60	1.20	2.80	0.17	57	43	
	3	0.27	0.27	0.54	0.03	50	50	
N-4-23	1	4.53	2.40	6.93	0.43	65	35	0.35
	2	0.67	0.27	0.94	0.05	71	29	
	3	0.27	0.13	0.40	0.03	67	33	
K-4-25	1	5.73	4.00	9.73	0.61	59	41	0.32
	2	0.67	0.40	1.07	0.07	63	37	
	3	0.13	0.13	0.26	0.01	50	50	

TABLE 12. (cont.)

Pole number	Zone of analysis[a]	Retention Cu (kg/m^3)	As (kg/m^3)	Total (kg/m^3)	Total ($lb./ft.^3$)	Relative percentage Cu	As	Retention prior to installation[b] ($lb./ft.^3$)
N-4-29	1	4.13	3.33	7.46	0.47	55	45	0.60
	2	0.67	0.53	1.20	0.08	56	44	
	3	0.27	0.27	0.54	0.03	50	50	
N-4-41	1	6.80	6.40	13.20	0.82	52	48	0.74
	2	1.33	1.07	2.40	0.15	56	44	
	3	0.40	0.27	0.67	0.04	60	40	
N-5-11	1	1.87	0.67	2.54	0.16	74	26	0.33
	2	1.07	0.40	1.47	0.09	73	27	
	3	0.27	0.13	0.40	0.03	67	33	
N-5-16	1	4.07	2.60	6.67	0.41	61	39	0.21
	2	0.83	0.41	1.24	0.08	67	33	
	3	0.27	0.13	0.40	0.03	67	33	
K-5-21	1	5.67	3.53	9.20	0.57	62	38	0.22
	2	0.53	0.27	0.80	0.05	67	33	
	3	0.13	0.13	0.26	0.01	50	50	
N-5-23	1	5.67	3.80	9.47	0.59	60	40	0.46
	2	1.33	0.67	2.00	0.12	67	33	
	3	0.13	0.13	0.26	0.01	50	50	

TABLE 12. (cont.)

Pole number	Zone of analysis[a]	Retention: Cu (kg/m^3)	Retention: As (kg/m^3)	Retention: Total (kg/m^3)	Retention: Total ($lb./ft.^3$)	Relative percentage: Cu	Relative percentage: As	Retention prior to installation[b] ($lb./ft.^3$)
K-5-26	1	4.40	3.47	7.87	0.49	56	44	0.33
	2	0.67	0.40	1.07	0.07	63	37	
	3	0.13	0.13	0.26	0.01	50	50	
N-5-29	1	4.53	2.80	7.33	0.45	62	38	0.29
	2	1.73	0.93	2.67	0.16	65	35	
	3	0.13	0.27	0.40	0.03	33	67	
K-5-31	1	4.27	3.60	7.87	0.49	54	46	0.45
	2	2.27	2.13	4.40	0.28	52	48	
	3	0.40	0.53	0.93	0.05	43	57	
K-5-39	1	6.00	5.33	11.33	0.71	53	47	0.70
	2	0.80	0.53	1.33	0.08	60	40	
	3	0.27	0.13	0.40	0.03	67	33	
N-5-50	1	3.07	2.13	5.20	0.33	59	41	0.48
	2	1.07	0.80	1.87	0.12	57	43	
	3	0.13	0.27	0.40	0.03	33	67	
N-5-51	1	6.13	4.13	10.26	0.64	60	40	0.56
	2	1.47	0.93	2.40	0.15	61	39	
	3	0.40	0.27	0.67	0.04	60	40	

TABLE 12. (cont.)

Pole number	Zone of Analysis[a]	Retention: Cu (kg/m^3)	Retention: As (kg/m^3)	Retention: Total (kg/m^3)	Retention: Total (lb./ft.^{3})	Relative percentage: Cu	Relative percentage: As	Retention prior to installation[b] (lb./ft.^{3})
Mean	1			8.06	0.50			0.44
	2			1.93	0.12			
Std. Dev.	1			2.63	0.16		6	0.16
	2			1.01	0.06			

[a] 1: core section from the surface of pole, cut to the length specified in CSA standard for the measurement of chemical retention.
2: zone next to the first section.
3: approximately 1 cm-long section immediately beyond the treated zone.

[b] The previous retentions were determined by Ruddick (1978).

Note: To convert lb./ft.^{3} to kg/m^3, multiply by 16.

As reported by Ruddick (1978), the majority of initial retentions in this white spruce pole study failed to achieve the level established by the CSA standard.

When the results from this study are compared with those reported by Ruddick, there is no significant difference at the 90% level in the mean retention for the two measurements (Table 13). The mean retention of 0.50 lb./ft.^{3}(8.0 kg/m^3) observed for zone 1 after several years of testing, is slightly greater than the original value of 0.44 lb./ft.^{3}(7.0 kg/m^3). This is associated with the fact that the samples were removed from the poles at different locations (i.e. for the present study, approximately 3 ft. (0.9 m) above the original zone, which was 10 ft. (3.0 m) from the butt of the poles. However, it should be noted that an assay based on a single boring of a pole can furnish only an estimate of chemical retention in the zone and at the point sampled.

As shown in Table 12, it is clear that there is an abrupt gradient in retention between the first and second zones. The results indicate that half of the test poles have retained less than 0.10 lb./ft.^{3}(1.6 kg/m^3) of Cu and As in the second assay zone. However, it is not possible to interpret this poor retention in white spruce as being solely due to a blockage of the pathways by which the chemical permeates the sapwood. Rather, low chemical retentions in

TABLE 13. Student t - test between the mean current and previous (prior to installation) totals.

	Present	Previous	Test statistic	DF	Significance
Mean	0.50	0.44	t = 1.2559	46	0.2155
Variance	0.027	0.026	F = 1.0361	23,23	0.4665
No. of poles	24	24	Probability (1^{st} mean > 2^{nd}) = 0.8872		

the ACA-treated spruce poles with excellent penetrations can be explained most plausibly in two ways, such as the treating process and the high initial moisture content of wood, thus diluting the ACA.

4.1.3 DISTRIBUTION OF CHEMICAL COMPONENTS

The effectiveness of a preservative treatment may also depend on the distribution of chemical components, particularly in the waterborne preservative system. The good performance of the salt treatments is partially attributed to the fact that they are able to penetrate easily into the cell wall of softwoods and are uniformly distributed in the wood.

From the results shown in Table 12, an interesting observation has been found in the ratio of copper to arsenic for the retentions in the first analytical zone. When this ratio is plotted against the total retention (Figure 11), it is clearly seen that the ratio of copper to arsenic is near unity at very high total retention, but increases in the form of a hyperbolic equation ($y = b_o + b_1x^{-1}$) as total retention decreases. From the multiple regression analysis shown in Table 14, hyperbolic model fits the data well at the 99.9% level, judging by the value of the multiple coefficient of determination (R^2). The estimates of the model parameters (b_o and b_1) are also presented in the same table, showing

