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COOPERATIVE
IMPACT ASSESSMENT
REPORT

# THE BIOLOGIC AND ECONOMIC ASSESSMENT OF

# PENTACHLOROPHENOL
# INORGANIC ARSENICALS
# CREOSOTE

## VOLUME I: WOOD PRESERVATIVES

UNITED STATES
DEPARTMENT OF
AGRICULTURE

*IN COOPERATION WITH*
STATE AGRICULTURAL EXPERIMENT STATIONS
COOPERATIVE EXTENSION SERVICE
OTHER STATE AGENCIES
U.S. ENVIRONMENTAL PROTECTION AGENCY

TECHNICAL BULLETIN
NUMBER 1658-I

# ABSTRACT

Pentachlorophenol, inorganic arsenicals, and creosote are the major pesticide chemicals now in use for wood preservation. An estimated 44.5 million pounds of pentachlorophenol (penta), 37.2 million pounds of inorganic arsenicals, and 124 million gallons of creosote and coal tar are used as wood preservatives annually to preserve 327.5 million cu. ft. of wood for many end uses such as crossties, lumber, timbers, plywood, crossarms, piling, poles, posts, and other products. Although large volumes of treated wood products are used, these use patterns are such that exposure of humans and animals is very low.

The maximum impact to the U.S. economy would result from cancellation of all three RPAR'd preservatives. Based on using substitute material at 1979 prices, this would result in higher costs in excess of 4.5 to $6.3 billion annually depending on which combination of substitute materials is used. The total costs are higher because the above range accounts for only 86% of the pressure-treated wood products and does not include 475 million cu. ft. of wood protected by non-pressure processes.

The non-wood-preservative uses of penta, arsenicals, and creosote include herbicide, defoliant, mossicide, biocide, desiccant, growth regulator, fungicide, insecticide, rodenticide, soil sterilant, disinfectant, larvicide, acaricide, arachnicide, miticide, and repellent. The most important of these are cotton desiccant (20 to $50 million impact), fungicide ($24 million impact over 6-year period), herbicide, insecticide, and growth regulator ($5.8 million impact).

Low levels of pentachlorophenol exist in the environment with possible sources being direct contamination, volatilization, degradation of organic compounds, or from chlorination of phenols in water. The breakdown of penta depends upon the factors that affect volatilization, photodegradation, absorption, and biodegradation. Small amounts of arsenates may leach from treated wood into either water or soil, and like naturally occurring arsenic, form insoluble complexes with soil or soil sediments. Arsenate can be metabolized by aquatic or soil microorganisms; however, oceanic sediments are the ultimate sink for all arsenic. The amount of creosote that enters the environment is relatively small. Only limited data are available on the environmental fate of the many chemical compounds of creosote or coal tar.

Based on no-observable-effect level for penta, the safety factors range from 20 to 580,000. Most work situations would result in safety factors of more than 100. The average daily consumption of arsenic by humans in food and water is 80 micrograms. Arsenically treated wood poses minimal exposure because the arsenic is tightly bound to the wood. There are only limited data on the exposure of most other agricultural uses of arsenic. Exposure data are available for application of arsenic as a cotton desiccant. OSHA has set 0.2 mg/cubic meter as the permissible limit for the particulate polycyclic organic material of creosote.

Keywords: Preservatives, arsenicals, pentachlorophenol, creosote, coal tar, neutral oil, preservative treatments, wood products, human exposure, animal exposure, economic impact, alternatives, RPAR, benefit, risk, crossties, switch ties, poles, piling, posts, crossarms, lumber, timbers, plywood, wood foundation, millwork, canceled use, exposure analysis, home and farm use, sapstain, particleboard, groundline, herbicide, defoliant, mossicide, biocide, desiccant, growth regulator, fungicide, insecticide, rodenticide, sterilant, disinfectant, larvicide, acaricide, arachnicide, repellent, miticide, pesticide, EPA registration, service life, biologic and economic assessment, toxicity, marine borers, decay, termites, costs, natural durability.

# THE BIOLOGIC AND ECONOMIC ASSESSMENT OF

# PENTACHLOROPHENOL

# INORGANIC ARSENICALS

# CREOSOTE

## VOLUME I: WOOD PRESERVATIVES

A report of the Pentachlorophenol, Inorganic Arsenicals, Creosote assessment team to the rebuttable presumption against registration of Pentachlorophenol, Inorganic Arsenicals, Creosote

Submitted to the Environmental Protection Agency on November 4, 1980

UNITED STATES
DEPARTMENT OF
AGRICULTURE

*IN COOPERATION WITH*
STATE AGRICULTURAL EXPERIMENT STATIONS
COOPERATIVE EXTENSION SERVICE
OTHER STATE AGENCIES
U.S. ENVIRONMENTAL PROTECTION AGENCY

TECHNICAL BULLETIN
NUMBER 1658-I

# PREFACE

This report is a joint project of the U.S. Department of Agriculture, the State Land-Grant Universities, and the U.S. Environmental Protection Agency, and is the eighth in a series of reports recently prepared by a team of scientists from these organizations in order to provide sound, current scientific information on the benefits of, and exposure to, pentachlorophenol, inorganic arsenicals, and creosote.

The report is a scientific presentation to be used in connection with other data as a portion of the total body of knowledge in a final benefit/risk assessment under the Rebuttable Presumption Against Registration Process in connection with the Federal Insecticide, Fungicide, and Rodenticide Act.

This report is a slightly edited version of the report submitted to the Environmental Protection Agency on November 4, 1980. The editing has been limited in order to maintain the accuracy of the information in the original report.

The use of chemicals to extend the life and usefulness of wood and wood products is extremely important to agriculture and forestry. Durability of wood used in fence posts, animal holding pens, and outbuildings is a major concern to almost every American farmer and rancher. How long the life of wood and wood products can be extended greatly influences our ability to produce adequate supplies of timber and fiber from our forest lands. Pentachlorophenol (penta), which is widely used as a wood preservative, is effective against both bacteria and fungi as well as insects. In addition, its use in preventing sapstain that discolors lumber contributes substantially to the usefulness, acceptability, and beauty of most wood products. Primarily due to their cleanliness and paintability, the arsenical preservative compounds are being used more widely in lumber, timbers, and plywood. This trend is expected to increase with current concerns for aesthetics. Creosote and coal tar products have been used commercially as wood preservatives for over 150 years.

Wood preservatives have made it economically possible to use wood in a wide variety of applications for which it would be unsuitable without treatment. Without wood preservatives, the cost of replacing electric power poles, forest protection facilities, bridges, marine pilings, railroad ties, and other such wood products would make it much more difficult to remain competitive in local and world markets.

The information on agricultural uses, exposure, and economics of penta, arsenicals and creosote is published in two volumes. Volume I covers wood preservative uses for such items as poles, piling, crossties, lumber, timbers, and plywood. Volume II covers non-wood-preservative uses, such as herbicides, growth regulators, desiccants, fungicides, and disinfectants.

Sincere appreciation is extended to the Assessment Team Members and to all others who gave so generously of their time in the development of information and in the preparation of the report. However, in an effort this large the task of revising and editing the contributions and final production of the report was accomplished by a special committee. Members of this committee, which was responsible for the all-encompassing effort, are:

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Issued December 1981

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# SPECIAL TERMS, CHEMICALS AND ACRONYMS

| | |
|---|---|
| AAC | alkylammonium compounds |
| ACA | ammoniacal copper arsenate |
| ACI | American Concrete Institute |
| ADI | acceptable daily intake |
| ai | active ingredient |
| $AlCl_3$ | aluminum chloride |
| APA | American Plywood Association |
| AREA | American Railway Engineers Association |
| $As(OH)_3$ | arsenous acid |
| ASTM | American Society for Testing and Materials |
| $As_2O_3$ | arsenic trioxide |
| $As_2O_5$ | arsenic pentoxide |
| AWPA | American Wood-Preservers' Association |
| AWPB | American Wood Preservers' Bureau |
| AWPI | American Wood Preservers' Institute |
| AWWF | All Weather Wood Foundation |
| BaP | benz (a) pyrine |
| bd. ft. | board foot |
| BIA | Bureau of Indian Affairs |
| Btu | British thermal unit |
| Bu. Rec. | Bureau of Reclamation |
| $CaCO_3$ | calcium carbonate |
| $Ca_3(AsO_4)_2$ | calcium arsenate |
| $Ca(H_2PO_4)_2$ | calcium phosphate |
| CCA | chromated copper arsenate |
| CCT | creosote, coal-tar solution |

| | |
|---|---|
| $Cd_3$ | deuterated methyl |
| COD | chemical oxygen demand |
| $CrO_3$ | chromic acid |
| CSA | Canadian Standards Association |
| CTC | coal tar creosote |
| $CuCl_2$ | copper chloride |
| cu. ft. | cubic feet |
| Cu-Naph | copper naphthenate |
| CuO | copper oxide |
| $Cu(OH)_2$ | copper hydroxide |
| $Cu_2(OH)_2CO_3$ | copper carbonate (basic) |
| $CuSO_4$ | copper sulfate |
| Cu-8 | copper-8-quinolinolate |
| CZC | chromated zinc chloride |
| DBTO | dibutyltin oxide |
| DMN | dimethylnitrosamine |
| DOD | Department of Defense |
| DPM | disintegrations per minute |
| DS | diploid strain |
| Eh | electro potential |
| EMS | ethylmethanesulfonate |
| FAST | Facility for Accelerated Service Testing |
| FCAP | fluor chrom arsenate phenol |
| FDA | Federal Drug Administration |
| $FeCl_3$ | ferric chloride |
| FIFRA | Federal Insecticide, Fungicide and Rodenticide Act |
| g | gram |
| GC | gas chromatography |

| | |
|---|---|
| GLC | gas-liquid chromatography |
| GLC-MS | gas-liquid chromatography-mass spectrometer |
| GSA | General Services Administration |
| GTA | geothermal area |
| ha | hectare |
| $H_2S$ | hydrogen sulfide |
| $H_2SO_4$ | sulfuric acid |
| $H_3AsO_4$ | arsenic acid |
| HpCDD | heptachlorodibenzo-p-dioxin |
| HxCDD | hexachlorodibenzo-p-dioxin |
| IR | infrared |
| kkg | 1,000 kilograms |
| km | kilometers |
| KV | kilovolt |
| $K_2CO_3$ | potassium carbonate |
| $K_2Cr_2O_7$ | potassium dichromate |
| $K_2SO_4$ | potassium sulfate |
| $KH_2PO_4$ | potassium phosphate |
| $LC_{50}$ | lethal concentration to kill 50% of test specimen |
| $LD_{50}$ | lethal dose for 50% of test specimen |
| LPG | liquid petroleum gas |
| m | meter |
| metham (Vapam$^{TM}$ or SMDC) | sodium methyldithiocarbamate |
| mg | milligram |
| MIC | minimum inhibitory concentration |
| MP | mine pollution |
| mv | millivolt |
| NA | not applicable |

| | |
|---|---|
| NAHB | National Association of Home Builders |
| Na-penta | sodium pentachlorophenate |
| NASN | National Air Sampling Network |
| NBS | National Bureau of Standards |
| NCMA | National Concrete Masonry Association |
| ND | not detected |
| NFPA | National Forest Products Association |
| NIOSH | National Institute of Occupational Safety and Health |
| NMR | nuclear magnetic resonance |
| NOEL | no-observable-effect level |
| $NaAsO_2$ | sodium arsenite |
| $Na_2CrO_4$ | sodium chromate |
| $Na_2Cr_2O_7$ | sodium dichromate |
| $Na_2HAsO_4$ | disodium arsenate |
| $Na_4As_2O_7$ | sodium pyroarsenate |
| NaCl | sodium chloride |
| NaOH | sodium hydroxide |
| $NH_3$ | ammonia |
| $NH_4AsO_2$ | ammonium arsenite |
| $NH_4NO_3$ | ammonium nitrate |
| $NH_4OAc$ | ammonium acetate |
| OCDD | octachlorodibenzo-p-dioxin |
| OSHA | Occupational Safety and Health Administration |
| pcf | pounds per cubic foot |
| penta | pentachlorophenol |
| pK | dissociation constant |
| $pK_a$ | acid dissociation constant |
| PNA | polynuclear aromatics |

| | |
|---|---|
| POTW | publicly owned treatment works |
| ppb | parts per billion |
| ppm | parts per million |
| PPOM | particulate polycyclic organic materials |
| psi | pounds per square inch |
| $Pb_3(AsO_4)_2$ | lead arsenate |
| $PbHAsO_4$ | lead arsenate (std) |
| $Q_{10}$ | temperature quotient |
| ® | Registered trademark |
| RPAR | Rebuttable Presumption Against Registration |
| SFPA | Southern Forest Products Association |
| SP | smelter pollution |
| sq. ft. | square feet |
| $SbCl_3$ | antimony chloride |
| TBTO | tributyltin-oxide |
| TCA | trichloroacetate |
| TCDD | tetrachlorodibenzo-p-dioxin |
| thiram | bis(dimethy)thiocarbamoyl-disulfide |
| TLC | thin layer chromatography |
| $TL_m$ | no-effect-level for a toxicant on aquatic life |
| $TL_{50}$ | tolerance limit for 50% of population |
| TLS | track laying system |
| TLV | threshold limit value |
| TVA | Tennessee Valley Authority |
| TWA | time weighted average |
| UV | ultra violet |
| WWPA | Western Wood Products Association |
| Zn-Naph | zinc naphthenate |

# EXECUTIVE SUMMARY

The Environmental Protection Agency (EPA) issued notices of Rebuttable Presumptions Against Registration (RPAR) on creosote, inorganic arsenicals, and pentachlorophenol (penta) on October 18, 1978. The presumptions indicated that these products met or exceeded the risk criteria for various acute and chronic effects (40 CFR 162.11). Approximately 99% of of these chemicals are used in protecting wood products against wood-destroying organisms. The balance is used on a wide variety of sites as fungicides, herbicides, insecticides, rodenticides, defoliants, desiccants, growth regulators, sterilants, repellents, and disinfectants. It is estimated that 44.5 million pounds of pentachlorophenol, 42 million pounds of inorganic arsenicals, and 124 million gallons of creosote and coal tar are used annually.

There are no practical chemical alternatives to these RPAR'd materials for structural wood protection where the risk of attack by wood-destroying organisms is high. However, the RPAR'd materials could, in most cases, be used as alternatives for each other. This fact makes the task of evaluating the economic impact of a cancellation difficult. There are no practical alternatives (chemical and non-chemical) to the organic arsenicals as a cotton desiccant, grapefruit growth regulator, or for grape disease control and ant bait uses.

## Wood Preservative Uses

The cancellation of all three of the RPAR'd wood preservatives would result in higher costs of 4.5 to $6.3 billion annually depending on which combination of substitute materials is used. The total costs would be higher than this because the 4.5 to $6.3 billion accounts for only 86% of the pressure-treated wood products and does not include the 475 million cu. ft. of wood protected by non-pressure processes.

### Pressure Treatments

The loss of all preservatives on railroad ties would result in average annual cost increases of $2.1 billion as railroads shifted to concrete ties. Virtually all ties are currently treated with creosote. A cancellation of creosote alone would result in average annual cost increases of $36.8 million if railroads shifted to penta-treated ties.

The loss of all three preservatives for wood poles used by utilities would result in average annual cost increases of 1.9 to $2.8 billion depending on the combination of concrete and steel poles that would be substituted.

Because all three materials are used to treat utility poles, the cancellation of any one or two of them while retaining the others would result in different impacts. If only creosote were used, average annual costs would increase by $45.7 million; use of only inorganic arsenicals would result in cost decreases of $51.8 million; and use of only penta would result in cost increases of $27.1 million.

The substitution ratio between steel, concrete, and wood piling affects the economic impact. If use of all three preservatives were canceled and concrete piling were substituted for wood piling on a 1.0:1.5 basis, annual average cost would decrease by $21.5 million. However, if steel pilings were substituted on a 1.0:1.0 basis, costs would increase by $129.1 million. For technical reasons it is likely that substitution of concrete or steel for treated wood piling would fall somewhere between the ratios of 1.0:1.5 and 1.0:1.0. Therefore, the actual economic impact would lie between the figures presented.

The loss of all three preservatives on fence posts probably would not result in any significant cost changes if users shifted to steel posts. However, wood posts are often preferred to steel for aesthetic reasons.

The loss of all three wood preservatives for treating lumber, timbers, and plywood would cost from 485 million to $1,279 million depending on the combination of alternatives used. Alternatives include untreated cedar, redwood, or pine, concrete, steel, and chromated zinc chloride treatments. About 70% of all treated lumber, timbers, and plywood is treated with inorganic arsenicals. Neither creosote nor penta is a satisfactory alternative for these uses.

### Non-Pressure Treatment

The cancellation of both penta and creosote for groundline treatment of utility poles would result in increased costs of $35.3 million annually. Because penta and creosote are equally effective, with equal treatment costs, the loss of either one while retaining the other would not result in significant cost changes.

The loss of penta for sapstain control in lumber would result in a shift to Cu-8 with increased costs of $280,000 annually. The loss of penta for millwork and plywood would result in a shift to TBTO at an increased cost of $2.2 million or to Cu-8 at an increased cost of $4.8 million.

## Non-Wood-Preservative Uses

### Pentachlorophenol and Pentachlorophenates

The non-wood-preservative uses of penta are: Herbicide, defoliant, mossicide, and biocide.

There are effective chemical alternatives for all of the non-wood-preservative uses of penta. The alternatives accomplish the desired results at equal or lower cost. The impact of canceling penta for these uses would, therefore, be negligible.

### Inorganic Arsenicals

The non-wood-preservative uses of arsenicals are: Desiccant, growth regulator (grapefruit), fungicide, insecticide, rodenticide, herbicide, and soil sterilant.

Of the 12 non-wood-preservative uses of arsenicals addressed, there are effective chemical alternatives for some, most of which can be used at equal or slightly higher cost. The four uses for which suitable alternatives are not available are: arsenic acid (cotton desiccant), lead arsenate (growth regulator--grapefruit), sodium arsenate (ant bait), and sodium arsenite (Black Measles--grapes). In addition, alternatives are not as effective as calcium arsenate for Poa annua control in turf, or for slug and snail control in California citrus.

Cancellation of arsenic acid for desiccation of cotton would reduce annual revenues of cotton producers in Texas and Oklahoma by an estimated 20.3 to $49.9 million. Cancellation of lead arsenate for use on grapefruit as a growth regulator would reduce annual revenues of Florida producers by $5.8 million. If sodium arsenate were canceled for ant bait, householders could shift to other materials that would need to be applied more frequently, but total costs would be similar; however, if commercial extermination is selected as the control measure, the annual increased cost would be $42 million. Loss of sodium arsenite for control of Black Measles would result in increased vineyard establishment costs and losses from reduction in grape yields and quality totaling $13.3 million for producers of fresh market grapes and $11.0 million for producers of raisin-type grapes over a 6-year period following cancellation.

### Creosote, Coal Tar, and Coal-Tar Neutral Oils

The non-preservative uses of creosote, coal tar, and neutral oils are: Disinfectant, larvicide, insecticide, fungicide, herbicide, acaricide, arachnicide, and animal repellent.

Of the 15 non-wood-preservative uses of these chemicals addressed, only 5 are significant from the standpoint of frequency of use and volume of material applied. Drain fly and gypsy moth control (spraying undercarriage of vehicles) are two uses for which registered alternative chemicals are not available.

## Fate in the Environment

Penta is ubiquitous in aquatic environments and its sources are unclear. It may result from direct contamination, from degradation of other organic compounds, or from chlorination of water. Penta may be removed from aquatic environments by volatilization, photodegradation, absorption, or biodegradation. Penta's moderate volatility suggests that volatilization may be a route to the atmosphere, but this is highly speculative. Persistence of penta in soil is extremely variable depending on pH, organic content, moisture content, clay mineral composition, free iron content, ion exchange capacity, and the microorganisms present.

Movement, persistence, and fate of arsenate in the environment are well known. Arsenate forms very insoluble compounds in soil and is generally moved only by erosion to aquatic environments where it may be adsorbed to sediment and removed from solution, adsorbed to plants, or ingested and metabolized by aquatic organisms. Under anaerobic conditions arsenate may be reduced to arsenite and metabolized to volatile alkylarsines. Volatilized arsenicals can be adsorbed on dust particles and oxidized to arsenate, methanearsonate, or cacodylate. Plants do not accumulate large quantities of arsenic if they grow well. Oceanic sediments are the ultimate sink for all arsenic.

Data on the environmental fate of the many chemical components of creosote and coal tar are limited. Naphthalene and its derivatives are rapidly biodegraded in both soil and water. The higher-boiling-point compounds such as fluorene, chrysene, anthracene, and pyrenes are much more slowly decomposed than naphthalenes. Available data are much too limited, however, to permit more than speculation on decomposition rates. Some studies have shown that reductions of these compounds in marine environments proceed exponentially with time and that residual amounts fall below the detection limit within 2 to 3 weeks.

## Exposure

The no-observable-effect level for fetotoxicity of penta cited by EPA is 5.8 mg/kg/day. This value, divided by actual exposure, gives the safety factor. Varying exposures gave safety factors ranging from 20 to 580,000 for penta and 868 to 25 million for HxCDD. It is expected that the exposure in most work situations will result in safety factors above 100.

Arsenic is present in all water, food and air. Average daily consumption of arsenic by humans in food and water in the United States is 80 micrograms. Exposure to people handling pressure-treated wood is minimal because arsenic is tightly bound and very insoluble. Urine analyses of exposed workers at a fabricating plant were no higher than the general population.

There are no exposure estimates for most non-wood-preservative applications of arsenicals; however, one study of arsenic acid found daily exposure estimates of 13, 9, and 9 micrograms/kg/day for ground rig applications, aerial applications, and ground crews, respectively. Considering the time spent using arsenic in a year, annual exposure estimates were 0.4, 0.2, and 0.8 micrograms/kg/day for these applications. Exposure to bait formulations of sodium arsenate or calcium arsenate would be negligible.

Exposure limits have not been established for chemical components of creosote; however, OSHA has set a permissible limit of 0.2 mg/cubic meter for the particulate polycyclic organic material of this preservative. Cooperative studies by NIOSH and the wood preserving industry showed that actual exposure levels generally fall well within the OSHA limit.

# SUMMARY

In October 1978, the U.S. Environmental Protection Agency (EPA) placed on record a notice of Rebuttable Presumption Against Registration (RPAR) of pesticides containing pentachlorophenol, inorganic arsenic, coal tar, creosote, and coal tar neutral oil.

This report has been prepared by a team of scientists from the U.S. Department of Agriculture, the State Land-Grant Universities, and the Environmental Protection Agency to provide the best data available on exposure to and benefits from the RPAR'd pesticides, as required by the RPAR process.

## The RPAR'd Chemicals

### Pentachlorophenol (Penta)

Commercial synthesis of penta is accomplished by direct chlorination of phenol. Penta and its salts are highly effective, broad-spectrum biocides. Penta is widely used as a wood preservative, normally carried in a petroleum solvent. A small quantity is converted to the sodium or potassium salt and carried in water solvent. The following compounds and their uses are addressed in this volume.

Pentachlorophenol (Penta)--wood preservative.
Sodium Pentachlorophenate (Na-penta)--sapstain control (lumber and poles).

### Inorganic Arsenicals

Arsenic is produced as a by-product of the nonferrous smelting industry. It has many uses in forestry, agriculture, and commerce. Restriction of its use would increase waste disposal problems of smelters. The following uses are addressed in this report:

Chromated Copper Arsenate (CCA)--wood preservative.
Ammoniacal Copper Arsenate (ACA)--wood preservative.
Fluor Chrome Arsenate Phenol (FCAP)--wood preservative.

### Coal Tar, Creosote, and Neutral Oil

Coal tar is a by-product from coking of bituminous coal. Creosote is a complex mixture of organic chemical products of fractional distillation of coal tar. Neutral oil is also a coal tar fraction. Coal tar is used in a number of pesticides and is used, in combination with creosote, as a wood preservative. Creosote is used alone or in combination with coal tar or petroleum as a wood preservative. Creosote, coal tar, and neutral oil are used in a number of other pesticides. Specific uses addressed in this volume are wood preservatives.

## Triggers

EPA has determined that penta meets or exceeds risk criteria relating to teratogenic and/or fetotoxic effects on mammalian test species; that inorganic arsenic meets or exceeds risk criteria relating to oncogenic, mutagenic, and reproductive or fetotoxic effects on mammalian species; and that creosote, coal tar, and neutral oil meet or exceed risk criteria relating to oncogenicity.

This report of exposure to and benefits from the RPAR'd pesticides is divided into two parts: Wood preservative uses and non-wood-preservative uses. Wood preservatives are covered in Volume I and non-wood-preservative uses in Volume II. Only the impacts of canceling one or more of the chemicals for use on one or more sites are considered. Analysis of regulatory options short of cancellation is not included.

## Wood Preservative Uses

In 1978, about 631 commercial treating plants treated an estimated 327.5 million cubic feet of crossties and switch ties, poles, piling, fence posts, lumber, timbers, plywood, and "other" miscellaneous wood products. About 47% of total volume was treated with creosote and creosote-coal tar solutions (123.7 million gallons), 25% was treated with penta (40 million pounds), and 28% was treated with arsenical salts (37.2 million pounds). Volumes of the various commodities treated with each of the major preservatives are estimated to be as follows:

| Product | Volume Treated With | | |
|---|---|---|---|
| | Creosote Solutions | Penta | CCA/ACA/FCAP |
| | 1,000 cubic feet | | |
| Crossties, switch ties, and landscape ties | 103,138 | 449 | 2,498 |
| Poles | 18,237 | 41,905 | 4,038 |
| Crossarms | 41 | 1,615 | 29 |
| Piling | 9,993 | 1,154 | 943 |
| Lumber and timbers | 10,780 | 21,209 | 73,317 |
| Fence posts | 4,584 | 10,983 | 4,461 |
| Other products | 7,815 | 2,681 | 7,616 |
| Total | 154,587 | 79,996 | 92,903 |

About 99% of the creosote solutions, 90% of the penta, and all of the arsenical salts in the preceding tabulation are applied by pressure methods in closed systems. A small amount of creosote, and about 3.8 million pounds of penta, are applied by commercial thermal and dip treatment methods in open tanks.

In addition to the above, penta and creosote are used for non-pressure treatment of a variety of products. Estimates of the preservatives used and products treated are as follows:

Groundline treatment of utility poles in service--172,000 pounds penta and 655,000 pounds creosote applied at and below the groundline. Approximately 1 million poles treated annually.

Sapstain control in green lumber and poles--1.02 million pounds penta (1.15 million pounds Na-penta) applied by dip or spray to about 255 million cu. ft. of wood products.

Millwork--600,000 pounds penta (5% penta in mineral spirits) used for dip or spray treatment of 60 million cu. ft. of millwork and 15 million sq. ft. of plywood.

Particleboard--less than 10,000 pounds penta used for spray treatment of furnish for 178,000 sq. ft. of particleboard.

Over-the-counter sales--1.5 million pounds penta (5% solution in light oil) and 1.5 million pounds creosote sold for farm and home use in brush, spray, dip, or soak treatment of lumber, posts, and other wood products.

## Exposure to Wood Preservatives

Generally, all preservative chemicals used in commercial treating plants are received, transferred, mixed, stored, and applied in closed systems where occasional leaks are the only sources of slight human contact. Handling of freshly treated wood is highly mechanized; thus, dermal exposure of employees is minimal. Some inhalation exposure to penta and creosote vapors and particulates occurs, especially in plants that use thermal and dip treatments in open tanks. Potential for dermal exposure is also greatest in these plants. The extent of exposure depends on type of protective clothing worn and the personal hygiene of the workers. Exposure to the various wood preservatives is summarized as follows:

### Penta

It is estimated that 4,400 production workers and 800 non-production workers encounter some degree of inhalation exposure at 295 pressure treating plants. Potential dermal exposure is limited to mixing and formulating operations and handling of treated wood. An additional 750 production workers and 100 non-production workers are exposed to some extent in commercial thermal- and dip-treatment plants. When tanks contain heated solutions, potential for inhalation exposure is enhanced.

An estimated 300 workers are involved in groundline treatment of poles. The likeliest form of exposure is dermal and the extent depends on the level of personal hygiene employed.

It is estimated that 20,000 production and 4,000 non-production workers may encounter some exposure to Na-penta during dip or spray treatment of wood for sapstain control. In view of the extremely low volatility of the salt in aqueous solution, most human exposure would be dermal and would probably be lower than that encountered in conventional thermal and dip treating operations.

An estimated 3 to 6 million people use the 5% penta solutions purchased over-the-counter each year. This exposure would be intermittent and infrequent. Ventilation in the application area and the care with which the liquid is applied are major factors influencing extent of exposure. With care, exposure can be low.

Workers who handle, install, inspect, and maintain treated wood are subjected to varying degrees of exposure. Poles and piling are usually installed mechanically, but require some manual contact for attachment of fittings, etc. Considerable manual contact is involved in installing lumber, timbers, plywood, crossarms, and fence posts. Installers range from do-it-yourselfers who handle treated wood infrequently to linemen or contractors who work with the material routinely. Exposure by inhalation is low. Exposure by skin contact varies from low for workers who use protective clothing to occasionally high for those who do not use gloves, etc. The latter situation is usually the case with irregular users of treated wood such as farmers and homeowners.

Limited exposure to penta is expected among members of the public who have occasional contact with treated wood, but is far lower than that experienced by occupationally exposed persons.

Quantitative estimates of exposure of humans to penta (both occupational and non-occupational) are included in the report. It is considered highly unlikely that penta inhalation among individuals in the wood-treating industry will exceed 0.07 mg/kg/day (safety factor 81). Recent data suggest that in a closed structure, under worst-case conditions, volatilization of penta from treated wood may result in ambient penta air levels approximating those found in wood-treating plants. Potential human exposure ranges from 0.0006 to 0.0219 mg/kg/day (safety factors of 4,142 to 265).

It is extremely difficult to estimate potential human dermal exposure to penta since this is highly dependent on personal hygiene. If complete dermal absorption is assumed, skin exposure to 5 ml. of a 7% solution of penta in oil will result in a dose of 5 mg/kg. This is based on the material remaining on the skin long enough for 100% absorption--a likely overestimate. Contact with treated wood is expected to result in very low penta absorption if the wood is dry and free from blooming.

Penta is ubiquitous in the aquatic environment. Circumstantial evidence, including the detection of penta in rain water, indicates that penta may occasionally be present in ambient air. Low levels of the compound have been detected in both wastewater and surface water. The source of these residues is often unclear and it has been suggested that, in addition to direct contamination of water by penta, degradation of other organic compounds or chlorination of water may result in the chemical production of the compound.

Penta in water may be removed by volatilization, photodegradation, absorption, or biodegradation. Penta is subject to rapid photodegradation under laboratory conditions. Microorganisms capable of metabolizing penta in soil and water have been identified and are used commercially in the treatment of penta containing waste water. Penta is moderately persistent in the aquatic environment, and was reportedly detected in lake water and fish 6 months after an accidental spill. The prevailing use patterns of penta, primarily as a wood preservative, should preclude significant contamination of water as long as spills and industrial accidents are prevented.

Penta is moderately persistent in soil. Published data indicate that persistence ranges from 21 days to 5 years. Under most conditions, penta will seldom persist in the soil for periods exceeding 9 months and its half-life will frequently be far less. Numerous studies have identified soil microorganisms capable of penta degradation. The extent of their distribution, however, is again unknown. In most studies of penta biodegradation, acclimated populations of microorganisms have been utilized. Penta is strongly sorbed to soil; hence, leaching through the soil profile and contamination of groundwater is considered unlikely. Since the major use of penta (wood preservation) does not involve application to the soil, the likeliest source of soil contamination is leaching or bleeding of the preservative from treated wood. Such phenomena may result in low levels of penta contamination in the immediate vicinity (several inches) of the treated structure.

Available data indicate that penta is not readily translocated by plants and that the compound is rapidly eliminated in both free and conjugated forms by mammals following exposure. Therefore, significant accumulation in plants and mammals is not likely to occur. It has been shown that technical penta preparations are sometimes contaminated. Chlorodibenzo-p-dioxins and chlorodibenzofurans are present in commercially available penta, as a result of the manufacturing process. The highly toxic 2,3,7,8-tetrachlorodibenzo-p-dioxin has never been found in penta of United States manufacture and has not been detected as a product of penta decomposition.

## Inorganic Arsenicals

The quantity of arsenic used in treatment of wood has more than tripled since 1970. In 1978, there were an estimated 325 treating plants treating with arsenical preservatives in the United States. These plants employed about 3,000 people, less than half of which worked in the treating area. The cylinder operator, unloader, and the stackers of treated wood receive the greatest exposure to arsenic.

The method of handling treated wood varies with the product treated. Poles, piling, and other large members are handled mechanically, and not by hand. Little or no treated wood is handled while it is wet. Treated wood that is to be kiln-dried is allowed to drip and air-dry before it is stacked and stickered by workers wearing protective equipment. There is little exposure of workers in CCA and ACA treating plants. Exposure has been lessened in recent years by OSHA regulations, cessation of production of FCAP dusts, and general awareness of safety.

All arsenicals are used in closed systems. There are no thermal or dip treatments. There are no known groundline treatments of utility poles, nor are there any non-commercial brush, dip, or spray treatments.

Those who handle, install, inspect, and maintain treated poles, piling, timbers, and other products are not likely to be exposed. The products will usually have dried in storage for several weeks, been transported, handled several times during loading and unloading, and weathered during this period of time. These factors, plus the fact that pentavalent arsenic is tightly bound to the wood, make the treated material an unlikely source of exposure.

Wipe tests show limited exposure to arsenic from handling treated wood. A study showed no apparent health hazard to consumers via vaporization, leaching, or other mechanism.

Carpenters or homeowners working with arsenically treated lumber, timbers, plywood, fence posts, etc., are exposed through sawdust and handling to limited amounts of arsenic.

Arsenic can be found in all components of the environment naturally or as a result of human activity. Levels are generally quite low except around smelters or where large applications of lead arsenate were made over many years (a use no longer permitted).

No problems have been found in the literature relative to the effects of arsenical wood preservatives on the environment. Arsenate, the form present in aerobic soils, is bound tightly to soil components and becomes unavailable for plant uptake or leaching. Arsenic in water is sorbed by sediments and becomes unavailable to aquatic plants or animals. Phytotoxicity has been observed in apple orchards treated with large amounts of lead arsenate, but plant residues are generally low. Other instances of phytotoxic arsenic levels are rare. Arsenic does occur naturally in aquatic organisms. Marine algae and seaweed contain appreciable amounts of arsenic bound in organic compounds.

## Creosote

An estimated 4,000 people are employed at about 188 pressure treating plants that treat with creosote solutions. Human contact with the preservative is minimized, but some of these workers are exposed to occasional high exposure by inhalation. About 100 workers are involved in commercial thermal and dip treatment. Some of these undergo consistently high inhalation exposure.

The largest numbers of people exposed to creosote, estimated to be 50,000, are those who apply it on-the-job, such as farmers, carpenters, and homeowners. Skin contact and inhalation may be high on occasion; but it is infrequent, perhaps only once to a few times per year.

Inhalation or skin contact to applicators is minimal in groundline treatments of standing utility poles.

During handling, storage, and installation of any creosoted items, there may be moderate inhalation of volatiles, especially on hot days with little wind. The largest numbers of individuals so exposed would be those installing fence posts, lumber and timbers, and railroad material. Once creosoted items are in place, the incidence of human contact is small because most of the wood is used outdoors and is wholly or partly buried in the soil.

There are no recorded instances of wild or domestic animals being injured by creosote. Creosote can be toxic to fish and other marine life, however, where it or wastewater containing creosote pollutes lakes or streams.

The amount of creosote as liquid that enters the environment is relatively small. Estimated liquid discharge from all wood-preserving plants using creosote in the United States totals 9 pounds of phenolic compounds and 68 pounds of "oil and grease" per day. The fate of creosote in the environment is not known, but some components are rapidly biodegraded. Phenols removal in soil exceeds 99%.

Creosote may be lost from treated wood by evaporation, exudation, or leaching. Some of the lower distilling fractions are lost very soon after the wood is treated, but the remainder is very slow to be lost. Exuded liquid moves into soil a few inches before biodegradation.

## Alternatives to Pressure-Treated Wood and Impacts of Cancellation

An estimated 327.5 million cu. ft. of wood products were treated with creosote, penta, and inorganic arsenical preservatives by about 631 wood-preserving plants in 1978. Total production of treated wood between 1970 and 1978 increased at an average annual rate of 3.2%. Volume treated with creosote during the period declined slightly at a rate of 0.8% annually, while volumes treated with penta and arsenicals increased at average annual rates of 2.5% and 18.9%, respectively.

The most dramatic change during the 8-year period was in treatment of lumber and timbers. Volume treated in 1978 was more than double the volume treated in 1970. The percentages of these products treated with creosote and penta both declined, while the percentage treated with arsenicals increased from 39 to 70. In terms of total treated wood, the percentage treated with creosote declined from 65 to 47; penta's share remained fairly constant at about 25%; and the percentage treated with arsenicals tripled from 9 to 28.

The South led the Nation with 55% of the treating plants, which produced 57% of the treated wood. The balance of the production was divided among the Northeast Region--8%, North Central Region--17%, Rocky Mountain Region--5%, and the Pacific Region--14%.

Based on information developed from the 1977 Census of Manufactures, it is estimated that the wood-preserving industry employed 13,300 people; paid $140 million in wages; spent $796 million for wood raw materials, preservative chemicals, fuels and other materials and supplies; added $388 million in value; and shipped 327.5 million cu. ft. of treated wood products with a value of $1,086 million in 1978. We estimate that an additional 17,400 jobs in producing, harvesting, and processing wood raw materials were dependent on the wood-preserving industry. This does not include employment generated by the production, distribution, and sale of some $206 million worth of preservative chemicals and other materials and supplies. The value of all products treated in 1978, at prices quoted in late 1979, is estimated to be about $1.46 billion, f.o.b. treating plant.

The wood-preserving industry provides markets for more than 500 million cu. ft. of standing timber. Much of the industry's raw material comes from relatively low-quality trees and logs which are not suitable for higher value uses, or from species for which there would be few, if any, markets without preservative treatment. The industry, thus, provides markets for large volumes of materials that could not otherwise be sold at a profit and, thereby, contributes to sound forest management and improvement of the forest environment in many areas of the United States.

The benefits of wood preservation in the form of employment, wages, and payments for wood raw materials, chemicals, and other materials and supplies accrue to many thousands of citizens directly and indirectly dependent on the industry in more than 500 communities throughout the land. Most of these are small, rural towns in which the wood-preserving plant and the production and processing of wood raw materials are major sources of employment and income.

Except for a sizable volume of arsenically treated materials, suitable chemical alternatives exist for all treated wood products. Cancellation of any of the three RPAR'd preservatives for any or all of its uses would, in most cases, lead to use of an alternate preservative rather than to use of a non-wood substitute. In many cases, if two of the three preservatives were canceled, the remaining preservative could be used as an alternate. For most arsenically treated lumber, timbers, and plywood, and for some arsenically treated poles and posts used in applications where cleanliness, paintability, and freedom from odor or volatile components are required, neither creosote nor penta is a suitable substitute. In these cases, cancellation of arsenicals would result in a shift to untreated wood or to a non-wood substitute (i.e., concrete or steel).

## Cancellation of Creosote

The costs, advantages, and disadvantages of chemical alternatives to creosote are summarized below. Crossties and switch ties (67%) and poles (12%) account for the bulk of creosote-treated wood, followed by lumber and timbers (7%), piling (6%), and fence posts (3%). The remaining 5% is "other" miscellaneous products which are not included in the cost analysis.

Crossties and switch ties could be shifted from creosote to penta with a reduction in service life from 35 to 25 years. Due to the lower cost of treating with penta, the cost per tie would be slightly less than for creosote. However, due to the shorter service life of penta-treated ties, the number of ties required, the annual investment, and the annualized cost to railroads would be substantially higher than for creosote.

All other creosote-treated products, with the exception of piling, lumber, and timbers used in marine applications, could be shifted to either penta or CCA/ACA. Material for marine use would require treatment with arsenicals.

Cancellation of creosote and a shift to penta where applicable would require an estimated $5.2 million investment to convert treaters from creosote to penta. First-year cost, if amortized over 10 years at 12% interest, would be $1.1 million. If one assumes continued production of these treated products at the estimated 1978 rate, 57 million pounds of penta and 101 million gallons of petroleum solvent would be required, annually, to replace creosote. This would be a 142% increase in the estimated 1978 industry consumption of penta and oil. Penta supply problems and production delays would likely result. Substantial capital investment would be needed to increase production of penta. The price of penta would probably be affected.

Based on late 1979 prices of preservative chemicals and treated wood products, the value (cost) of treated products would decrease by more than $26 million due to the lower cost of treating with penta. About $18 million of this apparent saving is in the lower initial cost of penta-treated crossties and switch ties. Due to their shorter service life, the average annual cost of using penta-treated ties would be $36.8 million higher than for creosote. Thus, the net result of switching to penta for all products now treated with creosote would be an increase in the annual cost of these treated products amounting to 28.4 to $28.8 million.

Inorganic arsenicals could be used in place of creosote for about one-third of the creosote-treated wood (all products except crossties and switch ties). Depending on which alternatives were chosen for piling, lumber, and timbers, an estimated 18 to $22 million investment would be required to convert treaters from creosote to arsenicals. First-year cost, amortized over 10 years at 12% interest, would be 4.0 to $4.8 million. If one assumes continued production of treated products at the 1978 rate, 26 to 34 million pounds of arsenicals would be required annually, to replace 45 million gallons of creosote--a 70% to 90% increase in estimated 1978 industry consumption of arsenicals. This increase in demand would probably necessitate investment in facilities for expanded production of arsenicals and would most likely affect the price of these chemicals.