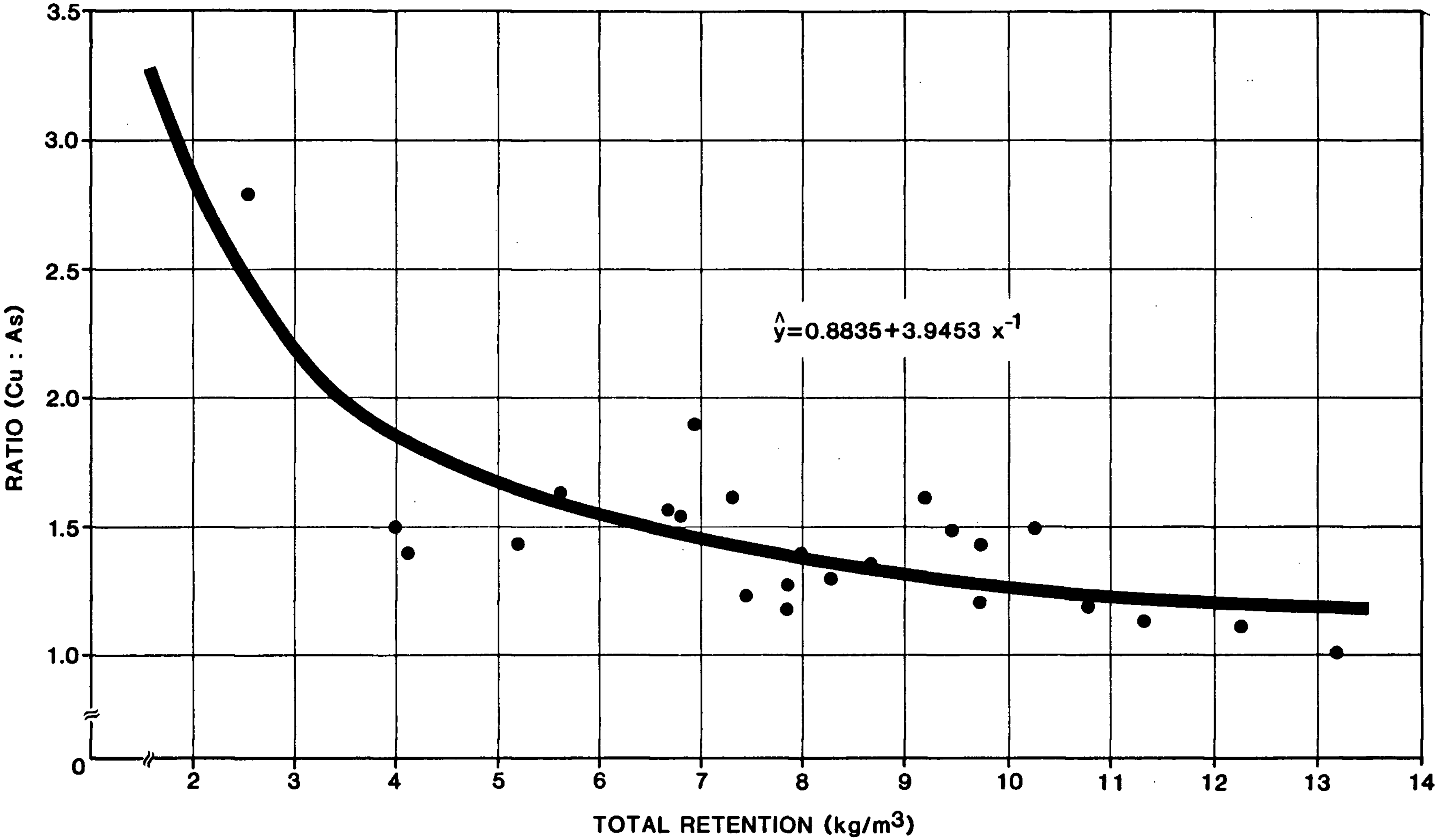

Figure 11. Ratio of copper to arsenic versus total retention.

TABLE 14. Multiple regression analysis of the ratio of copper to arsenic for the retentions in the first analytical zone.

Source	DF	SS	MS	F	Signif.
Regression	1	1.7406	1.7406	35.135*	0.0000
Error	22	1.0899	0.0495		
Total	23	2.8305			

Multiple R = 0.78418 R^2 = 0.61495 SE = 0.22258

Variable	Partial	Coefficient	Std. error	t	Signif.
Constant		0.8835	0.10565	8.3624*	0.0000
1/ total	0.78418	3.9453	0.66561	5.9275*	0.0000

Note: * significant at 0.1% level.

the prediction equation of $\hat{y} = 0.8835 + 3.9453x^{-1}$ for the total retention.

Recently Ruddick _et al._ (1981) and Ruddick (1984) have reported the ratio of copper and arsenic in ACA-treated hardwoods grown in Southeast Asia. In both studies, the disproportionate uptake of these chemical components has been clearly noted. According to Ruddick (1984), a disproportionate uptake previously observed in those ACA-treated hardwoods can be explained as being due mainly to the adaptability of copper and arsenic to the fixation process, suggesting that during treatment of ACA solutions greater amount of copper would be absorbed than arsenic. As a result, this would tend to increase the ratio of copper to arsenic compared with that present in the treating solution. However, since the results of this disproportionate uptake were obtained from weathered spruce poles in exposure tests for several years, low arsenic distributions where low retentions were observed would also suggest that the arsenic component has been gradually leached out. Where disproportional uptake occurs during the treating process, as reported in freshly treated hardwoods by Ruddick and his co-workers (1981 and 1984), it is necessary to monitor the treating solution compositions, and add additional arsenic as required.

The importance of these observations lies in the fact that the arsenic content in the wood should not be allowed to fall below a specific level, because arsenic is needed to prevent decay by copper-tolerant fungi such as *Phialophora* spp. Indeed the microbiological investigations to follow indicate that numerous species of the genus *Phialophora* have been frequently isolated near the treated surface of poles.

4.2 BIOLOGICAL STUDY

Wood-inhabiting fungi were isolated from the 24 ACA-treated white spruce poles sampled. As described previously, these fungi were isolated from the four different zones of each core. A total of 71 fungal isolates belonging to 17 genera and 4 taxa were identified to genus, with 15 of these being identified as to species (Table 15). The most frequently isolated fungi were *Phoma herbarum* (24/24, obtained from 24 poles out of 24 sampled), *Exophiala jeanselmei* (19/24), *Oidiodendron* spp. (16/24), *Acremonium* and *Penicillium* spp. (14/24), *Phialophora* spp. (13/24), *Sclerophoma pythiophila* (6/24), and *Verticillium* spp. (4/24). Bacteria were also commonly associated with these microfungi isolated. However, no Basidiomycetes, regarded as being true decay fungi on the basis of clamp connections, were isolated from any ACA-treated

TABLE 15. Identity and frequency of fungi isolated from 24 white spruce poles at Westham Island test field site.

Fungus[a]	Isolation frequency[b]	
	Poles(24)	Cores(72)
Acremonium spp.	14	20
A. butyri (Van Beyma) W. Gams	1	1
A. fusidioides (Nicot) W. Gams	1	1
A. kiliense Grutz	8	11
A. strictum W. Gams	1	2
other species	5	6
Alternaria tenuissima (Kunze ex Pers.) Wilts.*	1	1
Aphanocladium album (Preuss) W. Gams	2	3
Aspergillus sp.	1	2
Exophiala jeanselmei (Langeron) McGinnis & Padhye	19	37
Fusidium sp.*	1	1
Geomyces pannorum (Link) Sigler & Carmichael	1	1
Gilmaniella sp.	1	2
Gliocladium sp.	1	1
Oidiodendron spp.	16	28
O. griseum Robak*	10	15
cf. *O. rhodogenum* Robak	2	2
cf. *O. tenuissima* (Peck) Hughes*	2	2
cf. *O. truncatum* Barron	1	1
other species	8	13
Penicillium spp.	14	24
P. canescens Sopp	1	1
unidentified species	14	24

TABLE 15. (cont.)

Fungus[a]	Isolation frequency[b]	
	Poles(24)	Cores(72)
Phialophora spp.*	13	28
P. americana	3	5
cf. P. fastigiata	6	12
cf. P. molorum	2	2
other species	7	15
Phoma herbarum Westend.	24	72
Sclerophoma pythiophila (Corda) Hohnel.	6	11
Scytalidium sp.	1	1
Stemphylium botryosum Wallr.	1	1
Verticillium spp.	4	6
V. nigrescens Pethybr.	2	2
other species	3	4
unidentified imperfects		
Taxon 1	1	1
Taxon 2	1	1
Taxon 3	1	1
Taxon 4	1	1

[a] The species marked with * are potential soft rot fungi on the basis of literature (Cserjesi, 1984; Leightley, 1980 and 1981; Nilsson, 1973; Zabel et al., 1982).

[b] The total numbers of poles and cores from which fungi were isolated are placed in parenthesis.

spruce poles.

An important consideration in wood protection is to determine whether or not certain fungi are being controlled by a preservative treatment. Such knowledge is essential for the selection of fungi to be used in future experimental testing and also for the evaluation of a preservative treatments. For these reasons, untreated spruce poles installed at Westham Island were examined for the presence of basidiocarps fruiting on their surfaces. Several wood-destroying fungi which have been attacking spruce control poles are listed in Table 16. Both white- and brown-rot fungi were observed, but *Gloeophyllum saepiarium* which causes a brown rot was the most common among the Baasidiomycetes. It is generally known that *G. saepiarium* is a very destructive and resistant (*i.e.* to drying and high temperatures) brown-rot fungus, which primarily attacks sapwood but may later degrade heartwood. As shown in Table 15, none of the true wood-destroying fungi identified from the spruce control poles (see Table 16) have been isolated from the ACA-treated poles.

The eight major genera of microfungi were grouped by their position in the cores as to the location and possible time of origin of fungal inhabitation in the poles. The data are summarized for the ACA-treated poles in Table 17.

TABLE 16. Fungi identified from basidiocarps on untreated spruce control poles at Westham Island test site (Cserjesi, 1984).

Pole number	Fungus
1980 SP 8	*Poria* sp. *Stereum sanquinolentum* (Alb. & Schw:Fr.) Pouz. *Dacrymyces stillatus* nees:Fr.
1980 15	*Gloeophyllum saepiarium* (Wolf.:Fr.) Karst.
1980 26	*Leucogyrophana molluscus* (Fr.) Pouzar
1980 28	*Gloeophyllum saepiarium*
1980 31	*Crustoderma dryinum* (Berk. & Curt.) Parm.
1980 32	*Gloeophyllum saepiarium* *Crustoderma dryinum* *Phlebia subserialis* (Bourd. & Galz.) Donk
1980 33	*Gloeophyllum saepiarium*

TABLE 17. Relationship between isolation frequency and core position for the genera of major fungi isolated from 24 white spruce poles.

Core position[a]	Frequency of isolations from a core position								Total
	Acremonium	*Exophiala*	*Oidiodendron*	*Penicillium*	*Phialophora*	*Phoma*	*Sclerophoma*	*Verticillium*	
1	8	35	25	16	13	68	5	4	174
2	3	1	0	3	6	61	2	0	76
3	3	0	1	1	6	57	2	0	70
4	10	2	9	9	11	37	4	2	84

[a] The core position are:

1. the outer zone of the treated wood;
2. the untreated wood immediately adjacent to the outer treated shell;
3. the heartwood region (outer heartwood);
4. the inner heartwood including pith.

These data clearly suggest that most fungi were present in the outer portion of poles. Since this was treated wood, the presence of these fungi could be attributed to a high tolerance to one or all of the chemical components in the ACA preservative. If the tolerant fungi were able to attack cellulose or lignin, then some decay of the wood could occur. In particular, members of the genus Phialophora are known to be copper-tolerant (Francis and Leightley, 1983; Leightley, 1979; Leightley and Armstrong, 1980; Nilsson and Henningsson, 1978). The presence of fungi in the treated wood may also have been attributed to lower chemical retention than that specified in the CSA standard, possibly with poor preservative macro-distribution between wood elements and micro-distribution within cell walls. Following colonization by certain microfungi frequently isolated from the treated wood, a subsequent stage might then be succession by true wood-destroying fungi such as those isolated from the untreated control poles.

Fungi occurred less frequently in the zone beyond the treated wood to the pith. Since this was untreated wood, the presence of fungi might be explained either by entry through deep checks penetration the outer treated shell, or by pretreatment invasions that survived the preservative treatment cycle. Although it is known that the increased decay incidence is generally associated with check depth in service, the time of fungal inception in most poles is unclear. As shown in Table 17, the numerical distribution of certain fungi in the poles would suggest attack from the outside inwards. This could have occurred in the graveyard test after installation. However, it can also be speculated that these ACA-treated spruce pole invasions by those fungi may have occurred in the trees, as well as in the poles prior to treatment, or shortly after treatment and during storage. Wood-inhabiting fungi may be present in standing trees and though some efforts are made to disallow their presence in utility poles, they can potentially be included in such a product. Since the ACA treatment of the spruce poles, using the Lowry empty-cell process (i.e. 29 to 51°C), did not involve high temperatures, the presence of a certain fungi such as Phoma sp. can be traced to the use of treatment cycles with moderate temperature regimes. This species could remain alive but dormant through a treatment process, yet when the wood met favourable conditions (i.e. re-wetted), dormancy could be broken and growth re-initiated. Thus it can be suggested that infection with Phoma sp. which show a constant presence in almost every position of the core had occurred in the living trees.

It is of interest to note that Exophiala sp., Oidiodemdron spp. and *Penicillium* spp. were associated most frequently with the treated zone (Table 17). Supporting evidence for this association with treated wood is also provided from fungal infection in the pith zone of kerfed poles. From the data shown in Table 18, the presence of these three species was almost exclusively in the treated pith area which received a certain chemical retention due to kerfing. This observation can be ascribed partly to the fact that in every instance (except *Phoma*), the pith position through kerfing had the maximum number of isolates among the three internal, untreated positions.

Very recently several researchers (Drysdale and Hedley, 1984; Holt, 1983; Nilsson, 1982; Nilsson and Daniel, 1983; Nilsson and Holt, 1984) have suggested that bacterial degrade is one of the major types of decay observed in untreated and preservative-treated wood. They have observed that bacterial degrade was usually restricted to the surface zones of wood products (*e.g.* piles and posts) and often associated with severe soft rot. The variability in type and severity of attack has been studied by Nilsson (1984). Based on his observations, it can be suggested that initial bacterial attack at the surface zones of poles may have contributed to subsequent colonization by certain microfungi. Although bacterial degrade has been confirmed in some wood products,

TABLE 18. Frequency of isolation of the major fungi in the pith zone from both kerfed and non-kerfed poles.

Pole condition	Frequency of isolations in the pith zone from a pole							
	Acremonium	*Exophiala*	*Oidiodendron*	*Penicillium*	*Phialophora*	*Phoma*	*Sclerophoma*	*Verticillium*
Kerfed	4	2	5	5	1	9	3	1
Non-kerfed	3	0	1	1	5	8	1	0
Total	7	2	6	6	6	17	4	1

whether or not it occurs in ACA-treated poles is uncertain. This would be an interesting area for further study, particularly when inadequate treatment of difficult-to-treat, non-durable woods, such as spruce, is encountered.

Although no Basidiomycetes were obtained from any ACA-treated spruce poles, it should be noted that cultural detection as conducted in this study is a conservative estimator of decay due to the limited point sampling inherent in the increment boring procedure. Also because some decay fungi could be rapidly overrun by bacteria or microfungi even with a selective culture medium, they may have failed to be recognized in the initial phases of isolation from cores. However, the associated condition of spruce pole material with numerous microfungi and some soft-rot fungi (e.g. Phialophora spp., Alternaria sp., Fusidium sp., and Oidiodendron sp.; see Table 15) could be judged generally to be in an early stage of development in all of the test poles, based on the frequency of isolation of non-Basidiomyceteous fungi obtained from the cores of each pole compared with those decay fungi isolated from the control poles. This judgement was also based on the sound visual appearance of most cores sampled and the results obtained from the Shigometer measurements (see Section 4.4).

From the results, it can also be suggested that the soft rot and microfungi isolated are more tolerant to ACA preservative than the wood-destroying Basidiomycetes. Some Phialophora species are known to be most tolerant to preservatives. It is recommended that further studies should be conducted to determine the soft rot capability of the major fungi isolated from the ACA-treated spruce pole materials.

4.3 NITROGEN ANALYSIS

The nitrogen analysis for the ACA-treated white spruce poles after several years of exposure in the graveyard test is presented in Table 19. Tables 20 and 21 are summaries of the analysis of variance for a split-plot design and Duncan's multiple range test, respectively. The following three observations are valid:

1. There is no significant difference between the mean residual nitrogen levels due to treatment (*i.e.* kerfed *vs.* non-kerfed) for the first three zones.
2. There is a significant difference between the mean residual nitrogen levels in the kerfed *vs.* non-kerfed poles when the last zone is included (significant at the 99.5% level). There is also a significant interaction between treatments and zones (significant at the 97.5% level). That is, the mean nitrogen level for the kerfed poles is

TABLE 19. Analysis of nitrogen percentage in ACA-treated white spruce poles.

	Non-kerfed				Kerfed				
	Zone[a]					Zone[a]			
Pole number	1	2	3	4	Pole number	1	2	3	4
N-3-49	0.163	0.061	0.044	0.032	K-3-24	0.210	0.097	0.050	0.093
N-4- 2	0.158	0.073	0.052	0.094	K-3-25	0.304	0.147	0.092	0.111
N-4-10	0.185	0.098	0.089	0.067	K-3-29	0.193	0.079	0.061	0.078
N-4-23	0.232	0.102	0.099	0.104	K-4- 1	0.277	0.121	0.078	0.141
N-4-29	0.197	0.095	0.060	0.107	K-4- 5	0.213	0.094	0.077	0.061
N-4-41	0.275	0.129	0.070	0.097	K-4- 8	0.180	0.102	0.058	0.159*
N-5-11	0.137	0.088	0.046	0.063	K-4-20	0.205	0.110	0.061	0.178*
N-5-16	0.248	0.089	0.046	0.079	K-4-25	0.246	0.139	0.080	0.215*
N-5-23	0.224	0.086	0.054	0.068	K-5-21	0.199	0.087	0.072	0.171*
N-5-29	0.268	0.131	0.103	0.100	K-5-26	0.191	0.081	0.059	0.136*
N-5-50	0.145	0.081	0.060	0.109	K-5-31	0.250	0.181	0.102	0.149
N-5-51	0.272	0.161	0.119	0.125	K-5-39	0.232	0.105	0.060	0.123
Mean	0.209	0.100	0.070	0.087	Mean	0.225	0.112	0.071	0.135
Std. Dev.	0.051	0.028	0.026	0.026	Std. Dev.	0.038	0.030	0.016	0.044

[a] 1) treated zone 2) untreated wood immediately adjacent to the outer treated shell
3) heartwood 4) pith

Note: The values in the pith zone of kerfed poles, marked with *, were measured from sawdust which showed a brown colour.

TABLE 20. Analysis of variance of residual nitrogen in the ACA-treated white spruce poles, using split-plot design.