Based on late 1979 prices of preservative chemicals and treated wood products, the value (cost) of treated products would be reduced by 16.2 to $20.2 million, assuming that arsenically treated material would be shipped wet. These indicated savings would be reduced by the high cost of converting treating facilities from creosote to arsenicals, by any increase in price of arsenicals that might result from the increased demand, by the cost of redrying any of the products treated with arsenicals, and by the probable need for additional treatment to protect some arsenically treated products from weather and mechanical wear in use.

## Cancellation of Penta

The costs, advantages, and disadvantages of chemical alternatives to penta are summarized below. Poles (52%), lumber and timbers (27%), and fence posts (14%) account for the bulk of penta-treated wood, followed by crossarms (2%) and piling (1.5%). About 3% is "other" miscellaneous products which are not included in the cost analysis. All of these products could be treated with either creosote or inorganic arsenicals. Due to cleanliness, freedom from odor, ease of handling, and lower cost, lumber and timbers would most likely be converted to arsenicals.

Cancellation of penta and a shift to creosote for all products except lumber and timbers (73% of penta-treated wood) would require an estimated $2.3 million investment to convert treaters from penta to creosote. If amortized over 10 years at 12% interest, first-year cost would be $500,000. Assuming continued production of these treated products at the estimated 1978 rate, 47 million gallons of creosote would be required, annually, to replace 23.5 million pounds of penta and 41.6 million gallons of petroleum solvent. This would be a 38% increase in estimated 1978 industry consumption of creosote. Supplies of creosote appear adequate for such an increase. Due to its high fuel value and resultant relationship to the price of petroleum, creosote can be expected to increase in price at about the same rate as the price of penta in oil. At late 1979 prices of preservative chemicals and treated wood products, the value (cost) of treated products would increase by $10.5 million due to the higher cost of treating with creosote.

Cancellation of penta and a shift to arsenicals for all products, including lumber and timbers, would require an estimated $40 million investment to convert treaters from penta to arsenicals. First-year cost, if amortized over 10 years at 12% interest, would be $8.8 million. If one assumes continued production at the estimated 1978 rate, 41.3 million pounds of arsenicals would be required, annually, to replace 35.3 million pounds of penta and 62.5 million gallons of petroleum solvent. This 111% increase in estimated 1978 industry consumption of arsenicals would probably necessitate investment in expanded production of arsenicals, and would most likely affect the price of these chemicals.

Based on late 1979 prices of preservative chemicals and treated wood products, the switch from penta to arsenicals would reduce the value (cost) of treated wood products by $28.7 million, assuming that arsenically treated material would be shipped wet. This apparent saving would be reduced by the high cost of converting treating facilities from penta to arsenicals, by any increase in price of arsenicals that might result from the increased demand, and by the cost of redrying any of the products treated with arsenicals.

## Cancellation of Arsenicals

The costs, advantages, and disadvantages of chemical alternatives to CCA/ACA are summarized below. Lumber and timbers (79%), fence posts (5%), and poles (4%) make up the bulk of arsenically treated wood, followed by landscape ties (3%) and piling (1%). About 8% is "other" miscellaneous products which are not included in the cost analysis.

Most arsenically treated lumber and timbers (about 86%) and some posts and poles are used in construction of buildings or other applications where clean, paintable, odorless treatment is required. Material for these uses cannot be shifted to either creosote or penta in heavy oil. In addition, arsenically treated products for marine use cannot be converted to penta. Thus, it is estimated that about 30% of CCA/ACA-treated wood could be shifted to creosote, and only 25% could be shifted to penta. Except for some limited above-ground, interior applications where chromate zinc chloride (CZC) might be substituted, cancellation of arsenicals would eliminate the availability of treated wood for use in confined, unvented, habitable space and for many residential, industrial, commercial, agricultural, and recreational uses where neither creosote nor penta could be substituted. About 70% of the market for arsenically treated materials would be lost to untreated wood or to non-wood substitutes. In addition, an effective, low-cost alternative to creosote and/or penta would be lost.

Conversion of about 30% of the CCA/ACA-treated wood to creosote would require an estimated $16 million investment to convert treaters from arsenicals to creosote. First-year cost, amortized over 10 years at 12% interest, would be $3.5 million. About 21 million gallons of creosote would be required, annually, to replace 15 million pounds of arsenicals. At late 1979 prices for preservative chemicals and treated wood products, the value (cost) of treated products would be $9.7 million higher than CCA/ACA-treated material shipped wet.

If about 25% of the CCA/ACA-treated wood were converted to penta, an estimated $12.5 million investment ($2.75 million the first year at 12% interest over 10 years) would be required to convert treaters from arsenicals to penta. About 6.7 million pounds of penta and 12 million gallons of petroleum would be required, annually, to replace 7.7 million pounds of arsenicals. The value (cost) of treated products would be $5.2 million higher than CCA/ACA-treated products shipped wet.

In addition to the increased costs associated with conversion of 25% to 30% of the arsenically treated wood to penta or creosote, there would be large costs associated with the use of untreated wood or non-wood substitutes for the 70% of CCA/ACA-treated wood that could not be converted. Average annual costs to users of this material would be increased by an estimated 283 to $1,007 million, depending on which substitutes were used for CCA/ACA-treated wood in its various applications. Thus, if arsenicals were canceled for all uses, the least-cost combination of substitutes would add about $293 million to annual costs of users. If untreated, non-durable species of wood were substituted wherever they might be used, annual costs would be increased by $1,087 million.

Finally, the loss of markets for 70% of the CCA/ACA-treated wood, due to cancellation of arsenicals, would have a severe impact on the wood-preserving industry and on its suppliers of wood and other raw materials and supplies. Recent growth trends in the wood-preserving industry would be halted. Few of the 221 treating plants that treat only with arsenicals would survive. Another 104 plants that treat with arsenicals, along with other preservatives, would also be affected. Losses are estimated to include 2,600 jobs in the treating industry and $28 million in wages, mostly in small plants in small, rural communities. In terms of value of products shipped, losses would approximate $400 million, consisting of the wages cited above, and payments to producers and processors of wood raw materials. There would be additional losses in production, distribution, and sale of preservative chemicals ($37 million worth of arsenicals in 1978) and other materials and supplies to the treating industry, and lost investments in treating facilities and equipment put out of business by such action. Substantial losses of secondary benefits to merchants, businesspersons, and others in communities where impacted treating plants are located would also result. Because 80% of arsenically treated materials is southern pine, these losses would be concentrated in the South Central and Southeastern regions. These impacts would be immediate and would continue until such time as affected individuals and resources could be put to other gainful uses. The extent and effect of offsetting cross-sectoral and regional shifts in employment and income have not been evaluated.

To the extent that users of treated products would switch to use of untreated wood, cancellation of arsenicals would result in increased employment in logging and sawmilling to produce the increased volumes of untreated products that would be required. The extent of such a switch, and its effect on the impacts described above, have not been evaluated.

## Cancellation of Creosote, Penta, and Arsenicals

The costs, advantages, and disadvantages of alternatives to treated wood are summarized below. Costs associated with the loss of 700,000 cu. ft. of creosote-treated block flooring, 1.6 million cu. ft. of CCA/ACA-treated foundation materials, 2.9 million cu. ft. of penta- and CCA/ACA-treated ties, 1.7 million cu. ft. of treated crossarms, and 18 million cu. ft. of "other" miscellaneous products are not included. Also, owing to the wide variation in types and cost of substitutes for treated fence posts, no estimates were made of the costs of substituting untreated wood or metal for treated posts. Together, these products comprise about 14% of all treated wood. Therefore, the costs given below represent the estimated benefits to the U.S. economy from 86% of the treated wood produced and used in 1978.

If all preservatives were canceled, users would probably switch to untreated wood for some applications of treated lumber and timbers, to concrete for crossties and switch ties, and to concrete or steel for poles, piling, and the remainder of the lumber and timbers. If concrete was used for crossties, poles, and piling, and untreated wood or concrete was used where applicable for lumber and timbers, the present value of future costs of using these substitutes would be 47.2 to $55.4 billion higher than for treated wood, depending on which combination of untreated wood and concrete substitutes was used.

If steel poles and piling were used instead of concrete in the above analysis, the present value of future costs of substitutes would exceed that for treated wood by 57.1 to $65.3 billion.

Based on this analysis, direct savings to consumers of treated wood railroad ties, poles, piling, lumber, timbers and other products average an estimated 4.5 to $5.3 billion, annually, compared to various combinations of untreated wood and concrete substitutes. If steel is used instead of concrete for poles and piling, the annual savings from use of treated wood increase to an estimated 5.5 to $6.3 billion. Additional savings from use of the 14% of treated wood not included in the analysis would increase the totals given above.

In addition to these direct economic losses to consumers of treated wood, cancellation of wood preservatives would have serious impacts on the wood-preserving industry and its suppliers in terms of losses of employment, capital investment, and community facilities. Substantial investments in plant and equipment used in timber harvesting, wood processing, and wood treatment would be lost.

An estimated 30,700 people were employed in treating plants and related timber production, harvesting, and processing operations in 1978. Wages paid to these workers and payments for wood raw materials totaled $650 million; an additional $286 million was spent for preservative chemicals and other materials and supplies, including fuels and electrical energy. In 1978, the industry shipped treated wood products valued at $1.46 billion at 1979 prices.

These benefits accrue to many thousands of citizens directly and indirectly dependent on the industry in more than 500 communities, most of which are small, rural towns in which the production, processing, and preservation of wood products are major sources of employment and income. Finding new jobs for workers displaced by cessation of wood-treating operations could entail substantial transfer costs to many families. Many workers might not find new jobs because of a lack of opportunities in some areas, or a lack of skills required in other industries. Many would be at least temporarily dependent on unemployment insurance and welfare.

Many small forest landowners who supply raw materials to the treating industry also would suffer economic losses if markets for treated wood were no longer available. Although some consumers might turn to untreated wood, thereby increasing demand for timber products, the ultimate result of the high cost of using untreated material would be a general loss in wood markets, and loss of cash income for many small woodlot owners, through extensive substitution of other structural materials.

Poles, posts, ties, mine timbers, and most other products generally treated today can be made from relatively small trees or from grades of material or species for which markets would otherwise be very limited. Loss of markets for this material would have a detrimental effect on timber management and the forest environment in many areas of the United States.

## Limitations of the Analysis

The projected savings to consumers from use of treated wood (costs of cancellation) are based on the assumption that supplies of alternative chemicals or alternative materials are sufficient to meet increased demands at current (1979) prices. In reality, shortages are likely to develop if any or all of the wood preservatives are canceled. Production delays, capital investments required to increase production of alternatives, and any increase in prices of alternative chemicals or materials that might result would add to the listed costs of cancellation and substitution.

Other impacts of canceling wood preservatives and switching to use of untreated wood, concrete, or steel have not been assessed. These include:

1. A need for more than 29 million tons of cement, sand, gravel, crushed stone and reinforcing steel, annually, to produce concrete ties, poles, piling, and other concrete substitutes for treated wood. This would more than double the amount of these materials used in the manufacture of all precast and prestressed concrete products in 1977. Such an increase could be expected to cause shortages, delays, and price changes that would affect all users of concrete products.

2. A need for more than 1.7 million tons of steel to produce poles, piling, and other steel substitutes for treated wood.

3. Effects of cross-sectoral and regional shifts in employment and income between the wood industry and the concrete or steel industries.

4. Capital investments needed to build facilities to produce required non-wood substitutes, and to purchase new installation and maintenance equipment to handle these materials.

5. Lost investment in present installation and maintenance equipment (especially by railroads and utilities) rendered obsolete by conversion to non-wood materials.

6. Problems and costs of intermixing concrete or steel substitutes with treated wood in maintenance programs during the period required to convert various systems to non-wood substitutes.

7. A probable increase in rail transportation and utility rates to cover increased costs of using substitute materials, and its effect on all users of these services.

8. A substantial increase in the amount of energy required to mine, process, and manufacture substitute materials, all of which are more energy intensive than treated wood.

9. Increased air and water pollution and degradation of the landscape (or increased costs of environmental pollution control) associated with production of substitute materials.

10. Increased dependence on imports of non-wood raw materials and energy, with attendant effects on our balance of payments.

These and other indirect impacts could add to the direct costs of cancellation and substitution described in this report.

## Alternatives to Non-Pressure Treatments and Impacts of Cancellation

Penta and creosote are registered for use in a number of non-pressure processes and applications. Some are commercial applications to manufactured products such as millwork, others are field treatments best classified as maintenance (e.g., groundline treatment of utility poles). The function of treatment is to improve performance and extend the life of treated items or structures.

Nonpressure applications generally require simple equipment and little capital investment. Users are many and widely dispersed. Specific end uses (products treated) are innumerable. Costs and benefits are extremely difficult to measure and evaluate. For these reasons, these analyses of non-pressure treatments are, in most cases, substantially less precise than for the pressure treatments.

### Groundline Treatment of Utility Poles

There are two major types of groundline treatments used on utility poles in service--one with a high creosote content, and the other with high penta content. The cost and efficacy of the two treatments are the same. There are no other alternatives. Continuation of groundline treatment depends on continued availability of either penta or creosote for this use.

Groundline treatments are most often used on sites where decay hazards are highest and expected life of pressure-treated poles is lowest. Treatment is applied to the pole from 6 inches above to 16 inches below the groundline. First treatment is generally applied 15 to 20 years after initial installation, and two subsequent treatments are applied at 10-year intervals ( i.e. at 30 and 40 years). This schedule adds an estimated 20 years to the life of the pole. An estimated 0.9 to 1.1 million standing poles were treated in 1978 at a cost of 10.3 to $12.3 million. It has been estimated that the number of poles treated will double in the next 5 years.

Benefits of groundline treatment were estimated by determining the savings in pole replacement costs resulting from a 20-year extension of pole life. The annual amount that must be set aside, drawing compound interest, to cover the cost of poles over their life cycle is referred to as the sinking fund. Pole line managers want to know how much the sinking fund can be reduced as a result of groundline treatment. By using 1978 treatment costs, a 20-year extension of pole life, a 10% interest rate, and a mix of 7% transmission and 93% distribution poles treated, a weighted annualized savings of $2.12 per pole was calculated.

Annual treatment of 1 million poles is sufficient to maintain a system of 16.67 million poles. The total annualized savings for the system would be:

$2.12 per pole X 16.67 million poles = $35,340,400

In this case, an annual expenditure of $10.2 million for treatment of 1 million poles yields significant savings. Potential benefits from groundline treatment would exceed $70 million per year if the number of poles treated were doubled. About 7.5 million poles would require treatment, annually, in order to include the entire 126 million poles in the U.S. utility system in a groundline treatment program.

If all groundline treatments were canceled, demand for new replacement poles would not change during the next 10 years; however, reduced life would cause an increase in replacement pole demand beginning 10 years after cancellation. In the long-run, annual requirements for replacement poles would increase about 222,300 above those expected with current levels of groundline treatment.

Benefits from groundline treatment are greatest for poles that have the highest installed cost. If a high percentage of the poles treated in 1978 was in urban areas, the average installation cost used in this analysis would result in an underestimate of savings.

## Na-Penta for Sapstain Control

Na-penta is applied in aqueous solutions, by dip or spray methods, to green lumber and freshly peeled poles for control of sapstain fungi. These applications provide short-term protection against unsightly stains which degrade freshly cut wood during storage and transportation. An estimated 3.06 billion bd. ft. of lumber and an unknown volume of poles are treated annually. About 65% of treated lumber is for domestic use, and the remainder is for export. Cost of chemicals for treatment with Na-penta averages $0.88 per 1,000 bd. ft. Total cost to lumber producers is, thus, $2.69 million for chemicals, only.

Copper-8-quinolinolate (Cu-8) is an effective substitute for Na-penta. Cost of Cu-8, for comparable treatment, would be $0.28 million higher than the cost of Na-penta. In addition, Cu-8 would cause corrosion of steel treating equipment. Modification of equipment to prevent corrosion would add to the costs of using this alternative.

The only other alternative for control of sap stain is rapid kiln drying. To be effective, the green material must be in the kiln within 48 hours of sawing or peeling. This greatly limits the potential of this alternative.

Information on the volume of poles treated for sapstain control is lacking, as is information on the cost of modifying equipment for use of Cu-8. The impact of canceling Na-penta and converting to Cu-8 is estimated to be a $0.28 million increase in cost of chemicals to lumber mills--an average of $0.09 per 1,000 bd. ft. of lumber treated.

## Penta Treatment of Millwork

Penta (5% solution in light oil solvent) is applied to an estimated 60 million cu. ft. of millwork products and about 470 thousand cu. ft. of softwood plywood to impart water repellency and to protect against mold, mildew, and staining fungi. Application is by dipping, spraying, or a vacuum process. Window frames, sash, screens, doors, door frames, and textured plywood siding--all of which are exposed to the weather--are the most commonly treated products. Few, if any, interior millwork products are treated. Total cost of penta preservatives used for these treatments is estimated to be $3.2 million.

Two percent tributyltin-oxide (TBTO) and 2% Cu-8 solutions are considered to be effective alternatives to penta for treatment of millwork and plywood. These preservatives are not currently registered for use at 2% concentrations. Nevertheless, the Assessment Team concludes, on the basis of published test results, that 2% concentrations are necessary for effective treatment comparable to 5% penta. Estimated costs of sufficient 2% TBTO and 2% Cu-8 to replace penta used on millwork and plywood (based on late 1979 prices of components) are 5.42 and $7.99 million, respectively. The impacts of canceling penta and converting to TBTO or Cu-8 would be an increase in chemical costs to treaters of $2.22 million for TBTO and $4.79 million for Cu-8--an average of $0.04 and $0.08 per cu. ft. of wood treated, respectively.

The effect of these cost increases on the price of treated wood products to consumers was not determined.

## Penta Treatment of Particleboard

A small amount of penta is used by one manufacturer in Oregon to treat particleboard for protection against drywood and Formosan termites (Coptotermes formosanus). The treated product is used in production of cabinets and similar products for use in Hawaii and other areas where these pests are present.

The penta formulation is sprayed, along with resin and wax, onto the wood particles during the particleboard production process, and is the only preservative that is compatible with the resin used as a bonding agent. There is no alternative to penta for this use. Penta has been successfully used to pressure treat finished particleboard by the Cellon process.

An average of 180,000 sq. ft. (3/4-inch basis) of treated board has been produced, annually, by the Oregon manufacturer over the past 7 years. This is less than 1% of the total production of the Oregon plant, and an infinitesimal percentage of total particleboard production.

The impact of canceling penta for this use would be slight from the standpoint of the manufacturer, and hardly noticeable from the standpoint of the total particleboard industry. The real impact would be concentrated on consumers in limited market areas, mostly in Hawaii, who would be deprived of this termite-resistant product for use in structures where the hazard of termite attack is high.

## Home and Farm Use—Penta and Creosote

About 1.5 million pounds of penta (3.75 million gallons of 5% penta in light oil solvent) are sold annually for use by homeowners, farmers, and others to protect various wood structures and products in use. About 1.5 million pounds of creosote are also sold in solutions for similar purposes.

Penta solutions frequently contain water repellents which reduce shrinking, swelling, checking, and warping of treated wood. Penta protects against numerous decay and stain fungi, insects, molds, and mildew. Typical items treated include decks, siding, fences, shingles, and outdoor furniture. Treatment is most effective for wood used above ground. Ready-to-use solutions may be colorless or may incorporate pigments for simultaneous staining of wood, in a variety of colors. Treated wood is clean and paintable.

Alternative chemicals registered for use at the home and farm level are copper naphthenate (Cu-Naph), zinc naphthenate (Zn-Naph), TBTO, Cu-8, and creosote. None of these has the broad-range effectiveness of penta, but all have some merit as substitutes for some uses.

Cu-Naph, Zn-Naph, and creosote products are all persistently malodorous. The Assessment Team considers registered concentrations of Cu-8 (0.25%) and TBTO (0.3%) to be ineffective (inferior to 5% penta) against insects and fungi and, therefore, recommends 2% solutions of both chemicals for protection comparable to 5% penta. The amounts of these alternate preservatives (except creosote) sold for home and farm use are unknown.

Cu-Naph ready-to-use solutions may contain water repellents. Most are for above-ground use, but some highly concentrated formulations contain directions for use in ground contact. Cu-Naph stains are for use above ground only. Cu-Naph imparts color to the wood, makes a poor base for paint, and is difficult to finish naturally.

Zn-Naph is colorless, but is considered to be less effective than Cu-Naph.

TBTO solutions are colorless, and leave the wood clean and paintable. TBTO can be degraded by sunlight. The chemical has some protective qualities but, as noted above, is inferior to 5% penta at registered concentrations. Technology is such that a 2% concentration of TBTO would be difficult to achieve, and considerably more costly than currently available formulations.

Cu-8 is colorless, clean, and paintable, but less effective than 5% penta at registered concentrations. Two-percent solutions would be substantially more costly than currently available formulations.

Creosote solutions discolor wood and render it unpaintable, thereby restricting the utility of the treated wood.

A check of retail prices at several Washington Metropolitan area building material and hardware stores revealed the following prices, per gallon, of the various preservative formulations discussed above:

| | |
|---|---|
| Penta--5%, in mineral spirits with water repellent, clear or pigmented | $9.50 |
| Cu-Naph--20% (2% Cu) in mineral spirits with water repellent, green | $13.45 |
| Zn-Naph--13.5% (2% Zn) with water repellent, clear | $12.40 |
| TBTO--0.3% | $14.50 |

No price was obtained for creosote or Cu-8 preservative. Available information on prices of components indicates that the cost of creosote would be about the same as that for penta, and Cu-8 formulations would cost 1.5 to 2 times as much as comparable TBTO solutions. As noted previously, 2% solutions of these chemicals would be considerably more costly than currently available formulations which are less effective than 5% penta.

Application rates (coverage) of these preservatives, per bd. ft. or cu. ft. of wood, would vary with product, species of wood, surface characteristics (rough vs.

planed), and thickness of material. If one assumes a rate of 4 gallons per 1,000 bd. ft. of 1-inch lumber for brush applications (approximately 500 sq. ft. per gallon when applied to all surfaces) the cost of these preservatives per 1,000 bd. ft. would be:

| | | Ratio: Cost of Alternatives to cost of Penta |
|---|---|---|
| Penta (5%) | $38.00 | 1.00 |
| Cu-Naph (2% Cu) | $53.80 | 1.42 |
| Zn-Naph (2% Zn) | $49.60 | 1.31 |
| TBTO (0.3%) | $58.00 | 1.53 |

At these prices, the cost of superficial treatment with these chemicals approaches the cost of pressure-treated wood. Lumber pressure treated with CCA/ACA to .25 pcf retention has an expected life of 50 years in above-ground use. Considering the fact that several brush applications of the above listed chemicals would be required over a period of years to come anywhere near the expected life of pressure-treated wood, use of pressure treated material would appear to be a very economical alternative to use of the do-it-yourself preservatives on untreated wood. One limitation of this alternative, at the outset, might be lack of availability of pressure-treated material in sizes and grades required for home or farm uses. Also, this alternative does not satisfy the continued need for supplemental treatment of existing structures, or for treatment of cuts and borings during installation of pressure-treated material.

# INTRODUCTION

# INTRODUCTION

## Purpose and Scope of the Report

In the October 18, 1978, Federal Register, the Office of Pesticide Programs of the U.S. Environmental Protection Agency (EPA) placed on record a notice of "Rebuttable Presumption Against Registration" (RPAR) of pesticide products containing pentachlorophenol, inorganic arsenic, coal tar, creosote, and coal tar neutral oil. Under the authority of the Federal Insecticide, Fungicide, and Rodenticide Act, EPA issues an RPAR when it has been determined that there is sufficient risk involved in the use of the pesticide to warrant a review of the advisability of its continued registration and use. This review, then, is required as part of the RPAR process.

The RPAR review process includes several steps: After the existence of a risk (trigger) has been demonstrated by EPA, (1) an RPAR is issued (EPA), (2) risk data may be rebutted, (3) benefits and exposure are determined (USDA/States/EPA Assessment Team), (4) risk/benefits are weighed (EPA), and (5) judgments regarding reregistration, regulatory options, and limited registrations are made (EPA). USDA, along with the States and the EPA, has the responsibility for developing information for item (3). The following report is a review of the benefits of the agricultural uses of the subject chemicals, the human exposure incurred in usage, and an estimate of the economic impacts of cancellation. The report is divided into two major parts: Volume I, wood preservative uses, and Volume II, non-wood-preservative uses.

The primary focus of this impact assessment report is on how the user is affected. Secondary and tertiary economic and social impacts are only cursorily addressed. This covers only those sites, pests, and chemicals which were deemed important to agriculture either from current use patterns or desirability to retain the compound since it is biologically beneficial. Only registered chemicals are fully considered as viable alternatives to the RPAR'd chemicals; however, for the sake of completeness and perspective, some non-registered chemical alternatives, and all viable alternative structural materials (such as concrete, steel, and plastic), are discussed.

## The RPAR'd Chemicals

### Pentachlorophenol (Penta)

Penta is a widely used wood preservative that is normally carried in a petroleum solvent. Approximately 54 million pounds of penta were produced in 1974 (Fuller, et al., 1977), and it is estimated that similar volumes are presently being produced by the three U.S. chemical firms engaged in its manufacture. Although a small quantity is converted to the sodium or potassium salt and used as a broad spectrum water-soluble biocide, most of the penta produced is used as a wood preservative.

The commercial synthesis of penta is readily accomplished by the direct chlorination of phenol. Chlorination proceeds stepwise and catalysts such as $FeCl_3$, $AlCl_3$, and $SbCl_3$ are employed. Production of the monovalent alkali salts is accomplished by reacting penta with the corresponding base.

Penta is effective against bacteria, fungi, and insects, and exerts its toxic effect by uncoupling oxidative phosphorylation in living cells. Since this biochemical process is essentially the same for the aerobic generation of adenosine triphosphate in all biological systems, penta and its salts are highly effective broad-spectrum biocides. This characteristic has resulted in the usage of these compounds in applications ranging from industrial preservation of cellulosic materials to slimicidal uses in papermills and cooling towers.

The following compounds and their uses are addressed in this document:

| | |
|---|---|
| Pentachlorophenol | wood preservation |
| Pentachlorophenol | herbicide, defoliant, and mossicide |
| Sodium pentachlorophenate | sapstain control |
| Sodium pentachlorophenate | herbicide, mossicide |
| Sodium pentachlorophenate | biocide in mushroom houses |

## Inorganic Arsenicals

Arsenic is produced as a by-product of the non-ferrous smelting industry, mainly from copper smelters but also from gold, zinc, and lead smelters. The air pollution and disposal problems associated with smelter operations will exist whether the arsenic is refined for further use or not. If its usage is restricted in commerce, smelters will have an increased waste disposal problem.

During smelting, white $As_2O_3$ fumes are formed and are then condensed in brick buildings called "kitchens" as the gases are cooled. The crude $As_2O_3$ is collected and further refined in this manner at one installation in the United States, the American Smelting and Refining Company in Tacoma, Wash.

Arsenic trioxide is used as a rodenticide and as a starting material for all other arsenical pesticides. Dissolution of $As_2O_3$ in sodium hydroxide produces sodium arsenite, a contact herbicide and fungicide. Oxidation to arsenate in the presence of various cations gives rise to the other arsenical pesticidal materials.

Some of the arsenic-containing products registered by EPA are no longer used for a variety of reasons: (1) better alternatives; (2) adverse side effects on the crop treated and the environment; (3) lack of supply as a result of governmental regulations Occupational Safety and Health Administration (OSHA) which resulted in plant closings; or (4) refusal to invest additional resources in manufacturing plants until a decision relative to re-registration of the arsenicals is made. These reasons work in concert to make an economic and benefits analysis for some products difficult since they are not currently being used, even though they may be as good or better than some alternate materials.

Some arsenicals, which are no longer a part of some current use patterns, are still registered with EPA. Therefore, these still appear on the site-pest lists derived from the registered labels.

The following uses are addressed in this document:

| | |
|---|---|
| Chromated copper arsenate | wood preservation |
| Ammoniacal copper arsenate | wood preservation |
| Fluor chrome arsenate phenol | wood preservation |
| Arsenic acid | desiccation--cotton |

| | |
|---|---|
| Arsenic trioxide | rodent control |
| Calcium arsenate | annual bluegrass--turf |
| | slug bait--citrus |
| | fly control--poultry |
| Lead arsenate | growth regulator--grapefruit |
| | cherry fruit fly--cherries |
| Sodium arsenate | ant bait--buildings |
| Sodium arsenite | Black Measles--grapes |
| | Dead Arm--grapes |
| | termites--buildings |
| | soil semi-sterilant |

## Coal Tar, Creosote, and Neutral Oils

Cresote is a complex mixture of organic chemicals that are products of the fractional distillation of coal tar. Coal tar is a by-product coking of bituminous coal. This may be conducted over a wide range of temperatures which affect the composition of the tar. Practically all coal tar produced in the United States results from high temperature processes. In this document the term "coal tar" refers to the so-called high temperature coal tar. Coal-tar neutral oil, as defined in PD-1 (Federal Register, 1978), is a mixture of several chemicals, other than tar acids and tar bases, and includes such compounds as naphthalene, fluorene, anthracene, and similar hydrocarbons. In fact, the product defined by that document basically is creosote with tar acids and tar bases removed and contains all of the compounds shown in Table 11. However, as currently used in the trade, the name "neutral oil" denotes those neutral fractions with boiling points between 150°C and 270°C which consist principally of coal tar naphtha, methylnaphthalenes, and dimethylnaphthalenes. Both creosotes and neutral oils may be obtained from a variety of organic materials, including petroleum and wood; but both are assumed to be distillates of coal tar for purposes of this document.

Commercial creosote is actually a blend of several coal tar distillation fractions selected to provide specific physical characteristics to the resulting product. This blend, in turn, may be used alone or diluted with coal tar or petroleum oil, depending upon end use. Almost all creosote is blended with tar acids and processed with fatty acids to form a water-emulsifiable product that is used as an insecticide, disinfectant, animal repellent, acaricide, and other miscellaneous uses. Coal tar, in addition to its uses in preservative solutions with creosote, also finds use in various non-wood-preserving applications, including insect repellents, disinfectants, and arachnicides.

Creosote, coal tar, and neutral-oil products have been used for both preservative and non-preservative purposes for nearly 150 years and have been registered for many site-pest applications. Because of the current availability of more efficacious products, coal tar and its distillates are no longer used--or are used only sparingly--for many of the purposes for which they are registered. In many instances it was difficult or impossible to ascertain whether a particular registered use was, in fact, still part of the current use pattern. Conversely, it was discovered that certain coal-tar products, primarily neutral oil, are regularly used in applications for which registrations have been canceled. The specific uses addressed in this document are as follows:

| Coal-Tar Products | Use |
|---|---|
| Creosote | Wood preservative[a] |
| | Animal repellent |
| | Larvicide |
| | Fungicide |
| | Herbicide |
| | Insecticide |
| | Acaricide |
| | Arachnicide |
| Coal-Tar | Wood preservative[a] |
| | Insecticide |
| | Disinfectant |
| | Animal repellent |
| | Fungicide |
| | Acaricide |
| | Arachnicide |
| Neutral Oil | Wood preservative |
| | Animal repellent |
| | Insecticide |
| | Acaricide |
| | Larvicide |
| | Disinfectant |

## Triggers

### Pentachlorophenol

EPA has determined that registrations of pesticide products containing penta meet or exceed the EPA risk criteria relating to teratogenic and/or fetotoxic effects on mammalian test species [(40 CFR 162.11 (a)(3)]. The EPA PD-1 (Federal Register, 1978) explains the basis for concluding that there is a Rebuttable Presumption of risk from the use of penta and compounds containing penta.

### Inorganic Arsenicals

EPA has determined that pesticide products containing inorganic arsenic meet or exceed the risk criteria relating to oncogenic effects (human epidemiology studies), mutagenic effects, and reproductive or fetotoxic effects on mammalian test species [40 CFR 162.11 (a)(3)]. The basis for this determination is set forth in the inorganic arsenic PD-1 (Federal Register, 1978).

### Coal Tar, Creosote, and Neutral Oil

EPA has determined that pesticide products containing coal-tar creosote and coal-tar neutral oil meet or exceed the risk criteria relating to oncogenicity [40 CFR 162.11 (a)(3)]. The basis for the determination is cited in the coal-tar, creosote, and coal-tar neutral oil PD-1 (Federal Register, 1978).

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[a] Creosote may be used alone or in combination with coal tar or petroleum as a wood preservative. Coal tar is never used as a wood preservative except in combination with creosote.

# Physical and Chemical Properties of RPAR'd Pesticides

## Pentachlorophenol and Its Salts

### Physical Properties

In the pure state, pentachlorophenol (penta) is a white, needlelike crystalline solid. Since it is practically insoluble in water, its readily water-soluble sodium salt is substituted for many practical uses. Some of the properties of penta are given in Table 1 (Bevenue and Beckman, 1967).

### Chemical Properties

Penta is quite stable. It does not decompose when heated at temperatures up to its boiling point for extended periods of time. Pure penta is considered to be rather inert chemically (Bevenue and Beckman, 1967). The chlorinated ring structure tends to impart stability, but the polar hydroxyl group tends to facilitate biological degradation (Renberg, 1974). It is not subject to the easy oxidative coupling or electrophilic substitution reactions common to most phenols. All monovalent alkali metal salts of penta are very soluble in water, but the protonated (phenolic) form is virtually insoluble. Hence, transport of penta in water is dependent largely on the pH of the environment.

Penta is volatile enough to be steam-distilled, a property that can be exploited by the analyst. A closed system should be used when heating environmental samples or recoveries are poor (Bevenue and Beckman, 1967). By analogy to other chlorinated organic compounds of low vapor pressure, volatility will cause losses of penta from soils as shown by Briggs (1975). Volatilization from treated wood may also occur.

### Photodecomposition

The photochemistry of penta and other chlorinated phenolic herbicides has been widely investigated. Model studies have shown that aqueous solutions of penta or its salts are subject to photodegradation and this observation has been borne out by practical experience in this field.

Photochemical reactions of halogenated aromatic compounds appear to follow free-radical pathways (Plimmer, 1970). Because of the free radical character of the reaction, the structure of the products depends on the properties of the solvent. Since water is the solvent involved in environmental photochemical reactions, studies of photochemical degradation in aqueous solution are particularly pertinent; extrapolation of photochemical reactions performed in nonaqueous solvents should be carefully considered for applicability to environmental conditions.

It is well known that the absorbance spectra of phenols undergo a characteristic bathochromic shift when changed from the protonated form to the anion. Since the wavelength of light absorbed is affected, it is reasonable to assume changes in photochemical behavior as well. According to Plimmer (1970), the nature of the reaction products also depends on the wavelength of light absorbed. Some other factors which influence the spectrum of a molecule are the surfaces with which it is associated in the environment, specifically, bonding interactions with the surface. Types of interactions which will affect the products of the reaction include simple adsorption, coulombic forces, van der Waals forces, and charge transfer. In short, the chemical environment of the molecule profoundly influences its photochemical behavior. Unfortunately, there have been relatively few studies of pesticide photochemistry on environmental surfaces (Plimmer, 1970). Adsorption on silica does cause

Table 1.--Physical properties of penta[a]

| Property | Value |
|---|---|
| Empirical formula | $C_6Cl_5OH$ |
| Molecular weight | 255.36 |
| Melting point | 190°C |
| Boiling point | 293°C |
| Density | 1.85 g/cc |
| Vapor pressure 20°C | 0.00011 mm Hg |
| 100°C | 0.12 mm Hg |
| $pK_a$ | 4.8 |
| Solubility: (g/100g solvent) | |
| In water 20°C | 0.0014 |
| In water 30°C | 0.0019 |
| In methanol 20°C | 57 |
| In methanol 30°C | 65 |
| In diethylether 20°C | 53 |
| In diethylether 30°C | 60 |
| In ethanol 20°C | 47 |
| In ethanol 30°C | 52 |
| In acetene 20°C | 21 |
| In acetene 30°C | 33 |
| In xylene 20°C | 14 |
| In xylene 30°C | 17 |
| In benzene 20°C | 11 |
| In benzene 30°C | 14 |
| In carbon tetrachloride 20°C | 2 |
| In carbon tetrachloride 30°C | 3 |

[a] Source: Modified from Bevenue and Beckman, 1967.

a shift in the ultraviolet (UV) spectra, providing evidence for hydrogen bonding of the phenol.

Aqueous solutions of sodium pentachlorophenate (Na-penta) were decomposed when exposed to sunlight as evidenced by a color change from clear to purple after about 10 days (Munakata and Kuwahara, 1969).

Hamadmad (1967) characterized some of the breakdown products of penta in various solutions. Ultraviolet irradiation of penta in hexane or methanol gave 2,3,5,6-tetrachlorophenol, presumably by reductive dechlorination. However, an aqueous suspension of penta produced little tetrachlorophenol when irradiated polymeric substances were the major photolysis products.

Crosby and Hamadmad (1971) concluded that 2,3,5,6-tetrachlorophenol was the major breakdown product of penta photolysis, but their work used only organic solvents and no aqueous solutions.

Munakata and Kuwahara (1969) studied the photochemical reaction products obtained on irradiation of an aqueous solution of 20 g/liter of Na-penta. After 10 days of sunshine 50% of the Na-penta had been lost. The chemical structures of the degradation products are shown in Figure 1.

Hiatt, et al. (1960) recognized that photochemical degradation may be a factor which reduces the efficacy of Na-penta on its target organism. They reported field observations of unexpectedly poor control of the snail vectors of schistosomiasis in South African streams. These streams were all small, shallow, and rapidly flowing and were exposed to full sunlight during the day. The water was exceptionally clear. It was speculated that photochemical destruction of Na-penta was the cause of the poor control. This phenomenon was confirmed by Hiatt, et al. (1960). A further discussion of penta photodecomposition can be found in Chapter 3 (fate of penta in the environment).

## Analytical Methods

Many methods of qualitative and quantitative analysis have been developed for penta (Tables 2 and 3). Since samples are sometimes expected to contain penta and no chemical analogs, methods for this type of sample are usually less sensitive and specific but more convenient than those used for residue analysis.

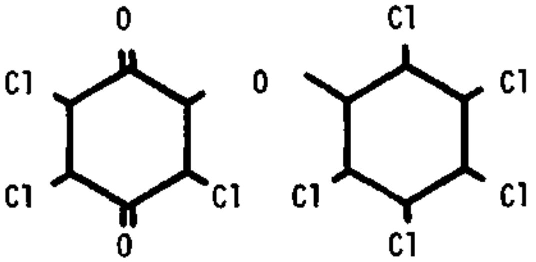
Colorimetric and oxidation methods of analysis are less sensitive and specific than chromatographic methods. Attempts to modify the nitric acid-oxidation method and the 4-amino-antipyrine (4-amino-2, 3-dimethyl-1-phenyl-3-pyrazolim-5-one) colorimetric method to improve selectivity and lower detection limits have not been especially successful when small amounts of sample are available (Bevenue and Beckman, 1967).

Chromatography has become very important as both a method of separation and as a means of assay. High-pressure liquid chromatography using Amberlite XAD-7 Resin (Fritz and Willis, 1973) has been used recently to separate complex mixtures of phenols and thin-layer chromatography or paper chromatography can be used to separate penta from many interfering substances (Bevenue and Beckman, 1967). Thin-layer chromatography can also be used to estimate semiquantitatively the amount of the component present in microgram quantities (Zigler and Phillips, 1967; Davies and Thuraisingham, 1968; Geike, 1972; and Frei-Hausler, et al., 1973).

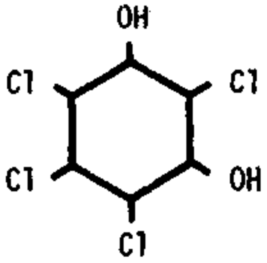
Infrared (IR) or UV spectrophotometry can be used to identify and determine penta. These spectrophotometric methods must be preceded by purification steps which effectively separate the penta from interfering substances of similar absorptivity.

The most widely used technique for analysis of penta in practically all sample types is gas-liquid chromatography (GLC). The electron capture detector is used routinely because of its high sensitivity to halogenated compounds; quantities in the nanogram to picogram range ($10^{-9}$ to $10^{-12}$g) can be measured. The GLC technique is often sufficient to analyze and identify the penta if retention times are determined on two or more different columns.

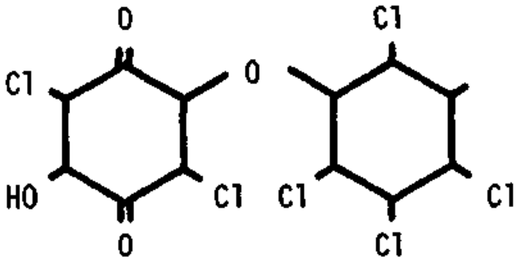
When more rigorous identification is required and a sufficient amount of sample is available for the collection of a gas chromatographic fraction of the suspected penta, final confirmation of identity may be obtained by UV or IR spectroscopy. With the advent of computerized gas chromatographmass spectrometer (GLC-MS) interfaces (Elkin, et al., 1973) it is possible to scan automatically the mass fragments



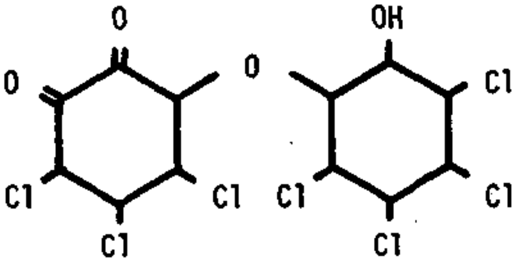
2,5-Dichloro-3-hydroxy-6-pentachlorophenoxy-1,4-benzoquinone
(red)



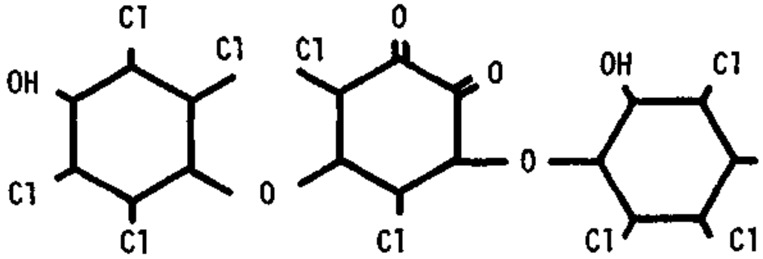
2,4,5,6-Tetrachloro-rescorcinol
(colorless)



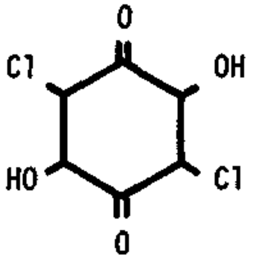
2,5-Dichloro-3-hydroxy-6-[3-hydroxy-2,4,5,6-tetrachloro-phenoxy]-1,4-benzoquinone
(orange-red)



3-[2-hydroxy-3,4,5,6-tetra-chlorophenoxy]-4,5,6-trichloro-1,benzoquinone
(yellow)



3,5-Dichloro-4-hydroxy-2,3,5,6-tetrachloro-phenoxy-6-2-hydroxy-3,4,5,6-tetrachloro-phenoxy-1,2-benzoquinone
(yellow)



Chloranilic Acid

Figure 1. Photochemical degradation products obtained from irradiation of an aqueous solution of penta. Source: Modified from Munakata and Kuwahara, 1969.