Source	DF	SS	MS	F	Tested against
1. Treatment(T)	1	8.87×10^{-3}	8.87×10^{-3}	3.27*	2
2. Pole	22	5.98×10^{-2}	2.72×10^{-3}	4.23***	5
3. Zone(Z)	3	2.87×10^{-1}	9.58×10^{-2}	149.10***	5
4. T x Z	3	7.19×10^{-3}	2.40×10^{-3}	3.73**	5
5. Error	66	4.24×10^{-2}	6.42×10^{-4}		
Total	95	4.06×10^{-1}			

Notes: * Not significant at 5% level, but at 10% level
** Significant at 2.5% level
*** Significant at 0.1% level

TABLE 21. Range tests for nitrogen in four different zones.

Zone	Frequency	Nitrogen mean	Standard Deviation
1	24	0.217	0.045
2	24	0.106	0.029
3	24	0.070	0.021
4	24	0.111	0.043

Duncan's multiple range test, ranges for $\alpha = 0.05$
2.8259 2.9714 3.0668

There are 3 homogeneous subsets (subsets of elements, no pair of which differ by more than the shortest significant range for a subset of that size) which are listed as follows:

1 <u>4 2</u> 3

significantly higher than that for the non-kerfed poles in the pith (zone 4) and the relationship between treatments and zones is different for the last zone. This is apparent from Figure 12.

3. There is a significant difference between the mean nitrogen levels across the zones (significant at the 99.9% level). The difference is mostly explained by the difference between the first zone and the other three zones.

In addition to these observations, the nitrogen content just beyond the outer treated shell (zone 2) is significantly higher at the 95% level than either that in the untreated heartwood, or the background nitrogen level (0.056%; Ruddick, 1979) established from the analysis of the untreated sapwood borings removed prior to treatment. For the heartwood (zone 3), the nitrogen level is comparable with the background nitrogen level of 0.056%, and also with the percentage nitrogen reported by Young and Guinn (1966) for several coniferous woods, ranging from 0.059% to 0.078%.

There are two general trends noted when comparing the nitrogen contents (Table 19) with the chemical retentions (Table 12) in the same zone of analysis from the same test samples. First, least squares regression analysis (Table 22) indicates that the amount of nitrogen is directly proportional

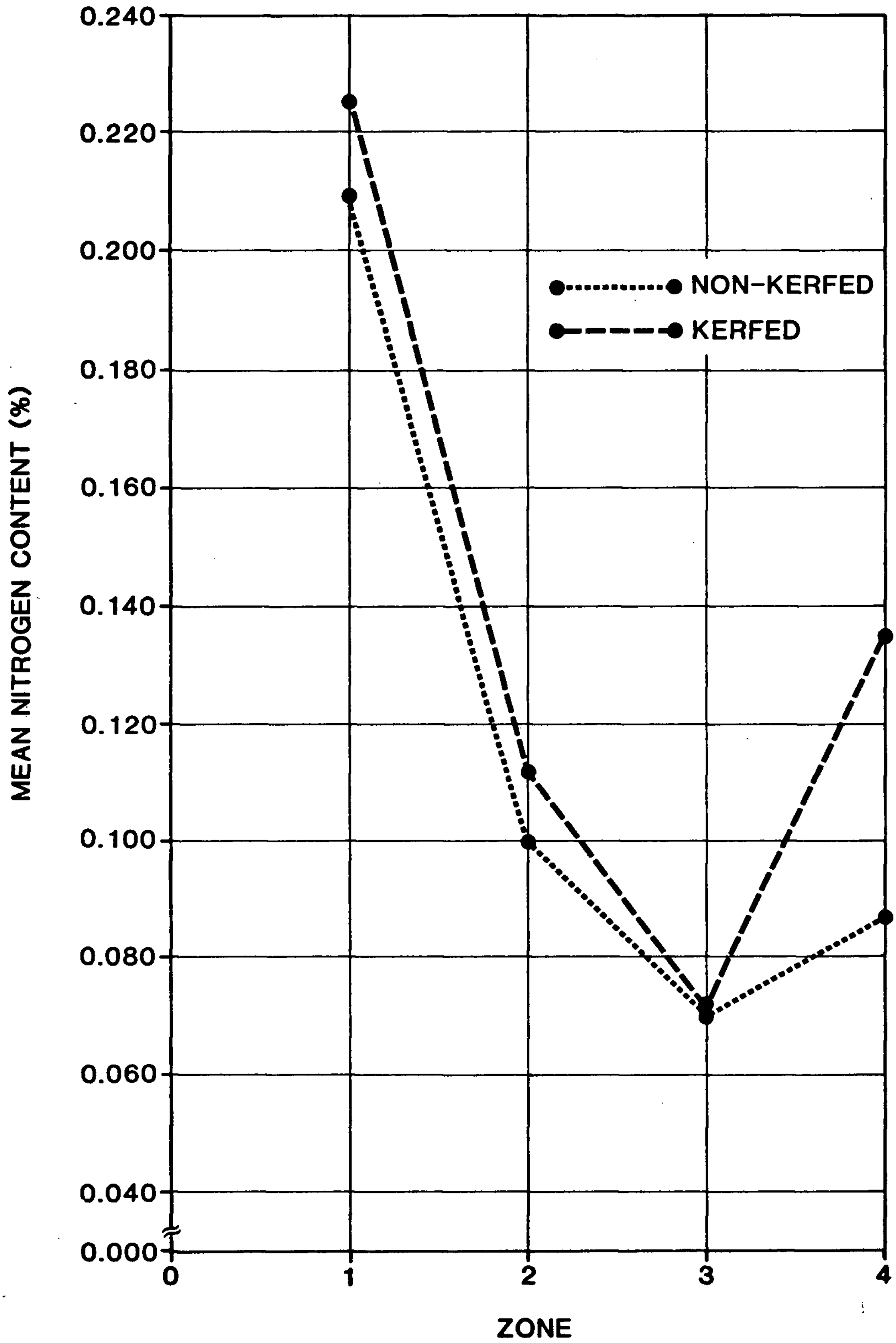

Figure 12. Mean residual nitrogen content versus zone.

TABLE 22. Least squares regression analysis for the nitrogen content and chemical retention in the first analytical zone.

Source	DF	SS	MS	F	Signif.
Regression	1	2.6443^{-2}	2.6443^{-2}	29.584^{*}	0.0000
Error	22	1.9665^{-2}	8.9385^{-4}		
Total	23	4.6107^{-2}			

Multiple R = 0.75730 R^2 = 0.57350 SE = 0.02990

Variable	Partial	Coefficient	Std. error	t	Signif.
Constant		0.11291	0.20059^{-1}	5.6287^{*}	0.0000
Retention	0.75730	0.12902^{-1}	0.23720^{-2}	5.4390^{*}	0.0000

Note: * significant at 0.1% level.

to that of the copper and arsenic contained in the wood. This trend clearly shows that the more chemical retention, the higher the nitrogen percentage (Fig. 13). Second, as described by Ruddick (1979), it is generally noted that when individual cores are examined, both the nitrogen percentage and the copper and arsenic contents decrease as the analytical zone moves from the surface to the heartwood where the chemical retention is assumed to be zero. The trend is shown by the analytical results for all cores (Table 19), and is illustrated graphically for the kerfed and non-kerfed poles using their mean values of the nitrogen percentage (see Fig. 12).

It had been generally assumed that, as mentioned previously, the ammonia is lost from the wood during the fixation of ammonia-based wood preservatives, and exposure of the ACA-treated wood to the action of rainwater markedly reduces the nitrogen enhancement caused by treatment with the ammonia solution. The results from this study confirm those of Ruddick (1979), namely, that all the ammonia present in ACA preservative has not been lost from the wood during the fixation process. Some may have reacted with the wood to increase its nitrogen content in both the treated zone and those zones beyond the limit of penetration. Compared with the results obtained by Ruddick (1979), it can be also