Table 2.--Methods of determination of penta in several sample materials

| Sample | Isolation Method | Analytical Method and Sensitivity | Remarks and Author[a] |
|---|---|---|---|
| Urine | Extract with petroleum ether; reextract with NaOH and acidify. | Turbidimetric; 5 mg/liter. | Rapid scanning, routine method (1). |
| Human adipose tissue[b] | Extract NaOH solution with hexane; acidity; extract with ether, ethylate with diasoethane; pentachlorophenyl ethylether separated from hexachlorophene on a silica gel column. | Electron capture gas chromatography; 5 micrograms/kg. | Method requires about 200 mg tissue (2). |
| Urine, blood, air | Air samples collected with midget impingers using alkaline water or iso octane. | Electron capture gas chromatography. | Air sampling procedure was inadequately described (3). |
| Urine | Add NaOH; extract with hexane; acidify; extract with hexane. | Electron capture gas chromatography; 2 micrograms/liter. | Seven alkyl ethers of penta were used and several different columns were used in detection (4). |
| Natural latex | Coagulate with acetic acid; extract with acetone. | Thin later chromatography with $CuSO_4$-pyridine spray; 10 mg/g rubber. | Semiquantitative, rapid method (5). |
| Natural water[c] | | Colorimetric using methylene blue or Safranin-0; 5 mg/liter. | Hard water or water containing Fe or Cu yield interfering precipitates (6). |

Table 2.--Methods of determination of penta in several sample materials--continued

| Sample | Isolation Method | Analytical Method and Sensitivity | Remarks and Author[a] |
|---|---|---|---|
| Natural water | Acidify and extract into chloroform. | Ultraviolet radio spectrometry; 2 micrograms/liter | Other phenols do not interfere at chosen wavelength (7). |
| Wood | | Electron probe microanalyses; 0.1% | Determine distribution of penta in wood (8). |
| Wood | Oxidize with chlorine dioxide. | Microscopy; 0.022% | Determine distribution of penta in wood (8). |
| Toy paints | Extract with acetone. | Flame ionization gas chromatography with dansyl chloride derivitization;<br>GC - 1 mg/liter<br>TLC - 4 mg/liter. | Minimum background obtained by acetone extraction (9). |
| Water and sewage effluents | Extract with benzene followed by $K_2CO_3$ solution:<br>acetylate and extract with hexane. | Electron capture gas chromatography;<br>0.01 microgram/liter | Acetylation in $K_2CO_3$ reduced interferences (10). |
| Soil<br>Water<br>Fish | For soil and fish extract with KOH; acidify; extract with toluene. | Electron capture gas chromatography of methyl ester;<br>soil - 0.5 microgram/kg;<br>water - 0.01 microgram/kg;<br>fish - 0.5 microgram/kg. | Trimethylsilyl ether prepared for mass spectroscopy for confirmation (11). |
| Biological tissue<br>Water | Acidify; extract with hexane, reextract with borax solution. | Electron capture gas chromatography of ethyl ether;<br>tissue - microgram/g;<br>water - 0.01 microgram/liter. | Organochlorine insecticides did not interfere (12). |

Table 2.--Methods of determination of penta in several sample materials--continued

| Sample | Isolation Method | Analytical Method and Sensitivity | Remarks and Author[a] |
|---|---|---|---|
| Blood<br>Urine<br>Tissue<br>Clothing | Extract with ethyl ether, extract ether solution with 5% NaOH, acidify, extract with benzene. | Electron capture gas chromatography; 0.01 mg/liter or 0.01 microgram/g. | (13). |
| Human blood | Acidify and extract with benzene. | Electron capture gas chromatography of methyl ether; 20 micrograms/liter. | (14). |
| Human urine | Acidify and extract with petroleum ether. | Electron capture gas chromatography; picogram to nanogram range. | No background interference (15). |
| Biological samples | Acidify, extract with ethyl ether, chromatograph on Celite-$H_2SO_4$ column; extract with Na pyrophosphate. | Paper chromatography followed by ultraviolet spectroscopy; 5 micrograms/g. | Laborious procedure (16). |

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[a] Source: Assembled from several publications, numbers in parentheses provide citations as follows: (1) Comstock et al., 1967; (2) Shafik, 1973; (3) Casarett et al., 1969; (4) Cranmer and Freal, 1970; (5) Davies and Thuraisingham, 1968; (6) Haskins, 1951; (7) Fountaine et al., 1975; (8) Resch and Arganbright, 1971; (9) Van Langeveld, 1975; (10) Chau and Coburn, 1974; (11) Stark, 1969; (12) Rudling, 1970; (13) Barthel et al., 1969; (14) Bevenue et al., 1968; (15) Bevenue et al., 1966; and (16) Erne, 1958.

[b] Sample contained penta and hexachlorophene.

[c] Sample contained Na-penta and Cu-penta.

Table 3.--Methods of determination of penta in several sample materials containing other phenols[a]

| Sample | Isolation Method | Analytical Method and Sensitivity | Remarks and Author[a] |
|---|---|---|---|
| Urine | Acidify and extract with petroleum ether. | Gas chromatography mass spectrometry; picogram to nanogram range. | Tetrachlorocatechol and tetrachlorohydroguinone also assayed (1). |
| Natural water | Acidify and extract with petroleum ether. | Two-directional thin layer chromatography with 4-aminoantipyrine or silver nitrate spray; 0.1 microgram using silver nitrate; 0.5 microgram using 4-amino-antipyrine. | Specific for chlorophenols; little or no interference from inorganic compounds, color or turbidity 2,4,6-; 2,4,5-trichlorophenols, 2,4-dichlorophenol, m-chlorophenol also assayed (2). |
| --- | --- | Chromatography on Amberlite XAD-7 resin using high pressure liquid chromatography with ultraviolet detector. | Bromophenols, chlorophenols, methylphenols and nitrophenols separated from penta (3). |
| Biological tissues<br>Natural Water | Steam distillation into sodium hydroxide. | Colorimetric nitric acid oxidation; 0.01 mg. | Other chlorophenols analyzed (4). |
| Wood | Acetic acid/methanol extraction and adsorption on Bio-Rad AG2-X8 resin. | Colorimetric 4-aminoantipyrine 2 micrograms/g. | 2,3,5,6-tetrachlorophenol also assayed (5). |
| --- | --- | Thin layer chromatography after dansyl chloride spray. | 2-chlorophenol, 4-chlorophenol, 2,4-dichlorophenol, 3,4-dichlorophenol, 2,4,5-trichlorophenol, penta, 3 chlorophenol, phenol all assayed (6). |

Table 3.--Methods of determination of penta in several sample materials containing other phenols[a]--continued

| Sample | Isolation Method | Analytical Method and Sensitivity | Remarks and Author[a] |
|---|---|---|---|
| Fish tissue<br>Soil<br>Natural water | Purification by binding acidic substances to anion exchanger. | Electron capture gas chromatography (derivatized; 0.3 microgram/g for fish; 1.5 micrograms/liter for water; 1.5 micrograms/g for soil. | Other chlorophenols also assayed (7). |
| Fats<br>Oils<br>Waxes<br>Commercial food grade fatty acids | Acidify, extract with petroleum ether, extract with NaOH, acidify and extract with chloroform. | Electron capture gas chromatography; 0.5 microgram/g. | 2,3,4,6-tetrachlorophenol also assayed (8). |
| Biological tissues | Steam distillation and extraction with pentane or toluene. | Electron capture gas chromatography ethyl ether; 10 nanograms/g for wood or litter extracts; 1.0 nanogram/g for fat; and 0.1 nanogram/g for muscle. | 2,3,4,6-tetrachloroanisole, pentachloroanisole and the corresponding chlorophenols also assayed (9). |
| Biological tissues | Acidify and extract with isopropanol/hexane. | Gas liquid chromatography of acetate; microgram/g range. | Chlorohydroxybiphenyl also assayed (10). |

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[a] Source: Assembled from several publications, numbers in parentheses provide citations as follows: (1) Elkin et al., 1973; (2) Zigler and Phillips, 1967; (3) Fritz and Willis, 1973; (4) Deichmann and Schafer, 1942; (5) Williams, 1971; (6) Frei-Hausler et al., 1973; (7) Renberg, 1974; (8) Higginbotham et al., 1970; (9) Gee et al., 1974; and (10) Zitko et al., 1974.

expected from the penta molecule. This technique uses the mass spectrometer as a molecule-specific detector. There are also less sophisticated systems of GLC-MS in which the mass spectrometer is used to take the spectrum of only a few selected peaks. This is still a very powerful tool since the mass spectrum of a compound is normally an unambiguous identifier.

Penta is most often isolated from samples by a series of liquid-liquid extractions. The most common technique for soil samples is extraction with sodium or potassium hydroxide, followed by acidification of the extract, and extraction from the acid solution with a nonpolar solvent such as benzene, toluene, or petroleum ether. The phenol is then reextracted from the nonpolar solvent with a basic aqueous solution if further purification is desired. Biological tissue samples have been treated in much the same way, but sometimes the tissue is treated with concentrated sulfuric acid (Erne, 1958) and anhydrous sodium sulfate and extracted by a Soxhlet technique. Recovery was variable (90 to 95%) but was similar to other methods. Steam distillation is used for isolation of larger (mg) amounts of penta in soil and biological tissue. Water samples are easiest to handle. Most authors simply acidify a large amount of water and extract it directly with a nonpolar organic solvent. Recoveries of penta are greater from water and detection limits lower (microgram/liter range) than for other environmental samples (Stark, 1969; Rudling, 1970; Renberg, 1974; and Chau and Coburn, 1974).

Some exceptions are reported: Difficulties were encountered in removal of penta from samples of high fat content (Renberg, 1974) especially fat of marine origin, and with certain soil samples which form gels when their alkaline extract is acidified to a pH lower than 6 (Stark, 1969). Since penta has a pK-value of 5, extraction under these circumstances can be difficult or impossible. These difficulties can be eliminated by ion exchange reactions (Renberg, 1974). In this procedure, acidic substances are bound to an anion exchanger and the liquid phases can be discharged. This method gave recovery values from soil and water of >97% and from fish a value of 92%.

In summary, the chemical methods of isolation and determination of penta exploit the dual nature of the compound, i.e., it exists as a polar anion under basic conditions and a nonpolar molecule when acidified. By using this property, its partitioning is controlled easily.

In determining penta in soil, water, or biological material, the validity of results is assured only when the sample is representative and the penta in the sample is identified and measured accurately. In sampling anything as complex as soil, water, and sediments, the experience and common sense of the investigator are very important in considering the unknown or complex relationships affecting representative sampling. Compromise must often be reached between the best method of sampling and the funding available.

Given a representative sample, the performance of an analytical method will depend on the quantitative extraction of penta and its accurate measurement and identification. Analysts must be careful that their method of determining extraction efficiency can be extrapolated to environmental samples and provide uniformly quantitative extraction from a variety of samples. For water samples, penta distribution between extractant and water is important. For soil and sediment samples, the removal of pesticide from sorption sites is necessary (Chesters, et al., 1974). In biological tissues, separation from lipids must be achieved (Renberg, 1974).

The actual method of analysis must be sensitive enough for quantities of penta present and not subject to interference from other compounds. Some methods (e.g.

ultraviolet spectroscopy) require "cleaner" extracts and more elaborate cleanup prior to final determination. Gas-liquid chromatography has inherently great potential for separation of compounds, so rigorous cleanups are not necessary.

These are some of the criteria that must be applied when assessing the suitability of a method for analysis of environmental samples. It is beyond the scope of this document to list the many other specific factors to be considered in evaluating such a method. For a detailed review see Chesters, et al. (1974).

Under guidelines discussed previously, the following publications were judged to present the best methods of analysis of those reviewed: Rudling (1970); Bevenue, et al. (1968); Renberg (1974); Zitko, et al. (1974); Buhler, et al. (1973); Frei-Hausler, et al. (1973); and Cranmer and Freal (1970).

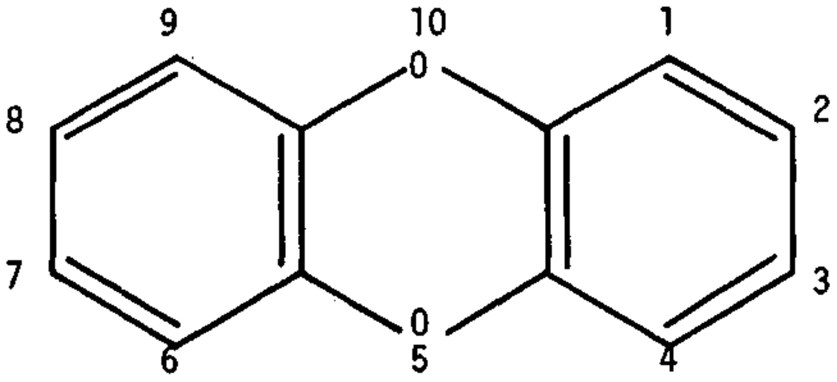
## Toxic Impurities In Penta

In examining the toxicity of penta and Na-penta it must be realized that one may be studying the toxicity of several distinct compounds. For example, it has been shown in recent years that technical penta preparations are sometimes contaminated with chlorinated dibenzo-p-dioxins and chlorinated dibenzofurans. Many isomers of these general compound classes are possible depending on the number of chlorine substituents and their location on the rings. The basic structures of dibenzo-dioxin and dibenzo-furan and the sites where chlorine substituents may be attached are presented in Figure 2. Many reports are available demonstrating the presence of these nonphenolic contaminants in commercial and technical penta, and it is likely that their generation as by-products occurs during penta synthesis. The lack of good standards and sensitive quantitative identification techniques frequently makes it difficult to discriminate between isomeric forms containing the same number of chlorine substituents. Consequently, chlorodioxin concentrations are usually expressed in terms of amounts of unspecified tetra, hexa, hepta or octa isomers.

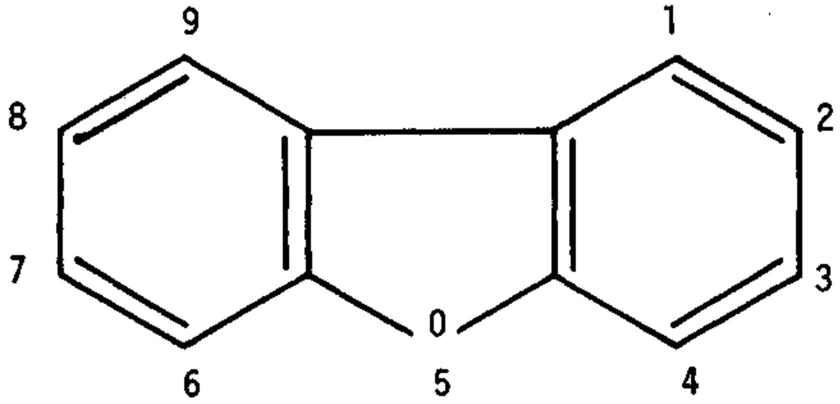
Some of the chlorinated dibenzodioxin isomers are extremely toxic compounds and have been implicated in chick edema disease, chloracne, various pathological changes of organs including alteration of enzyme activities, and teratogenicity in humans or experimental animals (Johnson, et al., 1973; and Kimbrough, 1972). The dibenzofurans are suspected to possess similar properties, but information on their toxicological properties is scant (Crossland and Shea, 1973).

One of the dioxins, 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), is particularly noxious although it has never been detected in penta of U.S. manufacture. Acute toxicity values as low as 0.6 microgram/kg body weight have been reported for guinea pigs. The compound is teratogenic at doses of 1 microgram/kg/day and embryo toxicity is noted at doses of 0.03 microgram/kg/day. Finally, chloracne may result from contact with solutions of 0.04 microgram/liter concentration. More highly chlorinated dioxins (hexa, hepta, octa) are far less toxic than this tetra isomer. Toxicities of a number of dioxin isomers have been compiled for comparative purposes and presented in Table 4.

The hexa, hepta, and octa isomers have been reported in commercially available penta. Levels of hexachlorodioxin in technical grade penta range from 0.17 to 39 micrograms/g penta depending on the specific sample and analytical technique employed. Heptachlorodioxin levels ranging from 2 to 1,000 micrograms/g penta have been reported and octachlorodioxin levels may be as high as 2,510 micrograms/g penta (Firestone, et al., 1972; Johnson, et al., 1973; Woolson, et al., 1972; USDA, 1971). Additionally, Firestone, et al. (1972) reported the qualitative identification of tetra, penta, hexa, hepta, and octa isomers of chlorodibenzofuran.



Dibenzodioxin



Dibenzofuran

Figure 2. Structures of Dibenzodioxin and Dibenzofuran. Chlorine may be attached, in various combinations, at the 1, 2, 3, 4, 5, 6, 7, 8 positions. Source: Modified from Kimbrough, 1972.

Table 4.--Toxicity of various dioxin isomers to experimental animals[a]

| Compound | LD-50 | Teratogenic Effect[b] | Embryo Toxicity[b] | Acnegenic Effect[b] |
|---|---|---|---|---|
|  | mg/kg Body wt. | mg/kg/day | mg/kg/day | mg/liter |
| 2,7-Dichlorodibenzo-p-dioxin | 1,000 | None | None | None |
| 2,3,7.8-Tetrachlorodibenzo-p-dioxin | 0.0006 | 0.001 | 0.00003 | 0.00004 |
| Hexachlorodibenzo-p-dioxin | 100 | 0.1 | 0.0001 | 0.01 |
| Octachlorodibenzo-p-dioxin | 1,000 | None | 100 | None |

[a] Source: Modified from Alliot, 1975.

[b] Values denote the lowest dosage or concentration which gives rise to the corresponding effect.

Hexachlorodibenzo-p-dioxin possesses teratogenic properties (Alliot, 1975; and Schwetz, et al., 1973). Octachlorodibenzo-p-dioxin is apparently not teratogenic while information on heptachlorodibenzo-p-dioxin and the chlorodibenzofurans (also present in technical penta preparations) is not available. Recent data indicate that penta may possess teratogenic and fetotoxic properties when the compound is administered in sufficient doses to maternal rats (Federal Register, 1978). It is not the intent of this document to examine the validity of these results or their possible extrapolation to humans. It will be assumed that the published data may be directly extrapolated to humans and that potential human health effects depend on the likelihood that sufficient exposure to the compound will occur. These questions will be dealt with in more detail in a later section.

Concern over possible production of dioxins from penta in the environment has recently surfaced. Dioxin production might occur during penta photolysis, pyrolysis or microbial degradation.

Production of trace amounts of octachlorodioxin from penta exposed to ultraviolet radiation has been reported (Plimmer, et al., 1973; and Stehl, et al., 1973), although other chlorodioxin isomers were not detected.

The production of dioxins during pyrolysis of penta is controversial. Jensen and Renberg (1973) reported the production of 0.73 mg heptachlorodibenzo-p-dioxin and 0.47 mg of the octachloro isomer after burning 73 mg of penta (in the form of impregnated sawdust). Dioxin formation also occurs during pyrolysis of Na-penta according to Langer, et al. (1973). On the other hand, Stehl, et al. (1973) analyzed the combustion products of wood and paper treated with penta and detected no increase and possibly a decrease in octachlorodibenzo-p-dioxin concentration. Arsenault (1976) heated penta-oil solutions at 104° C for 200 hours and noted no change in octachlorodioxin content. It was noted, however, the higher processing temperatures (180° to 500° C) could conceivably lead to dioxin formation.

Dioxins have never been detected as microbial breakdown products of penta.

In summary, it is clear that chlorodibenzo-p-dioxins and chlorodibenzofurans are present at various levels ranging from 2 to 2,500 micrograms/g in commercially available penta, probably as a result of the manufacturing process. The highly toxic 2,3,7,8-tetrachlorodibenzo-p-dioxin has never been found in penta of U.S. manufacture and, furthermore, has not been detected as a pyrolytic or photolytic product of penta decomposition. Hexa-, hepta-, and octa-chlorodibenzodioxin as well as various chlorodibenzofurans have been qualitatively (and sometimes quantitatively) identified in technical grade penta. The compounds probably do not pose an acute toxicity hazard; however, the possibility that chronic effects may result from exposure to them has not been sufficiently evaluated. Several chlorodioxin isomers have been detected following photolytic or pyrolytic decomposition of penta, but the extent to which these processes contribute to environmental contamination by dioxins is unknown. Much more research is needed in order to evaluate the hazards posed by dioxins and furans in penta.

## Inorganic Arsenicals

In the natural environment, arsenic is rarely encountered as the free element. More frequently it is a component of sulfidic ores, in which it occurs as metal arsenides. Arsenates of aluminum, barium, bismuth, calcium, cobalt, copper, iron, lead, magnesium, manganese, uranimum, and zinc also occur naturally, along with arsenic trioxide, which is formed as the weathering product of arsenides. Realgar (tetraarsenic tetrasulfide) and orpiment (arsenic trisulfide) are naturally occurring sulfides of arsenic. In one form or another, arsenic is present in rocks, soils, water, and living organisms in concentrations of parts per billion to parts per million. The commercial use and production of inorganic and organic arsenic compounds have raised local concentrations of this element in the environment much above the natural background concentrations.

When metallic arsenides or arsenic-containing sulfides are roasted in air, and when arsenic-containing coal is burned, arsenic trioxide is formed. The vapors condense in the flues and on the walls of the stacks as a powder commonly called "white arsenic." Some arsenic trioxide finds its way into the air. Condensation of the vapors on a surface at temperatures above 250°C forms the glassy modification, which slowly changes to the crystalline, monoclinic form.

Arsenic trioxide is the primary product of arsenic smelters. This oxide has direct applications in industry. Other commercially useful organic and inorganic arsenic derivatives are prepared from it.

Oxidation of elemental arsenic or arsenic trioxide by nitric acid, followed by evaporation of the resulting mixture and dehydration of the residue, yields white hygroscopic crystals of arsenic pentoxide. Thermal decomposition of the pentoxide converts it to the trioxide with concurrent loss of oxygen. The pentoxide, in contrast with the trioxide, is very soluble in water; 630 g of arsenic pentoxide dissolve in 100 g of water.

Presumably, when arsenic trioxide is dissolved in water, the solution contains o-arsenous acid, $H_3AsO_3$. When $As_4O_6$ was dissolved in an acidic aqueous solution, only the undissociated species, $As(OH)_3$, was detected. Raman spectral and nuclear-magnetic-resonance studies indicate that, unlike the phosphorous acid molecule, which has both hydrogen-phosphorus and hydrogen-oxygen bonds, all the hydrogen atoms in arsenous acid are linked to oxygen atoms. Arsenous acid, however, cannot be isolated. On evaporation of its solutions, arsenic trioxide is obtained. The successive $pK_a$ values for $As(OH)_3$ have been reported as 9.23, 12.13, and 13.40. In alkaline solution, the anions $AsO(OH)_2^-$, $AsO_2(OH)^{-2}$, and $AsO_3^{-3}$ might be present. However, it has been claimed that the m-arsenite ion, $AsO_2^-$, is also present in such solution.

o-Arsenous acid and m-arsenous acid could form as products of the hydrolysis of $As_4O_6$. By analogy with the phosphorus compound, the meta acid would be expected to be polymeric. However, the arsenic-oxygen-arsenic bond is known to possess extreme hydrolytic instability. Hence, the monomeric ortho form would be expected to be the predominant species. This question merits additional investigation.

The hydroxides of iron(II) or iron(III), chromium, and aluminum readily absorb arsenous acid.

o-Arsenic acid, $H_3AsO_4$, can be prepared in the form of a white crystalline solid, $H_3AsO_4$--½$H_2O$. This is the product formed when arsenic trioxide is dissolved in nitric acid and the solution is evaporated. It is a fairly strong acid, with $pK_a$ values reported as 2.20, 6.97, and 11.53. Arsenic acid is an oxidizing agent in acid solution.

It is generally agreed that trivalent arsenic is considerably more toxic than pentavalent arsenic, so the question of whether arsenic exists in aqueous media in the form of arsenite or arsenate--i.e., $AsO_3^{-3}$ or $AsO_4^{-3}$--is very important. Thermodynamic calculations indicate that, in oxygenated ocean water, the ratio of the activity of arsenate to that of arsenite should be $10^{26}$:1.

Arsenites of the formulas $MH_2AsO_3$, $M_2HAsO_3$, and $M_3AsO_3$ are known. In these formulas, M represents a univalent metal cation or one equivalent of a multivalent cation. The alkali-metal arsenites are freely soluble in water, the alkaline-arsenites are slightly soluble, and the heavy-metal arsenites are insoluble.

Arsenic acid forms a corresponding series of salts that have similar solubility properties. Commercial lead arsenate, used as an insecticide, consists of $PbHAsO_4$ and some $Pb_3(AsO_4)_2$. The pH of a saturated solution of $PbHAsO_4$, containing 0.22 mg/liter at 25°C, is 4 to 5. The solubility product constant for $Pb_3(AsO_4)_2$ has been reported to be $10^{-35}$. Commercial calcium arsenate, also used as an insecticide, consists of 61 percent calcium arsenate and 9 percent calcium arsenite (of variable composition).

Some chemical and physical properties of various arsenic compounds are listed in Table 5.

## Creosote and Other Coal-Tar Products

The four principal oils produced in coal-tar distillation are chemical oil, top-of-column oil, uncorrected creosote oil, and heavy oil. The residue is pitch.

Table 5.--Chemical and physical properties of some arsenic compounds

| Chemical |  | Molecular Weight | Density | Form | Solubility | Melting Point |
|---|---|---|---|---|---|---|
| Name | Formula |  |  |  |  |  |
|  |  |  |  |  | g/liter | °C |
| Arsenic acid | $H_3AsO_4$ | 151.1 | 2.0-2.5 | White translucent crystals | 167 | 35.5 |
| Arsenic pentoxide | $As_2O_5$ | 229.8 | 4.5 | White amorphous powder | 1,500 | 315 (decomposes) |
| Sodium arsenate | $Na_2HAsO_4$ | 129.9 | 1.9 | Gray-white powder | Very soluble |  |
| Sodium pyroarsenate | $Na_4As_2O_7$ | 353.8 | 2.2 | White crystals | Very soluble | 1,000 (decomposes) |
| Lead arsenate (Std) | $PbHAsO_4$ | 347.1 | 5.8 | Monoclinic leaf crystals | Insoluble | 720 (decomposes) |
| Calcium arsenate | $Ca_3(AsO_4)_2$ | 398.1 | 3.6 | Colorless amorphous powder | 0.13 |  |
| Ammonium arsenite | $NH_4AsO_2$ | 125 | 1.3 | Colorless rhombic crystals | Very soluble | decomposes in hot water |
| Arsenic trioxide | $As_2O_3$ | 197.8 | 3.7 | Amorphous white powder | 20.6 | sublimes at 193 |
| Sodium arsenite | $NaAsO_2$ | 129.9 | 1.9 | Gray-white powder | Very soluble |  |

Figures 3 and 4 are schematics of the distillation processes. Creosote is a blend of the various distillates designed to impart specific physical characteristics that meet standards of the American Wood-Preservers' Association. A typical blend used to meet the provisions of Standards P1, P2, and P13 might be as follows:

<u>AWPA P1</u>

| | |
|---|---|
| Solvent naphtha | 10 parts |
| Naphthalene still residue | 35 parts |
| Uncorrected creosote | 55 parts |

<u>AWPA P13</u>

| | |
|---|---|
| Solvent naphtha | 5 parts |
| Naphthalene still residue | 35 parts |
| Uncorrected creosote | 45 parts |
| Heavy oil | 15 parts |

<u>AWPA P2</u>

| | |
|---|---|
| Coal tar | 10 parts |
| Uncorrected creosote | 90 parts |

Some formulations may employ slightly different ratios or omit the naphtha solvent or still residues.

In terms of the starting material, the yield of fractions that are blended to make creosote ranges from 25 to 40%, depending upon the point at which distillation is terminated. Both the yield and the chemical and physical properties of the various fractions are influenced by the characteristics of the coal from which the tar originates, the type of equipment used in the distillation process, and the particular process used.

There were 64 producers of coal tar in the United States in 1972 and 24 tar distillation plants producing creosote (EPA, 1975). A list of the latter plants, with production data, is given in Table 6. Only one company currently produces neutral oil. This fraction is normally blended with the acid fraction of creosote and sold under the name "tar acid oil" to formulators and packagers of disinfectants, insecticides, and related products.

## Physical Properties

Because their chemical composition and properties are not uniform, creosote and blends of creosote and coal-tar are normally described in terms of their physical properties. American Wood-Preservers' Association (AWPA) specifications for creosote for various uses are given in Table 7. Similar standards have been promulgated by the American Society for Testing and Materials (ASTM) and the General Services Administration (GSA). The principal differences among creosotes for the three uses shown are in specific gravity and the fraction of the oil distilling within various temperature ranges. This is likewise the case for creosote-coal-tar solutions, AWPA specifications for which are shown in Table 8.

A comparison of physical properties of coal-tar and creosote in Table 9 indicates much higher distillation residue for coal-tar. Various proportions of coal-tar

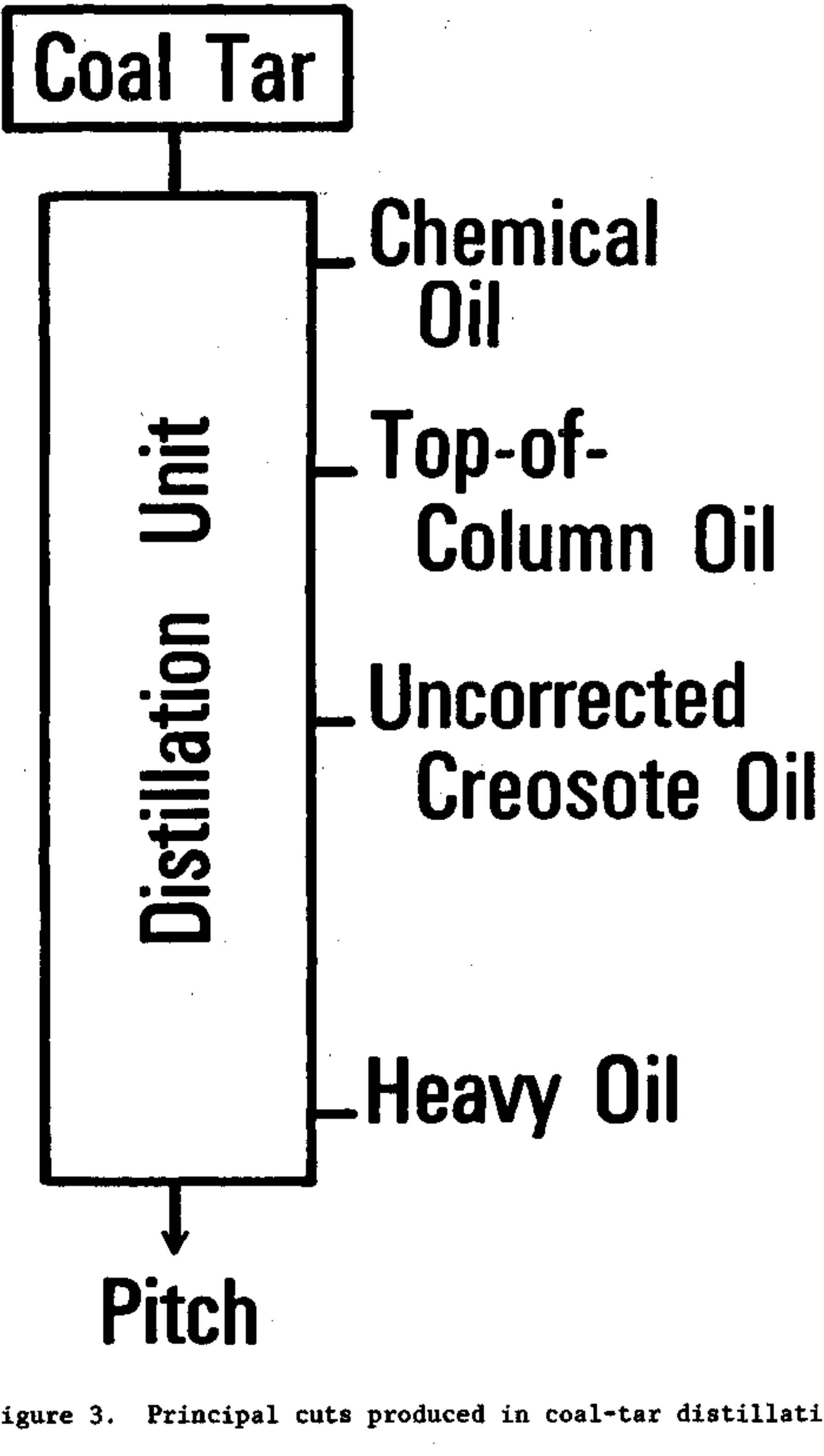


Figure 3. Principal cuts produced in coal-tar distillation.

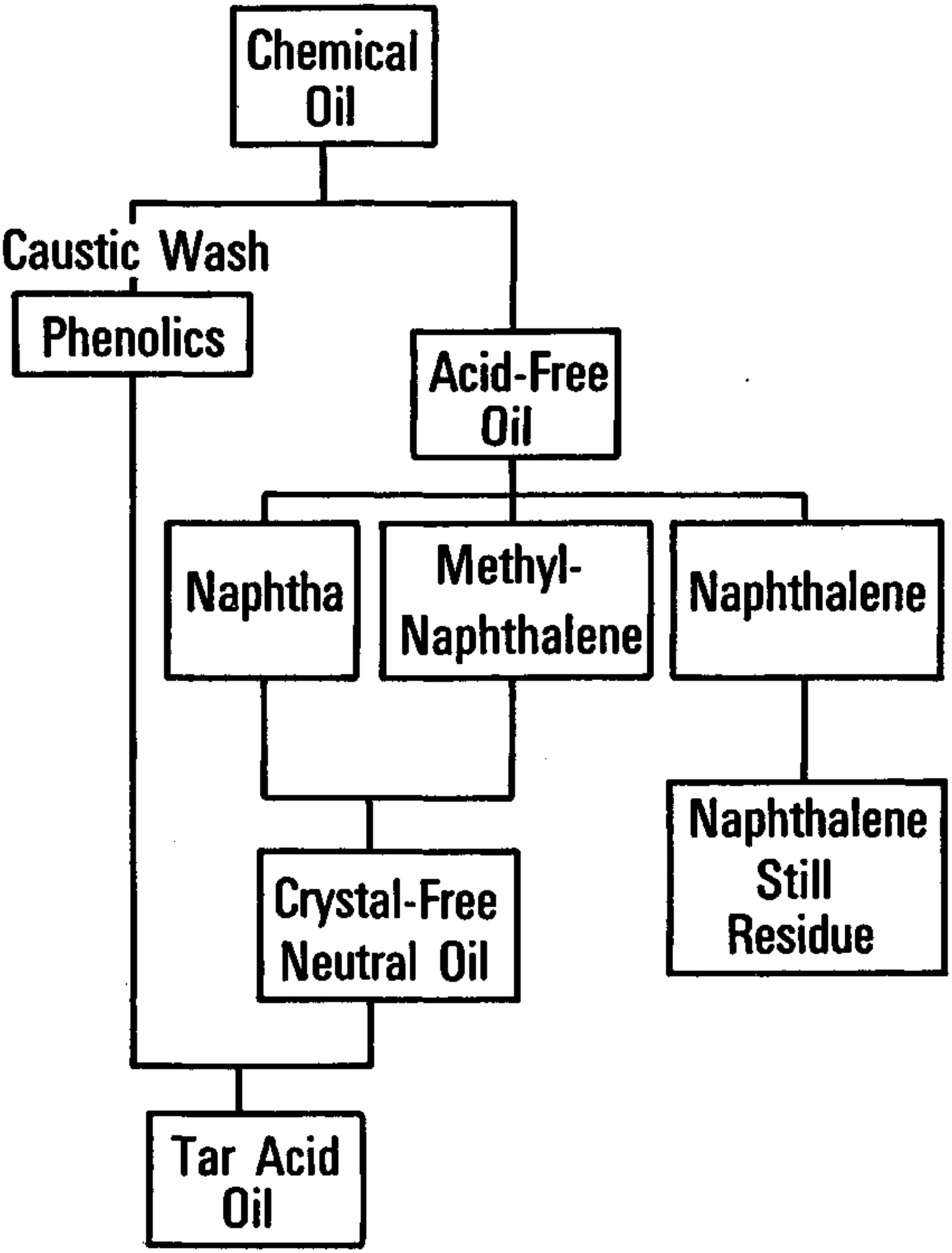


Figure 4. Distillates obtained from chemical oil.

Table 6.--Creosote production in the United States in 1972 by plant[a]

| | Estimated Plant Capacity | Estimated Annual Production |
|---|---|---|
| | Million Pounds/yr. | Million Pounds |
| Allied Chemicals Corporation | | 250-350 |
| Detroit, Michigan | 100-200 | |
| Ensely, Alabama | 100-200 | |
| Ironton, Ohio | 100-200 | |
| Koppers Company, Inc. | | 350-450 |
| Cicero (Chicago), Illinois | 100-200 | |
| Follansbee, West Virginia | 100-200 | |
| Fontana, California | 200-300 | |
| Houston, Texas | 10-20 | |
| Portland, Oregon | 10-20 | |
| Kearny (Seaboard), New Jersey | 10-20 | |
| St. Paul, Minnesota | 10-20 | |
| Swedeland, Pennsylvania | 10-20 | |
| Woodward, Alabama | 100-200 | |
| Youngstown, Ohio | 100-200 | |
| Reilly Tar and Chemical Corporation | | 50-100 |
| Cleveland, Ohio | 10-20 | |
| Granite City, Illinois | 10-20 | |
| Ironton, (Provo), Utah | 10-20 | |
| Lone Star, Texas | 10-20 | |
| Chattanooga, Tennessee | 10-20 | |
| USS Chemicals | | 250-350 |
| Clairton, Pennsylvania | 100-300 | |
| Fairfield, Alabama | 100-200 | |
| Gary, Indiana | 100-200 | |
| The Western Tar Products Corporation | | 20-40 |
| Memphis, Tennessee | 10-20 | |
| Terre Haute, Indiana | 10-20 | |
| Witco Chemical Corporation | | 10-20 |
| Point Comfort, Texas | 10-20 | ----- |
| Total Annual Production (1972) | | 1,150 |

[a] U.S. Environmental Protection Agency (EPA, 1975).

Table 7.--Physical properties of creosote and its fractions[a]

| | American Wood-Preservers' Association Standards | | | | | |
|---|---|---|---|---|---|---|
| | P1-65[a] | | P7-72[b] | | P13-65[c] | |
| Water % volume | < 1.5 | | < 1.0 | | < 1.5 | |
| Xylene, insoluble, % wt. | < 0.5 | | < 0.5 | | < 0.5 | |
| Specific gravity 38/15.5°C | | | | | | |
| Whole creosote | > 1.050 | | > 1.060 | | > 1.080 | |
| Fraction 235-315°C | > 1.027 | | -- | | > 1.030 | |
| Fraction 315-355°C | > 1.095 | | -- | | > 1.105 | |
| Residue above 355°C | -- | | -- | | > 1.160 | |
| Distillation, % by wt. | Min. | Max. | Min. | Max. | Min. | Max. |
| Up to 210°C | -- | 2.0 | -- | 1.0 | -- | 2.0 |
| 235°C | -- | 12.0 | -- | 10.0 | -- | 12.0 |
| 270°C | 20.0 | 40.0 | -- | -- | 20.0 | 40.0 |
| 315°C | 45.0 | 65.0 | -- | -- | 45.0 | 65.0 |
| 355°C | 65.0 | 82.0 | 65.0 | -- | 65.0 | 75.0 |
| | Shall remain fluid and crystal free after 3 hours at 5°C. | | | | | |

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[a] For land and fresh water use.

[b] For brush or spray application.

[c] For marine (coastal water) use.

Table 8.--American Wood-Preservers' Association specifications for creosote-coal tar solutions[a]

| | Grade | | | |
|---|---|---|---|---|
| | A | B | C | D |
| Composition | | | | |
| Creosote | <80 | <70 | <60 | >50 |
| Coal Tar | -- | -- | -- | -- |
| Water (% by volume) | > 3.0 | > 3.0 | > 3.0 | > 3.0 |
| Xylene, insol. (% by weight) | > 2.0 | > 3.0 | > 3.5 | > 4.0 |
| Coke residue (% by weight) | > 5.0 | > 7.0 | > 9.0 | >11.0 |
| Specific gravity 38/15.5°C | | | | |
| Whole oil | 1.06-1.11 | 1.07-1.12 | 1.08-1.13 | 1.09-1.14 |
| 235-315°C | 1.025 | 1.025 | 1.025 | 1.025 |
| 315-355°C | 1.085 | 1.085 | 1.085 | 1.085 |
| Residue | -- | -- | -- | -- |
| Distillation | | | | |
| To 210°C | 5 | 5 | 5 | 5 |
| To 235°C | 25 | 25 | 25 | 25 |
| To 270°C | -- | -- | -- | -- |
| To 315°C | 36 | 34 | 32 | 30 |
| To 355°C | 60 | 56 | 52 | 48 |
| Residue | -- | -- | -- | -- |

[a] AWPA Current Book of Standards (P2-68).

Table 9.--Comparison of the physical properties of coal tar and creosote

| | Creosote[a] | Coke Oven[b] Coal Tar |
|---|---|---|
| Benzene insoluble, % wt. | 0.99 | 4.6 |
| Specific gravity 38/15.5°C | | |
| Whole oil | 1.102 | 1.180 |
| Fraction 235-315°C | 1.054 | ----- |
| Fraction 315-355°C | 1.133 | ----- |
| Distillation, % wt. | | |
| Up to 210°C | 1.87 | 1.8 |
| 235°C | 6.89 | 7.1 |
| 270°C | 19.39 | 18.2 |
| 315°C | 49.8 | 28.3 |
| 355°C | 72.58 | 41.9 |
| Residue above 355°C | 26.67 | 57.6 |

---

[a] Lorenz and Gjovik, 1972.

[b] Martin, 1949.

are mixed with creosote to treat crossties, switch ties, and piling where surface appearance is not critical.

## Chemical Properties

At least 200 chemical compounds have been identified in creosote. Although the chemical composition of this material varies for reasons discussed above, it is generally agreed that several thousand different compounds could perhaps be identified with modern analytical instruments. Most of these are present in very small amounts, however. The major components of a typical creosote of U.S. origin and one of German origin are shown in Table 10. There are some rather striking differences between the two, especially as regards phenanthrene, anthracene, dibenzofuran, and several other constituents. The significance of such variations in composition, as they relate to efficacy as wood preservatives, is not clearly understood.

The greater part of the composition of creosote consists of neutral fractions. Tar acids, such as phenol and the cresols, as well as such tar bases as pyridenes, quinolines, and acridines, constitute a rather small percentage of the total weight of creosote. Unlike the neutral fractions the tar acids and bases are usually soluble in water and hence contribute very little to the efficacy of creosote as a wood preservative. It follows from the foregoing statements that the chemistry of creosote and that of the coal-tar neutral fractions are quite similar. So, for that matter, is the chemistry of the parent material--coal-tar. Compositional data for coke-oven coal tar from three sources are given in Table 11.

Table 10.--Chemical composition of a United States and a German creosote

| Compound or Component | U.S. Creosote[a] | German[b] |
|---|---|---|
| Naphthalene | 3.0 | 7.3 |
| Methyl naphthalene | 2.1 | 4.2 |
| Diphenyl dimethylnaphthalene | --- | 3.2 |
| Biphenyl | 0.8 | --- |
| Acenaphthene | 9.0 | 4.1 |
| Dimethylnaphthalene | 2.0 | --- |
| Diphenyloxide | --- | 3.4 |
| Dibenzofuran | 5.0 | --- |
| Fluorene-related compounds | 10.0 | 9.6 |
| Methyl fluorenes | 3.0 | --- |
| Phenanthrene | 21.0 | 12.6 |
| Anthracene | 2.0 | --- |
| Carbazole | 2.0 | --- |
| Methylphenanthrene | 3.0 | 5.4 |
| Methyl anthracenes | 4.0 | --- |
| Fluoranthene | 10.0 | 6.8 |
| Pyrene | 8.5 | 5.0 |
| Benzofluorene | 2.0 | 4.6 |
| Chrysene | 3.0 | 2.8 |
| Other components not identified | | 31.0 |

[a] Lorenz and Gjovik, 1972.

[b] Becker, 1977.

Table 11.--Average chemical composition of three coke-oven coal tars

| Component | British | German | American |
|---|---|---|---|
| Water, % | 4.9 | 2.5 | 2.2 |
| Carbon, % (on dry tar) | 90.3 | 91.4 | 91.3 |
| Hydrogen, % (on dry tar) | 5.5 | 5.25 | 5.1 |
| Sulfur, % (on dry tar) | 0.84 | 0.75 | 1.2 |
| Nitrogen, % (on dry tar) | 0.95 | 0.86 | 0.67 |
| Ash, % (on dry tar) | 0.24 | 0.15 | 0.03 |
| Toluene insolubles, % (on dry tar) | 6.7 | 5.5 | 9.1 |
| Components wt., % (on dry tar) | | | |
| Benzene | 0.25 | 0.4 | 0.12 |
| Toluene | 0.22 | 0.3 | 0.25 |
| o-xylene | 0.04 | -- | 0.04 |
| m-xylene | 0.11 | 0.2 | 0.07 |
| p-xylene | 0.04 | -- | 0.03 |
| Ethylbenzene | 0.02 | -- | 0.02 |
| Styrene | 0.04 | -- | 0.02 |
| Phenol | 0.57 | 0.5 | 0.61 |
| o-cresol | 0.32 | 0.2 | 0.25 |
| m-cresol | 0.45 | 0.4 | 0.45 |
| p-cresol | 0.27 | 0.2 | 0.27 |
| Xylenols | 0.48 | -- | 0.36 |
| Higher-boiling tar acids | 0.91 | -- | 0.83 |
| Naphtha fraction (bp 150-200°C) | 1.18 | -- | 0.97 |
| Naphthalene | 8.94 | 10.0 | 8.80 |
| 1-methylnaphthalene | 0.72 | 0.5 | 0.65 |
| 2-methylnaphthalene | 1.32 | 1.5 | 1.23 |
| Acenaphthene | 0.96 | 0.3 | 1.06 |
| Fluorene | 0.88 | 2.0 | 0.84 |
| Diphenylene oxide | 1.50 | 1.4 | |
| Anthracene | 1.00 | 1.8 | 0.75 |
| Phenanthrene | 6.30 | 5.7 | 2.66 |
| Carbazole | 1.33 | 1.5 | 0.60 |
| Tar bases | 1.77 | 0.73 | 2.08 |
| Medium-soft pitch (70°C, R and B softening pt.) | 59.8 | 54.4 | 63.5 |

# VOLUME I—WOOD PRESERVATIVE USES

## CHAPTER 1: BACKGROUND AND DATA BASE

# CHAPTER 1: BACKGROUND AND DATA BASE

## Introduction

The amount of round wood used in the United States each year is comparable in weight to all steel, aluminum, Portland cement, and plastic products combined (National Commission on Materials Policy, 1973). Wood is of major importance in commerce and construction. Since wood is abundant, low cost, renewable, expandable, recyclable, and environmentally beneficial, it is anticipated that it will assume a position of even greater importance as a construction material in the future.

A limitation of the use of wood is its susceptibility to attack by insects and marine borers, and to decay by fungi and other microorganisms. Living wood is usually quite immune to such attack, as are the heartwoods of certain durable woods such as locust, white oak, cypress, redwoods, and cedars. However, when moisture and air are present, most woods will decay rapidly, and even those with natural durability will eventually be degraded. Ground contact is a particularly high decay condition. In contact with moist soil, a pine fence post may have a service life of only 2 years, while a durable heartwood may last 8 to 15 years. If the same pine fence post is pressure-treated with preservatives, it will have a service life of more than 30 years. Treatments with preservatives expand the utility of wood tremendously. Preservative treatment makes it economical to use wood for poles, piling, and railroad ties. The product volumes and dollar values of these major products are enormous.

These wood products are treated with pentachlorophenol, inorganic arsenicals, and creosote, the major wood preservatives. The major use of this group of chemicals is in wood preservation. However, none of these preservatives is satisfactory for all wood products. Nevertheless, among the three chemicals, the important needs for treated wood are met: Creosote is mainly used for ties, utility poles, and pilings; penta is mainly used for utility poles, crossarms, posts, and lumber; and the arsenicals are used mainly for lumber, plywood, and poles. Thus, the spectrum of needs is covered effectively.

This report focuses primarily on (1) the dollar benefits derived from using treated wood and (2) the exposure associated with the processing and use of treated wood. The uses, benefits, and potential for human exposure are delineated in detail for each major preservative (Chapters 3, 4, and 5); alternative chemicals and materials are listed (Chapters 6 and 7); and the economic benefits and impacts of cancellation are quantified (Chapter 8).

Pertinent energy, environment, and social considerations are addressed in this report mainly in Chapter 8 (economic impacts). The low energy requirements for manufacture of wood products and the environmental advantages of forest production and utilization are well known but not always widely appreciated. By encouraging the use of wood products, these benefits become a reality. The use of wood preservatives significantly extends the service life of wood and has been perhaps the single most important factor in expanding the use potential of wood while not actually leading to the consumption of more trees.

## Research

In the development of this assessment report, information gaps were discovered. Several short-term research projects were initiated to help fill those gaps. For example, new research has better quantified the levels of penta volatilized from wood under different conditions of temperature and humidity; concentrations of penta have been measured in enclosed buildings that have incorporated penta-treated wood in their structure; and migration of creosote into a marine environment is under study.

The RPAR process provides valuable information that is useful in making reliable decisions, plus a means of broadening the data base in wood preservation through additional research. Since this process is on-going, it will continually be of value to the USDA-States-EPA pesticide management programs.

## Wood Preservative Chemicals—Background

### Pentachlorophenol

Penta was first introduced as a wood preservative in the 1930's and has enjoyed continued growth, becoming one of the major wood-preserving chemicals in the United States and abroad. Since penta is nearly insoluble in water, petroleum carriers are used as solvents, and the product has historically been used in applications where a clean paintable surface is not required. Although it has recently become possible to produce a clean product by using penta with solvents that are evaporated from the wood after impregnation, penta in solvents of low volatility is used primarily to treat poles, crossarms, timbers, and fenceposts. Approximately 1.2 million pounds of Na-penta are used each year in aqueous formulations that are applied to lumber and poles to control sapstain fungi. Such applications provide short-term protection against unsightly and aesthetically objectionable staining of fresh cut lumber during storage and transportation. Long-term protection against decay and insect damage is not provided by such treatments, however.

Penta is currently available to homeowners and small volume users as a 5% solution. These formulations are used in non-pressure processes for the protection of decks and other miscellaneous outdoor wood structures subjected to above-ground exposure. Most of the penta used in wood preservation is applied by pressure treatments in a large number of wood-preserving plants located throughout the United States. Details of the pressure treatment processes currently used may be found in Chapter 2 of this document. Commercial penta usually contains about 80% pentachlorophenol, 6% of the three tetrachlorophenol isomers, and 6% other chlorinated phenols, with the remainder composed of other chlorinated compounds including chlorinated dibenzo-p-dioxins and dibenzofurans. These latter compounds have generated considerable interest and their contribution to penta toxicity has been addressed in PD-1 (Federal Register 1978). Mention of these contaminants frequently occurs within this document, and the exposure analysis conducted by the Assessment Team includes an evaluation of potential human exposure to dioxins.

### Inorganic Arsenicals

The chemical composition and historical information on the establishment of the three arsenical salts, as wood preservatives, are summarized by Hartford (1973). He further discussed the manufacture of the arsenic, copper, and chromium compounds for preservation, and their formulation.

The three arsenical preservatives and the year of patent or initial use in the United States are fluor chrome arsenic phenol (FCAP, 1918), ammoniacal copper arsenate (ACA, 1939), and chrome copper arsenate (CCA; Type A, 1938; Type B, 1947; and Type C, 1968). The physical properties of the chemicals used are given in Table 12.

Table 12.--Physical properties of compounds used in formulating preservatives[a]

| | Formula | Physical Form | Solubility[b] | Remarks |
|---|---|---|---|---|
| Arsenic | | | | |
| Arsenic acid | $H_3AsO_4.1/2H_2O$ | White crystals | v.s. $H_2O$ | Usually sold as 75% $H_3AsO_4$. |
| Arsenic pentoxide | $As_2O_5$ | White deliquescent | v.s. $H_2O$ | |
| Arsenic trioxide | $As_2O_3$ | White powder | Ins. $H_2O$, sol. alks. | |
| Disodium arsenate | $Na_2HAsO_4$ | White powder | Sol. $H_2O$ | |
| Chromium | | | | |
| Chromic acid | $CrO_3$ | Red flakes | v.s. $H_2O$ | |
| Potassium dichromate | $K_2Cr_2O_7$ | Red-orange crystals | Sol. $H_2O$ | |
| Sodium chromate | $Na_2CrO_4$ | Yellow powder | Sol. $H_2O$ | |
| Sodium dichromate | $Na_2Cr_2O_7.2H_2O$ | Red-orange crystals | v.s. $H_2O$ | Sold as 69-70% soln. |
| Copper | | | | |
| Copper carbonate (basic) | $Cu_2(OH)_2CO_3$ | Green powder | Ins. $H_2O$, sol. acids | |
| Copper chloride | $CuCl_2.2H_2O$ | Green crystals | Sol. $H_2O$ | |
| Copper hydroxide | $Cu(OH)_2$ | Blue powder | Ins. $H_2O$, sol. acids | |
| Copper oxide | $CuO$ | Black powder | Ins. $H_2O$, sol. acids | |
| Copper sulfate | $CuSO_4.5H_2O$ | Blue crystals | Sol. $H_2O$ | |
| Copper sulfate | $CuSO_4.H_2O$ | White powder | Sol. $H_2O$ | |
| Others | | | | |
| Dinitrophenol | $2,6(OH)C_6H_3(NO_2)_2$ | Yellow crystals | Sl. sol. $H_2O$ | |
| Sodium pentachlorophenate | $C_6Cl_5ONa$ | White powder | Sol. $H_2O$ | Dust very irritating. |

---

[a] Source: Hartford, 1973.

[b] V.S. = Very Soluble, Ins. = Insuluble, Sol. = Soluble, Sl. sol. = Slightly Soluble.

ACA is an ammoniacal solution of copper and arsenic which forms an insoluble precipitate of copper arsenate in the wood on evaporation of ammonia. All ACA used in the United States is manufactured in a single plant located in Utah. Until recently, it was formulated from dry arsenic trioxide and finely divided metallic copper in an ammonia solution. The treatment plant now receives the arsenic as arsenic acid, and the treating solution is formulated by oxidizing the copper in aqua ammonia in the presence of air. This is followed by controlled introduction of the arsenic acid, to avoid corrosion problems. The nominal composition is shown in Table 13.

Table 13.--Nominal chemical composition of Ammoniacal Copper Arsenate (ACA), Chromate Copper Arsenate (CCA), and Fluor Chrome Arsenic Phenol (FCAP)

| Chemical | ACA[a] | CCA | | | FCAP |
|---|---|---|---|---|---|
| | | A | B | C | |
| | Percent | | | | |
| $CrO_3$ | | 65.5 | 35.3 | 47.5 | 37 |
| CuO | 49.8 | 18.1 | 19.6 | 18.5 | |
| $As_2O_5$ | 50.2 | 16.4 | 45.1 | 34.0 | 25 |
| F | | | | | 22 |
| Dinitrophenol | | | | | 16 |

[a] The weight of the ammonia ($NH_3$) contained in a treating solution shall be a minimum of 1.5 times the weight of the copper oxide (CuO).

CCA exists in three separate formulations in this country, designated Types A, B, and C in the order of their introduction. Although significant quantities of types A and B are used in the preservative treatment of wood, Type C has gained rapid acceptance since its introduction in 1968 and is now the dominant formulation. It was proposed in an effort to standardize formulations in the AWPA Book of Standards.

Type A solutions are frequently mixed at the plant by blending dry potassium dichromate or chromium trioxide and copper sulfate with arsenic acid. It also can be prepared and shipped to the treating plant as a solution with a 60% concentration on an oxide basis, with a pH between 1.6 and 3.2. Type B is supplied to the treating plant in paste form. Its pH range is specified to be between 1.6 and 3.0. This paste is diluted by the plant to the concentration required. Type C is supplied to the treating plant as a 50% solution concentrate, for dilution by the plant. Its pH is in the range of 1.6 to 3.0. Table 13 gives the approximate composition of the three types as specified in AWPA Standard P5. The standard allows variation in a narrow range about these percentages. All CCA formulations result in insoluble complexes within the treated wood, but the fixation of the components is greatest in types A and C.

FCAP was used as early as 1918 in the preservative treatment of wood in the United States. It is received by the treating plant as a dry mixture with the nominal composition indicated in Table 13. A major disadvantage is that the chemicals remain partially soluble in the wood and are readily leached by water. This has limited its use to the relatively mild exposures of above-ground applications. Its use has declined rapidly in recent years and all of the current limited demand is met by imports from overseas.

The arsenical preservative compounds, due to their cleanliness, durability, and safety, have been finding wider application in lumber, plywood, residential poles, urban poles, recreational equipment, and decks. In marine piling CCA or ACA is used alone or in combination with creosote. Given the current concerns for aesthetic values, the growth trend in the use of arsenic-treated wood products is expected to continue.

## Coal Tar, Creosote, and Neutral Oils

Tar products of both coal and wood origin have been used as wood preservatives since Biblical times. However, the use of creosote and coal tar as commercial wood preservatives had its beginning in 1838 in England when the first practical pressure treating process was patented by Bethel. The development of this process paved the way for the wood-preserving industry as it exists today.

Pressure preservative treatments with creosote were introduced in the United States in 1875 when the first Bethel process plant was constructed in Gautier, Miss. The industry grew rapidly during the period from 1875 to 1925, due to the demand of the railroads for crossties and bridge timbers. Growth was stimulated further after 1925 by the development and rapid expansion of the utility companies and the demand they created for treated poles. It was primarily the result of the demand for treated wood products on the part of the railroads and the utility companies that the wood preservation industry attained and subsequently maintained a position of prominence in the wood products field. During this period of development, which spanned approximately 60 years, creosote and its coal-tar and petroleum solutions were the only "heavy-duty" preservatives available. Their continued importance in modern times is attested to by the fact that essentially all railroad ties and timbers, a preponderance of marine piling, a significant part of all utility poles, and an impressive fraction of other preserved wood products are still treated with preservatives of coal-tar origin.

Creosote is a blend of several of the fractions produced during the distillation of coal tar. Because of its complex chemical composition--consisting, as it does, of some 200 "major" constituents and several thousand "minor" components--and because its composition varies from batch to batch, creosote traditionally is described in terms of its physical properties. The most important in this regard are specific gravity, water content, benzene-insoluble matter, and the percentage distilling within fixed temperature ranges.

Three grades, each of which is described in appropriate AWPA specifications in terms of these properties, are recognized within the industry. They are:

P1 Creosote for land and fresh water use.
P7 Creosote for brush or spray applications.
P13 Creosote-coal tar blend for marine use.

In addition, P-1 creosote may be blended with coal tar in the ratios of 80:20, 70:30, 60:40, or 50:50; or it may be combined with petroleum in the same ratios, although the ratio of 50:50 is most commonly used. The choice between petroleum and coal tar as a diluent for creosote in crosstie treatments is generally based on local costs including freight. The creosote-petroleum solutions are used to treat certain products, such as railroad ties, the in-service exposure of which is such that performance of straight creosote or creosote-coal tar are not needed for protection.

Well over 90% of all creosote used as a preservative is applied by pressure processes. However, a small percentage--about 0.2% of the total--is applied by non-pressure processes, including brush and spray applications. Creosote and its solutions are normally applied alone, but creosote may also be injected into marine piling as the second component of a dual treatment, the first of which is an arsenical-type preservative.

Neutral oil as presently formulated is not an efficacious wood preservative, although small amounts are sold for that purpose. When used for preservative purposes, it is invariably applied by dip, brush, or spray methods.

## Data Base—Production of Treated Wood Products

Accurate assessment of exposure to wood-preserving chemicals and benefits derived from the use of treated wood require accurate information about the amounts and kinds of treated wood produced.

Wood preservation statistics, based on surveys of the industry, have been published annually by the AWPA since 1909. Statistics on consumption of preservative chemicals and volume of wood treated for the period 1970-77 are shown in Table 14.

The number of plants surveyed, and response to the survey, for the period 1970-1977 are as follows:

| Year | Number of Known Plants[a] | Number of Plants Reporting[b] | Number of Plants Not Reporting | Survey Response Plants | Survey Response Capacity[c] |
|---|---|---|---|---|---|
| | | | | - - - Percent | - - - - |
| 1970 | 395 | 337 | 58 | 85.3 | 94.0 |
| 1971 | 390 | 334 | 56 | 85.6 | 93.0 |
| 1972 | 407 | 346 | 61 | 85.0 | 94.0 |
| 1973 | 397 | 333 | 64 | 83.8 | 92.0 |
| 1974 | 387 | 306 | 81 | 79.1 | unknown |
| 1975 | 394 | 297 | 97 | 75.4 | unknown |
| 1976 | 415 | 294 | 121 | 70.8 | unknown |
| 1977 | 472 | 344 | 128 | 72.9 | unknown |

[a] Plants to which survey questionnaires were mailed.

[b] Includes plants reported inactive.

[c] Estimated industry pressure-treating capacity.

From 1970 to 1973, the annual surveys accounted for about 85% of the known treating plants, and an estimated 92% to 94% of total pressure treating capacity. Since 1973, the number of treating plants has increased while response to the annual survey has declined. Thus, the number of plants not reporting increased from 58 in 1970, to 64 in 1973, and 128 in 1977. Moreover, people familiar with the wood-treating industry generally agree that the number of treating plants significantly exceeds the "number of known plants" surveyed in recent years, and that the under-reporting of industry activity is considerably greater than is indicated by recent

Table 14.--Wood Preservation Statistics, 1970-77[a]

| Preservative | Units | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|---|
| PRESERVATIVES USED, 1,000 UNITS | | | | | | | | | |
| Creosote | Gallons | 125,624 | 116,553 | 110,499 | 97,582 | 111,261 | 96,266 | 94,837 | 89,302 |
| Coal tar | do | 21,903 | 21,449 | 21,670 | 17,063 | 19,763 | 23,635 | 23,110 | 23,357 |
| Petroleum | do | 75,624 | 81,122 | 85,664 | 79,986 | 77,258 | 65,410 | 63,962 | 57,146 |
| Total liquids | do | 223,151 | 219,124 | 217,833 | 194,631 | 208,282 | 185,311 | 181,909 | 169,805 |
| Penta | Pounds | 28,461 | 32,039 | 46,011 | 38,837 | 43,493 | 35,479 | 38,924 | 21,537 |
| CCA | do | 6,033 | 8,572 | 9,748 | 11,667 | 15,257 | 15,875 | 17,092 | 24,778 |
| FCAP | do | 2,687 | 2,169 | 1,914 | 1,683 | 1,515 | 1,167 | 245 | 122 |
| Other[b] | do | 820 | 749 | 999 | 1,270 | 1,336 | 2,248 | 1,728 | 2,400 |
| Total arsenicals | do | 9,540 | 11,490 | 12,661 | 14,620 | 18,108 | 19,290 | 19,065 | 27,300 |
| ACC | do | 755 | 1,178 | 1,238 | 1,635 | 1,694 | 843 | 707 | 762 |
| CZC | do | 451 | 471 | 599 | 610 | 348 | 272 | 513 | 536 |
| Total dry preservatives | do | 39,207 | 45,178 | 60,509 | 55,702 | 63,643 | 55,884 | 59,209 | 50,135 |
| WOOD TREATED, MILLION CU. FT | | | | | | | | | |
| Creosote solutions | | 159.5 | 159.1 | 154.3 | 130.0 | 144.9 | 142.5 | 138.2 | 137.4 |
| Penta | | 65.7 | 69.5 | 75.8 | 80.0 | 75.8 | 60.8 | 65.6 | 54.8 |
| Creosote-penta | | 5.4 | 4.0 | 1.2 | 0.6 | (D) | 0.9 | 0.8 | 4.7 |
| CCA | | 15.1 | 20.1 | 25.6 | 29.4 | 41.1 | 29.9 | 44.8 | 42.7 |
| FCAP | | 5.2 | 7.4 | 5.5 | 3.6 | 2.4 | 1.8 | 0.8 | 0.2 |
| Other[b] | | 2.9 | 1.0 | 1.4 | 2.0 | 1.5 | 1.8 | 2.2 | 9.2 |
| Total arsenicals | | 23.2 | 28.5 | 32.5 | 35.0 | 45.0 | 33.5 | 47.8 | 52.1 |
| ACC | | 1.1 | 2.0 | 1.9 | 2.4 | 2.4 | 1.4 | 1.8 | 1.1 |
| CZC | | 0.8 | 0.7 | 0.9 | 0.7 | 0.6 | 0.5 | 0.9 | 1.2 |
| Total preserved wood | | 255.7 | 263.8 | 266.6 | 248.7 | 269.0 | 239.6 | 255.1 | 251.3 |

[a] Maloney and Pagliai, 1978.

[b] Mostly ACA.

published statistics. Assessments of exposure to wood preservatives and benefits from treated wood, based on published statistics are, therefore, likely to be inaccurate and misleading.

To remedy this situation, the Assessment Team conducted a supplemental survey of treaters in June-July 1979 to measure the volume of treated wood that was not reported in the most recent industry statistics. With the assistance of the AWPA and various suppliers of wood preservatives and wood-treating equipment, we compiled a list of 347 wood-treating plants that were not included in the most recent industry statistics. The list included plants that were not on the mailing list for the 1978 industry survey (1977 statistics), as well as those that were on the list but did not respond to the industry survey. In June, we mailed a letter and report form to each of the 347 firms on our list, requesting information about 1) the type and size of treating facilities, 2) kinds of preservatives used, and 3) annual production of treated wood products. In July, we mailed a second request to those who had not responded to the first mailing. By mid-August, we had accounted for 229 of the 347 plants on our list as follows:

| | | |
|---|---|---|
| Forms mailed | | 347 |
| Returned by postmaster (out of business, insufficient address, undeliverable as addressed, etc.) | 26 | |
| Returned by AWPA respondents and plants with duplicate names | 30 | |
| Net mailed to apparent treaters not represented in 1977 industry statistics | | 291 |
| Forms returned by: | | |
| Treaters who provided usable data | 130 | |
| Firms which are not treaters | 26 | |
| Treaters who are inactive or out of business | 17 | |
| Total response | | 173 |
| Nonrespondents to two mailings | | 118 |

Twenty-six of the 347 letters (7.5%) were returned by the Postmaster. In addition, forms were returned by firms that were listed under two or more names, or who had responded to the 1978 industry survey under a different name. Elimination of AWPA respondents and duplicate names accounted for another 30 firms on our initial list. The letter and report form were, thus, mailed to 291 apparent wood treaters who were not included in 1977 industry statistics.

Reports were returned by 173 of the 291 firms. Seventeen of these were inactive or no longer treating; 26 were not wood treaters (chemical sales, distributors of treated wood, etc.); and 130 were active treaters who supplied usable data on their annual production of treated wood products. The remaining 118 firms did not respond to two requests for information about their operations.

While checking on response to our survey, we acquired the names of 41 additional treaters who were not on our initial list. Production data were supplied for 20 of these firms. Thus, our survey obtained data from 150 treaters, and 139 firms did not respond.

## Wood Products Treated by Survey Respondents

The 150 respondents treated 55.6 million cu. ft. of wood products in 1978 (Table 15). About 14% of the total was treated with creosote solutions, 32% was treated with penta, and 54% was treated with inorganic arsenicals. Respondents also reported about 280,000 cu. ft. of products treated with CZC and fire-retardant chemicals. Lumber and timbers made up 62% of the total treated products. Poles (14%), fence posts (12%), and crossties (6%) accounted for most of the remainder.

Table 15.--Production of treated wood by respondents to Assessment Team Survey, 1978

| Products | Treated With | | | |
|---|---|---|---|---|
| | All Preservatives[a] | Creosote Solutions | Penta | CCA/ACA |
| | 1,000 cu. ft. | | | |
| Crossties and switch ties[b] | 3,554 | 3,432 | 23.0 | 99.6 |
| Poles | 8,008 | 1,568 | 6,193 | 247 |
| Crossarms | 243 | -- | 225 | 18.3 |
| Piling | 495 | 300 | 79.7 | 115 |
| Lumber and timbers | 34,215 | 1,022 | 8,016 | 25,176 |
| Fence posts | 6,520 | 1,240 | 2,980 | 2,300 |
| Plywood | 322 | -- | 23.4 | 298 |
| Other products | 2,232 | 20.1 | 378 | 1,834 |
| All products | 55,588 | 7,582 | 17,917 | 30,089 |

[a] Creosote, Penta, and CCA/ACA only. CZC and fire retardants not included.

[b] Includes landscape ties.

Note: Components may not add to totals due to rounding.

Most respondents reported production in board feet. Others reported cubic feet or number of pieces treated. Production was converted to cubic feet using the following factors:

| | |
|---|---|
| Crossties | 83 cu. ft. per 1,000 bd. ft. |
| | 3.33 cu. ft. per piece |
| Poles | 83 cu. ft. per 1,000 bd. ft. |
| Utility (West) | 25 cu. ft. per piece |
| Utility (South) | 15 cu. ft. per piece |
| Construction | 3 cu. ft. per piece |
| Crossarms | 83 cu. ft. per 1,000 bd. ft |
| | 1 cu. ft. per piece |

| | |
|---|---|
| Piling | 83 cu. ft. per 1,000 bd. ft. |
| Lumber and timbers treated with: | |
| penta and creosote | 80 cu. ft. per 1,000 bd. ft. |
| CCA/ACA | 66 cu. ft. per 1,000 bd. ft. |
| Fence posts | 83 cu. ft. per 1,000 bd. ft.<br>.67 cu. ft. per piece |
| Plywood | 31.25 cu. ft. per 1,000 sq. ft. |

Some of the respondents to our survey were new firms which began operation during 1978 or in early 1979. Production of plants that began operation in 1979 is not included in Table 15. For those that started up during 1978, production is included only for the months that they were in operation.

## Estimated Production of Treated Wood by Nonrepondents to the Survey

Although we did not receive reports of production from 139 plants, we did obtain some information about the operations of most of the non-respondents. From various sources, we learned whether they are pressure or nonpressure plants, what preservatives they use, and the number and size of cylinders operated. Ninety-eight of the 139 nonrespondents are pressure treaters, and 11 are nonpressure plants. We obtained no information, except a name and address, for 30 firms. The 98 pressure treaters operate 111 cylinders--54 treating with CCA, 37 with penta, and 20 with creosote. Using this information, we estimated the volume of wood treated by 109 of the nonrespondents. No estimates were made for the 30 plants for which we had no information as to type of operation or preservative used.

From the information supplied by 130 respondents, we determined average cylinder size, and volume of wood treated in relation to cylinder void volume, for different types of operations. For example, the average cylinder size for one-cylinder plants treating only with CCA was 6 x 50 feet (1,414 cu. ft. void volume), and volume of wood treated averaged 325 times the cylinder void volume. This level of production is equivalent to approximately 650 charges per year, or 2.2 charges per day for 300 working days.

Multi-unit treating plants tended to have larger cylinders than single-cylinder plants. Plants treating with penta had larger cylinders and lower production rates than plants using CCA/ACA. Creosote treaters had the largest cylinders and lowest production rates of all. The averages, as determined from 130 respondent plants, are as follows:

| Plants treating with: | Average cylinder | Production rate[a] |
|---|---|---|
| | feet | |
| CCA/ACA (one cylinder) | 6 x 50 | 325 |
| CCA/ACA (multi-cylinder) | 6 x 77 | 225 |
| Penta | 6 x 69 | 133 |
| Penta and creosote | 8 x 85 | 84 |

[a] Volume treated ÷ cylinder void volume.

In estimating production by nonrespondents, we assumed that reports had been received from most of the larger firms, and that the majority of nonrespondents are small firms whose production is somewhat lower than the average of the respondents. For this reason, we further assumed that nonrespondent firms would produce at one-half the average rate determined for respondents. Estimates for nonrespondents are based on the following factors:

| Plants treating with | Average cylinder | Production rate |
|---|---|---|
| CCA/ACA | 6 x 50 | 160 x void vol. |
| Penta | 6 x 60 | 100 x void vol. |
| Creosote | 6 x 70 | 80 x void vol. |

Where cylinder size was known, estimated production was based on actual cylinder void volume multiplied by the appropriate production factor (above). Where cylinder size was not known, the void volume of the average cylinder shown for the respective preservatives was multiplied by the appropriate production factor.

The average production of 33 respondent nonpressure plants was used to estimate production of the nonrespondent, nonpressure plants.

Using the procedure described, we computed total production of CCA/ACA-, penta-, and creosote-treated wood by nonrespondent plants. Then, we allocated the total volume treated with each preservative to the various products using ratios derived from Table 15, (e.g., 83.7% of CCA/ACA-treated wood is lumber and timbers, 34.6% of penta-treated wood is poles, etc.). The resulting estimates of wood treated by nonrespondents are shown in Table 16.

## Estimated Production of Treated Wood, 1978

To complete the picture of the amounts and kinds of treated wood products produced and used, we took the volumes reported by 342 respondents to the 1978 industry survey (1977 production) as a base. To these volumes we added the volumes reported by our respondents (Table 15) and those estimated for nonrespondents (Table 16). The resulting estimates of 1978 production by 601 treating plants are shown in Table 17. No estimates are included for an additional 30 plants for which we had no basis for estimates. Estimated 1978 production is summarized in Table 18.

Total production of treated wood in 1978 is estimated at 327.5 million cu. ft.--154.6 million cu. ft. treated with creosote solutions, 80 million cu. ft. treated with penta, and 92.9 million cu. ft. treated with inorganic arsenicals. Wood treated with CZC, ACC, and fire-retardant chemicals is not included. The estimated 1978 total production is 78.7 million cu. ft. (32%) higher than the 248.8 million cu. ft. reported for 1977 by the industry survey. Since all but a few of the plants that contributed to this increase were in operation in 1977, it is reasonable to assume that 1977 production was substantially under-reported.

Table 16.--Estimated volume of wood treated by nonrespondents, 1978

| Product | Treated With | | | |
|---|---|---|---|---|
| | All Preservatives[a] | Creosote Solutions | Penta | CCA/ACA |
| | 1,000 cu. ft. | | | |
| Crossties and switch ties[b] | 2,305 | 2,264 | 9.4 | 32.4 |
| Poles | 3,640 | 1,034 | 2,520 | 86.3 |
| Crossarms | 102 | -- | 91.4 | 10.8 |
| Piling | 274 | 198 | 32.4 | 43.2 |
| Lumber and timbers | 12,968 | 674 | 3,262 | 9,033 |
| Fence posts | 2,850 | 818 | 1,212 | 820 |
| Plywood | 117 | -- | 9.5 | 108 |
| Other products | 825 | 13.3 | 154 | 658 |
| All products | 23,083 | 5,002 | 7,290 | 10,792 |

[a] Creosote, Penta, and CCA/ACA, only.

[b] Includes landscape ties.

Note: Components may not add to totals due to rounding.

The 78.7 million cubic-foot difference between estimated 1978 and reported 1977 production breaks down as follows:

40.9 million cu. ft. are CCA/ACA-treated material.

= 52% of total increase.
= 79% increase in CCA/ACA-treated material.

25.2 million cu. ft. are penta-treated material.

= 32% of total increase.
= 46% increase in penta-treated material.

12.6 million cu. ft. are creosote-treated material.

= 16% of total increase.
= 9% increase in creosote-treated material.

47.2 million cu. ft. are lumber and timbers.

= 60% of total increase.
= 81% increase in treated lumber and timbers.

9.4 million cu. ft. are fence posts.

= 12% of total increase.
= 88% increase in treated fence posts.

11.6 million cu. ft. are poles.

= 15% of total increase.
= 22% increase in treated poles.

Based on the volumes of wood treated with the different preservatives (Table 18) and average retentions for the various products, we estimate that consumption of preservative chemicals by the pressure-treating industry in 1978 was as follows:

| | |
|---|---|
| Creosote and coal tar | 123.7 million gallons |
| Penta | 40.8 million pounds |
| Inorganic arsenicals | 37.2 million pounds |

We believe our estimates of 1978 production of treated wood are conservative for the following three reasons:

1. The volumes of treated wood reported in the 1977 industry report appear to be low, especially for wood treated with inorganic arsenicals. The report shows 27.3 million pounds of arsenical salts consumed, and 52.1 million cu. ft. of wood treated with inorganic arsenicals. The resultant retention of arsenical salts (0.524 pcf) is high, indicating that the reported volume of wood treated is low.

2. Knowledgeable industry officials indicate that 1977 was an "off" year for the treating industry. Most plants increased production in 1978 by about 10%. If this is so, using 1977 production by 342 respondents to the industry survey as a base for our 1978 estimates would result in a low estimate for 1978.

3. Our estimates of 1978 production by nonrespondents to the Team survey may well be low because we assumed a below-average rate of production for these plants.

Table 17.--Estimated production of treated wood, 1978

| Products | | Treated With | | | |
|---|---|---|---|---|---|
| | | All Preservatives[a] | Creosote | Penta | CCA/ACA/FCAP |
| | | 1,000 cu. ft. | | | |
| Ties[e] | 1977[b] | 100,226 | 97,442 | 417 | 2,366 |
| | Resp[c] | 3,554 | 3,432 | 23.0 | 99.6 |
| | Nonresp[d] | 2,305 | 2,264 | 9.4 | 32.4 |
| | | 106,085 | 103,138 | 449 | 2,498 |
| Poles | 1977 | 52,531 | 15,634 | 33,193 | 3,704 |
| | Resp | 8,008 | 1,568 | 6,193 | 247 |
| | Nonresp | 3,640 | 1,034 | 2,520 | 86.3 |
| | | 64,179 | 18,237 | 41,905 | 4,038 |
| Crossarms | 1977 | 1,340 | 41.0 | 1,299 | (d) |
| | Resp | 243 | -- | 225 | 18.3 |
| | Nonresp | 102 | -- | 91.3 | 10.8 |
| | | 1,685 | 41.0 | 1,615 | 29.1 |
| Piling | 1977 | 11,322 | 9,495 | 1,042 | 785 |
| | Resp | 495 | 300 | 79.7 | 114 |
| | Nonresp | 274 | 198 | 32.4 | 43.2 |
| | | 12,090 | 9,993 | 1,154 | 943 |
| Lumber and timbers | 1977 | 58,122 | 9,083 | 9,931 | 39,108 |
| | Resp | 34,215 | 1,022 | 8,016 | 25,176 |
| | Nonresp | 12,968 | 674 | 3,262 | 9,033 |
| | | 105,305 | 10,779 | 21,209 | 73,317 |
| Fence posts | 1977 | 10,658 | 2,526 | 6,791 | 1,341 |
| | Resp | 6,520 | 1,240 | 2,980 | 2,300 |
| | Nonresp | 2,850 | 818 | 1,212 | 820 |
| | | 20,028 | 4,584 | 10,983 | 4,461 |
| Other products[f] | 1977 | 14,617 | 7,782 | 2,117 | 4,718 |
| | Resp | 2,553 | 20.1 | 401 | 2,132 |
| | Nonresp | 943 | 13.3 | 163 | 766 |
| | | 18,113 | 7,815 | 2,681 | 7,616 |
| All products | 1977 | 248,814 | 142,003 | 54,789 | 52,022 |
| | Resp | 55,588 | 7,582 | 17,917 | 30,089 |
| | Nonresp | 23,083 | 5,002 | 7,290 | 10,792 |
| | | 327,485 | 154,587 | 79,996 | 92,903 |

[a] Creosote, Penta, and CCA/ACA only.

[b] 1977 base, Maloney and Pagliai, 1978.

[c] Respondents to Assessment Team Survey.

[d] Estimate for nonrespondents to Assessment Team Survey.

[e] Includes landscape ties.

[f] Includes plywood.

Note: Components may not add to totals due to rounding.

Table 18.--Estimated production of treated wood, 1978[a]

| Products | Treated With | | | |
|---|---|---|---|---|
| | All Preservatives[b] | Creosote Solutions | Penta | CCA/ACA/FCAP |
| | 1,000 cu. ft. | | | |
| Crossties and switch ties[c] | 106,085 | 103,138 | 449 | 2,498 |
| Poles | 64,179 | 18,237 | 41,905 | 4,038 |
| Crossarms | 1,685 | 41.0 | 1,615 | 29.1 |
| Piling | 12,090 | 9,993 | 1,154 | 943 |
| Lumber and timbers | 105,305 | 10,779 | 21,209 | 73,317 |
| Fence posts | 20,028 | 4,584 | 10,983 | 4,461 |
| Other products[d] | 18,113 | 7,815 | 2,681 | 7,616 |
| All products | 327,485 | 154,587 | 79,996 | 92,903 |

[a] Volume reported for 1977 (AWPA), plus volume reported by respondents to Assessment Team Survey, plus volume estimated for nonrespondents.

[b] Creosote, Penta, and CCA/ACA/FCAP only.

[c] Includes landscape ties.

[d] Includes plywood.

Note: Components may not add to totals due to rounding.

# CHAPTER 2: METHODS OF APPLICATION

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## Introduction

Preparatory to preservative treatment, round wood products must be debarked and conditioned. Conditioning of round or sawn wood may be accomplished by air seasoning or kiln drying. Alternatively, the moisture content of wood may be reduced sufficiently to permit preservative treatment with certain types of preservatives by either steaming the wood in the retort, heating it in oil under reduced pressure, or by exposing it to hot vapors of organic solvents in a process called vapor drying. Preservative treatment of refractory species may be expedited by incising, a process in which the wood is pierced by knives to provide avenues for penetration of the preservative solution.

Preservative impregnation may be accomplished by either pressure or non-pressure methods. Pressure treatments involve the application of pneumatic or hydrostatic pressure to wood in a vessel designed for that purpose to expedite movement of the preservative liquid into wood. These processes account for fully 95 percent of all wood treated. Non-pressure processes involve treatments accomplished at atmospheric conditions. These include thermal, brush, dip and spray, diffusion, vacuum, and cold soak methods. Also included here are groundline treatments that are applied to wood in use to extend its service life.

## Pressure Processes

The distinction between pressure and non-pressure processes was stated above. In the normal application of preservative treatments by pressure processes, wood loaded on trams is introduced into the pressure vessel and, after appropriate conditioning, may be subjected to either one of two treatment schedules: full cell or empty cell.