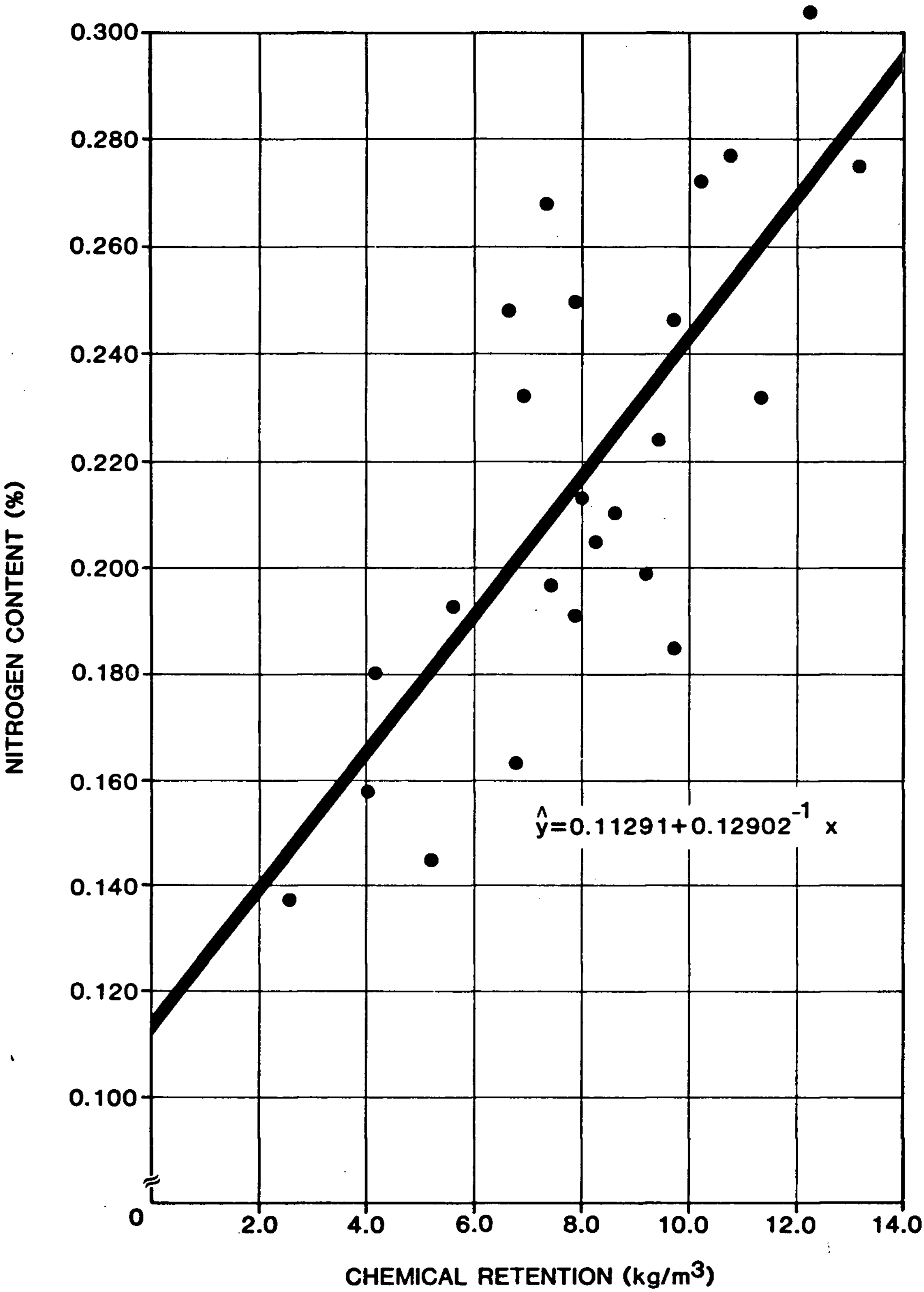

Figure 13. Regression line of nitrogen content over chemical retention in the first analytical zone.

concluded from the present study that the enhanced nitrogen level has not been reduced during exposure over prolonged period of several years in test.

Recently, King and his co-workers (1980) have reported that nitrogen compounds migrate to wood from surrounding soil, thus increasing its total nitrogen content during soil burial. If nitrogen transfer is a function of microbial translocation as postulated by these authors, then the considerable nitrogen increases observed in the treated wood would have been attributed, to a certain extent, to microbial biomass which suggests a significant involvement of sacrificial colonization by microorganisms. However, it is believed that the nitrogen enhancement in the treated zone has resulted mainly from the ACA treatment alone.

There is no question about the highly increased amount of nitrogen observed in the treated zone. On the other hand, two possible suggestions could be made in order to explain significantly high nitrogen percentage found in the wood immeidately adjacent to the outer treated shell compared to that in the heartwood. One is due to abnormal background levels of nitrogen and the other is through nitrogen fixation by fungi and bacteria.

The possibility of these observations resulting from abnormal background nitrogen levels can be eliminated on the basis of the nitrogen level (0.056%) found for the untreated sapwood borings and the range, from 0.059% to 0.078%, of nitrogen percentage reported by Young and Guinn (1966) for several coniferous trunk woods.

It could be summarized that the nitrogen levels adjacent to the treated shell have been enhanced through nitrogen fixation by wood-inhabiting bacteria. This might be a reasonable suggestion since the results obtained from the microbiological assay show a certain evidence of fungal and bacterial attack in the same analytical zone. However, although the nitrogen enhancement could be partly attributed to the presence of microorganisms inhabiting the wood, it could be expected to have only a very small effect. In a survey of cultivated fungi (Heck, 1929), the percentage of their dry weight attributable to nitrogen was found to vary between 2.27% in *Coprinus radicans* to about 5.13% in *Trichoderma lignorum*. Thus it is concluded that the nitrogen enhancement results mainly from the ACA treatment alone. Supporting evidence for this conclusion is also provided by the analytical results obtained in the pith zone, wherein the nitrogen level for the kerfed is significantly higher than that for the non-kerfed. Assuming that an average value of penetration, 1.14 in. (2.90 cm; Table 11), was obtained through kerfing in the pith zone, it would then be obvious that a higher nitrogen content, similar to that found in the treated zone, might result. This is confirmed by the linear relationship between nitrogen content and chemical retention in the first analytical zone (see Fig. 13).

The following two scenarios have been postulated by Ruddick (1979) in order to explain how and when the enhancement of nitrogen level occurs beyond the treated zone:

1. During the pressure treatment of wood with ACA.

2. During the fixation process.

When certain wood species such as white spruce and Douglas-fir are pressure-treated with ACA, they darken in colour during treatment. The cause of this darkening has not been verified yet, but is presumably due to the use of ammonium hydroxide in the ACA preservative, since treatment with other waterborne preservatives (e.g. CCA) which also contain copper and arsenic does not give this color reaction. In ACA, as described earlier, the ammonia in the solvent reacts with copper arsenate to form a soluble complex. Although this ammonia is stable in ammonium hydroxide solution, it is readily liberated from ammonium hydroxide when the solvent is removed. Thus, it is possible that the ammonia penetrates the wood cells prior to the preservative solution during the pressure treatment of wood with ACA. Based on this fact, Rak (1977) indeed explained the enhanced permeability of spruce wood to ACA compared with CCA. It is also reasonable to suggest that, during the fixation process, some of the ammonia diffuses further into the wood cells.

Since all the test poles have been at the Westham Island test field site for several years, it is possible that the leaching action of rainwater may have reduced the nitrogen level. From the results shown in Table 12, however, this is not so. Supporting evidence is also provided by the analytical results reported by Ruddick (1979) for ACA-treated spruce pole sections, showing that the nitrogen level remained enhanced after two years of exposure outdoors. Based on these observations, therefore, it is also possible to suggest that some of the ammonia has moved further into wood with moisture content above the fiber saturation point, down a concentration gradient of ammonia in the form of ammonium hydroxide or other ammonium solutions.

In summary, although the exact cause of this nitrogen enhancement has not been verified yet, the two scenarios seem to best describe the circumstances permitting enhancement of nitrogen observed in the ACA-treated wood.

It is generally known that increasing the nitrogen content of wood frequently increases the rate of decay by wood-destroying fungi. Therefore, the importance of these observations from this study lies in the fact that the addition of nitrogeneous materials to wood may increase its susceptibility to decay. The high nitrogen levels at the surface of the poles are unlikely to be important, since the preservative retentions are also high and would deter fungal attack. However, at other locations farther from the surface where higher nitrogen levels have been observed, the preservative retention is very much lower than that required to prevent decay. Thus any damage extending to this zone, either by deep checking during subsequent weathering or by mechanical damage, could expose wood with a high nitrogen content and low or very little preservative retention. Although there is conflicting evidence as to whether decay can be increased appreciably by artificially adding nitrogen to wood, such situations could lead to decay of the exposed wood, particularly when non-durable spruce wood is encountered.