In the full-cell process (Figure 5), an initial vacuum is applied to the charge for a period of about 30 minutes. At the end of this period, and while still maintaining the vacuum, the vessel is filled with preservative. The vacuum is released and pressure equal to 50 to 250 psi, depending upon species, is applied to the system. Pressure is maintained until the required gross absorption of preservative has been achieved. This value varies depending upon the species being treated.

At the end of the pressure cycle, the pressure is reduced to atmospheric level, the preservative returned to storage, and the treated wood often subjected to a final vacuum to remove excess preservative from the surface of the stock. The vacuum is released, the door of the vessel opened, and the treated wood removed. Retentions achieved by the full-cell process vary from 20 to 30 pounds per cubic foot for most species.

In the empty-cell process the retort is filled with preservative while either at ambient conditions or under an initial air pressure of 15 to 75 psi (Figure 6). The remainder of the treating schedule is the same as that described for the full-cell process. Retentions achieved by the empty-cell process range from 6 to 12 pounds per cubic foot, depending upon the specifications of the customer.

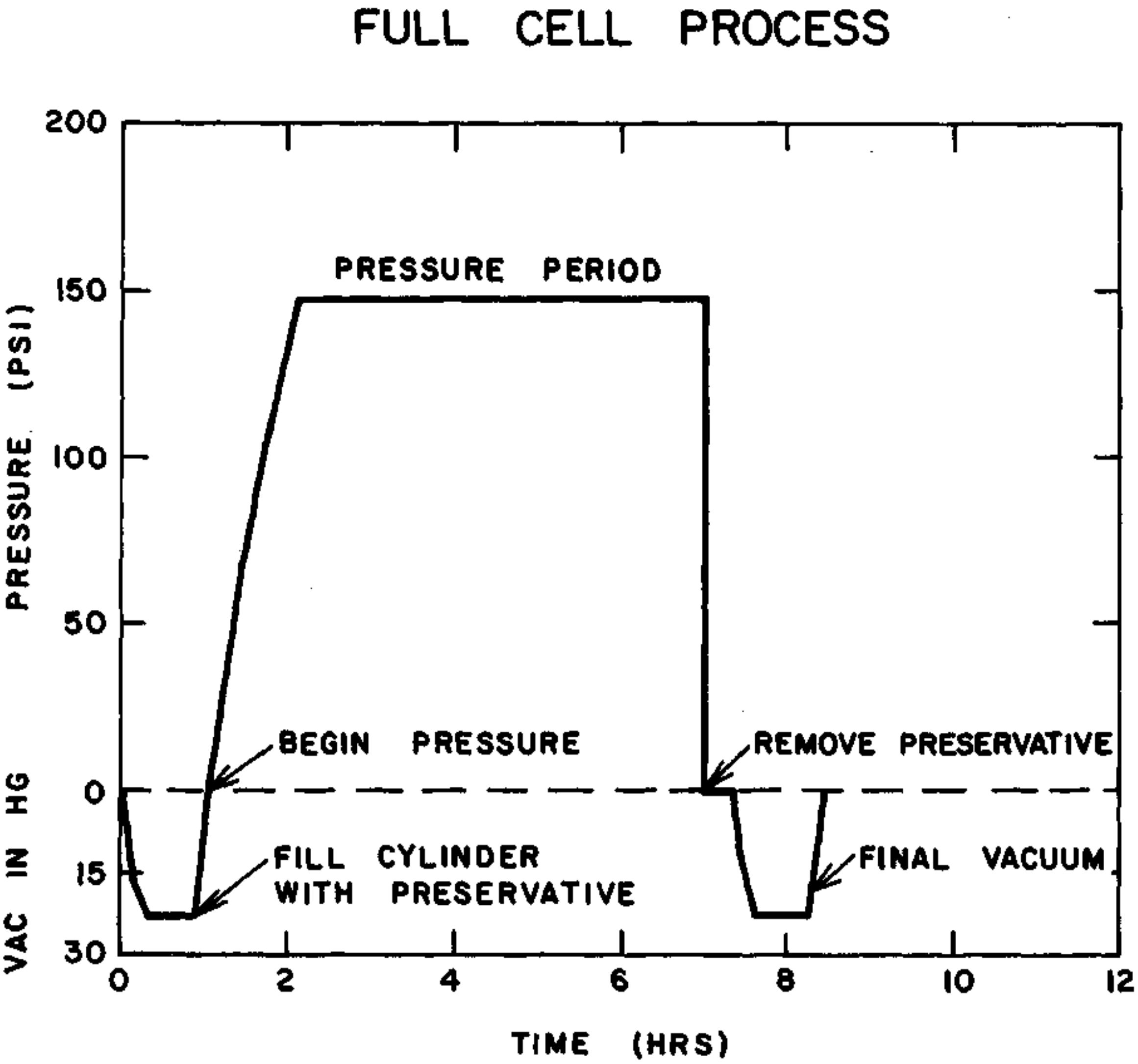

Figure 5. Schematic showing the treating schedule for full cell treatment.

Products such as marine piling are treated by the full-cell process. Conversely, products such as poles, crossties, and fence posts are treated by the empty-cell process. Differences in retention are determined by the biological hazard to which the treated wood will be subjected in service. The full-cell process is used for all products treated with waterborne preservatives.

Creosote may be applied in undiluted form or diluted with coal tar or petroleum. Pentachlorophenol is applied in a solvent of low volatility or in such volatile solvents as mineral spirits, methylene chloride, or liquefied petroleum gas. When a solvent of low volatility is used, the solvent is left in the wood at the conclusion of the treating cycle. Conversely, when the proprietary processes that employ certain volatile solvents are used, the solvents are recovered from the wood for reuse at the end of the treating cycle.

Preservative temperatures employed during the treating cycle vary with the preservative used. Creosote and its solutions are normally applied at temperatures of 210° to 230° F. The temperature used with penta solutions varies with solvent and may range from ambient to 220° F. Except for ACA all waterborne preservatives are always applied at ambient temperature.

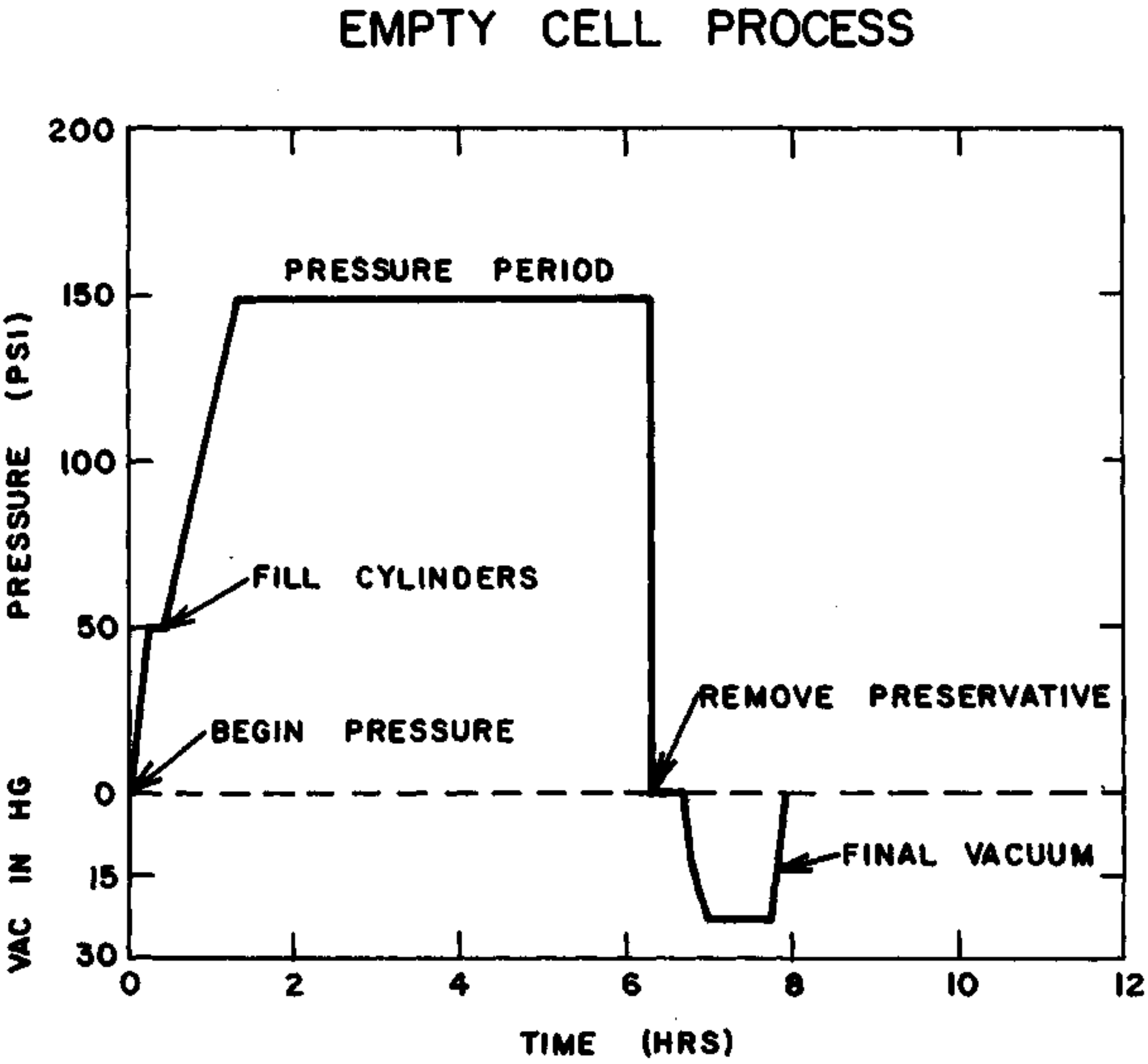

Figure 6. Schematic showing the treating schedule for empty cell treatment.

## Non-Pressure Processes

Non-pressure processes may be employed commercially or by individuals for home, farm, and garden uses. Wood treated by these processes must be seasoned to a moisture content of 30% or less prior to treatment. In one exception to this general rule, wood preserved by diffusion processes is treated in an unseasoned state.

Most commercial non-pressure treatments are applied by cold-soak or thermal processes. In both processes, wood is exposed to the preservative in an open vessel. The preservatives used with the cold-soak process are usually penta-petroleum solutions, although waterborne salts may also be employed. The process simply entails soaking seasoned wood in the preservative for a fixed period of time, or until a predetermined gross retention has been achieved. The thermal process is normally used with penta-petroleum solutions, but may also be used with other preservatives. This process involves exposing wood to hot preservative for 6 to 12 hours followed by exposure to preservative at ambient temperature for about 2 hours. Both round and sawn stock may be treated by these methods.

Diffusion treatments constitute a variation of the cold-soak process in which unseasoned wood is exposed to an aqueous solution of a salt-type preservative for a predetermined time period. Treatments in which two salts (e.g. copper sulfate and sodium arsenate) are applied sequentially are sometimes used to achieve a leach-resistant preservative following the reaction of the two salts in situ.

Brush, dip, and spray treatments are applied by homeowners or on the job by carpenters during construction. Penta-petroleum solutions, creosote, and copper naphthenate packaged in 1- and 5-gallon containers for this market are used in these types of treatments. Dip treatments are also used commercially to treat millwork. Such treatments significantly increase the life of wood in above-ground service and are widely used for this purpose.

Vacuum treatments are applied in a closed vessel similar to that used with pressure processes. Stock placed in the vessel is subjected to a vacuum for a predetermined period of time; and, while still under vacuum, is covered with preservative solution. The vacuum is released, and after a soaking period, the preservative solution is withdrawn from the vessel. A second vacuum is frequently applied to remove excess preservative from the wood. This process, while widely used in Europe, has received only limited use in the United States. It is applicable to non-refractory species and such specific products as millwork and lumber. Penta in a light petroleum solvent is the most common preservative used with the process.

Groundline treatments involve the application of preservative in a grease matrix to the groundline zone of utility poles in line to arrest existing decay and to extend the service life of the product. Both creosote and penta are common ingredients in groundline treatment formulations. They may be applied from ready made bandages or troweled onto the pole. In both cases, the preservative is placed in direct contact with the wood and separated from the soil by a paper and plastic film.

Hunt and Garratt (1967), Nicholas (1973), and Gjovik and Baechler (1977) should be consulted if more background is necessary on the general subject of wood preservation.

# CHAPTER 3: PENTACHLOROPHENOL AND PENTACHLOROPHENATES

# CHAPTER 3: PENTACHLOROPHENOL AND PENTACHLOROPHENATES

## Use Patterns and Efficacy

The major use of penta is the treatment of wood to prevent attack by wood-destroying fungi and insects. The major fungi responsible for biodeterioration of wood are the Basidiomycetes, which have the ability to enzymatically consume the structural cellulose and lignin in wood. In addition, the soft-rot fungi, generally Ascomycetes or Fungi Imperfecti, are responsible for a certain amount of wood biodeterioration. Typical wood-destroying insects include subterranean (Reticulitermes and Coptotermes sp.), dampwood (Zootermopsis sp.) and drywood (Kalotermes sp.) termites, powderpost beetles (Lyctus and Anobidium sp.), flat-headed borers (Buprestis sp.), round-headed borers (Saperda sp.), ambrosia beetles (Platypus sp.), and carpenter ants (Componotus sp.). Another important use is for the control of fungi which cause mold and sapstain discoloration of poles and freshly sawn lumber.

In 1978, approximately 43.6 million pounds of penta were used in the treatment of wood products in the United States (Dorman, 1979). The usage by region in 1976 is shown in Table 19 (Ernst and Ernst, 1977).

Table 19.--Amounts of penta used by treating plants in various regions of the United States in 1976

| Northeast | North Central | Southeast | South Central | Rocky Mt. | Pacific | Total |
|---|---|---|---|---|---|---|
| | | | 1,000 Pounds | | | |
| 1,315 | 6,560 | 9,730 | 14,761 | 1,871 | 4,687 | 39,924 |

Ninety-three percent of the penta used for commercial treatment is applied in "closed" pressure treating systems, and the other 7% in thermal and dip treatment systems and groundline treatment.

## Commercial Pressure and Non-Pressure Treatments

The volumes of wood treated with penta are listed in Table 20. From this table, it is obvious that in the past 10 years the use of penta for treatment of various wood products had increased to a small degree, but there have been no significant changes in any individual product. It is anticipated that this general situation will continue in the future for all products except lumber, in which case there is a definite trend toward treatment with waterborne salts. An estimated 40.8 million pounds of penta were used in these applications in 1978. Commercial pressure and thermal treatments account for 40 million pounds of penta while dip treatments consume 700,000 pounds (consisting of 600,000 pounds for the treatment of millwork and 100,000 pounds for miscellaneous wood products) of the chemical (NFPA, 1979).

"Millwork" is a general term for such items as window frames, door jambs, doors, shutters, mouldings, railings, etc., which are used in home construction. Treatment

Table 20.--Volumes of wood materials treated with penta in the United States by product in the years 1966, 1972-78

| Year | Crossties and Switch Ties | Piling | Poles | Cross-arms | Lumber and Timbers | Fence Posts | Other | Total |
|---|---|---|---|---|---|---|---|---|
| | - - - - - - - - | - - - - | - - - - | 1,000 cu.ft. | - - - - | - - - - | - - - - | - - - - |
| 1966[a] | 262 | 1,959 | 31,615 | 4,386 | 14,252 | 9,074 | 2,361 | 64,179 |
| 1972[a] | 129 | 239 | 45,230 | 2,093 | 16,394 | 9,924 | 1,786 | 75,795 |
| 1973[a] | 60 | 288 | 47,193 | 2,234 | 19,663 | 9,055 | 1,528 | 80,022 |
| 1974[b] | 321 | 135 | 42,031 | 1,947 | 19,302 | 9,580 | 2,450 | 75,445 |
| 1975[b] | 358 | 384 | 32,155 | 1,301 | 15,837 | 9,953 | 783 | 60,771 |
| 1976[b] | 19 | 368 | 36,525 | 4,541 | 13,873 | 9,096 | 1,208 | 65,611 |
| 1977[c] | 417 | 1,042 | 33,193 | 1,299 | 9,931 | 6,791 | 2,117 | 54,789 |
| 1978[d] | 449 | 1,154 | 41,905 | 1,615 | 21,209 | 10,983 | 2,681 | 79,996 |

[a] Gill and Phelps, 1974.

[b] Ernst and Ernst, 1977.

[c] Maloney and Pagliai, 1978.

[d] Micklewright, 1979.

with wood preservatives is generally limited to those wood products which are subject to exterior exposure since interior products are not susceptible to decay.

Most millwork is coated with paint, stain or varnish, so it is important that the preservative treatment does not have any detrimental effect on these finishes. In addition, the treatment must be compatible with the various types of metal fastenings that are used in construction.

At the present time, virtually all millwork that requires a wood preservative is treated with a water-repellent system containing 5% penta in petroleum solvent, by a nonpressure process. The water repellent helps control excessive swelling, shrinking, and warping due to a change in moisture content and the preservative controls wood decay organisms. The preservative is generally applied at the factory after the wood components are fully machined. A number of treatment methods are used, but the majority of the millwork is treated by simply dipping the wood products in a tank filled with preservative. In some instances a more complex vacuum process is used which requires a sealed chamber. In this process the wood is loaded into a chamber, an initial vacuum of 2 to 5 in. of Hg is drawn and held while the cylinder is filled with solution. Following this the solution is returned to a storage tank and a final vacuum of 20-25 in. of Hg is drawn to remove excess preservative before the wood is removed from the treatment chamber. In addition, a few plants use a spray or flowcoat method for treatment. In this method the wood is moved by conveyors under spray nozzles or a stream of the treating solution. Following this the wood moves into ovens, heaters or other equipment to accelerate the volatilization of the solvent.

Under the category of miscellaneous wood products, a large variety of items is covered. For example, such things as tent pegs, ladders, trailer bodies, ammunition boxes, crates, pallets, etc., are included. Because of this wide diversity of products, there is very little detailed information on these uses.

An additional 50,000 to 60,000 pounds of penta are used annually for dip or spray treatment of plywood and particleboard (NFPA, 1979). For these two products, plywood is by far the largest volume product, consuming approximately 50,000 pounds of penta annually. Most of the material treated is rough-sawn textured plywood that is used for exterior siding. The penta preservatives generally contain water repellents and the combined system provides protection against mildew and water stain that can develop before a finish is applied.

The use of penta in particleboard is limited to a single manufacturer who treats approximately 10,600 cu. ft. at a level of 0.65%, based on the oven-dry weight of wood (NFPA, 1979). At this rate of application, and assuming a board density of 50 pounds/cu. ft., the total annual use of penta for this application would be 3,400 pounds.

The general use pattern for penta in commercial applications is shown in Table 21. As can be seen from this table, poles are, by far, the major product treated with this preservative.

## Commercial Field Treatments for Poles

This type of treatment is used to fortify the groundline area of poles that are in service. Approximately 200,000 pounds of penta were used for this application in 1978 (NFPA, 1979). Various combinations of preservatives (i.e., penta, creosote, fluorides, borax, etc.) are generally used for this application by formulating a paste which is applied by a trowel or brush and is frequently wrapped with plastic to contain the preservative. The typical formulation contains 10% penta. Treatment is limited to a small area above and below the groundline.

## Commercial Sapstain Control Treatment for Lumber and Poles

Approximately 1.15 million pounds of Na-penta (produced from 1.02 million pounds of penta) are used each year in preservative formulations that are applied to lumber and poles to control sapstain fungi (NFPA, 1979). A common formulation consists of 40% Na-penta and 60% borax, but other combinations are employed. The actual treating solutions contain approximately 0.5% Na-penta. Spraying and dipping are the normal methods of applying these preservatives. The general use patterns are shown in Table 21.

## Non-Commercial Brush, Dip, Spray and Soak Treatments

Approximately 1.5 million pounds of penta are used at the home and farm level for the protection of various wood structures and products subjected to exterior exposure (NFPA, 1979). This is 3.4% of total use of penta as a wood preservative. Penta solutions are applied by homeowners, farmers, and to some extent on the job by carpenters, to protect wood from insect attack and decay. The application can be by brushing, roll on, dipping, soaking, or spraying. Typical items sometimes treated include decks, siding, millwork, lumber, fences, shingles, outdoor furniture, and other miscellaneous wood products.

This type of treatment is intended only for above-ground exposures and is considered inadequate for ground contact situations because of very limited penetration of the side grain. In its principal application, to exterior millwork such as window sash and door jambs, it is quite effective because of good end grain penetration.

Table 21.--Commercial use patterns for penta in 1978

| Item | Application Method | Volume Treated[a] | Percent of Total Volume[b] | Amount of Preservative[a] | Pests Controlled | Average Rate of Application |
|---|---|---|---|---|---|---|
| | | 1,000 cu. ft. | | Million Pounds | | Pcf |
| Poles | Pressure and thermal treatment | 41,905 | 57 | 25.1 | Wood decay fungi and insects | 0.6 |
| Lumber and timbers | Pressure, thermal and dip treatment | 21,209 | 19 | 8.5 | Wood decay fungi and insects | 0.4 |
| Fence posts | Pressure, thermal and dip treatment | 10,983 | 10 | 4.4 | Wood decay fungi and insects | 0.4 |
| Crossarms | Pressure treatment | 1,615 | 1.5 | 0.65 | Wood decay fungi and insects | 0.4 |
| Piling | Pressure and thermal treatment | 1,154 | 1.8 | 0.81 | Wood decay fungi and insects | 0.7 |
| Crossties and switch ties | Pressure treatment | 449 | 0.4 | 0.18 | Wood decay fungi and insects | 0.4 |
| Other | Pressure, thermal and dip treatment | 2,681 | 2.5 | 1.1 | Wood decay fungi and insects | 0.4 |
| Millwork[c] | Pressure, vacuum and dip treatment | 60,000 | 1.4 | 0.6 | Wood decay fungi and insects | 0.01 |

Table 21.--Commercial use patterns for penta in 1978--continued

| Item | Application Method | Volume Treated[a] | Percent of Total Volume[b] | Amount of Preservative[a] | Pests Controlled | Average Rate of Application |
|---|---|---|---|---|---|---|
| | | 1,000 cu. ft. | | Million Pounds | | Pcf |
| Lumber, Sapstain control | Dip and spray treatment | 257,000 | 2.3 | 1.02[d] | Sapstain fungi and insects | 0.004 |
| Home and farm uses | Brush, dip or spray treatment | 150,000[e] | 3.4 | 1.5 | Wood decay fungi and insects | 0.01 |
| Groundline | Brush treatment | NDA[f] | 0.5 | 0.2 | Wood decay fungi and insects | NDA[f] |

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[a] Values are for 1978 and were taken from Micklewright 1979 for all items except millwork, sapstain, and groundline, values which are derived from NFPA 1978 data (NFPA, 1979).

[b] Percent of total penta used to treat this product.

[c] This refers to window and door frames, cabinets, etc. Volume and amount of preservative estimates are from industry sources.

[d] This value for penta is equivalent to 1.15 million pounds of Na-penta.

[e] The volume of wood treated was estimated from the average rate of application and amount of preservative.

[f] No data available.

This provides protection at the joints, where decay normally occurs in these members. Verrall (1959 and 1965) studied this treatment process extensively. A subsequent paper indicates a 90% increase in service life of unpainted boxes when treated with a typical 5% penta formulation and exposed at Gulfport, Miss. (Verrall and Sheffer, 1969). More recently, Feist and Mraz (1978) reported that a simple water repellent performed as well as water repellent with 5% penta on exposure at Madison, Wis. However, the exposure severity at this site is considerably less than that throughout most of the United States. Hence, the use of water repellents alone cannot be considered to be a viable alternative.

Typical penta products available for retail sale include (1) a 5% penta ready-to-use solution in oil, (2) 10-1 concentrate containing 40% penta to be mixed with fuel or diesel oil, (3) 5-1 penta water-repellent concentrate to be mixed with oil or mineral spirits, and (4) ready to use 5% penta water-repellent preservative. Penta solutions are available in 55-gallon drums but are more commonly sold in quart, gallon, or 5-gallon containers. Concentrates would most likely be purchased for the farm rather than the home since most farmers have diesel and fuel oil available for diluting concentrates.

The ready-to-use water-repellent penta formulation is the most widely used. Treatment can be for structures already standing (e.g., fences, sheds, etc.) or it can be for items such as millwork prior to installation. Even though the majority of treated items are finished with paint, varnish, or stain, some users prefer the natural finish of the preservative itself. Several water-repellent penta products are also available as stains in various colors for home and farm applications.

Penta is effective against numerous decay and stain fungi, insects, molds, and mildew. The water repellent reduces warping, checking, swelling, and shrinking caused by the changes in moisture content of the wood. Homeowners and farmers rely heavily on penta formulations to extend the useful life of wood in above-ground applications. Formulations are also used to obtain limited protection for wood in ground contact, such as retaining walls and posts, but treatment effectiveness is limited in this application because of low retentions and poor penetration.

## Exposure Analysis

### Qualitative Exposure of Humans at Application Site

A general description of the qualitative exposure at the application site is presented below. In addition, a summary of the amounts of penta used for various applications, number of people exposed and relative level of exposure is presented in Table 22. It should be emphasized that this discussion is strictly qualitative in nature and none of the exposure ratings should be construed to indicate quantitative doses.

### Commercial Pressure Treatment

There are approximately 37 million pounds of penta used annually at 295 pressure-treating plants. Some degree of exposure is encountered by approximately 4,400[1] production workers and 800 non-production personnel at these plants.

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[1] Estimates are based on the number of treating plants and an estimate of the number of workers/plant. The number of workers/plant varies from 10 to 50.

Table 22.--Summary of exposure to penta preservatives at the application site

| Application Method | Amount Used | Estimated Personnel Exposed |  | Intensity of Exposure[b] |  |
|---|---|---|---|---|---|
|  |  | Number[a] | Job Description | Skin Contact | Inhalation |
|  | Million Pounds |  |  |  |  |
| Commercial pressure treatment | 37.0 | 4,400 - | Treating plant personnel | 5 | 2 |
|  |  |  | Yard personnel | 4 | 2 |
|  |  |  | Maintenance personnel | 2 | 3 |
|  |  | 800 - | Non-production personnel | 5 | 4 |
| Commercial thermal and dip treatment | 3.8 | 7,300 - | Treating plant personnel | 5 | 1 |
|  |  |  | Yard personnel | 5 | 2 |
|  |  |  | Maintenance personnel | 5 | 2 |
|  |  | 2,400 - | Non-production personnel | 5 | 4 |
| Commercial in-place treatments of poles, piling, and associated timber members | 0.20 | 350 | Applicators | 5 | 4 |

Table 22.--Summary of exposure to penta preservatives at the application site--continued

| Application Method | Amount Used | Estimated Personnel Exposed |  | Intensity of Exposure[b] |  |
|---|---|---|---|---|---|
|  |  | Number[a] | Job Description | Skin Contact | Inhalation |
|  | Million Pounds |  |  |  |  |
| Commercial dip treatment for sapstain control | 1.2 | 20,000 - | Lumber stackers | 1 | 1 |
|  |  |  | Forklift drivers | 5 | 3 |
|  |  |  | Preservative mix operators | 2-4 | 1-5 |
|  |  |  | Yard workers | 5 | 4 |
|  |  |  | Spray operators | 1 | 1 |
|  |  | 4,000 - | Non-production personnel | 5 | 4 |
| Non-commercial brush, dip, spray, and soak treatment | 1.5 | $3 \times 10^6$ to $6 \times 10^6$ | Applicators (homeowners/farmers) | 2-5[c] | 2-4 |

[a] For commercial operations, estimates are based on the total number of treating plants and an estimated number of personnel at each plant (10-50 employees per plant). For non-commercial operations that total amount of preservative is known so the estimate is based on the estimated amount of preservative used by each homeowner.

[b] 1 = consistent high exposure; 2 = occasional high exposure; 3 = consistent medium exposure; 4 = occasional medium exposure; 5 = low exposure. These are relative qualitative comparisons only and do not signify quantitative doses.

[c] This application method will normally be used at most only once or twice a year by individual applicators. Thus, high exposure is very infrequent and for most of the year there is no exposure.

Penta is received at the treating plants in bags, bulk, and solid blocks. Following this, the penta is dissolved in a petroleum solvent to provide a 5 to 7.5% solution for pressure treatment. The type of mixing operation and exposure varies for the three forms listed above. When penta is received in bags, the mixing operation involves manual labor and results in a high[2] level of exposure. Essentially, each bag is opened and dumped into a fine screen basket which has warm solvent flowing through it. The level of exposure depends on the ventilation system and extent of protective gear worn by the workers.

When penta is received in bulk form, it is handled in closed system from the delivery truck to a storage tank and then to the mixing operation. This greatly reduces the exposure level during these operations.

Exposure levels for delivery and mixing operations with penta blocks are fairly low, since the solid form minimizes exposure from airborne particles. Some exposure from vapor will occur during handling and storage of blocks, but this is minimal during the mixing operation, since it is carried out by immersing the block in solvent.

Once the penta solution has been prepared and transferred to the storage tanks, other personnel are exposed to the preservative at various stages of the pressure treatment process. The basic treating operation consists of loading the wood products on tram cars, which are then pushed into the treating cylinder. No exposure to the preservative is incurred during this step in the operation.

During the treating operation, the preservative solution is pumped into the cylinder and pressure is applied to impregnate the wood. The residual solution is then pumped back to the storage tanks. Because of venting, pump leaks, etc., some exposure is incurred by the plant operators during this step in the operation.

After treatment, the material is removed from the cylinder by pulling the trams out with a forklift or tractor. The personnel that open the cylinder door and make connections with the trams are exposed to a heavy level of preservative vapors, but the duration of exposure is short and normally occurs one to two times per work shift. The wood products are removed from the trams with a forklift, crane or similar piece of equipment and stacked in the yard. The personnel involved in this operation, along with inspectors and supervisors, are subjected to consistent medium exposure to preservative vapors, but receive only a low exposure by skin contact because the operations are generally highly mechanized.

Since equipment maintenance is an integral part of any operation, these workers are exposed to the preservative. This can occur by both skin contact and inhalation of vapors. A high level of exposure can occur at times, but, in general, they are subject to a medium degree of exposure throughout the work period.

Some office workers and other non-production personnel are subject to occasional low exposure, but this is limited to preservative vapors.

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[2] The high, medium, and low levels of exposure used in this text do not refer to the quantitative dose received, but rather to a relative comparison between different operations. For a quantitative analysis, see later sections in this chapter.

## Commercial Thermal and Dip Treatment

There are approximately 3.8 million pounds of penta used annually at thermal and dip treating plants. Some degree of exposure is encountered by approximately 7,300 production workers and 2,430 non-production workers.

Thermal treatment involves the use of open vats which are mainly used for treating poles and posts. In this process, the poles are submerged in the hot solution which is then allowed to cool. The exposure in this operation is, in general, similar to that of the pressure treating operation with the exception that personnel working around the vats are subjected to much higher levels of preservative vapor.

Dip treatment with penta is mainly used for the treatment of posts and millwork. The exposure during treatment and handling of posts is similar to that occurring during thermal treatment. On the other hand, considerably more handling of individual pieces is required for millwork after it is treated. Hence, the exposure from both vapors and skin contact is medium to high for those workers involved. Slightly less exposure occurs when the vacuum process is used for treatment of millwork since much of the excess solvent is removed during the final vacuum process. Exposure is low for the spray and flowcoat treatment processes because this operation is carried out in a contained room with adequate ventilation.

## Commercial In-Place Treatment of Poles, Piling and Associated Timbers

There are approximately 200,000 pounds of penta used annually in the groundline treatment of poles. It is estimated that this work is performed by approximately 350 workers.

The preservatives used for this application are prepared either in a grease type formulation which is applied with a brush, paddle, caulking gun, etc., or as impregnants in bandages which are applied by wrapping them around the pole. These bandages have a plastic layer on the outside to minimize loss of the preservative and permit diffusion into the wood. Treatment is limited to a small area above and below the pole groundline so only a small portion of the pole is treated.

The treatment of the poles is performed by small (2 to 3) person crews. Exposure by skin contact is low, if the workers use protective clothing and practice good hygiene.

## Commercial Dip Treatment for Sapstain Control

Na-penta is used in preservative formulations for control of sapstain in green lumber after it is cut in sawmills and in freshly peeled poles to prevent discoloration. Approximately 1.15 million pounds are used annually at 2,000 mills. Some degree of exposure is encountered by approximately 20,000 production workers and 4,000 non-production personnel at these mills.

Approximately 75% of the Na-penta sapstain preservative is sold as a liquid concentrate and the remainder as a dry powder. Most of the liquid concentrate is sold in 55 gallon drums, but a small amount is received in bulk containers. These liquid concentrates are then diluted with water to achieve the desired treating solution concentration. This dilution is carried out either in the dip tanks or in separate mix tanks. In some cases, the mixing operation is done automatically which results in a low level of exposure. When the manual method of mixing is employed, a medium level of exposure is experienced.

When penta is received in the dry powder form, the mixing operation is carried out manually. This results in a high level of exposure because of the dust problem.

The sapstain preservative solutions are applied to lumber by three different methods, namely, bulk dip, across chain dip and across chain spray.

In the bulk dip operations, the lumber is pulled from the green chain and stacked in bundles. These bundles are then moved by forklift to a large dip tank where they are submerged in the solution. Following this they are moved to the storage yard. The forklift operator is subjected to a medium vapor exposure level during this operation.

In the across chain dip method, the green chain passes down through a tank which contains the sapstain preservative. As a result, the lumber is dipped briefly in the treating solution as it moves on the chain. This treated lumber is then removed from the chain either by automatic stacking equipment or manually. When the automatic stacking equipment is used, the machine operators experience a medium level of vapor exposure. On the other hand, when the treated lumber is handled manually, the workers are subjected to a high level of exposure from the vapor and skin contact.

In the across chain spray method, the preservative is sprayed on the lumber as it passes on the chain. The overspray is collected and returned to the storage tanks. The spray equipment is automatic and therefore requires no operator except occasional attention to keep the nozzles from becoming plugged etc. Mixing is usually done at some modest distance (enough for air dilution), therefore exposure to vapor may be high but only for intermittent short periods. The exposure conditions for the workers removing the lumber from the chain are the same as for the across chain dip method.

After treatment and stacking, the bundles of lumber are stored in a yard. Personnel working in this area are exposed to a low level of penta vapors.

In addition to the lumber, an unknown number of poles are also treated for sapstain control each year. The preservative solution is applied by spraying poles emerging from the peeler. Personnel working in the vicinity of the spray operation are subject to a high level of exposure to vapors. After treatment, the poles are stored in the yard to dry, which is a low-exposure situation for workers in this area.

## Non-Commercial Brush, Dip, Spray and Soak Treatment

There are approximately 1.5 million pounds of penta used annually for non-commercial applications. It is estimated that approximately 3,000,000 to 6,000,000 people are involved in the application of this preservative.

A number of preservative formulations are registered for this use, but the majority of it is sold as a 5% water-repellent solution using mineral spirits as a carrier. These preservatives are applied by homeowners, farmers, etc., to various wood products either before or after installation by brushing, spraying, dipping, or soaking.

Individual applicators probably use penta solutions only once or twice a year for home or farm application. Thus, the total exposure time to either skin contact or inhalation is low. When the preservative is being applied, exposure depends on the adequacy of label instructions and how well they are followed. Inhalation exposure will range from occasional medium exposure to occasional high exposure depending on ventilation in the area where the penta is applied and on whether the preservative is heated or used cold. Exposure by skin contact ranges from low to occasional high exposure depending on whether or not adequate protective clothing and rigorous hygiene are used.

## Quantitative Exposure Analysis of Humans at Application Site (Commercial)

To assist the evaluator in determining the significance of specific exposure situations, the PD-1 (Federal Register, 1978) penta trigger levels are summarized here. In the course of examining various situations with penta exposure, the estimated exposure will be compared to the calculated exposures used in the PD-1 triggers. The ratio between the PD-1 calculated exposures and the known or estimated exposure will be referred to as the safety factor. If the occupational exposure is very low compared to the experimental exposure then the safety factor will be large. Conversely, the larger the occupational exposure the lower will be the safety factor. A safety factor ratio of 1 would mean that the occupational exposure was the same as the PD-1 trigger exposure.

The exposure levels for both penta and hexachlorodibenzo-p-dioxin (HxCDD) in PD-1 used fetotoxicity as the biologic response of concern. In setting the exposure levels, the highest dose level reported in experimental studies that did not cause fetotoxicity was used as the level of exposure against which to compare human exposures. Therefore, the safety factors are based on a comparison with a no-observable-effect level (NOEL) for that end point. The NOEL for fetotoxicity cited in PD-1 are 5.8 mg/kg/day for penta and 1 microgram/kg/day for HxCDD.

Toxicologists usually examine the chronic toxicity of a compound when determining an acceptable daily intake (ADI). In this regard Schwetz et al. (1978) have shown that the NOEL for low-dioxin penta is 3 mg/kg. This NOEL is based on a study where groups of rats were fed different levels of penta for their lifetime. Observations included growth, body weight, hematology, clinical chemistry and terminal gross and microscopic pathology. The largest dose that did not result in any significant adverse health effects was 3 mg/kg.

A further application of these data is to determine an ADI for humans. Because of the data that are available on the effects of penta in humans and the short 1-2 day half-life of penta in the body, a safety factor of 100 may be appropriate (National Academy of Sciences, 1977). Consequently, the extrapolated exposure for man is 3 mg/kg divided by 100 or 0.03 mg/kg/day. The total body exposure for a 70 kg man is then 70 x 0.03 = 2.1 mg penta/man/day. These calculated exposure levels are of use in determining the significance of occupational or end use exposures in humans.

One way to use these data is to compare the ADI of 0.03 mg/kg with the RPAR trigger exposure of 5.8 mg/kg. The ratio of 5.8 to 0.03 is 193, which is termed the safety factor. Therefore, any exposure with a safety factor of 193 or more represents an exposure that is below both the RPAR trigger level and a level of exposure based on a conventional approach to chronic toxicity in safety evaluation.

## Potential Routes of Exposure

Chemicals can enter the animal or human body in the following ways: (1) by oral ingestion, (2) by inhalation, (3) by dermal adsorption, and (4) by injection into body tissues, fluids, or cavities. Of these routes oral ingestion, inhalation, and dermal adsorption are the most significant exposure routes for penta. An example of exposure by injection would be a wood sliver impregnated with penta that penetrated the skin. This would result in a low exposure that is of insufficient concern to warrant detailed analysis.

## Available Methods for Estimating Exposure

An evaluation of the exposure of humans or animals to chemicals can be approached in several ways. One method involves a chemical analysis of food and water to determine the level of the specific chemical in the total diet. Oral exposure is then calculated based on the residue in each dietary component and the amount of that food component consumed per day. Exposure rate is expressed as weight (usually milligram or microgram) of chemical per kg of body weight per day.

Inhalation exposure, which results from adsorption of chemicals across the alveolar respiratory membrane, is determined by measuring the amount of chemical in the air. Concentrations in air are expressed as either ppm or weight of chemical per cubic meter of air. The amount of air actually entering the lung per minute (minute alveolar ventilation) is determined and multiplied by the number of minutes of exposure and the air concentration. The resulting exposure is expressed as weight of chemical per kg body weight per day. There are two major difficulties with this approach. First, minute alveolar ventilation is not constant. Respiratory rate and the amount of air per breath (tidal volume) can change many fold depending on level of physical exertion and tissue oxygen demand. Consequently, assumptions need to be made about level of physical activity for a particular type of work. The second problem involves the nature of the chemical in the air. If the material is in the form of particulates, then the larger particles (i.e., greater than 10 microns in diameter) are filtered out by the turbinates in the nose or are deposited in the pharynx, trachea or larger bronchi. Material deposited in these places is removed via ciliary action and the material is gradually moved to the back of the oral cavity where it is swallowed or expectorated. If it is swallowed, then oral exposure occurs in addition to inhalation exposure. Smaller particles and vapors reach the deep parts of the lung where absorption into the blood or lymph occurs with subsequent translocation and exposure to the rest of the body. Another variable is the amount of vapor or particulate absorbed. Small particles can stay suspended in inspired air and subsequently be exhaled. The percent absorption could range from 10 to 90% of the amount inhaled.

Dermal absorption is particularly difficult to quantify and is not well studied. Important variables are amount of skin surface area exposed, chemical form, solvents, and type of skin (i.e., callused skin, nails, hoof). From a toxicologic concern, three dermal exposure situations are of most interest: first, dermal exposure to highly toxic agents; second, poor work habits that result in continuous skin contact; and third, poor work hygiene that results in the wearing of clothing contaminated with chemical. Unfortunately, there is little information on the rate of dermal absorption of penta. However, there is no doubt that it can be absorbed since the dermal $LD_{50}$ has been determined in a wide variety of experimental animals. Also, deaths have occurred in humans from what appeared to be primarily dermal exposures (Kozak, et al., 1979).

The second major method for determining exposure is to determine the amount of chemical in the animal or human body and to determine the pharmacokinetics. Principles of pharmacokinetics are used to describe mathematically the rates of uptake and excretion from the body. By definition, at equilibrium the same amount of chemical will be eliminated from the body as is taken in during the same period of time. This is called the steady state level. The exposure duration required to reach steady state condition depends on the kinetics, principally the biologic half-life. In the instance of penta the use of pharmacokinetics is a particularly good approach since penta has a short half-life in animals and humans and, consequently, steady state conditions are reached in a few days. Additionally, penta is primarily eliminated in the urine. Therefore, if the urine penta concentration is known, then the total body exposure can be estimated. The principal variable is the amount of urine produced per day. Urine production is not constant but varies principally with fluid intake in normal individuals. A 0.5- to 2-fold difference in daily urine volume can be expected.

The plasma half-life of penta in humans is 30.2 hours (1.3 day) and 86% of an oral dose is excreted in the urine with a urine elimination half-life of 33.1 hours (Braun, et al., 1978). In rats, the whole body excretion kinetics show a half-life of 17 hours for the rapid phase and 40 hours for the slow phase of excretion. Again, 70 to 80% of the penta is excreted in the urine (Braun, et al., 1977). In mice the half-life for urinary clearance is 24 hours with 72 to 83% of injected doses eliminated in the urine in 4 days (Jakobson and Yllner, 1971). In cattle the blood plasma penta level decreases with a half-life of 1.8 days (Osweiler, et al., 1977). The monkey is the only animal found, so far, that excretes penta more slowly. The plasma half-life is 72 to 83 hours (3 to 3.4 days) and the urine half-life is 41 to 96 hours. The monkey does not form penta conjugates which may explain in part its slower removal from blood (Braun and Sauerhoff, 1976). From all of this information it is concluded that the half-life for penta in humans is less than 2 days and that 86% of an oral dose is eliminated in the urine. From the mouse data where penta was injected subcutaneously or intraperitoneally, the chemical was still primarily eliminated in the urine; consequently, it is reasonable to assume that irrespective of the route of exposure the kidney is the primary route of elimination.

From studies using mathematical modeling of rates of uptake and rates of elimination (a process called pharmacokinetics) it is possible to draw conclusions about the relationships between exposure and body burden (Goodman and Gilman, 1975). One major point is if exposure is held constant for 4 half-lives, then the body burden will be 93% of the steady state or maximum level for that exposure rate. Consequently, for human exposures to penta the steady state level will be reached in 4 x 1.3 day = 5.2 days, or to be more conservative, 4 x 2 = 8 days. For the industrial worker with a 5 day/week exposure, those individuals will eliminate approximately 60% (30 hour half-life divided by 48 hours) of the body burden in a 2-day weekend.

For the chlorodioxins the pharmacokinetic data are less plentiful. In the rat, octachlorodibenzo-p-dioxin (OCDD), the principal dioxin in commercial penta, has a half-life of 21 days (Norback, et al., 1975). The half-life of the more toxic dioxin tetrachlorodibenzo-p-dioxin (TCDD), which is not present in penta, has been reported several times for rats as follows: 17.4 ± 5.6 days (Piper, et al., 1973), 31 ± 6 days after a single dose and 23.7 days after repeated doses (Rose, et al., 1976), or 12 days for males and 15 days for female rats (Fries and Marrow, 1975). Consequently, it is estimated body dioxin burden will approximate a steady state in 4 x 21 = 84 days.

One additional consideration in estimating exposure is to select the most appropriate model. In this evaluation two models are possible, namely the 70 kg male and the 60 kg female. A few comments are in order to explain the effects of different models on the resulting exposure estimates. In one method used to estimate penta exposure, the starting point is urine penta residue. Urine volume is a function of body weight and an average value of 20 ml/kg body weight is used as a standard. Therefore, the expected daily urine void for the 70 kg male is 1,400 ml and for the 60 kg female is 1,200 ml. Consequently, when total urine penta is calculated and divided by body weight for any given urine penta level, the same exposure on a mg/kg body weight basis results.

In another method used to estimate exposure, various breathing rates are assumed. The amount of air inhaled per 8 hour period used to calculate exposure are, (1) resting: male = 2.02 $m^3$, female = 2.16 $m^3$, (2) moderate work: male = 8.06 $m^3$, female = 10.94 $m^3$, and (3) heavy work: male = 20.16 $m^3$, female = 16.05 $m^3$. The numbers were derived from different sources and one obvious reason for the differences lies in the definition of work intensity. It is important to realize that the exposure estimates derived later in this document will vary and, consequently, must be viewed as estimates and not fixed values.

## Exposure of Humans at Application Site

Human exposure to penta has been calculated using three different methods.

### Method 1: Exposure Based on Urine Penta Level

Before the exposure analysis is presented, the method used to calculate penta based on residue in urine will be presented. A normal 70 kg person will produce a daily urine volume of 1.4 liters (Guyton, 1971). This could decrease to 0.5 liter or increase to 2.8 liter or more depending on temperature, degree of sweating, and fluid intake.

Braun, et al. (1978) have shown that the plasma half-life of penta in humans is 1.25 days and that 86% of an oral dose is eliminated in urine. Consequently, it is possible to estimate penta exposure in the general population by assuming that exposure is constant and equilibrium conditions exist. The general formula is:

$$\text{Exposure Rate (mg/kg)} = \frac{\text{Level in urine (mg/liter)} \times \text{Volume of urine (liter)}}{\text{Body weight (kg)} \times 0.86}$$

The 0.86 in the denominator corrects the exposure for the fact that 86% of the penta body burden is eliminated in urine. The formula stated above was used to calculate the penta exposures based on reported urine penta levels as cited in the following discussion.

One source of variation in this analysis stems from the chemical method used to analyze the urine for penta. It is possible that not all investigators used a method to include penta-glucuronide in the analysis. Consequently, the exposure estimates could be low by 10 to 15%. The exposure estimates should be regarded as an indication or range of exposure and not as absolute values.

Several studies have reported urine penta levels from occupationally exposed individuals. Table 23 is a summary of these data based on average urine penta levels. Based on available data the average total exposure for workers ranges from 0.0038 to 0.066 mg/kg. The safety factor is 5.8 ÷ 0.0038 or 5.8 ÷ 0.066 and ranges from 1,526 to 88.

Table 23.--Estimated daily penta exposures of wood treaters based on average urine penta levels

| Reference | Wood Treatment Operation | Average Urine Penta | Estimated Exposure | |
|---|---|---|---|---|
| | | mg/liter | Total mg | mg/kg |
| Wyllie *et al*, 1975 | varied | 0.164 | 0.266 | 0.0038 |
| Arsenault, 1976 | spray | 0.98 | 1.59 | 0.0227 |
| Arsenault, 1976 | pressure | 1.24 | 2.02 | 0.0288 |
| Arsenault, 1976 | dipping | 2.83 | 4.62 | 0.066 |
| Casarett *et al*., 1969 | dipping | 2.6 | 4.22 | 0.0603 |
| Casarett *et al*., 1969 | pressure | 1.6 | 2.60 | 0.0371 |

The above analysis is based on average exposures. Exposure analysis based on maximum reported urine penta levels results in the exposures shown in Table 24. The safety factor is 5.8 ÷ 0.082 or 5.8 ÷ 0.232 and ranges from 71 to 25.

Table 24.--Estimated daily occupational exposure based on maximum reported urine penta concentrations

| Reference | Maximum Urine Concentration | Estimated Exposure | |
|---|---|---|---|
| | mg/liter | Total mg | mg/kg |
| Casarett *et al*., 1969 | 10 | 16.3 | 0.232 |
| Arsenault, 1976 | 9.68 | 15.6 | 0.225 |
| Wyllie *et al*., 1975 | 3.55 | 5.74 | 0.082 |

This exposure analysis is generalized in Figure 7. In the graph urine penta concentration is plotted against exposure in mg/kg. The assumptions are: 70 kg body weight and average urine production of 1.4 liter/day. Exposures are also shown for assumed daily urine volumes of 0.5 and 2.8 liter. To use this graph it is only necessary to know the urine penta level.

The maximum and minimum occupational exposures and safety factors are given in Table 25 for both penta and HxCDD.

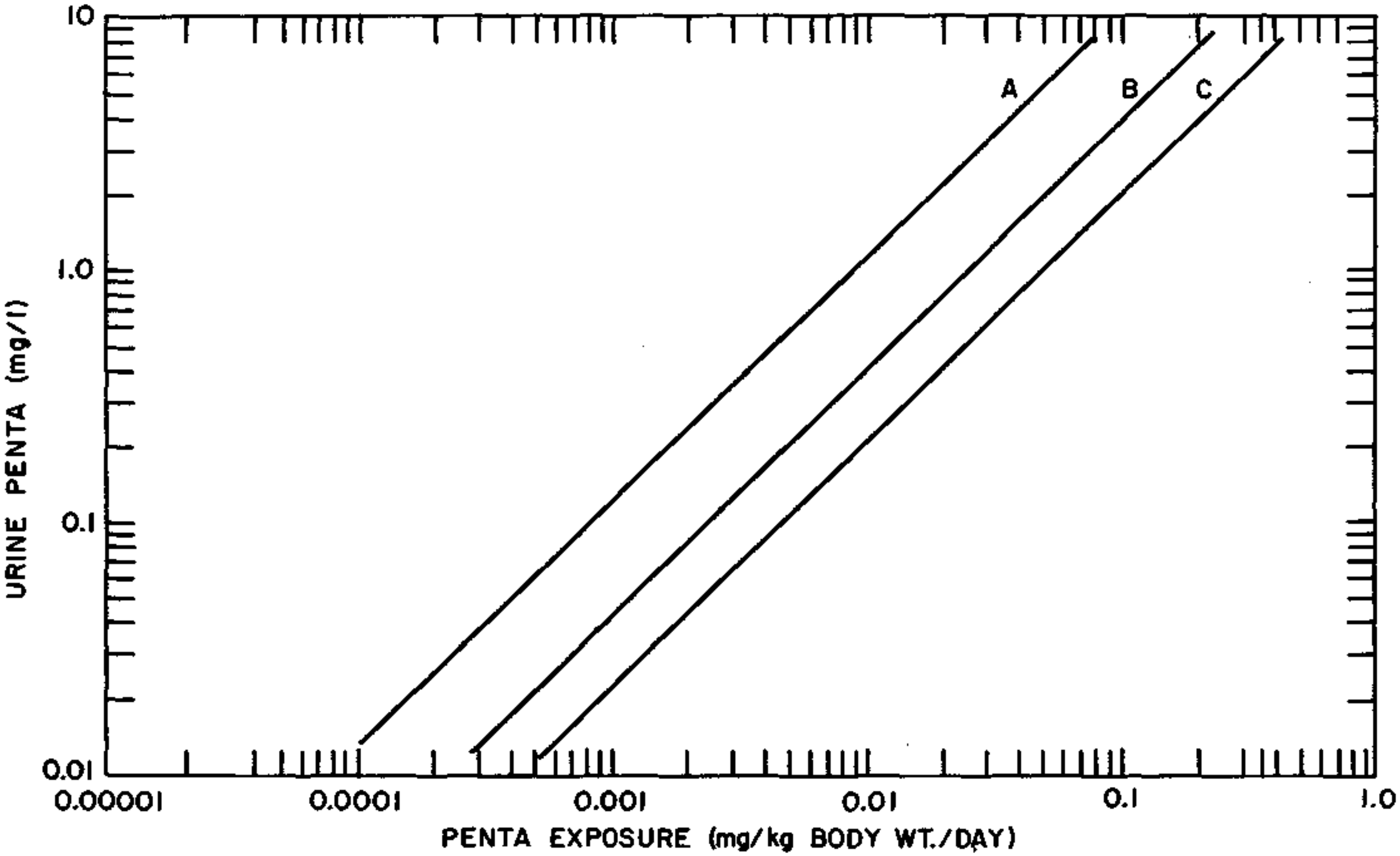

Figure 7. Relationship between urine penta residue and whole body penta exposure. Penta exposure on a mg/kg body weight basis is plotted on the abscissa and urine penta level in mg/liter is plotted on the ordinate. The three lines labeled "A, B, C" are based on 3 levels of urine volume/day. Line "A" corresponds to a daily urine void of 0.5 liter/day, line "B" to 1.4 liter/day, and line "C" to 2.8 liter/day. Line "B" is the expected normal volume for a 70-kg person. To use this graph to estimate exposure; 1) determine the urine penta residue, 2) find the value on the ordinate, and 3) read across to the 3 urine volume lines and follow the intersection to the abscissa. The intersects between lines "A" and "C" will give an estimate of the exposure range and the intersect at line "B" will be the single best estimate. If daily urine volume is known, then a more exact estimate of exposure can be derived using the formula in the text.

Table 25.--Maximum and minimum occupational exposures for penta and HxCDD and calculated safety factors (see Table 23 and 24)

| Penta Exposure | Safety Factor | HxCDD Exposure | Safety Factor |
|---|---|---|---|
| mg/kg | | mg/kg | |
| 0.0038 | 1,526 | $0.0038 \times 4 \times 10^{-6}$ | 65,789 |
| 0.232 | 25 | $0.232 \times 4 \times 10^{-6}$ | 1,078 |

EPA has assumed a hexachlorodibenzo-*p*-dioxin (HxCDD) level of 4 ppm in commercial penta. Consequently, assuming that the HxCDD exposure and absorption is proportional to penta exposure, then HxCDD exposure rate is obtained by multiplying the penta exposure by $4 \times 10^{-6}$.

In summary, the exposure analysis based on actual urine levels is a reliable way of estimating penta exposures for both general population and occupationally exposed individuals. This is an accurate and reliable index of what levels of exposures are actually occurring with this chemical irrespective of the source and route of exposure.

Method 2. Exposure Based on Inhalation of Reported Air Penta Levels

Penta levels in air have been reported for wood treating plants (Wyllie, *et al*., 1975; and Arsenault, 1976). These data can be used to determine respiratory exposures. The volume of air moved in and out of the alveolar portion of the lung per minute is about 4.2 liters/min under resting conditions. Under work conditions pulmonary ventilation increases up to 6- to 7-fold with moderate exercise and 16- to 20-fold with heavy exercise for short periods of time (Guyton, 1971). Consequently, inhalation exposure will vary with exercise. Alveolar ventilation increases with increasing body size; consequently, an exposure calculation based on unit body weight has general applicability (Figures 8 and 9).

The data in the graphs are presented for three different work-muscular activity levels for 1 hour, 8 hour, and 24 hour durations within each work level. The air penta concentrations cover the range from 0.0001 $mg/m^3$ to 10 $mg/m^3$. Exposure rates are calculated on a mg penta/kg body weight basis. Alveolar ventilation rates used were 4.2 liters/min (0.252 $m^3$/hr) for resting, 1.008 $m^3$/hr for moderate work, and 2.52 $m^3$/hr for heavy work.

In a real work situation it is likely that breathing rates vary as well as air penta levels. The graphs can be used to model a wide variety of assumed work conditions. The exposures in mg/kg resulting from each work segment defined by duration of exposure, air penta level and work intensity can be summed to determine the total 24 hour exposure. For example, an occupational exposure might consist of 1 hour of high exposure, 7 hours of moderate exposure, and 16 hours of low or zero exposure.

Applying this exposure analysis to the air penta levels reported in wood-treating plants results in the data shown in Table 26. These exposures are based on data resulting from air monitoring studies in different operations in wood-treating plants.

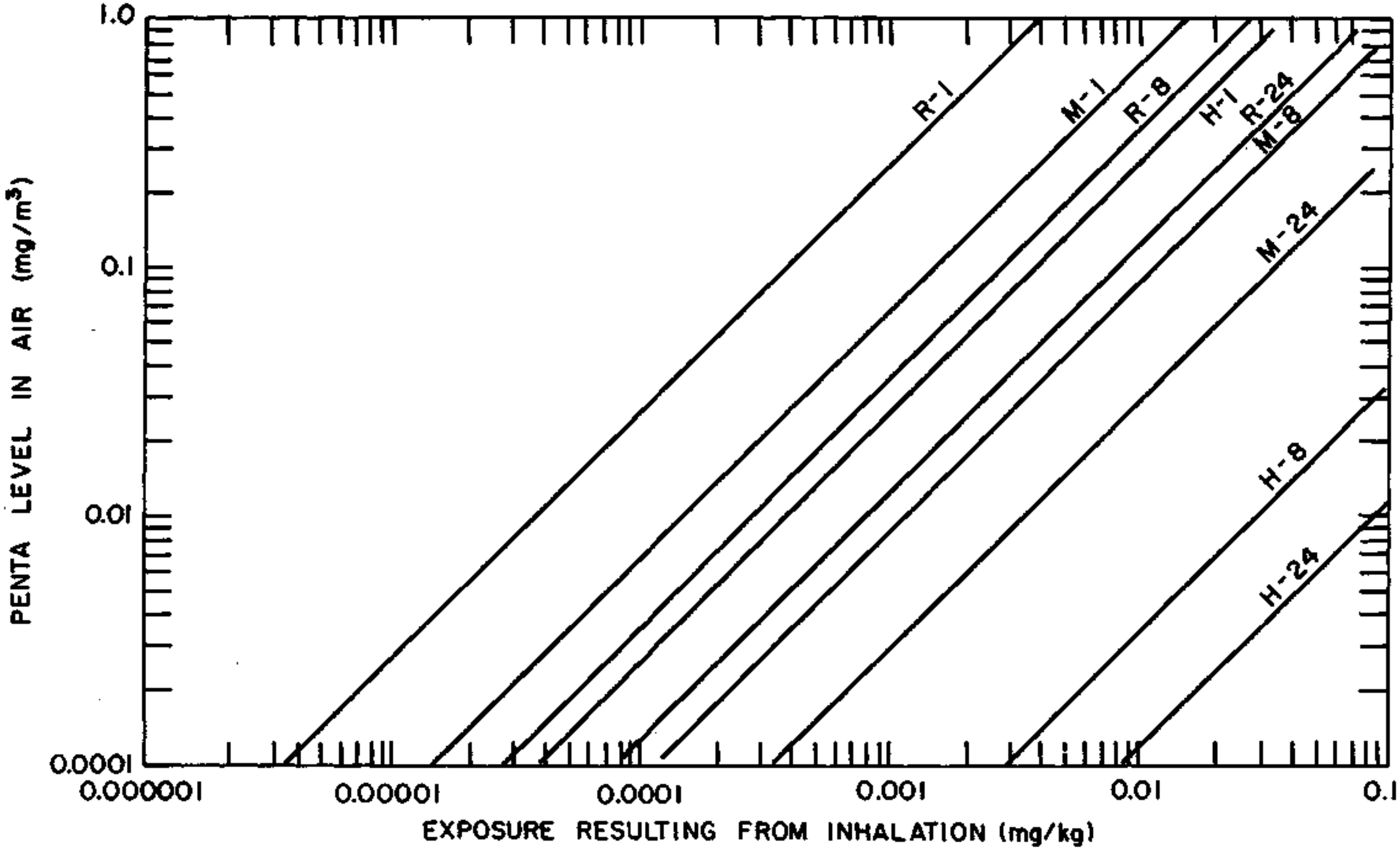

Figure 8. Relationship between air penta level (ordinate) and penta exposure (abscissa) for a 70-kg person at varying levels of exercise and durations of exposure. Because air levels, breathing rates and duration of exposure will vary between and within work situations, the graphs were developed to cover a wide range of possibilities. Air penta levels from 0.001 to 10 mg/cubic meter are plotted. The resulting exposures range from 0.000004 to 9.0 mg/kg. Exposures of 1-, 8-, or 24-hour durations are plotted at each of the 3 exercise levels; resting (R), moderate (M), or heavy (H). The lines on the graph are coded by exercise level (R, M, H) and duration 1, 8, 24 hours. To determine exposure for a given situation, use an estimated or measured air penta level and then find the line that corresponds to the duration of exposure and corresponding exercise level. The hourly rates can be multiplied by the hours of exposure to get the total exposure for that period. Summation of all the hourly or 8-hour-period exposures will yield the total 24-hour daily exposure. Exposures of less than 1 hour can be obtained by using the appropriate hourly rate and dividing by the fractional hour exposure.

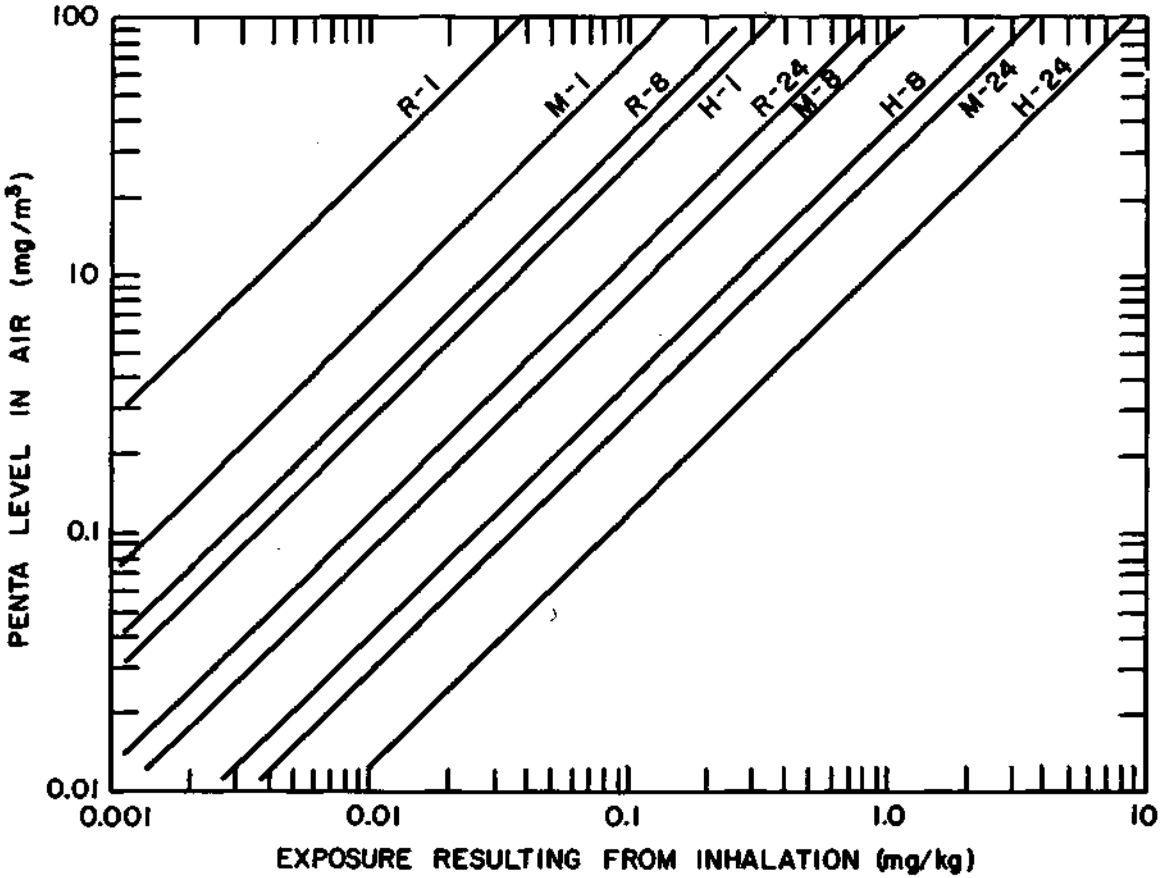

Figure 9. Relationship between air penta level (ordinate) and penta exposure (abscissa) for a 70-kg person at varying levels of exercise and durations of exposure. Because air levels, breathing rates and duration of exposure will vary between and within work situations, the graphs were developed to cover a wide range of possibilities. Air penta levels from 0.001 to 10 mg/cubic meter are plotted. The resulting exposures range from 0.000004 to 9.0 mg/kg. Exposures of 1-, 8-, or 24-hour durations are plotted at each of the 3 exercise levels; resting (R), moderate (M), or heavy (H). The lines on the graph are coded by exercise level (R, M, H) and duration 1, 8, 24 hours. To determine exposure for a given situation use an estimated or measured air penta level and then find the line that corresponds to the duration of exposure and corresponding exercise level. The hourly rates can be multiplied by the hours of exposure to get the total exposure for that period. Summation of all the hourly or 8-hour period exposures will yield the total 24-hour daily exposure. Exposures of less than 1 hour can be obtained by using the appropriate hourly rate and dividing by the fractional hour exposure.

Table 26.--Calculated inhalation penta exposure for workers (70-kg body weight) in wood-treating plants for three levels of exercise/breathing rates

| Reference | Area or Activity | Air Level | Resting 2.02 $m^3$/8 hr | Exposure-mg/kg/8 hr Moderate 8.064 $m^3$/8 hr | Heavy 20.16 $m^3$/8 hr |
|---|---|---|---|---|---|
| | | mg/$m^3$ | - - - - - - - - - - | mg/kg/8 hr | - - - - - - - - |
| Arsenault, 1976 | Dip | 0.019[a] | 0.0005 | 0.002 | 0.005 |
| do | Dip | 0.063[b] | 0.0018 | 0.007 | 0.018 |
| do | Spray | 0.006[a] | 0.0002 | 0.0007 | 0.002 |
| do | Spray | 0.069[b] | 0.002 | 0.008 | 0.020 |
| do | Pressure | 0.014[a] | 0.0004 | 0.002 | 0.004 |
| do | Pressure | 1.0[b,c] | 0.029 | 0.115 | 0.288 |
| Wyllie et al., 1975 | Office | 0.0003[b] | 0.00009 | 0.0003 | 0.0009 |
| do | Pressure | 0.015[b] | 0.0004 | 0.002 | 0.004 |
| do | Wood storage | 0.0005[a] | 0.00001 | 0.00006 | 0.0001 |

[a] Average value reported.

[b] Largest value reported.

[c] Short-term, worst-case exposure, estimated to occur for no more than 20 minutes out of an 8-hour work period.

The range of exposures calculated using reported air levels range from 0.00001 to 0.288 mg/kg depending on air level and activity. It should be emphasized that the maximum air level of 1 mg/$m^3$ represents a short-time, worst-case exposure when the treating cylinder door is opened. This exposure will only occur once or twice during an 8-hour work shift and will be of only a few minutes duration. Assuming that this exposure occurs twice a day, each exposure lasts 10 minutes and occurs during heavy exercise, then the exposure encountered during this period will be:

$$\text{air breathed} = 0.042\ m^3/\text{min} \times 20\ \text{min} = 0.84\ m^3/20\ \text{min}$$

$$\text{exposure} = \frac{(0.84\ m^3) \times 1\ mg/m^3}{70\ kg}$$

$$= 0.012\ mg/kg\ (20\ \text{minute exposure}).$$

In the actual work exposure the individual operating the treating cylinder will have an exposure of 0.012 mg/kg for the 20 minutes spent at the cylinder door and the remaining time the exposure will be on the order of 0.0004 to 0.004 mg/kg. This range of exposures is summarized in Table 27 and the safety factor determined.

The lowest safety factor results from the assumption of a continuous 8-hour exposure to vapors resulting from the opening of the cylinder door while performing maximum physical exercise. This is highly unlikely because the cylinder door

Table 27.--Range of occupational exposure rates and safety factors based on calculated inhalation exposures[a]

| Penta Exposure | Safety Factor | HxCDD Exposure | Safety Factor |
|---|---|---|---|
| mg/kg | | mg/kg | |
| 0.00001 | 580,000 | $0.00001 \times 4 \times 10^{-6}$ | 25,000,000 |
| 0.0001 | 58,000 | $0.0001 \times 4 \times 10^{-6}$ | 2,500,000 |
| 0.001 | 5,800 | $0.001 \times 4 \times 10^{-6}$ | 250,000 |
| 0.01 | 580 | $0.01 \times 4 \times 10^{-6}$ | 25,000 |
| 0.1 | 58 | $0.1 \times 4 \times 10^{-6}$ | 2,500 |
| 0.288 | 20 | $0.288 \times 4 \times 10^{-6}$ | 868 |

[a] *These exposures span the calculated exposures in Table 26.*

normally will be opened only once or twice in an 8-hour work shift because of the 4- to 8-hour treating cycle and also no one would stand for 8 hours at an open cylinder door. The HxCDD exposures are probably overestimates because of the proportionately lower vapor pressures of the dioxins.

Method 3: Exposure Based on Inhalation of Vapors from Treated Wood

Another way to analyze possible exposure is to start with vaporization from treated wood under specified conditions. If there was no air exchange, the equilibrium vapor density based on a vapor pressure of $1.1 \times 10^{-4}$ mm Hg at 20°C (68° F) would be 0.0016 mg/liter or 1.6 mg/$m^3$. This represents the maximum expected air penta concentration possible from vaporization at 20°C. In reality, surface area, air volume, co-solvents, interaction with wood, and air exchange rate would decrease the air penta level. Thompson, et al. (1979) measured air penta levels in a test chamber containing wood treated with penta and different solvent systems. When measured at 30°C (86°F) and an air flow rate of 1 liter/min in a 30 liter chamber, Thompson, et al. (1979) reported the air penta levels as shown in (Table 28).

As indicated in the preceding paragraph, the maximum theoretical air penta concentration at 20°C is 1.6 mg/$m^3$. The results of Thompson, et al. (1979) suggest that the presence of the wood plus solvents or co-solvents retards the vaporization of the penta from treated wood.

Table 28.--Experimentally determined air penta levels resulting from vaporization from treated wood (Thompson, et al., 1979)

| Type of Treatment | Air Penta Level |
|---|---|
| | mg/$m^3$ |
| Penta in heavy oil | 0.02 |
| Cellon$^R$ treatment | 0.048 |
| Methylene chloride | 0.076 |

Under worst-case assumptions the resulting human exposure from penta vapors would be calculated as follows: Using the equilibrium vapor density penta level of 1.6 mg/m$^3$, a heavy exercise level with a breathing rate of 20.16 m$^3$/8 hr, an 8-hour exposure and a 70 kg body weight, the resulting exposure is 0.46 mg/kg. In actual situations these are extreme values that are unlikely to occur.

The predicted respiratory exposures for the three types of wood treatment processes are shown in Table 29. The values are based on the measured vaporization rates from wood with different types of treatment. A range of work intensities is assumed. The values are on the same order of magnitude as those in Table 26. This means that the predicted inhalation exposure comes out the same if one starts with observed penta air levels in wood treating plants or starts with observed vaporization rates from treated wood.

Table 29.--Calculated 8-hour worker exposure rates (70-kg worker) based on vaporization data from penta treated wood at three levels of physical exercise

| Type of Treatment | Air Level | Exposure Rate | | |
|---|---|---|---|---|
| | | Resting | Moderate | Heavy |
| | mg/m$^3$ | - - - - - - - mg/kg/8 hr - - - - - - - | | |
| Heavy oil | 0.02 | 0.006 | 0.0023 | 0.0058 |
| Cellon$^R$ | 0.048 | 0.0014 | 0.0055 | 0.0139 |
| Methylene chloride | 0.076 | 0.002 | 0.0088 | 0.0219 |

Based on measured vaporization rates of penta from treated wood, the exposures range from 0.0006 to 0.0219 mg/kg. These are the same order of magnitude as calculated previously and the reader is referred to Table 27 for a safety factor assessment.

It is also important to consider that chlorodioxin exposure from vaporization is probably insignificant because of the lower vapor pressure of the chlorodioxins compared to penta.

Dermal exposures are difficult to predict due to a lack of experimental data. It is possible to get enough skin absorption to result in clinical illness and death (Kozak, et al., 1979). The reported exposure accidents have involved situations where workers have not used protective clothing and barrier creams or have resulted from wearing contaminated clothing.

If treated wood is dry and free from blooming (the formation of crystals on the surface of treated wood as a result of exudation and evaporation of the solvent), little dermal absorption would be expected. In Table 30 estimated exposures are calculated assuming complete absorption of x ml of 7% treating solution per 8-hour work period.

Comparing the calculated inhalation exposures in Table 26 (range: 0.00001 to 0.288 mg/kg) with the best estimates of daily penta exposures in Table 23 based on urine penta levels (range: 0.004 to 0.066 mg/kg), it is possible to conclude that the entire exposure is respiratory. However, most measured air penta levels (Table 26)

Table 30.--Calculated penta exposures based on complete dermal absorption of a stated volume of 7% penta in oil treating solution, based on 70 kg body weight

| ml of Solution | mg Penta | mg Penta/kg Body Weight |
|---|---|---|
| 0.1 | 7 | 0.1 |
| 1 | 70 | 1 |
| 5 | 350 | 5 |
| 10 | 700 | 10 |
| 20 | 1,400 | 20 |
| 100 | 7,000 | 100 |

are low except for the value at the pressure cylinder door. Consequently, if one averages the air penta levels while eliminating the one short term high value the resulting "average" air penta level is 0.0237 mg/m$^3$. This compares favorably with the 0.02 mg/m$^3$ air penta level Thompson et al. (1979) reported for vaporization from wood treated with penta in oil.

An air level of 0.0236 mg/m$^3$ would result in a best estimate average respiratory penta exposure of 0.0027 mg/kg for a 70-kg worker doing 8 hours of moderate work. If one averages the observed penta exposures based on urine penta levels (Table 23), then one finds that the best estimate of average total exposure is 0.0365 mg/kg. Subtracting the best estimate average respiratory exposure from the best estimate of total exposure (0.0365 -0.0027 = 0.0338 mg/kg) results in an estimate of 0.0338 mg/kg from non-respiratory routes (93%) and 0.0027 mg/kg (7%) via respiration. The 0.0338 mg/kg could result from the dermal absorption of 0.03 ml of treating solution by a 70-kg human. The reader should be aware of the tentative nature of the assumptions made in this comparison. Yet, at the same time it is intuitive that both respiratory and non-respiratory routes of exposure are likely to be operative in the work place. The difficulty is in developing reliable estimates of the contributions of each route of exposure to total body exposure.

Because the average exposures are low, it is also apparent that any single large dermal, oral or respiratory exposure could account for the total exposures observed. Table 31 contains a summary of the estimated human exposures.

Based on these exposure estimates the minimum safety factor is 159. Obviously an accident or carelessness could result in higher exposures. Yet, it is emphasized that exposure analysis using a variety of approaches based on best available data does not indicate any serious problems. Another way of looking at this is to conclude that the evidence supports the contention that this material can be used in such a way as to result in low levels of exposure.

## Exposure Based on Threshold Limit Value and Toxicologic Response to Penta

The threshold limit value is 0.5 mg/m$^3$ (American Industrial Hygiene Association, 1970). A threshold limit value represents the average maximum concentration in air

Table 31.--Summary of estimated occupational penta exposures and safety factors for penta and HxCDD exposure

| Condition | Estimated Penta Exposure | Safety Factor | |
|---|---|---|---|
| | | Penta[a] | HxCDD[b] |
| | mg/kg | | |
| Exposure based on urine penta level (best estimate) | 0.0365 | 159 | 9,125 |
| Exposure based on measured air penta level (best estimate)[c] | 0.0027 | 2,148 | 92,592 |
| Exposure based on vaporization of penta from treated wood[c] | | | |
| Heavy oil | 0.0023 | 2,521 | 108,695 |
| Cellon$^R$ | 0.0055 | 1,054 | 45,454 |
| Methylene chloride | 0.0088 | 659 | 28,409 |

[a] Based on the RPAR trigger exposure of 5.8 mg/kg/day.

[b] HxCDD exposure based on 4 ppm HxCDD level in penta and exposure proportionate to penta.

[c] Based on a moderate level of exercise for an 8-hr day.

for an 8-hour, 5-day/week exposure that if not exceeded is not expected to result in any adverse effects. A worker breathing 8.064 $m^3$/8 hr (a moderate level of exercise) at the TLV would have an exposure of:

$$\frac{0.5\ \text{mg/m}^3 \times 8.064\ \text{m}^3}{70\ \text{kg}} = 0.058\ \text{mg/kg}.$$

This results in a safety factor of 5.8 mg/kg divided by 0.058 = 100 for penta and (0.001) divided $(0.058 \times 4 \times 10^{-6})$ = 4,310 for HxCDD.

## Exposure Considerations Regarding Contaminants

Commercial technical penta contains varying levels of other chemical species as shown in Table 32. The vapor pressure of the chlorodioxins ranges from $1.8 \times 10^{-7}$ to $6.6 \times 10^{-7}$ (temperatures not specified)(EPA, 1978). Consequently, exposure resulting from vaporization is predicted to be very low. The vapor pressure of the chlorinated dibenzofurans in penta ranges from $1.9 \times 10^{-7}$ to $7.3 \times 10^{-6}$ at 25° C. Dermal absorption data for the chlorinated dibenzodioxins and dibenzofurans have not been reported.

For purposes of discussion and evaluation it is assumed that oral exposure to penta will result in exposure to contaminants at a level proportionate to their level in penta. It can be expected that contaminant absorption kinetics will be different

Table 32.--Calculated penta related contaminant exposure (micrograms/kg/day) depending on contaminant level and penta exposure rate

| Contaminant by Level | Penta Exposure Rate mg/kg/day | | | |
|---|---|---|---|---|
| | 0.001 | 0.01 | 0.1 | 1.0 |
| | Exposure to Contaminants Micrograms/kg/day | | | |
| Dioxins | | | | |
| OCDD[a] - 2000 ppm | 0.002 | 0.02 | 0.2 | 2.0 |
| OCDD - 15 ppm | 0.000015 | 0.00015 | 0.0015 | 0.015 |
| HpCDD[b] - 200 ppm | 0.0002 | 0.002 | 0.02 | 0.2 |
| HpCDD - 6 ppm | 0.000006 | 0.00006 | 0.0006 | 0.006 |
| HxCDD[c] - 20 ppm | 0.00002 | 0.0002 | 0.002 | 0.02 |
| HxCDD - 1 ppm | 0.000001 | 0.00001 | 0.0001 | 0.001 |
| Furans | | | | |
| C16 - 15 ppm | 0.000015 | 0.00015 | 0.0015 | 0.015 |
| C16 - 1 ppm | 0.000001 | 0.00001 | 0.0001 | 0.001 |
| C17 - 200 ppm | 0.0002 | 0.002 | 0.02 | 0.2 |
| C17 - 1.8 ppm | 0.0000018 | 0.000018 | 0.00018 | 0.0018 |
| C18 - 200 ppm | 0.0002 | 0.002 | 0.02 | 0.2 |
| C18 - 1.0 ppm | 0.000001 | 0.00001 | 0.0001 | 0.001 |
| Hexachlorobenzene-400 ppm | 0.0004 | 0.004 | 0.04 | 0.4 |

[a] Octachlorodibenzo-p-dioxin.

[b] Heptachlorodibenzo-p-dioxin.

[c] Hexachlorodibenzo-p-dioxin.

than the absorption kinetics of penta; however, Table 32 shows the calculated contaminant exposure for a 70-kg person based on various levels of contaminants in penta and varying penta exposures.

## Qualitative Exposure of Humans at Point of End Use

A general description of the qualitative exposure to penta at the application site is presented below. In addition, a summary of the volume of penta-treated material for various products along with the estimated exposure during installation, inspection and maintenance, and casual contact are presented in Table 33.

### Poles

Poles are usually installed mechanically, but require some manual contact for attachment of fittings, etc. Exposure by inhalation is consistently low. Skin contact is low, if personnel use protective clothing and follow accepted hygiene procedures.

Table 33.--Summary of qualitative exposure to products treated with penta type preservatives at point of end use

| Product | Volume Treated in 1978[a] | Exposure at | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Installation | | | Inspection, Maintenance | | | Casual Contact | | |
| | | Number Exposed[b] | Intensity of Exposure[c] | | Number Exposed[b] | Intensity of Exposure[c] | | Number Exposed[b] | Intensity of Exposure[c] | |
| | | | Skin Contact | Inhalation | | Skin Contact | Inhalation | | Skin Contact[d] | Inhalation |
| | 1,000 cu. ft. | | | | | | | | | |
| Poles | 41,905 | B | 5 | 5 | B | 5 | 5 | C | 5 | 5 |
| Lumber and timbers-outdoors or in well ventilated buildings[e] | 21,209 | C | 2-5 | 3 | C | 5 | 5 | C | 5 | 5 |
| Lumber and timbers in enclosed, poorly ventilated buildings | | B | 2-5 | 3 | A | 5 | 3 | A | 5 | 3 |
| Fence posts | 10,983 | C | 2-5 | 3 | C | 5 | 5 | C | 5 | 5 |
| Crossarms | 1,615 | B | 5 | 3 | B | 5 | 5 | NA[f] | -- | -- |
| Crossties and switch ties | 449 | A | 5 | 3 | A | 5 | 5 | B | 5 | 5 |
| Piling | 1,154 | B | 5 | 3 | NA | -- | -- | NA | -- | -- |

[a] Values are from Micklewright, 1979.

[b] A = <1,000; B = 1,000 to 10,000; C = >10,000.

[c] All exposure ratings are qualitative for purposes of comparison only. 1 = consistent high exposure; 2 = occasional high exposure; 3 = consistent medium exposure; 4 = occasional medium exposure; 5 = low exposure.

[d] Wood products pressure treated with some penta/petroleum formulations have a tendency to bleed leaving concentrated deposits of penta/petroleum on the surface of the wood. Casual contact with such products causes occasional medium exposure to skin contact.

[e] Includes pressure treated bridge timbers, piers, retaining walls, fencing, shelters, and pole barns.

[f] NA = not applicable.

Inspection of poles is routinely made at the groundline and involves removal of earth around the pole, visual inspection, sounding with a hammer, and boring of the pole, and where warranted, the pole is climbed for detailed inspection. Poles are also climbed routinely for maintenance. Personnel responsible for inspection and maintenance wear protective clothing. Exposure to inhalation and skin contact is low. This also applies to exposure through casual contact.

## Lumber, Timbers, and Plywood

### Installation Outdoors or In Well-Ventilated Buildings

Considerable manual contact is involved in the installation of lumber, timbers, and plywood in structures such as buildings, bridges, retaining walls, fencing, shelters, pole barns, etc. Personnel installing the material will range from "do-it-yourselfers" who handle the treated wood only once a year, to contractors who work with the material routinely. Exposure via inhalation will be low when personnel are working with treated wood. Exposure to skin contact will vary from low for personnel who use protective clothing to occasionally high for personnel who do not use gloves, etc. The latter will usually be the case with irregular users of penta-treated wood such as farmers or homeowners.

In many instances, treated lumber, timber, and plywood is cut to length during the installation process. Since this practice often exposes untreated wood, the cut ends are generally treated with a 5% penta solution either by brushing or spraying. During this operation the applicator is subjected to medium to high levels of penta vapors, depending on the application method and type of protective gear worn. Skin contact exposure will vary from low to high, depending on the attention that is given to proper hygiene and use of protective clothing.

Intensity of exposure to skin contact and inhalation during inspection, maintenance, and casual contact with treated lumber and timbers is low.

### Installation In Enclosed Poorly Ventilated Buildings

Exposure during installation of lumber, timbers, and plywood in enclosed spaces is similar to those for these items outdoors. The major difference between the two categories is in exposure during inspection, maintenance, and casual contact. There is low exposure to skin contact, but consistent medium exposure to inhalation where penta-treated materials are used in enclosed areas.