The results from this study show that the wood treated with ACA has been enhanced in its nitrogen level. However, it is still questionable in which chemical form this enhanced nitrogen is present in the wood, and also whether fungi are capable of metabolizing this source of nitrogen to promote their growth. To date, little or no work has been performed concerning these questions. Based on the metabolism of nitrogen described previously, it may be suggested that this nitrogen is available in at least one of three possible forms, *i.e.* nitrate, nitrite or ammonium ion. As discussed earlier, some of the ammonia which has not been lost from the wood either during the fixation process or after several years of exposure still remains in the form of ammonium hydroxide. The nitrate ion (NO_3^-) may also have been incorporated into the wood cells as ammonium nitrate, potassium nitrate or calcium nitrate (Cochrane, 1958); if so, it then must be reduced to the oxidation level of ammonia before the nitrogen can be assimilated into organic compounds. If either of these suggestions are correct, the enrichment of the nitrogen level is likely to promote the growth of some wood-inhabiting microorganisms. Even with frequent isolations of bacteria and microfungi in the treated zone, on the other hand, the alkali effect due to ammonium hydroxide in association with the high chemical retentions would almost certainly exclude wood-decaying fungi in this zone. It has been assumed that the alkali treatment may destroy thiamine (Dwivedi and Arnold, 1973), which is essential for the growth of many wood-decaying fungi, and that the treatment may also increase decay resistance in wood by reducing the availability of other micronutrients essential for fungal growth (Baechler, 1959), or by increasing the pH or ammoniacal nitrogen content (Highley, 1973).

Further research is necessary to show whether the enrichment of the nitrogen level in the ACA-treated spruce wood is favoured positively or negatively by numerous fungi inhabiting the wood. If found to be positive, further work is also necessary to confirm that this observation is indicative fo ACA-treated wood in general, and to determine in which chemical form fungi are capable of metabolizing nitrogen to promote their growth.

4.4 EVALUATION OF THE SHIGOMETER

4.4.1 MOISTURE MEASUREMENTS

As previously described, moisture measurements were taken in each of the total 24 spruce poles selected, using the cores sampled for the chemical analysis. These measurements served to determine if additional moisture was required prior to Shigometer measurements and to indicate the extent to which the Shigometer is responding to moisture rather than to decay (Perrin, 1978).

Moisture measurements determined for all test poles are shown in Table 23. The moisture contents of individual core sections removed from the poles ranged from 24.5% to 61.54%, with an overall average of 31,12%. However, moisture levels in each pole were not normally substantially different between the outer treated surface and pith zone, with some exceptions found in the two kerfed poles (K-4-5 and K-5-26).

TABLE 23. Moisture contents of the ACA-treated spruce test poles.

Pole number	Moisture content[a] (%) 1	2	3	4	Average	Weather condition when sampled[b]
K-3-24	28.48	30.74	32.61	31.21	30.81	A
K-3-25	29.79	30.28	28.15	30.33	29.64	B
K-3-29	28.28	30.94	32.00	33.83	31.26	A
N-3-49	33.13	29.71	32.41	28.83	31.02	B
K-4- 1	32.14	33.68	32.38	33.65	32.96	A
K-4- 2	33.33	30.37	30.91	29.25	30.97	A
K-4- 5	30.65	44.54	61.54	58.54	48.82	A
K-4- 8	31.65	26.72	28 57	28.83	28.94	B
N-4-10	31.78	34.31	30.77	30.16	31.81	B
K-4-20	25.60	28.97	28.46	31.71	28.69	B
N-4-23	35.66	27.03	27.93	27.96	29.64	C
K-4-25	25.93	29.15	25.10	28.07	27.06	A
N-4-29	25.40	27.59	30.39	32.14	28.88	A
N-4-41	29.41	31.68	28.79	29.30	29.80	B
N-5-11	35.65	30.51	29.25	29.63	31.26	B
N-5-16	30.77	30.11	27.18	28.83	29.22	A
K-5-21	28.49	25.27	32.71	29.00	28.87	A
N-5-23	33.87	31.25	30.84	29.41	31.34	E
K-5-26	34.15	30.10	32.65	51.58	37.12	D
N-5-29	32.20	29.41	30.15	29.70	30.37	E
K-5-31	26.95	28.23	27.66	29.31	28.04	A
K-5-39	24.59	29.00	30.11	31.78	28.87	E
N-5-50	33.90	33.33	31.25	28.36	31.71	A
N-5-51	25.71	29.90	31.63	31.40	29.66	A
Mean	30.31	30.54	31.40	32.20	31.12	
Std.Dev.	3.41	3.66	6.73	7.30	4.26	

[a] Each sampled core was cut into four equal sections and numbered from the surface to the pith.

[b] A) sunny B) rained the day before C) rained till the morning D) "C" and again during sampling E) cloudy

The Shigometer functions only above the fiber saturation point of wood tissue, which averages about 27% moisture content (Shigo et al., 1977). It has usually been found that, at groundline, the moisture content of poles in the ground is above the fiber saturation point, and that when microorganisms are active in wood, the moisture content is above the fiber saturation point with a few rare exceptions. Although there is some opinion that moisture contents between 25% and 35% are below the critical limit for the Shigometer (Brudermann, 1977), based on instrument specifications (Osmose Wood Preserving Co., 1980) and the results from the measurements of moisture content (see Table 23), the holes drilled for the Shigometer measurements were not additionally saturated with deionized water. Support for this decision was also gained from the observation that an abrupt drop in electrical resistance readings may be simply due to high moisture content above fiber saturation. Very recently, Morris and his co-workers (1984) have reported that there is a large difference between readings of wood below 38% and above 45% moisture content, suggesting that moisture content alone could result in a marked lowering of resistance.

As shown in Table 23, it is interesting to note that for poles K-4-5 and K-5-26, relatively high moisture contents were observed particularly in the inner zones. Since both poles were kerfed, abnormally high moisture content could be due to the effect of the kerf through which ground water could move into the inner parts of the poles. As mentioned already, moisture content would be well above the fiber saturation point if microorganisms were active in wood. Thus, these high moisture contents may mean that there has been extensive decay or degradation by other non-decay microorganisms inside the poles. However, it should be noted that moisture detection alone would not normally serve to detect decay in a field situation where different parts of a pole would be subject to different environmental conditions. Therefore, a high degree of significance cannot be attached to these measurements at this time, as far as decay by active microorganisms is concerned.

For the purposes of this study, knowledge of the absolute wood moisture content is not essential. In order to take measurements with the Shigometer, it is important to know that the wood moisture content is above fiber saturation so that the Shigometer can successfully function. Thus moisture measurements were not taken in the same hole as Shigometer measurements. On the other hand, at the higher moisture contents observed, it would be desirable to see whether the moisture content causes the Shigometer to respond to moisture rather than to decay. In this way, relative changes in Shigometer readings would be compared with some validity to relative changes in moisture. The effect of moisture content on electrical resistance will be discussed in detail in Section 4.4.3.

4.4.2 SHIGOMETER MEASUREMENTS

Although the literature contains conflicting views as to the effectiveness of the Shigometer for detecting internal wood condition, this instrument has been used, to a certain extent, to detect discoloured and decayed wood in utility poles. Decayed wood is detected not on the basis of absolute resistance measurements, but on the change of the resistance measurements between sound and decayed zones.

Shigometer readings are presented in Table 24, with deflection percentage calculated as the difference between the lowest and the highest value for a core. Shigo and his co-workers (1977 and 1978) have emphasized that the pattern of readings at intervals along one hole and not individual readings, should be taken to indicate the wood condition. Decay is indicated with a deflection of 75% or more in the readings. The Shigometer manual (Osmose Wood Preserving Co., 1980) also states this criterion for predicting decay. Thus the core positions where the deflection percentage was 75% or greater were initially regarded to suffer from decay.

TABLE 24. Electrical resistance readings[a] (kΩ) with the Shigometer in ACA-treated spruce poles.

Pole number[b]	Pole radius	Sequential number	Deflection[c] (%)	Depth in pole (cm) 0.3	1	2	3	4	5	6	7	8	9	10	11	12
K-3-24(1)	11.9	A	45	275	360	465	+	+	+	+	+	+	+	+	460	395
K-3-25(1)	12.4	B	28	360	+	+	+	+	+	+	+	+	+	+	+	+
K-3-29(3)	12.8	C	50	160	220	195	220	320	320	300	310	310	275	250	260	250
N-3-49(1)	13.2	D	59	215	205	260	385	+	+	+	+	+	+	+	+	+
K-4- 1(1)	11.9	E	12	+	+	+	+	+	+	+	+	+	+	+	455	440
N-4- 2(1)	12.1	F	0	+	+	+	+	+	+	+	+	+	+	+	+	+
K-4- 5(1)	11.5	G	78	430	460	+	+	+	+	+	+	120	110	120	100	
K-4- 8(3)	12.0	H	31	345	440	460	+	+	+	+	+	+	+	+	+	440
N-4-10(1)	12.4	I	46	405	+	+	+	+	+	+	+	+	+	+	330	270
K-4-20(3)	11.9	J	36	320	365	+	+	+	+	+	+	+	+	+	+	370
N-4-23(2)	11.6	K	36	320	370	+	+	+	+	+	+	+	+	+	+	
K-4-25(2)	11.8	L	28	360	490	+	+	+	+	+	+	+	+	480	460	
N-4-29(3)	12.2	M	25	375	440	+	+	+	+	+	+	+	+	+	+	420
N-4-41(3)	11.9	N	64	+	+	210	180	180	185	200	190	195	200	185	180	
N-5-11(1)	10.7	O	64	210	200	285	+	+	+	+	+	180	205	420	375	
N-5-16(3)	10.2	P	36	320	440	+	+	+	+	+	+	+	+	+		
K-5-21(2)	11.6	Q	36	320	+	+	+	+	+	+	+	+	+	+	+	
N-5-23(2)	10.9	R	64	180	220	320	340	350	500	460	500	470	+			
K-5-26(1)	11.4	S	79	100	150	200	220	400	440	480	430	460	180	100	(right to the kerf)	
		T	88	180	240	340	+	500	+	+	+	440	60	260	(left)	

TABLE 24. (cont.)