## Fence Posts

Installation of penta-treated fence posts is usually manual. It may be done by contractors who install posts routinely or by homeowners, farmers, etc., who install posts infrequently. In both cases, exposure to inhalation will be consistently low during installation. Exposure to skin contact will also be low for contractors, who will usually wear protective clothing. For farmers, homeowners, etc., exposure by skin contact will range from occasionally high to low, depending on whether or not protective clothing is used.

Fence posts are usually inspected visually, pushed, or probed at ground level and exposure by skin contact and inhalation is low. There is also low exposure during casual contact.

## Crossarms

Installation of crossarms involves considerable handling by the workers involved. There is consistent low exposure by inhalation and low exposure by skin contact because of the use of protective clothing and rigorous hygiene.

There is low exposure by skin contact and inhalation during inspection and maintenance. The placement of crossarms on poles prevents casual contact after installation.

## Piling

Personnel have little physical contact with piles during installation. There is a low exposure by skin contact when protective clothing is worn. There is consistent low exposure by inhalation of penta from freshly treated material.

Once the piles have been driven below ground, all exposure is eliminated. Other types of piles may be inspected and treated as detailed previously for poles with similarly low exposure.

## Crossties

Because of its superior properties, creosote is the major preservative used to treat crossties; however, penta-petroleum solution is employed in some cases. Penta is rarely used for ties in mainline track applications, where mechanical installation equipment is employed, so installation may involve manual handling. In these instances there is medium exposure to inhalation of penta during tie installation. Exposure by skin contact can range from occasional high exposure for personnel who manually install ties frequently to low exposure for personnel who manually install ties routinely and wear protective clothing.

Railroad companies routinely inspect ties in service. Inspection usually involves appraisal of the condition of the ties and sometimes sounding with a hammer. There is low exposure by skin contact and inhalation during inspection.

Railroad personnel, industrial and commercial workers, and to a lesser extent, members of the general public will have casual contact with treated crossties from time to time. Exposure by contact and inhalation is low in these situations.

Crossties are also used in landscaping. Exposure for landscape contractors involved in the sale and installation of old ties will be consistently low for inhalation, and low to occasionally high for skin contact depending on how thoroughly safety precautions are followed in handling the ties.

## Quantitative Exposure of Humans at Point of End Use

Several studies have been reported that aid in estimating total human penta exposures for the general population. Kutz, et al. (1978) reported finding penta in 84.8% of 418 urine samples representing the general population. The arithmetic mean was 6.3 ppb (6.3 micrograms/kg of urine; 1 kg equals about 1 liter since the specific gravity of urine is about 1.03). A normal 70-kg person will produce a daily urine volume of 1.4 liters (Guyton, 1971). This could decrease to 0.5 liter or increase to 2.8 liters or more depending on temperature, degree of sweating and fluid intake.

Braun et al. (1978) have shown that the plasma half-life of penta in humans is 1.25 days and that 86% of an oral dose is eliminated in urine. Consequently, it is possible to estimate penta exposure in the general population.

Calculation of average daily general population penta exposure:

$$\frac{\text{level in urine x volume of urine}}{\text{body weight x \% eliminated in urine}} = \text{Exposure Rate}$$

$$\frac{0.0063 \text{ mg/liter x } 1.4 \text{ liter}}{70 \text{ kg x } 0.86} = 0.00014 \text{ mg/kg}$$

AVERAGE EXPOSURE ESTIMATE
GENERAL POPULATION

Kutz et al. (1978) reported that the maximum urine penta level found in their survey was 0.193 mg/liter. Using the above formula the exposure rate for this individual would be:

$$\frac{0.193 \text{ x } 1.4}{70 \text{ x } 0.86} = 0.00448 \text{ mg/kg is}$$

MAXIMUM EXPOSURE ESTIMATE
GENERAL POPULATION

In Hawaii the background exposure levels are higher. Bevenue, et al. (1967a) reported urine penta levels for 173 non-occupationally exposed individuals. The range was 0.0003 to 0.570 mg/liter with an average of 0.044 mg/liter. Using the above method the resulting calculated exposures are:

Average urine penta of 0.044 mg/liter:

$$\frac{0.044 \text{ x } 1.4}{70 \text{ x } 0.86} = 0.00102 \text{ mg/kg}$$

AVERAGE EXPOSURE ESTIMATE (HAWAII)

Maximum urine penta of 0.570 mg/liter:

$$\frac{0.570 \text{ x } 1.4}{70 \text{ x } 0.86} = 0.0133 \text{ mg/kg}$$

MAXIMUM EXPOSURE ESTIMATE (HAWAII)

The above exposure analysis does not identify the source or route of exposure. Penta has been found in foods, and Duggan and Corneliussen (1972) estimated dietary exposure to be 0.001 to 0.006 mg/person/day or 0.000014 to 0.000085 mg/kg/day. If the above average General Population Exposure of 0.00014 mg/kg (based on urine level) for general population is correct, then only 0.00001 to 0.00008 mg/kg of this is accounted for by diet based on levels in food.

In Table 34 the general population exposure rates derived above are summarized and compared to the NOEL. The derived safety factor is the ratio of the NOEL (5.8 mg/kg for penta and 1 microgram/kg for HxCDD) to the exposure estimate.

The preceding analysis is the best estimate of penta exposure in the general population. The remaining consideration is what are the possible exposure limits in a person using this material in or around the home.

Table 34.--Summary of general population exposure rates and safety factor

| Penta Exposure | Safety Factor | HxCDD Exposure | Safety Factor |
|---|---|---|---|
| mg/kg | | mg/kg | |
| 0.00014 (avg. gen. pop.) | 41,428 | $0.00014 \times 4 \times 10^{-6}$ | 1,785,714 |
| 0.00102 (avg. Hawaii) | 5,686 | $0.00102 \times 4 \times 10^{-6}$ | 245,098 |
| 0.00448 (max. gen. pop.) | 1,294 | $0.00448 \times 4 \times 10^{-6}$ | 55,803 |
| 0.0133 (max. Hawaii) | 436 | $0.0133 \times 4 \times 10^{-6}$ | 18,797 |

## Exposure Analysis Based on Point of End Use in the Home

Penta is used to treat millwork such as window and door frames. These wood surfaces are later partially covered by sheetrock or paneling and the remaining surface is covered with something like paint or varnish. The penta exposure resulting from these applications is unknown. The PD-I (Federal Register, 1978) cites an air level of 0.16 mg penta/$m^3$ reported by Gebefugl *et al*. (1976). It is not known to what extent this value is representative.

On occasion, larger amounts of penta have been used inside of homes to treat natural wood ceilings, walls or paneling. Such uses have resulted in problems and some of the considerations are discussed below.

If penta is used inside a house several physiochemical processes can occur that influence the resulting exposure. First the over-the-counter (OTC) penta formulations for home use are typically a 5% penta in mineral spirit solution containing co-solvents, waxes, and antiblooming agents. The material is brushed on, the mineral spirits evaporate in a matter of hours and the penta is left in the wood. If the antiblooming agent is not completely effective, then small crystals of penta will form on the surface of the wood (this phenomenon is called blooming). At this point two factors are important considerations. First, air currents or housecleaning activities such as brushing could cause the small crystals to become airborne, thus generating a dust for respiratory exposure either in the lung or via the mucosa of the upper respiratory tract. It is difficult to estimate the air penta concentration resulting from this process. Theoretically, the exposure could range from 0 to a level high enough to be of health concern. This problem must be dealt with by prevention through use restrictions. The second factor relating to exposure resulting from blooming is that crystalline penta is available for vaporization. Under these conditions it is likely that air penta levels in a closed system with a low air exchange, will come closer to the theoretical vapor density equilibrium value of 1.6 mg/$m^3$ than will result from vaporization from wood treated with penta in oil and installed in a well-ventilated space. The resulting exposure for an adult female is shown in Table 35 using both the reported (0.16 mg/$m^3$) and theoretical air vapor density (1.6 mg/$m^3$) values.

Under the conditions of penta vaporization there would not be proportional levels of chlorodioxins in the air because of the lower vapor pressure of the chlorodioxins. However, assuming proportionate levels for a worst-case analysis at the vapor density equilibrium value, the resulting safety factors are penta = 9.35 and

Table 35.--Exposure analysis for a 57.5-kg female in a closed house with an air penta level at the vapor density equilibrium value

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Assumptions

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1) Body weight = 57.5 kg
2) Sex: female
3) Breathing rates (Respiration & Circulation, 1971)
   Housewife -
   - a) resting - 0.27 $m^3$/hr
   - b) light work - 0.978 $m^3$/hr
   - c) moderate work - 1.368 $m^3$/hr
   - d) strenuous work - 2.052 $m^3$/hr
4) Air penta level = 1.6 mg/$m^3$ (the vapor density equilibrium value at 20°C (68°F)).

| 5) Exposure calculations | | mg/kg |
|---|---|---|
| a) 8 hours resting (8 x 0.27 x 1.6) ÷ 57.5 | = | 0.0601 |
| b) 8 hours light work (8 x 0.978 x 1.6) ÷ 57.5 | = | 0.2177 |
| c) 6 hours moderate work (6 x 1.368 x 1.6) ÷ 57.5 | = | 0.2284 |
| d) 2 hours strenuous work (2 x 2.052 x 1.6) ÷ 57.5 | = | 0.1141 |
| 6) Daily exposure (a + b + c + d) | = | 0.6203 |

---

HxCDD = 403. The above is a worst case, 24-hour/day exposure to penta vapors using the exposure rate (0.062 mg/kg) calculated from the maximum theoretical air vapor density. If one calculates exposure using the reported air level (0.16 mg/$m^3$), the safety factors based on a 24 hour/day exposure are penta = 93.5 and HxCDD = 4,032.

The last exposure phase to be considered in the home is dermal adsorption associated with application. The critical factor is estimating an average level of sloppiness or carelessness. On one extreme it could be assumed that the individuals spilled a gallon of 5% solution on themselves, thoroughly saturated their clothing, and did not change clothes or bathe for 24 hours, and that there was complete absorption of the approximately 182 grams of penta/gallon. The resulting exposure for a 60 kg person would be 3,033 mg/kg which would clearly be lethal. On the other extreme is the fastidious person who follows directions and uses the material in a well-ventilated space, wears rubber gloves, and avoids skin contact. In this case the exposure would be low.

On the average, it seems reasonable that the typical application could involve some skin exposure. Since mineral spirits have a low viscosity the material does not cling to skin as readily as a more viscous material such as paint. The rate of dermal absorption is not directly known. However, Bevenue et al. (1967) reported an episode that, with some assumptions and calculations, can be used to obtain some insight into the possible limits of dermal exposure.

In the case reported, a worker washed a brush in a 0.4% penta in mineral spirits solution. The exposure was a 10-minute immersion of both hands in the solution, followed by washing in soap and water. A 24 hour urine sample taken 2 days later contained 0.236 mg penta/liter. Using the following assumptions and mathematical models the total exposure will be estimated. A simple one compartment first order elimination model with a urine elimination half-life of 33.1 hours describes the elimination of penta in humans (Braun, et al., 1978). In the calculations that follow, the more rapid elimination of the metabolite penta glucuronide will be ignored and the final calculated exposure adjusted by 25% to correct for fecal excretion and the 12% penta-glucuronide elimination. The equation describing the elimination of penta in urine is $C_x = C_I e^{-kt}$ where $C_I$ is the concentration at time zero ($t_o$) which in this instance will be the urine concentration during the first 24-hour period after exposure. $C_x$ is the concentration at any time following exposure, t is time in days, k is a constant determined by the rate of elimination, and e is the base of natural logarithms. Based on a half-life of 33.1 hours, the resulting value for k is 0.503. In this instance the urine penta level was determined for the period of 48 to 72 hours post-exposure. Using the equation $C_x = C_I e^{-.503t}$, the following amounts of penta are calculated to have been excreted in the urine during the 6 days following exposure (Table 36).

Table 36.--Predicted urine concentrations for the 6 days following an acute dermal exposure and resulting total body exposure based on extrapolation of the data of Bevenue et al., 1967a

| Day | Penta in Urine | | Total Penta (mg/liter x 1.4 liter/day) |
|---|---|---|---|
| | gm/liter | | mg |
| 1 | 0.645 | | 0.903 |
| 2 | 0.391 | | 0.547 |
| 3 | 0.236 | | 0.330 |
| 4 | 0.143 | | 0.200 |
| 5 | 0.086 | | 0.120 |
| 6 | 0.052 | | 0.073 |
| | | Total | 2.173 |

A six-day period is used because 93% of the original amount present is eliminated in four half-lives which in this case is 1.38 days x 4 = 5.5 days. The final correction is to adjust the exposure for fecal excretion and the more rapid elimination of the glucuronide. Using available information the worst-case assumption is that the measured urine penta values account for 75% of the whole body dose. Therefore, the resulting best estimate of exposure resulting from a 10 minute immersion of both hands in a 0.4% penta in mineral spirits is 2.173 ÷ 0.75 = 2.89 mg. Assuming a 70-kg body weight, the resulting exposure rate is 2.89 ÷ 70 = 0.041 mg/kg.

Up to this point this analysis has been based on known principles of pharmacodynamics. The next point in this analysis is based on the assumption that a more concentrated penta solution would result in a linearly proportionally larger exposure. It is unlikely that the exposure rate would be higher than this and in reality might be lower than the linear extrapolation. The OTC penta product is a 5% solution and is (5 ÷ 0.4) 12.5 times more concentrated than the solution encountered in the above example. A linear extrapolation predicts an exposure of (0.289 x 12.5) 36.1 mg for a 10 minute immersion of both hands in a 5% penta solution. The exposure rate for a 70 kg individual would be 36.1 ÷ 70 = 0.52 mg/kg. The safety factors would be: penta = 11.1 and HxCDD = 480.

While the above can be criticized for being speculative, it is no more speculative than simply assuming the absorption of any arbitrary quantity of 5% solution. In either case the exposure analyses reinforce the recommendation to avoid skin contact.

## Exposure of Animals at Point of End Use

Food animals can come into contact with wood treated with penta. These are discussed below. In summary, the principal problem is chemical residues in food products of animal origin rather than overt toxicity in animals following exposure.

### Cattle

Cattle can come into contact with penta in several ways. Based on laboratory vaporization studies of Thompson, et al. (1979), the maximum expected air penta level in a barn constructed in part from poles and boards treated with penta in heavy oil would be 0.02 mg/m$^3$. A 514-kg cow breathes 104 liters/min when lying down and 114 liters/min when standing (Respiration and Circulation, 1971). Using the average value of 109 liters/min then the total volume of air inhaled in 24 hours is 156,960 liters or 156.9 m$^3$. The penta exposure using 100% retention is 3.138 mg/cow or 0.006 mg/kg. This level of exposure is well below the NOEL for penta in rats.

An exposure of 0.006 mg/kg would result in a predicted blood residue level of 0.013 mg/liter (ppm) (Osweiler, et al., 1977). The prediction is based on extrapolation of blood levels determined by feeding cattle known amounts of penta for 14 days and analysis of blood penta levels.

Cattle can also be exposed by licking or chewing on treated wood. Penta-treated wood will contain 10 to 16 gm penta/board foot. Sample calculations are shown in Table 37 which relates levels of penta exposure, amount of wood consumed, and predicted biologic effects. There is no evidence that there is any significant accumulation of penta in meat or milk of cows.

Table 37.--Relationship between wood consumption and rate of penta exposure in a 514-kg cow. A wood penta retention of 14 gm/board foot is assumed

| Penta Exposure | Amount of Wood Eaten | Predicted Biologic Effect[a] |
|---|---|---|
| mg/kg | bd. ft./day | |
| 1 | 0.039 | No significant effect even if consumed over a long time |
| 20 | .777 | Some chronic effects after 90 days at this level, decreased weight gain |
| 70 | 2.72 | Toxic dose, likely to be lethal in 10 days or longer |
| 140 | 5.44 | Acute toxic dose, death possible after 1 dose |

[a] The predictions are based on current information on the toxicity of penta in cattle and other species. Long term no effect studies have not been reported for cattle.

Trace levels of exposure can also occur from low level contamination of feed coming into contact with treated wood. Examples of this are silage stored in wood bunker silos and animals fed from feed bunks or self-feeders constructed from treated wood. The largest exposure would occur with freshly treated lumber that was bleeding (oozing) the oil-treating solution from the surface. The treating solution is usually a 5 to 7% penta/oil mixture. Table 38 relates the quantity of treating solution ingested, penta exposure level and expected biologic effects.

Table 38.--Penta exposure and predicted biologic effects in a 514-kg cow consuming a 7% penta-in-oil solution

| Solution Consumed | Penta Exposure | Predicted Biologic Effect[a] |
|---|---|---|
| ml | mg/kg | |
| 9.06<br>(3 teaspoons) | 1 | No significant effect even if consumed over a long time |
| 181<br>(0.75 cup) | 20 | Some chronic effects after 90 days |
| 634<br>(2.75 cups) | 70 | Toxic dose may be lethal after 10 doses |
| 1,269<br>(5.5 cups) | 140 | May be lethal after 1 dose |

[a] The predictions are based on current information on the toxicity of penta in cattle and other species. Long-term, no-effect studies have not been reported for cattle.

Exposure via licking the treating solution from wood surfaces or from bleeding wood is self-limiting due to the fixed amount of material present. One board foot of lumber will contain about 0.6 pound of treating solution or 263 ml of solution. Consequently, a cow would receive a toxic dose only from a large amount of oil bleeding from a small amount of wood or a systematic licking of a large wood surface containing a small amount of oil/unit surface area. Neither of these possibilities is very likely. The nature of cattle is to do little licking of foreign objects except when malnourished or salt starved. The occasional cow that licks foreign objects for unknown reasons tends to stand in one place rather than walking up and down the barn licking everything in sight.

Blood penta levels in dairy cattle housed in total confinement-free stall pole barns without a penta treated feedbunk have ranged from 0.010 to 0.050 mg/liter (ppm) which equates to an exposure of 0.004 to 0.033 mg/kg. In one barn where a larger than usual amount of treated wood was used and the sides of the new feedbunk were constructed of treated wood the average blood penta level was 0.279 mg/liter, which equates to a penta exposure of 0.3 mg/kg (Van Gelder, 1977).

## Horses

Horses are more infamous for their chewing habits (cribbing) than are cattle. Horses can fall into both the companion animal and food animal categories.

Nothing has been reported about the toxicity of penta in horses. Assuming that horses respond similarly to cows, the amount of wood a horse would have to consume per day is shown in Table 39.

Table 39.--Penta exposure and wood consumption for a 454-kg horse.
Assumption: 14 g penta/board foot

| Penta Exposure | Amount of Wood | Predicted Biologic Effect[a] |
|---|---|---|
| mg/kg | bd. ft./day | |
| 1 | 0.032 | No effect |
| 20 | 0.648 | Possible health effect after 90 days |
| 70 | 2.27 | Toxic effects. Death possible after 10 doses |
| 140 | 4.54 | Death possible after single dose |

[a] Prediction based on extrapolation of the effects of penta in other species. No toxicity studies on the effects of penta in horses have been reported.

### Pigs

Exposure to penta has resulted in deaths in pigs (Schipper, 1961). The problem results when sows are farrowed (give birth) on freshly treated lumber or on wood that is bleeding. Deaths in the piglets and skin burns on the sow's udder have been reported. Covering the wood with bedding or untreated wood prevents the problem.

### Poultry

The problems related to penta in poultry occur when sawdust/wood chips containing penta are used for bedding (litter) (Curtis et al., 1974). Fungi in the litter convert the penta and tetrachlorophenol to the corresponding chloroanisole. The chicken absorbs the chloroanisole with the resulting development of a musty taint to the meat and eggs. This problem has been reported several times. The problem is prevented by not using treated wood shavings for bedding.

## Fate of Penta in the Environment

Kozak, et al. (1979) have prepared a comprehensive review which includes an extensive discussion of the sources and fate of penta in the environment. Rao (1978) also presents much of the recent work on this subject. Therefore, this section is limited to a brief overview of the subject and is not intended to be all-inclusive.

### Air

Penta can enter the atmosphere by several routes. However, information on atmospheric levels is limited because penta has not been included in the National Air Monitoring program. Therefore, it is difficult to determine the rates of penta entrance into the atmosphere, its transport and transport mechanisms.

Penta is moderately volatile (0.00011 mm Hg at 20°C), suggesting that volatilization may be a significant route for penta entrance to the air. Other possible routes for penta to enter the air include spray drift from herbicide use and adsorption onto small particles, which can later become airborne. Penta may recrystallize on the surface of treated wood (blooming) depending on the solvent systems and conditions and these crystals can be brushed off into the air. It is likely that volatilization is the major dispersal mechanism of the compound to the atmosphere.

The significance of atmospheric transport may be inferred from a number of studies. Casarett, et al. (1969) found that blood and urine penta concentrations among workers in a wood preservation plant were significantly higher than levels in the blood and urine of non-occupationally exposed persons. Significant concentrations of penta were qualitatively detected in the plant atmosphere and the workers were considered to have received part of their penta exposure by respiratory absorption. Wyllie, et al. (1975) studied penta levels in air and in the urine and serum of workers in a wood treating plant. Average air levels over a 6-month period ranged from 108 nanograms/$m^3$ in an outdoor storage area to 5,930 nanograms/$m^3$ in the enclosed treating area. Average urine levels ranged from 64 micrograms/kg for the office manager to 296 micrograms/kg for the pressure treater while the unexposed control subjects averaged 3.4 micrograms/kg. The significant level for the office manager who presumably had no direct contact with penta suggests that inhalation was an important route of exposure.

Bevenue, et al. (1967) found an average of 40 nanograms/g penta in the urine of non-occupationally exposed persons in Hawaii. The source of exposure was unclear, but penta is widely used in Hawaii for the protection of wooden structures against decay and termite infestation. This led to the suggestion (Casarett et al., 1969) that the respiratory tract adsorption was a reasonable explanation. The levels of penta in rain water collected in Hawaii ranged from 2 to 284 nanogram/liter (Bevenue et al., 1972a) providing circumstantial evidence for the presence of penta in the atmosphere. The authors also found penta in snow samples from Mauna Kea summit (14 nanograms/liter) and in lake water (10 nanograms/liter) taken from Lake Waiau, which is fed by summit snows.

Airborne penta has been toxic to plants and humans in confined spaces. Ferguson (1959) reported damage to conifer seedlings grown in flats treated with penta, apparently as a result of volatilization of the penta. Treatment of interior redwood paneling of a home (Anonymous, 1970) resulted in the intoxication of the inhabitants, presumably by volatilization of penta from the paneling. Cattle housed in total confinement in a barn that had been constructed in part with penta-treated wood had blood levels of penta ranging from 270 to 570 micrograms/kg (Michigan Dept. Agric., 1978).

One can only speculate on the prime sources of penta in air and its movements through air, because no monitoring studies on atmospheric levels of penta have been conducted. Finding penta in rain water and snow melt indicates that it can be removed from air by wash out. But it also seems reasonable to assume that penta can be degraded by photolytic reactions; however, information on the vapor phase photolysis for penta is lacking.

## Water

Penta in the aquatic environment may be dissolved, sorbed to suspended matter or bottom sediments, or sorbed by aquatic organisms. Penta is non-ionized in aqueous solutions with pH lower than 5 and becomes increasingly dissociated as the pH rises. The degree of dissociation will determine the extent of solubility and the degree of adsorption on clays present in the aquatic system. Movement of penta will depend on hydrologic factors such as current patterns and mixing. There is evidence of microbiological degradation of penta in aquatic environments. Other routes of removal from water include photodegradation and volatilization.

Penta can enter aquatic systems from several sources. It may be discharged from factories that manufacture penta or use it in wood treatment or slime control. Non-point sources of penta pollution of water are diverse in character and may involve its use over wide areas as a molluscicide, algicide, herbicide, or desiccant. Another possible non-point source arises from extensive use of penta treated wood. Leaching from this wood could serve as a continuing source of environmental pollution in the absence of breakdown.

Raw waste water from five wood treatment plants contained penta ranging from 25 to 150 mg/liter (Thompson and Dust, 1971). Treatment of the water with 2 g lime/liter reduced levels from 150 to 17 mg/liter. Bevenue, et al. (1972) detected 1.14 micrograms/liter of penta in water of a ditch that drained the grounds of a wood treatment plant. The samples were collected after a heavy rain and it was believed that a large pile of penta-treated lumber was responsible for the penta in the ditch. Pierce and Victor (1978) studied a lake that received runoff from the overflow of a pond containing wood treating waste including penta. Water level was about 10 micrograms/liter two months after the spill. While fish levels were 295 mg/kg in the whole body two months after the spill, the levels decreased to background within 10 months. Sediments averaged 100 micrograms/kg and leaf litter 4,500 micrograms/kg throughout the year, providing a chronic source of pollution to the ecosystem.

Dougherty (1975--as cited by Arsenault, 1976) found penta in the Tallahassee, Florida water supply at 0.1 microgram/liter. It was suggested that the source may have been chlorination of phenols in the water supplies. Arsenault (1976) demonstrated that 10 mg/liter of chlorine is capable of chlorinating 1 mg/liter of phenol, yielding about 0.2 microgram/liter of penta.

The Sand Island outfall in Hawaii, which receives all the sewage from the Honolulu area, contained 2.6 micrograms/liter of penta in a 24-hour composite discharge (Bevenue et al., 1972). Buhler, et al. (1973) found penta levels ranging from 1 to 4 microgram/liter from the sewage effluent of three Oregon cities. Water samples from the Willamette River ranged between 0.1 and 0.7 microgram/liter. These concentrations in the river were at least 10 times greater than the calculated values derived from assuming that the only source of penta was municipal sewage. It is possible that industrial sources may explain the discrepancy.

The contribution of non-point penta pollution to the total environmental load is difficult to assess. Death of wildlife in Surinam (Vermeer et al., 1974) was attributed to the use of penta as a molluscicide in rice fields. Fish kills have been attributed to the use of penta in rice fields in Korea (Shim and Self, 1973) and Japan (Nita, 1972).

Penta has limited usage in the USA as a herbicide, molluscicide or algicide. However, in other countries penta usage has continued unabated and residues found in river waters in southwestern Japan ranged from 0.01 to 10 micrograms/liter in 1969 (Goto, 1971). Zitko, et al. (1974) surveyed penta levels in the aquatic fauna of New Brunswick, Canada. Values in fish ranged from 0.82 microgram/kg in cod to 3.99 micrograms/kg in white flounder. The source of the penta is not clear, but the area was considered "relatively clean." Pierce and Victor (1978) studied extensive fish kills in a freshwater lake following the accidental release of wood-treating wastes containing penta. The penta water level was about 10 micrograms/liter

2 months after the spill but decreased to background levels (<50 microgram/kg) after 10 months.

The persistence of penta in the aquatic environment is dependent on a number of environmental variables, but the interrelationships have not been fully characterized. Penta may be removed from the aqueous space by volatilization into the atmosphere, photodegradation, adsorption, and biodegradation.

Hilton et al. (1970) demonstrated that penta content of aerated solutions decreases rapidly by volatilization. The contribution of this phenomenon to penta removal from water in the environment is unclear.

The chemical environment of the molecule profoundly influences its photochemical behavior. Therefore, photolysis studies carried out in aqueous solution are the only ones relevant to problems of the environment. Wong and Crosby (1978) studied the photolysis of penta in dilute water solution and proposed the pathway shown in Figure 10. Photodegradation products were found to be chlorinated phenols, tetrachlorodihydroxy-benzenes and non-aromatic fragments such as dichloromaleic acid. Prolonged irradiation of penta degradation products yielded colorless solutions containing no ether extractable volatile materials, and evaporation of the aqueous layer left no observable polymeric residue such as humic acid. A detectable level of octachlorodibenzo-p-dioxin was formed when a high concentration of the sodium salt of penta was irradiated. Water samples from several northern California locations were analyzed and penta was detected from several sources. It was occasionally accompanied by 2,3,4,6-tetrachlorophenol, but none of the other suspected products were found.

Pierce and Victor (1978) studied the fate of penta in an aquatic ecosystem after wood treating waste containing penta was accidentally spilled into a fresh water lake. Samples of water, sediment, leaf litter, and fish were collected from the lake and analyzed to determine the persistence and distribution of penta and its degradation products. Penta persisted over 6 months in water and fish following the spill. Sediment and leaf samples contained high concentrations of penta throughout the two-year period of investigation. The major degradation products were pentachloroanisole and the 2,3,5,6- and 2,3,4,5-tetrachlorophenol isomers. Tetrachlorophenol appeared to be formed by photodegradation in the fuel oil solution before entering the lake while pentachloroanisole appeared to be formed within the aquatic environment. Lu et al. (1978) studied the fate of $^{14}$C-labeled penta in a model ecosystem. Principal degradation products were tetrachlorohydroquinone, pentachlorophenyl acetate, and conjugates.

## Soil

Soil is one of the more important sinks for synthetic organic chemicals, including penta, in the environment. Mobility, persistence and fate of penta in soils depend on physical and chemical characteristics of the soil as well as the prevailing microbial population.

Hilton and Yuen (1963) compared soil adsorption of penta to the soil adsorption of a number of substituted urea herbicides. They found that the adsorption of penta was the highest of all compounds studied. Good preemergence weed control was achieved only in soils of low adsorption. Excessive levels of application provided little improvement. This observation is consistent with steep slopes of the adsorption isotherms found for penta.

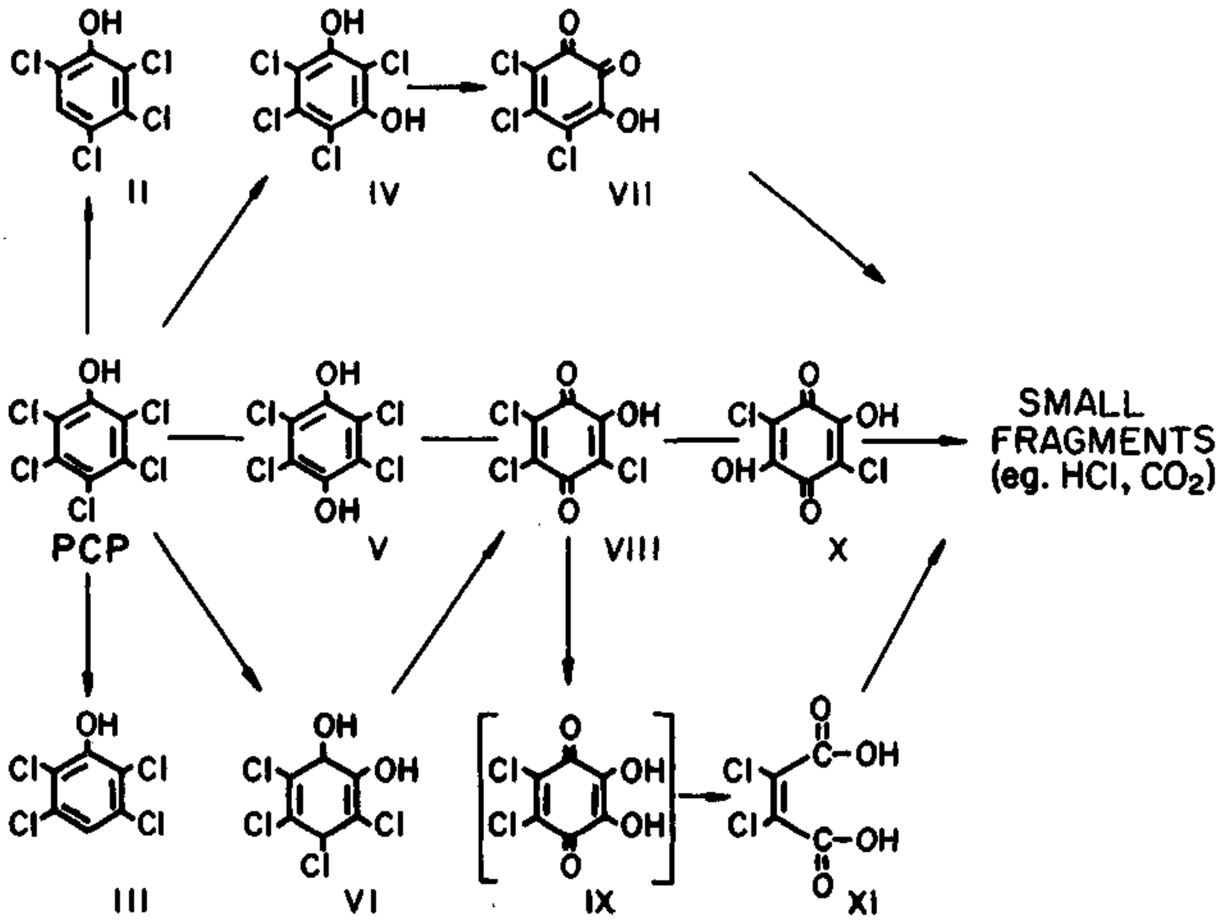

Figure 10. Proposed photolysis pathway for pentachlorophenol. (Wong and Crosby, 1978)

Choi and Aomine (1972, 1974, 1974a) studied interaction of penta and soil in detail. Adsorption and/or precipitation of penta occurred to some extent on all soils tested. The inhibition of wheat seedlings was greater for a soil suspension than for the supernatant aqueous solution above it. This indicates that adsorbed and/or precipitated penta retains some toxicity to plants.

Choi and Aomine (1974) concluded in a study of 13 soils that adsorption of penta primarily depended on the pH of the system. The more acid the soil, the more complete was the "apparent adsorption" of penta. Different mechanisms of adsorption dominate at different pH values. In acid clays "apparent adsorption" involved the adsorption on colloids, and precipitation in the micelle and in the external liquid phase. Organic matter content of soils is important to adsorption of penta at all pH values. Humus containing soil always adsorbs more penta than soil treated with $H_2O_2$ to remove organic matter. Later investigations led to the conclusion that adsorption of penta by humus is important when the concentration is low, but at higher concentrations the inorganic fraction increases in importance.

Three of four allophanic soils showed a significant increase in penta adsorption at higher temperatures, while the fourth soil showed a decrease (Choi and Aomine, 1974a). The difference between the three soils and the fourth soil could be explained by assuming that andosols chiefly adsorb penta as anions, whereas, the major factor influencing penta adsorption by the fourth soil, showing a decrease with increasing temperature, is a Van der Waals force. Decreasing the concentration of chlorides or sulfate ions also increases the adsorption of penta to soil. These results indicate the occurrence of competition between inorganic anions and penta anions for adsorption sites on the soil colloid.

Penta mixed with layer silicate clay minerals such as illite, montmorillonite and kaolinite sublimes at about 200°C. Penta mixed with or adsorbed on allophane did not sublime but pyrolized between 250° and 500°C, showing a strong exothermic reaction (Choi and Aomine, 1974a).

The persistence of penta in soil depends on a number of environmental factors. Young and Carroll (1951) noted that penta degradation was optimum when the moisture content of soil was near saturation. Kuwatsuka and Igarashi (1975) reported that the degradation of penta is faster under flooded conditions than under upland conditions. Loustalot and Ferrer (1950) found that the sodium salt of penta was relatively stable in air-dried soils, persisted for 2 months in soil of medium moisture content, and for 1 month in water-saturated soil.

Soil composition has a great effect on the persistence of penta. It persisted longer in heavy clay than in sandy or sandy clay soils (Loustalot and Ferrer, 1950). An extensive study of the soil variables affecting the rate of degradation of penta was carried out by Kuwatsuka and Igarashi (1975). The rate was correlated with clay mineral composition, free iron content, phosphate adsorption coefficients and cation exchange capacity of the soil, while the greatest effect was the correlation with organic matter. Little or no correlation could be found with soil texture, clay content, degree of base saturation, soil pH, and available phosphorus.

The preponderance of information indicates that microbial activity plays an important part in the degradation of penta in soil. Penta decays more rapidly when the ambient temperature approaches the optimum value for microbiological activity (Young and Carroll, 1951). Ide et al. (1972) found no decay in sterilized soil samples. The positive correlation between organic matter content of soil and penta degradation also suggests that microorganisms play an important role (Kuwatsuka and Igarashi, 1975; and Young and Carroll, 1951). Kuwatsuka and Igarashi (1975) studied degradation of penta in soils collected from flooded and upland areas. Upland soils degraded penta more rapidly in the laboratory when studied in the aerated condition, while soils obtained from flood conditions degraded penta more rapidly when tested in the flooded stage. Thus, penta degrading microorganisms present in the soil survived the transfer to the laboratory and were most active when placed in an environment to which they were adapted.

A summary of the literature values for the persistence of penta in soil is presented in Table 40. The persistence ranged between 21 days and 5 years. The 5-year value obtained by Hetrick (1952) was from dry soil sealed in a jar and probably does not represent a realistic evaluation of the environmental half-life. Thus, penta can be considered moderately persistent under most conditions.

Numerous degradation products have been isolated for penta-treated soil. Ide et al. (1972) identified 2,3,4,5-, 2,3,5,6-, 2,3,4,6-tetra-chlorophenol; 2,4,5- and 2,3,5-trichlorophenol; 3,4- and 3,5-dichlorophenol; and 3-chlorophenol. Similar products were obtained by Kuwatsuka and Igarashi (1975), who also identified pentachloroanisole as a penta degradation product. This reaction is reversible and pentachloroanisole can subsequently degrade back to penta. Demethylation and methylation of phenolic groups in biological systems are well known (Williams, 1959). Ide et al. (1972) found 2,3,4,5-, 2,3,5,6- and 2,3,4,6-tetrachloroanisoles; 2,3,5-trichloroanisole; 3,4- and 3,5-dichloroanisoles; and 3-chloroanisole as methylated

Table 40.--Persistence of penta in soil

| Degradation Parameter | Soil Type | Special Conditions | Time | Reference |
|---|---|---|---|---|
| 90% degradation | Arable layer in rice fields (11 soils) | 60% water<br>25% water | Approx. 50 days<br>Approx. 30 days | Kuwatsuka and Igarashi, 1975 |
|  | Forest red-yellow soil sublayer | 60% water<br>250% water | No degradation in 50 days |  |
| 90% degradation | Wooster silt loam | 7.5 kg/ha penta, optimum conditions for microbial growth | Approx. 22 days | Young and Carroll, 1951 |
| -- | -- | -- | >5 years | Hetrick, 1952 |
| Effect on growth of corn and cucumbers | Fertile sandy loam | Air-dried<br>Medium water<br>Water saturated | >2 months<br>2 months<br>1 month | Loustalot and Ferrer, 1950 |
| 90% degradation | Mature paddy soil | Low organic content | 1 month | Ide _et_ _al_., 1972 |
| Complete degradation | Dunkirk silt loam | Aerated, aqueous soil suspension | Approx. 72 days | Alexander and Aleem, 1961 |
| Complete degradation | Paddy soil | Soil perfusion | 21 days | Watanabe, 1973 |
| -- | Warm, moist soil | -- | >12 months | Bevenue and Beckman, 1967 |
| 98% degradation | Permeable soil | Composted with sludge from wood-treating plant | 205 days | Arsenault, 1976 |

products of penta in incubated soil. Based on the results obtained from these investigations, Matsunaka and Kuwatsuka (1975) proposed the soil degradation pathway as shown in Figure 11.

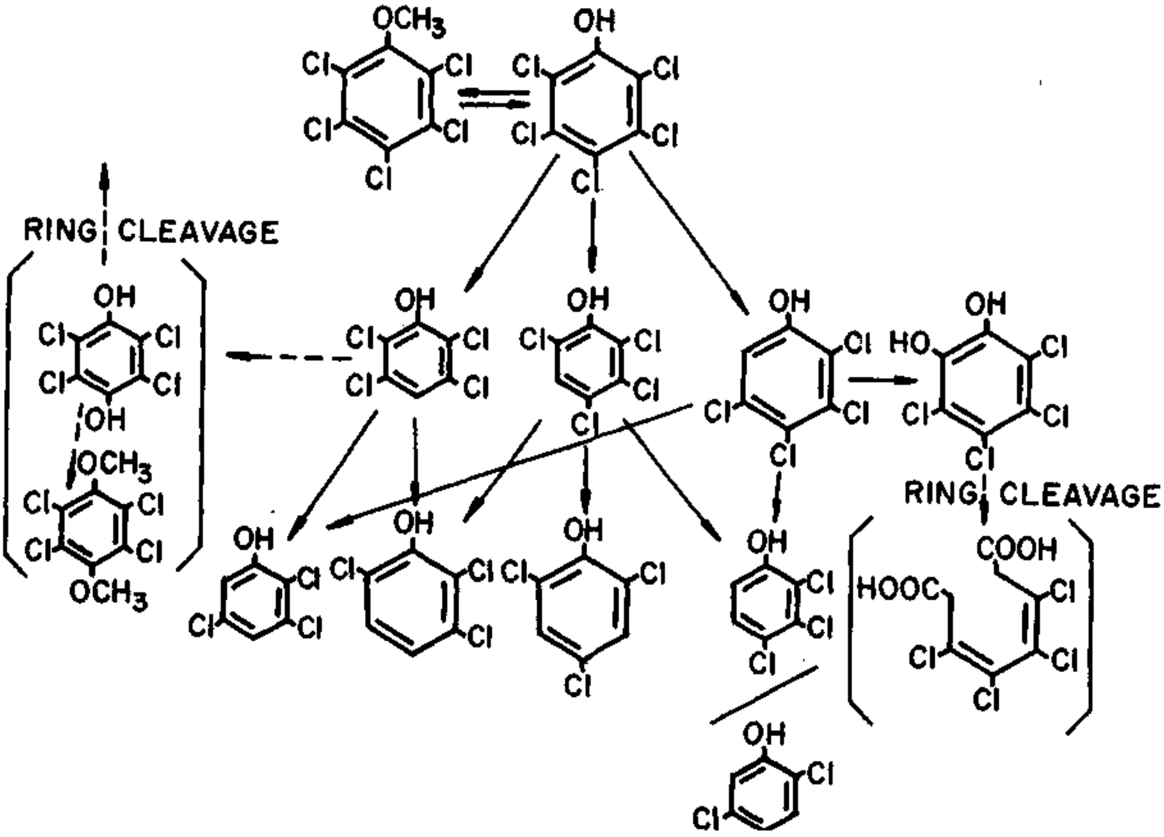

Figure 11. Proposed pathway of pentachlorophenol degradation in soil (as modified from Kaufman, 1978).