Pole number[b]	Pole radius	Sequential number	Deflection[c] (%)	Depth in pole (cm) 0.3	1	2	3	4	5	6	7	8	9	10	11	12
N-5-29(1)	10.9	U	27	365	+	+	+	+	+	+	+	+	+	+	+	
K-5-31(2)	11.4	V	0	+	+	+	+	+	+	+	+	+	+	+	+	
K-5-39(1)	11.4	W	62	+	430	480	+	+	+	425	205	190	190	200	230	(right)
		X	60	200	350	400	+	+	+	+	330	220	250	350	360	(below)
N-5-50(3)	11.1	Y	34	330	400	+	+	+	+	+	+	+	+	480		
N-5-51(3)	10.7	Z	36	320	+	+	+	+	+	+	+	+	+	475		

[a] "+" sign indicates resistance reading over 500 kΩ.

[b] Numbers in parentheses represent the positions where Shigometer measurements were made.
(1): right of the first core position made for biological investigation;
(2) and (3): right of the second and third cores, respectively.

[c]
$$\frac{\text{Maximum electrical resistance - minimum electrical resistance}}{\text{Maximum electrical resistance}} \times 100;$$
To calculate deflection percentage, readings over 500 kΩ were taken as 500 kΩ.

Note: For two poles (K-5-26 and K-5-39), readings were taken at two different positions.

Prior to further analysis, the following three basic patterns of electrical resistance were observed in the total of 24 poles where no voids were detected by physical drilling and probing:

1. All readings $<$ 500 kΩ
2. All readings $>$ 500 kΩ
3. Mixed readings

In two poles (N-4-2 and K-5-31), all resistance readings were above 500 kΩ the entire length of the hole and therefore beyond the scale of the meter. In two poles (K-3-29 and K-5-26), all readings were below 500 kΩ. In the other twenty poles, some readings were below 500 kΩ and some above 500 kΩ.

In numerous studies of a pulsed electrical current to detect internal decay in utility poles (Brudermann, 1977; Shigo _et al._, 1977; Shortle _et al._, 1978; Wilkes and Heather, 1982; Wilson _et al._, 1982), a visual assessment of the state of decay was also made on the pole cross section at the same locations where Shigometer readings had been taken. Thus the Shigometer readings were subsequently related to the results of the corresponding visual assessments in order to be able to evaluate the accuracy and suitability of the instrument for detection of decay and stain. In this study, however, such visual assessments could not be made since the poles must remain in test for further studies. Consequently, the Shigometer readings were compared instead to the results obtained from fungal isolation studies.

From the results of the microbiological study and also observations during drilling, i.e. the difficulty of penetration of the drill, none of the 24 spruce poles seemed to have decay. However, based on the Shigometer readings alone, symptoms of decay were predicted in a few poles having the following readings of electrical resistance (Table 25):

1. Some > 500 kΩ, some < 125 kΩ (G and T in Table 24);
2. All < 500 kΩ, lowest less than 75% of highest (S).

According to the Shigometer manual, no symptoms of decay are indicated in wood of most poles having the following readings of resistance (Table 25):

1. All > 500 kΩ (F and V in Table 24);
2. Some > 500 kΩ, none 250 kΩ (A,B,E,H-M,P,Q,U,Y,Z);
3. All < 500 kΩ, but lowest not less than 75% of highest (C);
4. Some > 500 kΩ, some < 250 kΩ, but none < 125 kΩ (D, N,O,R,W,X).

Various results from other studies of a pulsed electric current to detect internal decay in wood generally have indicated that the patterns of readings which show abrupt decreases represent decay. The question is, however, how much

TABLE 25. Electrical resistance readings of poles classified to indentify those greatest deflection readings (indicative of decay)[a].

Electrical resistance readings (kΩ)	No. of poles[b]	
	Low or deflection moderate	High deflection
All > 500	2	-
Some > 500, none > 250	14	-
All > 500, but lowest not less than 75% of highest	1	-
Some > 500, some > 250, but none > 125	5(1)	-
Some > 500, some > 125	-	1(1)
All > 500, lowest less than 75% of highest	-	-
Total	22(1)	2(1)

[a] This classification was made on the basis of that of Shortle et al. (1978).

[b] Number in brackets indicates those poles (K-5-26 and (K-5-39) where two drill holes were measured.

of a drop in the reading is necessary to indicate decay in poles that are made from a variety of tree species and preserved with a variety of preservatives. Data from numerous studies give some answers but definitely not all.

The Shigometer manual, as mentioned previously, only states that a decrease of 75% or more indicates decay. In addition to this criterion, Shortle et al.(1978) also stated that where the highest reading was over 500 kΩ, a reading of less than 250 kΩ would indicate the condition of internal decay. It has been shown in their study that wood in poles having some readings above 500, some below 250, and none less than 125 kΩ was sometimes decayed. Although some of the suspect poles did not appear to have decay, they decided that if errors were to be made in using these criteria, such errors should be made in favor of calling a sound pole decayed rather than a decayed pole sound. For this reason, they have claimed that all such poles must be considered decay candidates. In this present study, however, those spruce poles (having some readings > 500, some < 250, but none < 125 kΩ) did not appear to have decay. This was based on the information from cultures obtained from borings taken adjacent to the Shigometer measurements, and the lack of ease of penetration of the drill. Thus those five suspect poles are categorized into the group without Shigometer symptoms of wood decay

(Table 25). From Table 26, which shows three test measurements obtained from suspect spruce poles, a close examination of the zones with low resistance reveals that relatively more fungi were isolated from approximately matched zones, but none were Basidiomycetes. Therefore, while those suspect poles are not decayed (or very little decayed due to the presence of soft rotters such as Phialophora spp.), they might have been altered or degraded by the presence of other types of microorganisms (e.g. bacteria and microfungi), resulting in relatively low readings of electrical resistance. In a very recent study of the effect of moisture content on the electrical resistance of timber, Morris et al.(1984) concluded that the abrupt drop in Shigometer readings between 38% and 45% moisture content may be due to the formation of a continuous water film between the two electrodes permitting easier ion movement. Thus low resistance readings in the suspect poles (Table 26) may be attributed just as likely to variation in moisture content rather than decay. The effect of moisture content on electrical resistance will be further discussed in the following section.

From the results shown in Table 24, relatively low readings of electrical resistance at the surfaces of most poles were observed. Since these surface zones have high preservative retentions with significantly large amounts of

TABLE 26. Examples of test measurements obtained from seven suspect spruce poles.

Category	Pole number	Test	Depth in pole (cm)												
			0.3	1	2	3	4	5	6	7	8	9	10	11	12
		Moisture[1] (%)	33.13			29.71			32.41			28.83			
	N-3-49	Shigometer (k)	215	205	260	385	+	+	+	+	+	+	+	+	+
		No. of fungi isolated[2]	2(1)			2(1)			1					1	
		Moisture	29.41			31.68			28.79			29.30			
	N-4-41	Shigometer	+	+	210	180	180	185	200	190	195	200	185	180	
		No. of fungi	4(1)			1			-					-	
		Moisture	35.65			30.51			29.25			29.63			
Some 500, some 250, but none 125k	N-5-11	Shigometer	210	200	285	+	+	+	+	+	180	205	420	375	
		No. of fungi	4			2			3					2	
		Moisture	33.87		31.25			30.84		27.41					
	N-5-23	Shigometer	180	220	320	340	350	500	460	500	470	+			
		No. of fungi	2			1			2(1)			2(1)			
		Moisture	24.59			29.00			30.11			31.78			
	K-5-39	Shigometer[3]	+	430	480	+	+	+	425	205	170	190	200	230	
			200	350	400	+	+	+	+	330	220	250	350	360	
		No. of fungi	2(1)			1			3					1	

TABLE 26. (cont.)

Category	Pole number	Test	Depth in pole (cm)												
			0.3	1	2	3	4	5	6	7	8	9	10	11	12
Lowest less than 75% of highest,	K-4- 5	Moisture	30.65			44.54			61.54			58.34			
		Shigometer	430	460	+	+	+	+	+	+	120	110	120	100	
		No. of fungi	4			2(1)			2					6(1)	
i.e. poles initially regarded as decay.	K-5-26	Moisture	34.15			30.10			32.65			51.68			
		Shigometer[3]	100	150	200	220	400	440	480	430	460	180	100		
			180	240	340	+	+	+	+	+	440	60	260		
		No. of fungi	3			2			1				3		

[1] Moisture contents determined in the zones produced by cutting core equally into four pieces.

[2] Number in bracket indicates that at least one soft rotting fungus was isolated in four different zones for microbiological assay work.

[3] The Shigometer measurements obtained at two different sites.

nitrogen,,it is expected that the presence of ACA preservative salts and/or other ionized materials (e.g. NH_4^+) could substantially affect resistance readings in the same manner as increasing ash content of decaying wood appears to affect the readings. Although very little work has been done in this regard, it is believed that the effectiveness of the Shigometer for treated wood in service is compromised by the possible effect of ionized materials in the wood. This is supported from the observation by James (1965) that water-soluble, salt-type wood preservatives had a substantial effect on the accuracyyof electric moisture meters. Indeed, Shigo and Shigo (1974) have reported that the Shigometer seems to be more effective in detecting decay in creosote-treated poles than in wood treated with fire retardants or water-borne preservative salts.

The microbiological study showed that a relatively large number of isolates of fungi were present in the ACA-treated zone to depths of several millimeters radially from the surface of poles. According to Banks and Evans (1984), the degradation of wood surfaces is due partly to water-created physico-chemical processes. Coupled with the assumption described by Carey (1982), that increased moisture contents also encourage colonization by microorganisms, it can be suggested that biological and physical degradation also contribute to relatively low readings of electrical resistance, particularly near the surfaces of most poles.

The Shigometer was originally designed for decay detection in living trees, where the wood moisture is well above the fiber saturation point and where there is most likely always some sound sapwood present. Since the meter readings are all relative values, they have to be related to wood of the same sample that is substantially devoid of fungal deterioration and that can be therefore be taken as a reference. This would be possible in a living tree but in timber in service, it is not possible to differentiate clearly between apparently sound wood and wood containing stain or any incipient decay. In this study, two factors have been identified which made evaluation of the effectiveness of the Shigometer more difficult. First, since there was no visual assessment, neither any possible decay nor other internal conditions (e.g. voids) could be detected. The results of fungal isolations provided only limited information on internal wood conditions. Second, as described in the study reported by Shortle et al.(1978), the meter measures resistance only to 500 kΩ, yet many readings exceed this value. Because the true resistance corresponding to readings beyond 500 kΩ was not known, the percentage deflection owing to the lower readings could not be accurately calculated. Thus, if poles with these characteristics make up a large percentage of poles to be inspected, further refinements of the method or the meter need to be developed.

4.4.3 EFFECT OF MOISTURE CONTENT ON THE SHIGOMETER MEASUREMENTS

The question of whether such reductions in electrical resistance as measured in the suspect spruce poles were due to the presence of decay or simply the variation in moisture content can be addressed to the two kerfed poles (K-4-5 and K-5-26) which showed the greatest deflection in resistance readings (Table 24). It is generally known that changes in moisture content are gradual in the vertical direction, but abrupt changes do occur in poles particularly in relation to the presence of checks. In kerfed poles, the kerf to the pith of a pole normally functions as a major check below groundline, permitting localized upward movement of moisture along a continuous capillary above the ground. If the Shigometer probe encounters such a column of wetter wood, the interpretation of the Shigometer readings could be particularly ambiguous. Moving the Shigometer probe from wood near the fiber saturation point to wood at significantly higher moisture contents would have caused a drop in resistance reading. For example, Table 26 shows that as the probe passed through moisture gradients, the Shigometer readings ranged from above 500 to 120 kΩ for the pole K-4-5, and from 440 to 60 kΩ (or 460 to 100 kΩ) for the pole K-5-26. This is more than a 75% drop even when taking the maximum as 500 kΩ as recommended by Shigo *et al.*(1977). With the previously observed moisture content distributions in spruce poles, it is concluded that the abrupt drops in Shigometer readings in the suspect poles are due to the effect of variation in moisture content above the fiber saturation point.

5.0 CONCLUSIONS

5.1 CHEMICAL STUDY

For the ACA-treated spruce poles after seven years in test, the penetration conformed to, but the retention was insufficient to conform to, the levels established by the CSA standard. Satisfactory penetration values in refractory spruce wood are attributed to the combination of incising and ACA treatment, while low chemical retentions in the ACA-treated spruce poles can be ascribed most plausibly to the use of an empty-cell process and the impregnation of poles which had been insufficiently dried.

The disproportionate uptake of the active ACA chemical components at low retentions, previously described by other researchers, has been confirmed. Since the original formulation of ACA contained equal amounts of cupric and arsenic oxides, the disproportionate retention of copper to arsenic can be explained as being due mainly to the differing adaptability of those components to the fixation process, and partly to possible leaching of arsenic during service.

5.2 BIOLOGICAL STUDY

Microbiological investigations indicated that numerous microfungi were commonly associated with the 24 ACA-treated spruce poles used in this study. The most frequently isolated microfungi were: Phoma herbarum (24 isolates obtained from 24 poles sampled), Exophiala jeanselmei (19/24), Oidiodendron spp. (16/24), Acremonium and Penicillium spp. (14/24), Phialophora spp. (13/24), Sclerophoma pythiophila (6/24), and Verticillium spp. (4/24). Bacteria were also commonly found associated with these microfungi.

However, in contrast to the untreated spruce control poles, no true wood-decaying fungi, Basidiomycetes, were isolated from the ACA-treated poles. It can be concluded that the microfungi isolated are more tolerant to ACA preservatives than are the wood-destroying Basidiomycetes.

5.3 NITROGEN STUDY

The results from the nitrogen analysis evidently prove that the treatment of spruce wood with ACA significantly increases the nitrogen content in the treated zone and also provides a significant enhancement of nitrogen level beyond the penetration limit. A linear relationship exists between nitrogen content and chemical retention in the first analytical zone.

It is not clearly understood whether the enrichment of nitrogen level due to ACA treatment in spruce wood is correlated with its susceptibility to fungal and bacterial colonization.

5.4 SHIGOMETER STUDY

Previously reported effects of moisture content variation within the range 38 to 45% on the Shigometer readings have been confirmed. Since no evidence of decayed wood was found, it is not possible to assess the accuracy of the Shigometer for detection of internal decay. However, resistance values observed for two of the poles show changes due to moisture content fluctuation which are similar to those reported by previous workers. Hence the practical application of the Shigometer for detection of internal decay may be limited due to the known variation in moisture content of the groundline region of poles.

5.5 GENERAL

Untreated spruce control poles in the graveyard test had already decayed severely at groundline contact after seven years of service simulation. Although the ACA-treated spruce poles were infected moderately with numerous microfungi and some soft-rot fungi, the complete absence of Basidiomycetes and the good physical condition of the treated poles is encouraging enough to warrant promise as an alternative for traditional pole species. With the availability of white spruce in large quantities, there should be considerable interest in the potential of this species for satisfying some of the future demand in Canada and making pole supply more flexible.

It is, however, recommended that periodic investigation in field test be performed to verify the utility of ACA-treated spruce as pole material. Since the poor retention in spruce is a fundamental, first order problem to overcome, the greatest step to be taken in preservative treatment is to improve the treatability of refractory spruce wood, by careful drying, improved incising and optimal pressure processes. From the results to date, it might be speculated that the CSA specifications are too conservative in that they call for a more retention than actual field requirements. However, further work would be required to prove or disprove this. Further studies are also required to provide an indication of the extent of checking in treated poles, and the ability of kerfing to prevent the formation of deep checks in ACA-treated spruce poles.

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APPENDIX A

MEDIA FORMULATIONS AND PREPARATIONS

1. Acidified Malt Agar (AMA)

Malt extract	20 g (2%)
Agar	20 g (2%)
Malic acid*	5 g (0.5%)
Distilled water	1000 ml

* Acid solution was autoclaved separately and added to 1 litre of the sterile media after autoclaving.

2. Benomyl Tetracycline Malt Agar (BTMA)

Malt extract	20 g (2%)
Agar	20 g (2%)
Benomyl*	15 ml (7.5 ppm)
Tetracycline**	10 ml (100 ppm)
Distilled water	1000 ml

* 0.1 g of 50% active ingredient powder in 100 ml distilled H_2O was used to yield $0.5/10^3$ for 7.5 ppm.

**0.5 g powder to 50 ml distilled H_2O yielded 10 mg/ml; 10 ml of 10 mg/10 ml tetracycline stock solution kept in a refrigerator were added separately to 1 litre of the sterile media to yield 100 ppm.

Note: All these media were autoclaved for 20 minutes at the temperature of 121°C with the pressure of 100 kPa.