When considering the biodegradation of penta in soils and other environments, it is important to consider which products are actually due to biodegradation and which are produced by photolytic degradation or are products contained in the original formulation. Typical commercial penta contains a variety of substances such as tetrachlorophenols, trichlorophenols, hexachlorobenzene, chlorinated dibenzo-p-dioxins, and chlorinated dibenzofurans. The degree of contamination varies with the commercial preparations examined (Johnson et al., 1973; Nilsson et al., 1978; and Dougherty, 1978).

Recently, Murthy et al. (1977) examined the degradation of $^{14}C$ penta in both aerobic and anaerobic moist soil. Losses by volatilization accounted for only 0.5% of the penta added and no $^{14}CO_2$ was detected. Gas chromatographic analysis of the soil extract showed the presence of the methyl ether of penta (0.7%). 2,3,5,6- and 2,3,4,5-tetrachlorophenols and 2,3,5-trichlorophenol were identified as degradation products following methylation. Total $^{14}C$ recoveries were about 95%. Similar results were obtained in aerobic soils with regard to product formation. However, the principal product was the methyl ether of penta or pentachloroanisole. Degradation of pentachloroanisole (Kaufman, 1978) was examined in both anaerobic and aerobic soils. In aerobic soils, only 5.6% of the pentachloroanisole was reduced back to penta in 24 days, whereas, in anaerobic soils 42.1% was reduced to penta. The results indicate that, while some interconversion of pentachloroanisole and penta occurs in both aerobic and anaerobic soil, the reactions involved in the degradation of these compounds are reductive in anaerobic soils and both reductive and oxidative in aerobic soils.

The preceding investigation indicates that degradation of penta in soil occurs primarily by reductive dehalogenation resulting in the formation of progressively less chlorinated phenols. This proceeds through a logical sequence with the initial dehalogenation reactions occurring in either the ortho or para positions. Methylation of the phenol group is also a common reaction in penta degradation as well as the degradation of the tetra and trichlorophenol products. Penta metabolism by isolated soil microorganisms appears to occur by oxidative mechanisms. Thus, some discrepancies exist between the degradative pathways observed in soils and those observed in isolated microbial cultures.

Chu and Kirsch (1972) isolated a bacterial culture by continuous flow enrichment that was capable of metabolizing penta as a sole source of organic carbon. The morphological and physiological characteristics of the organisms suggest a relationship to the saprophytic coryneform bacteria. Chu and Kirsch (1973) established that the organism was responsive to enzyme induction with penta as the inducer. Lesser induction occurred with 2,4,6-trichlorophenol. The degradation products resulting from the metabolism of penta by this organism were not characterized.

Kirsch and Etzel (1973) derived a microbial population capable of rapid penta degradation from a soil sample obtained on the grounds of a wood products manufacturer. When fully acclimated, the populations were dosed with 100 mg/liter penta and 68% of the penta was degraded in 24 hours. The cultures were most effective when the penta was the sole source of carbon.

Watanabe (1973) reported penta degradation in soil samples perfused with 40 mg/liter penta. Bacteria isolates capable of penta decomposition were derived from a soil perfusion enrichment culture. Degradation and complete dechlorination occurred after 2 to 3 weeks of incubation. The bacterium was characterized as a Pseudomonas sp. or an organism from a closely related genus. Tetrachlorodihydroxyphenols and their monoethyl ethers were tentatively identified as a metabolic product of penta by an Aspergillus sp. (Cserjesi, 1972). A soil bacterium isolated by Suzuki and Nose (1971) was capable of degrading penta. The major metabolite was pentachloroanisole and dimethyl ether, a minor metabolite was tetrachlorohydroquinone.

It is clear that bacteria and fungi capable of degrading penta exist in the environment. However, the number of species and their population may be limited. In most cases where rapid degradation of penta by microorganisms has been demonstrated, the source of inoculum was from areas where penta had been used for a long time.

## Plants and Animals

Information on the uptake and translocation of penta by plants is limited and there is no information on the metabolism of penta by plants. Jaworski (1955) found less than 0.01 mg/kg penta in cottonseed oil of field-grown plants sprayed with $^{14}$C-penta. Similarly, Miller and Aboul-Ela (1969) could not detect penta in cottonseed kernels of open bolls on sprayed plants. However, in contrast to Jaworski (1955), they found some translocation of penta or a possible metabolite within the plants. Penta residues definitely existed in seed from bolls that were closed at the time of treatment. Miller and Aboul-Ela (1969) also observed the movement of $^{14}$C-labeled penta in the first two leaves of cotton within 1 hour of treatment. After 8 hours, radioactivity was distributed through all the veins of treated leaves, but there was no movement of radioactivity out of the treated leaves even after 8 days.

Hilton, et al. (1970) studied the distribution of radioactivity in sugar cane following either foliar or root application of $^{14}$C-penta. With leaf application, 100% of the radioactivity was recovered in the treated leaf after 2 weeks. After 8 weeks, 84% of the activity was in the treated leaf with minor amounts in all plant parts except roots. Root application was studied by growing plants in a nutrient solution containing $^{14}$C-penta for 4 weeks. Approximately 90% of the original radioactivity was recovered from the plants after 4 weeks, and of the activity in the plant, over 99% was in the root system.

Animal intake of penta can arise by inhalation, oral ingestion including consumption of penta-contaminated food and licking or chewing treated wood, and dermal absorption by direct contact with treated wood. There is some evidence that penta may be a metabolic product of other environmental contaminants, but the significance of this source is not known. Koss and Koransky (1978) demonstrated the formation of penta from hexachlorobenzene in rats, mice, hens, and trout. Hexachlorobenzene is widely spread in the environment and low-level residues are frequently encountered in animal tissues. The rate of penta formation from hexachlorobenzene is slow compared to the rate of penta elimination. Thus, the levels of hexachlorobenzene encountered in tissues are not sufficient to account for the levels of penta generally found.

Many phenols undergo conjugation reactions in animals (Williams, 1959). These reactions include the formation of glucuronides, ethereal sulphates, and monoesters of sulphuric acid. Some penta is excreted unchanged and the amount that is metabolized or conjugated depends on the species.

Approximately 40% of the $^{14}$C-labeled penta given to mice and rats was excreted unchanged in the urine (Ahlborg, et al., 1974). $^{14}$C-tetrachlorohydroquinone accounted for 5% of the excreted radioactivity in rats and 24% in mice. Larsen, et al. (1972) found that 50% of the radioactivity of orally administered $^{14}$C-penta was excreted in the urine of rats in 24 hours and 68% was excreted in 10 days. Between 9 and 13% was excreted in the feces. Tissue analysis showed small amounts of $^{14}$C activity in all tissues, with the highest level in liver, kidney, and blood. In blood, 99% of the radioactivity was in the serum. A two-compartment urinary excretion pattern was proposed that had a 10 hour half-life for the first 2 days, followed by a 102 day half-life.

Braun, et al. (1976) studied the pharmacokinetics and metabolism of penta in rats and monkeys. Excretion of $^{14}$C from the labeled penta was mainly through the urine in both species. In the monkeys, only penta was found, while in rats, penta, tetrachlorohydroquinone, and glucuronide conjugate of penta were found. Residues were high in liver, kidney, and blood, thus agreeing with Larsen, et al. (1972). It was suggested that there was reversible binding of penta to blood proteins. The half-life ranged from 13 to 17 hours in rats and from 72 to 84 hours in monkeys. This work failed to confirm the presence of the long half-life compartment suggested by Larsen, et al. (1972). The short half-lives of penta suggest that there will be no buildup of residues to a toxic level with continuing intake of penta.

## Summary of Biological Analysis of Pentachlorophenol and Pentachlorophenates

According to AWPA statistics, approximately 42 million pounds of penta were used for the commercial treatment of wood products in the United States in 1978.

Approximately 90% of the penta used for commercial wood treatment is applied in "closed" pressure treating systems and the other 10% in thermal- and dip-treatment systems and groundline treatment. Total penta usage for treatment of various wood products has increased slightly over the past 10 years but there has been little change in its use pattern. It is anticipated that this trend will continue in the future for products except lumber, where penta treatment will likely be supplemented by treatment with waterborne salts.

Approximately 60% of the penta applied by the commercial wood-treating industry is used for pole treatments. Lumber and timber, and fence posts, are other major products, and comprise approximately 19 and 10% of the industry totals, respectively. Other important uses for penta include the pressure, vacuum, and dip treatment of millwork crossarms, piling, and the dip treatment of lumber for control of sapstain fungi. This latter use involves the immersion of fresh-cut lumber and poles in aqueous solutions containing Na-penta. Although lasting protection from wood-destroying organisms does not result from this treatment, the production of aesthetically objectionable discoloration is prevented during wood storage and handling. It is estimated that 1.02 million pounds of penta (equivalent to 1.15 million pounds Na-penta) are used each year in the control of sapstain fungi. Lesser amounts of penta are used for the treatment of piling and crossties.

A significant volume of penta (approximately 1.5 million pounds in 1978) is used outside of the commercial wood-treating industry for wood treatments. The chemical is generally formulated as a 5% mineral spirits solution and is available to consumers for the brush, dip, spray, or soak treatment of a wide variety of exterior wood structures.

About 90% of all penta used by the wood preserving industry is applied in commercial pressure treating plants, which minimizes human contact with the chemical. It is stored and applied in a closed system and human dermal exposure is limited to mixing and formulating operations. Handling of freshly treated wood is a highly mechanized operation; thus, dermal exposure of employees in such operations is minimal. Some inhalation exposure to penta vapor and particulates occurs. It is estimated that 4,400 production workers and 800 non-production personnel encounter some degree of penta exposure in the 295 U.S. pressure treatment plants using this preservative.

Commercial thermal- and dip-treatment plants use approximately 3.8 million pounds of penta annually, and it is estimated that some degree of exposure is encountered by approximately 750 production and 100 non-production personnel in the U.S.

Since thermal and dip treatments involve the use of open vats filled with preservative solution, the potential for dermal and inhalation exposure exists. When the vats contain heated solutions, the potential for inhalation exposure is enhanced. The extent of any dermal exposure depends on the type of protective clothing worn and the personal hygiene of the workers.

Approximately 200,000 pounds of penta are used annually by an estimated 300 workers for groundline treatment of poles. The likeliest form of penta exposure to these workers is dermal, and the extent of such exposure is determined by the level of personal hygiene employed.

It is estimated that 20,000 production and 4,000 non-production personnel may encounter some degree of exposure to Na-penta during the commercial dip treatment of wood for sapstain control. Approximately 1.15 million pounds of Na-penta are used annually for such treatments. In view of the extremely low volatility of the salt in aqueous solution, most human exposure would likely occur via the dermal route. The extent of such exposure would depend on the level of personal hygiene employed, but would probably be lower than that encountered in the conventional penta thermal and dip processes since sapstain formulations are typically more dilute.

Over-the-counter sales of penta to homeowners, farmers, etc., for brush, spray, soak, or dip treatment of wood products provide a diffuse but essentially unquantifiable source of human exposure. It is estimated that 3 to 6 million people use (most on an intermittent basis) the 1.5 million pounds of penta sold as a 5% formulation each year. The level of exposure experienced by these individuals is highly dependent on the location and manner in which the formulations are applied. The degree of ventilation in the application area and the care with which the liquid is applied are the major factors influencing the extent of exposure.

Limited exposure to penta is expected among members of the general public who have occasional contact with treated wood. Such exposure, however, is expected to be far lower than that experienced by occupationally exposed persons.

Quantitative estimates of human penta exposure (both occupational and non-occupational) have been developed in this document. Quantitative exposure data were developed using two different approaches. First, published values for urine penta levels in both occupationally and non-occupationally exposed humans were used to calculate the levels of penta exposure which would result in the measured urine values. The pharmacokinetic approach assumed a steady-state condition where uptake and excretion of the compound are in equilibrium. The second approach utilized measured values of penta in food, water, or air to predict human exposure. Assumptions regarding the amounts of food or water consumed and the amount of air respired with different levels of physical activity were made. Both exposure levels and safety factors were calculated for penta and hexachlorodibenzo-p-dioxin (HxCDD). Safety factors were based on a comparison with the no-observable-effect levels for fetotoxicity cited by the EPA (5.8 mg/kg/day for penta and 1 microgram/kg/day for HxCDD).

Utilizing published urine penta levels from occupationally exposed persons, a pharmacokinetic estimate of exposure yield values ranging from 0.0038 to 0.232 mg/kg/day. The corresponding HxCDD exposures are from $1.7 \times 10^{-5}$ micrograms/kg/day to $9.3 \times 10^{-4}$ micrograms/kg/day. These levels correspond to safety factors of 1,525 to 25 for penta and 65,789 to 1,078 for HxCDD.

Penta levels in air have been reported for wood treating plants and these data were used to predict human inhalation exposures at various levels of physical exercise. The penta exposures calculated, using reported air levels, ranged from 0.00001 to 0.288 mg/kg/day depending on air level and activity. Safety factors ranged from 580,000 to 20 for penta and from 25,000,000 to 868 for HxCDD. The higher exposure calculated above assumed a continuous 8-hour exposure to penta vapors while opening the pressure cylinder door and performing maximum physical exercise. Since this situation cannot occur, another exposure component must account for the 0.232 mg/kg/day level calculated earlier from the measured urinary penta levels of a wood treater. The most likely explanation for this discrepancy is dermal or oral exposure resulting from poor personal hygiene. It is considered highly unlikely that penta inhalation exposure among individuals in the wood treatment industry will exceed 0.07 mg/kg/day (safety factor 81).

The Threshold Limit Value, (TLV), established by the American Industrial Hygiene Assoc. (1970), is 0.5 $mg/m^3$ for penta in ambient air. At a moderate level of exercise, a worker would have a penta exposure of 0.058 mg/kg/day which results in a safety factor of 100. Heavy exercise over an 8-hour work shift with penta levels at the TLV would result in a predicted exposure of 0.14 mg/kg/day.

Recent data suggest that in a closed structure under worst-case conditions, volatilization of penta from treated wood may result in ambient penta air levels approximating those found in wood-treating plants. Based on these vaporization rates, potential human exposure ranges from 0.0006 to 0.0219 mg/kg/day (safety factors of 4,142 to 265).

It is extremely difficult to estimate the potential for human dermal exposure to penta since such exposure is highly dependent on personal hygiene. If complete dermal absorption of penta is assumed, skin exposure to 5 ml of a 7% solution of penta in oil will result in a dose of 5 mg/kg. This estimate is based on the material remaining on the skin for a time period sufficient for 100% absorption and is likely an overestimate. Contact with treated wood, the other means of dermal exposure, is expected to result in very low penta absorption if the wood is dry and free from blooming.

A quantitative estimate of the degree of penta exposure experienced by the general population has been developed from reported penta urine residues. Utilizing a steady-state pharmacokinetic model, the following exposures and safety factors have been calculated based on available urinary data:

| Basis for Exposure | Penta Exposure (mg/kg/day) | Safety Factor | HxCDD Exposure (mg/kg/day) | Safety Factor |
|---|---|---|---|---|
| Average urine penta levels--general population | 0.00014 | 41,428 | $5.6 \times 10^{-7}$ | 1,785,714 |
| Average urine penta levels--general population in Hawaii | .00102 | 5,686 | $4.1 \times 10^{-6}$ | 245,098 |
| Maximum urine penta level detected--general population | .00448 | 1,294 | $1.8 \times 10^{-5}$ | 55,803 |
| Maximum urine penta level detected--general population in Hawaii | .0133 | 436 | $5.3 \times 10^{-5}$ | 18,797 |

The above exposure analysis does not identify the source or route of the exposure. Although penta has been detected in human foodstuffs, the available data suggest that this source of exposure cannot account for the measured levels of penta in human urine. The sources of the remaining penta residues are speculative.

Penta is used to treat some of the millwork, such as window and door frames, in homes. Such surfaces are usually partially or completely covered with sheetrock, paneling, paint, or varnish. Penta exposure from such applications is unknown, but is expected to be extremely low. On occasion, larger amounts of penta have been used inside homes to treat natural wood ceilings, walls, or paneling. Such usage has resulted in problems in the past and a quantitative estimate of potential human exposure to penta vapor under worst-case conditions results in an exposure level of 0.62 mg/kg/day penta (safety factor, 9.4).

The last exposure phase considered in this document is dermal absorption which could be associated with application of over-the-counter penta formulations. A linear extrapolation method using data from a documented case of human dermal exposure predicts that the exposure rate for a 70-kg individual following total immersion of both hands in a 5% penta solution for 10 minutes would be 0.52 mg/kg (safety factor, 11). If on the other hand we assume 100% dermal absorption of a 5% penta formulation, exposure to 5 ml would result in a total exposure of 3.6 mg/kg (safety factor of 1.6). The exposure analysis reinforces the general recommendations to avoid skin contact with penta solutions.

The moderate volatility of penta suggests that volatilization may be a significant route for penta entrance to the air. Occupational studies reveal that significant penta air levels exist in wood treatment plants and other commercial operations where large quantities are used. Circumstantial evidence, including the detection of penta in rain water, indicates that penta may occasionally be present in ambient air. However, since penta has not been included in the National Air Monitoring program, information on ambient penta air levels is non-existent. Thus the sources, transport mechanisms, and fate of penta in the atmosphere remain highly speculative.

Penta is ubiquitous in the aquatic environment. Low levels of the compound have been detected in both wastewater and surface water. The source of these residues is often unclear and it has been suggested that, in addition to direct contamination of water by penta, degradation of other organic compounds or chlorination of water may result in the chemical production of the compound.

Following its introduction into the aqueous environment, penta may be removed by volatilization, photodegradation, adsorption, or biodegradation. Penta is subject to rapid photodegradation under laboratory conditions. Microorganisms capable of metabolizing penta have been identified, but the extent of their environmental distribution is unknown. Penta is moderately persistent in the aquatic environment and was reportedly detected in lake water and fish 6 months after an accidental spill. The prevailing use pattern of penta, primarily as a wood preservative, should preclude significant contamination of water as long as spills and industrial accidents are prevented.

The half-life of penta in soil is dependent on a large number of environmental parameters including: pH, organic matter content, moisture content, clay mineral composition, free iron content, and ion exchange capacities of the soil.

Penta is moderately persistent in soil. Published data indicate that persistence ranges from 21 days to 5 years. As explained in the text, the 5-year value mentioned above probably does not represent a realistic evaluation of the environmental half-life of penta. Under most conditions, penta will seldom persist in the soil for periods exceeding 9 months and its half-life will frequently be far less. Numerous studies have identified soil microorganisms capable of penta degradation. The extent of their distribution, however, is unknown since most studies where penta biodegradation has been studied, acclimated populations of microorganisms have been utilized. Penta is strongly sorbed to soil, hence leaching through the soil profile and contamination of groundwater is considered unlikely. Since the major use of penta (wood preservation) does not involve application to the soil, the likeliest source of soil contamination is leaching or bleeding of the preservative from treated wood. Such phenomena will result in low-level contamination in the immediate vicinity of the treated structure.

Available data indicate that penta is not readily translocated by plants and that the compound is rapidly eliminated in both free and conjugated forms by mammals following exposure. Therefore, significant accumulation in plants and mammals is not likely to occur.

# CHAPTER 4: INORGANIC ARSENICALS

# CHAPTER 4: INORGANIC ARSENICALS

## Introduction

The waterborne salt treatments offer the widely recognized advantages in treated lumber and plywood of being clean, odorless, and paintable as well as effective and permanent. These characteristics make these treatments preferred for use in residential construction, to the almost total exclusion of other treatments. These applications are growing rapidly (Figure 17). This increasing recognition of the advantages of the arsenical salt treatments is not limited to the United States, but has occurred generally in other parts of the world (Figure 12). Some of the major factors motivating this growth are: 1) the increasing acceptance resulting from widely recognized good performance; 2) the decline in availability of naturally durable woods; 3) a greater desire for longer service life as the in-place cost of wood increases; 4) increasing availability.

The waterborne salts include chromated zinc chloride (CZC) and acid copper chromate (ACC), as well as the arsenic-containing FCAP, CCA, and ACA. CZC and FCAP do not become fixed in the wood. They are leached on exposure to water and so are limited to less demanding above-ground exposures.

The use of CZC has declined over the past 20 years, to 50% of its 1955 level. The decline was rather steady between 1955 and 1975, to a low of 500 thousand cubic feet as treaters shifted to fixed arsenical treatments. Increases in 1976 and 1977 are the result of greater demand for waterborne salt-treated wood and a reluctance to convert the remaining plants to arsenicals in the face of the uncertain future of these chemicals. The conversion of plants from FCAP to non-leachable formulations, primarily CCA, has been much more dramatic and it appears likely that FCAP will disappear within a short period.

ACC, CCA, and ACA are fixed in the wood in insoluble form and are specified for ground-contact applications. CCA and ACA give predictable performance in a wide range of exposures. ACC, lacking arsenic, does not provide adequate protection against copper-tolerant organisms (Levi, 1973). It is not specified for high risk exposures and provides less positive protection in other applications.

Both ACA and CCA have given excellent performance in studies of effectiveness conducted by the U.S. Forest Service (Gjovik and Davidson, 1979). Treatment with CCA is worldwide while treatment with ACA is primarily accomplished on the U.S. Pacific Coast and in Canada. It is also used to a limited degree by a few plants in other areas but the principal reason is for the treatment of western or northern species shipped into the area without treatment. The limited use of ACA is due to problems associated with its ammoniacal solution. The color of the treated wood is often a dark brown; also, the ammonia vapors must be controlled at the treating plant. The fact that it is used, and in substantial volume, is a tribute to its ability to achieve penetration of the heartwood in many refractory species.

Nearly all wood treated in the West is of species that require heartwood penetration. CCA is either ineffective or at best inconsistent when used on these woods. While ACA is not successful on all species (i.e., heartwood of Interior Douglas-fir), it consistently gives results far superior to CCA (Dost, 1977; and Davidson, 1979).

The industry has recently developed and effectively promoted the concept of arsenically treated wooden foundations. There are numerous advantages to the system

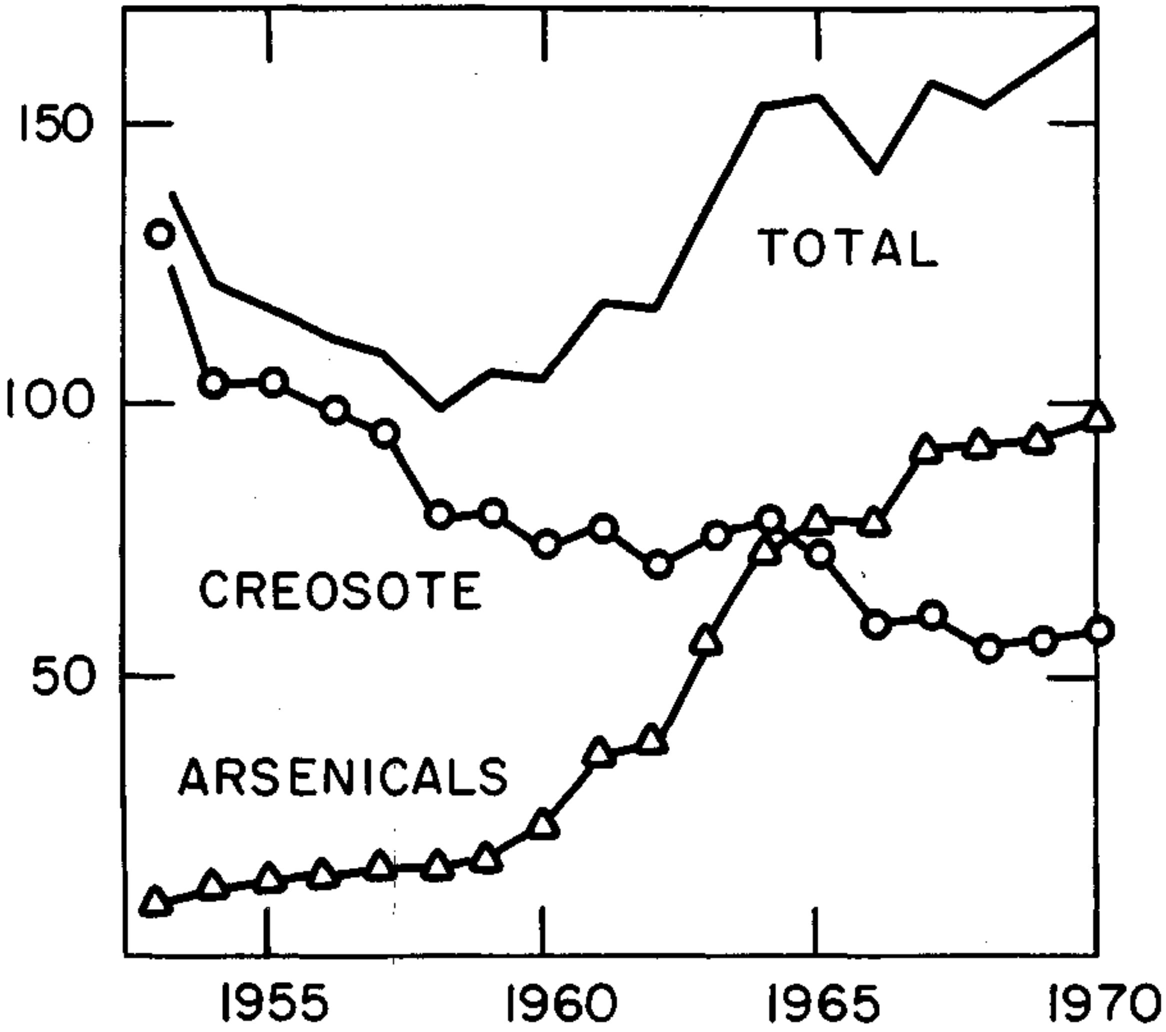

Figure 12. Production of preservatively treated wood (thousand cubic meters) in Norway (Klem, 1972).

when compared to concrete or masonry systems. In consequence, the volume of material treated for this application is rising rapidly (Figure 13).

The wood foundation system has found wide acceptance only where basement construction is common. In areas where slab-on-grade construction is the norm, a more recently approved method using the crawl space as a plenum for delivery of heated and cooled air is gaining wide recognition, since it, too, offers many advantages over conventional construction. This system will generally call for preservative treatment only where wood (the footings, floor joists, etc.) is closer than 12 inches to the earth. Much of this material, consequently, will be treated only to the aboveground retention of 0.25 pcf. The total volume that can reasonably be anticipated for this use is sizable.

Still other factors point to an acceleration in the rate of growth in arsenically treated wood. These are the nearly complete exhaustion of the supply of naturally durable wood (Anonymous, 1979), the continuing expansion of interest in "outdoor living" areas, and the rapid rise in cost of wood structures in general. The outdoor living phenomenon is well known. In addition to providing a pleasant and

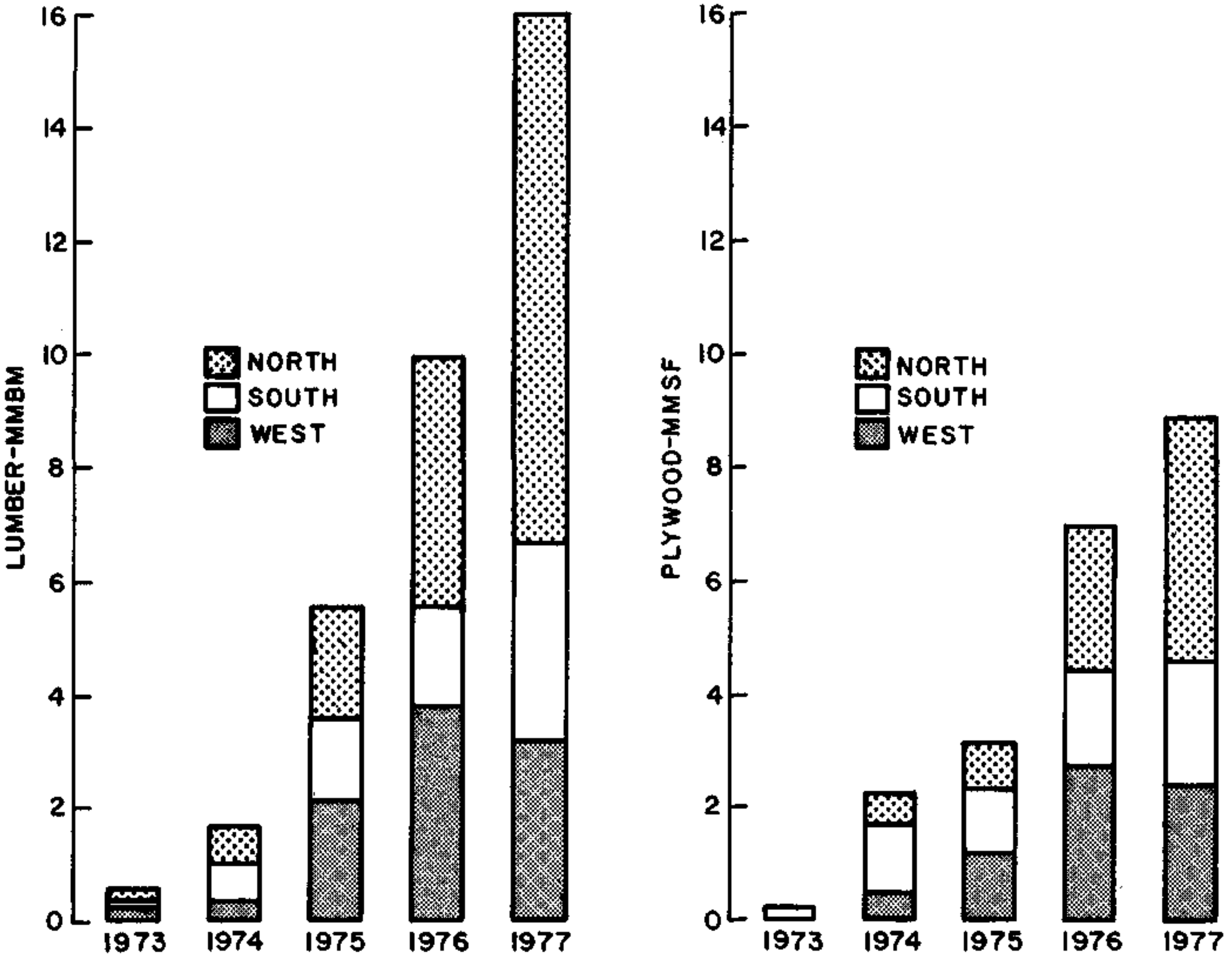

Figure 13. Production of foundation lumber and plywood inspected under the AWPB (1977) by regions.

relaxing retreat at home, it will increasingly be seen as a way to expand living space at a modest cost.

The most widely accepted standards for treatment are those of the AWPA, the industry technical society. Further, other specifications generally agree with AWPA treating requirements and frequently refer directly to AWPA standards. These standards cover many aspects of treatment, but in the final analysis simply assure the user of satisfactory performance by requiring the right chemical (preservative balance) in the right amount (retention) in the right place (penetration). All three are necessary to satisfactory performance.

Required retentions are changed to fit commodity and anticipated exposure conditions. Table 41 is incomplete because of the many different combinations used, but gives typical examples for some of the major products. Also, in general, there are two quite different but parallel standards depending upon species. These differences are most pronounced for lumber. Lumber of species with a high percentage of sapwood and virtually untreatable heartwood (such as the southern pines) is required to have penetration through 85% of the sapwood, up to a 2-1/2 inch maximum, and no treatment required in the heartwood. Species with limited sapwood and difficult but treatable

Table 41.--Table of retention and penetration required for major classes of arsenical treatment

| | Species[a] | Assay Zone | Reten-tion | Penetration |
|---|---|---|---|---|
| | | Inches | Pcf | Inches |
| Roundwood | | | | |
| Piling | | | | |
| Marine | SP | 0-0.5<br>0.5, 2.0 | 2.5<br>1.5 | 3.5 or 95% of sapwood |
| | DF | 0-1.0 | 2.5 | Varies with sapwood thickness, 1.75 inches if sapwood is 2 inches or more, charge average of 1.4 inches. |
| Marine (dual treatment) | SP + DF | 0-1.0 | 1.0 | 1.0 |
| Land & fresh water | SP | 0-3.0 | 0.8 | 3 or 90% of sapwood |
| | DF | 0-1.0 | 1.0 | 0.75 and 85% of sapwood to 1.6 max. |
| Foundation | SP | 0-2.0 | 0.8 | 3 or 90% of sapwood |
| | DF | 0-1.0 | 1.0 | 0.75 and 85% of sapwood to 1.6 max. |
| Poles | SP | 0.5-2.0 | 0.6 | 3.5 or 90% of sapwood |
| | DF | 0.25-1.0 | 0.6 | 2.5 or 85% of sapwood |
| Fence posts | SP | 0-1.0 | 0.4 | 2.0 or 85% of sapwood |
| | DF | 0-0.6 | 0.4 | 0.375 and 100% of sapwood to 1.0 max. |
| Lumber | | | | |
| Wood foundation | SP | 0-0.6 | 0.6 | 2.5 or 85% of sapwood |
| | DF | 0-0.6 | 0.6 | 0.4 and 90% of sapwood |
| Ground contact | SP | 0-0.6 | 0.4 | As above |
| | DF | 0-0.6 | 0.4 | As above |
| Above-ground | SP | 0-0.6 | 0.25 | As above |

[a] SP = Southern pine; DF = Coastal Douglas-fir.

heartwood (such as coastal Douglas-fir and redwood) are required to be incised, have 90% penetration of the sapwood, 0.4- or 0.5-inch penetration in the heartwood depending on thickness, and retention determinations made only on heartwood samples. Somewhat similar differences exist for other commodities. There are radical differences between softwoods and hardwoods and, except for oak, standards are available for a limited number of uses.

## Use Patterns and Efficacy

### Commercial Pressure and Non-Pressure Treatment

The reported consumption of waterborne salts for wood preservative purposes is given in Table 42.

Table 42.--Volume of arsenical and non-arsenical wood preservatives[a]

| | Non-Arsenicals | | | Arsenicals | | | |
|---|---|---|---|---|---|---|---|
| | CZC | ACC | Total | FCAP | CCA | Other[b] | Total |
| | | | | 1,000 Pounds | | | |
| 1978 | -- | -- | -- | NA | -- | -- | 37,200[c] |
| 1977 | 536 | 762 | 1,298 | 122[d] | 24,778 | 2,400 | 27,300 |
| 1976 | 513 | 707 | 1,220 | 245 | 17,582 | 1,728 | 19,065 |
| 1975 | 272 | 843 | 1,115 | 1,167 | 15,875 | 2,248 | 19,290 |
| 1974 | 349 | 1,694 | 2,042 | 1,515 | 15,257 | 1,336 | 18,108 |
| 1973 | 610 | 1,635 | 2,245 | 1,683 | 11,667 | 1,270 | 14,620 |
| 1972 | 599 | 1,238 | 1,837 | 1,914 | 9,748 | 999 | 12,661 |
| 1971 | 471 | 1,178 | 1,649 | 2,169 | 8,572 | 749 | 11,490 |
| 1970 | 451 | 755 | 1,206 | 2,687 | 6,033 | 820 | 9,540 |
| 1969 | 828 | 872 | 1,700 | 4,539 | 4,668 | 1,050 | 10,257 |
| 1968 | 831 | 1,139 | 1,970 | 3,971 | 3,168 | 1,601 | 8,740 |
| 1967 | 813 | 1,405 | 2,218 | 5,341 | 2,330 | 1,281 | 8,952 |

[a] Maloney and Pagliai, 1978.

[b] Primarily ACA.

[c] Micklewright, 1979.

[d] Nicholas, 1978.

The quantity of arsenic used in treatments of wood has increased more than threefold in 10 years and in this regard it is unique among major preservatives. Creosote and pentachlorophenol have declined in the same period. Table 43 presents data on treated wood production in 1978 (Micklewright, 1979). It shows that the arsenicals are a very important class of preservatives, accounting for nearly 20% of treated wood products. Further, arsenicals were used to treat 35% of all preserved wood excluding railroad ties.

The data also show that by far the principal use for arsenicals is in the treatment of lumber, with significant use of treatment of "other" products (including plywood) and "fence posts." The arsenicals are extremely important in the treatment of certain classes of marine piling since they provide the only proven means of preventing attack by Limnoria tripunctata, although the volume is relatively small. Trends in the production of commodities treated with arsenicals can be seen in Table 44.

While the use of all arsenicals doubled over a 10-year period as noted above, the fixed treatments (CCA and ACA) show a fourfold increase. Much of additional growth in the use of the fixed arsenicals has resulted due to a shift from the non-fixed FCAP, largely in treatment of lumber and timber.

Additionally, it should be noted that the arsenically treated ties are not generally used in railway trackage but rather are used as landscaping materials. Some salt-treated ties are used in the mining industry where the oil in creosote and penta treatments makes them undesirable because of the fire and smoke hazard, and the

Table 43.--Production of commodities treated with arsenicals and other preservatives in 1978[a]

| | Ties | Piling | Poles | Crossarms | Lumber and Timbers | Posts | Other | Total |
|---|---|---|---|---|---|---|---|---|
| | | | | 1,000 cu. ft. | | | | |
| Arsenical salts | 2,498 | 943 | 4,038 | 29 | 73,317 | 4,461 | 7,616 | 92,903 |
| Total volume treated | 106,085 | 12,090 | 64,179 | 1,685 | 105,305 | 20,028 | 18,113 | 327,485 |
| | | | | Percent | | | | |
| of total treated with arsenicals | 2.4 | 7.8 | 6.3 | 1.7 | 70.0 | 22.0 | 42.0 | 28.0 |
| | | | | Percent | | | | |
| of arsenically treated wood | 2.6 | 1.0 | 4.3 | 0.03 | 79.0 | 4.8 | 8.2 | 100 |

[a] Micklewright, 1979.

Table 44.--Production of arsenically treated commodities in 1977 by treatment type[a]

|  | Ties | Piling | Poles | Crossarms | Lumber and Timbers | Posts | Other | Total |
|---|---|---|---|---|---|---|---|---|
|  | 1,000 cu. ft. |  |  |  |  |  |  |  |
|  | Fixed Treatment (CCA and ACA) |  |  |  |  |  |  |  |
| 1978[b] | 2,498 | 943 | 4,038 | 29 | 73,317 | 4,461 | 7,616 | 92,903 |
| 1977 | 2,366 | 785 | 3,704 | 0 | 38,890 | 1,341 | 4,687 | 51,901 |
| 1976 | 133 | 564 | 1,423 | 8 | 36,757 | 1,837 | 6,387 | 46,999 |
| 1975 | 95 | 484 | 1,277 | 30 | 25,888 | 2,013 | 1,765 | 31,661 |
| 1974 | 29 | 412 | 1,833 | 29 | 36,782 | 2,056 | 1,473 | 41,072 |
| 1973 | 82 | 313 | 1,839 | 6 | 27,146 | 758 | 1,246 | 31,390 |
| 1967 | 133 | 16 | 570 | 2 | 10,320 | 305 | 1,373 | 12,719 |
|  | Non-Fixed Treatment (FCAP) |  |  |  |  |  |  |  |
| 1978 | -- | -- | -- | -- | -- | -- | -- | NA |
| 1977 | 0 | 0 | 0 | 0 | 218 | 0 | 11 | 229 |
| 1976 | -- | 0 | 0 | 0 | 597 | -- | 235 | 842 |
| 1975 | 0 | 0 | 0 | 0 | 1,433 | 10 | 357 | 1,810 |
| 1974 | 0 | -- | -- | 0 | 1,922 | 64 | 461 | -- |
| 1973 | 34 | 1 | 15 | 0 | 3,000 | 28 | 527 | 3,604 |
| 1967 | 210 | 5 | 61 | 0 | 12,241 | 191 | 1,315 | 14,023 |

[a] Maloney and Pagliai, 1978.

[b] Micklewright, 1979.

checking problem normally associated with salt-treated ties is avoided because of the stable atmosphere. The increased use of arsenically treated poles has largely been at the expense of penta treatments.

The following use patterns are presented in tabular form for purpose of clarity (Micklewright, 1979).

## Crossties and Switch Ties

|  | Fixed treatment (CCA & ACA) |
|---|---|
| Reported volume treated in 1978 (1,000 cu. ft.) | 2,498 |
| Percent of arsenically treated wood | 2.7 |
| Amount of preservative (million pounds) | 3.01 |
| Application methods | Pressure |

| | |
|---|---|
| Pests controlled | Wood-destroying fungi & insects |
| Application rate (pcf) | 0.6 to 1.0 |

## Poles

| | |
|---|---|
| Reported volume treated in 1978 (1,000 cu.ft.) | 4,038 |
| Percent of arsenically treated wood | 4.3 |
| Amount of preservative (million pounds) | 2.22 |
| Application methods | Pressure & non-pressure |
| Pests controlled | Wood-destroying fungi & insects |
| Application rate (pcf) | 0.6 |

## Lumber and Timbers

| | Fixed treatment (CCA & ACA) | Non-fixed treatment (FCAP) |
|---|---|---|
| Reported volume treated in 1978 (1,000 cu. ft.) | 73,317 | 218 |
| Percent of arsenically treated wood | 79.0 | 0.4 |
| Amount of preservative (million pounds) | 31.72 | 0.087 |
| Application methods | Pressure & non-pressure | Pressure & non-pressure |
| Pests controlled | Wood-destroying fungi, insects, & marine borers | Wood-destroying fungi & insects |
| Application rate (pcf) | 0.25 to 2.50 | 0.25 to 0.50 |

## Fence Posts

| | |
|---|---|
| Reported volume treated in 1978 (1,000 cu. ft.) | 4,461 |
| Percent of arsenically treated wood | 4.8 |
| Amount of preservative (million pounds) | 0.36 |

| | |
|---|---|
| Application methods | Pressure & non-pressure |
| Pests controlled | Wood-destroying fungi, insects, & marine borers |
| Application rate (pcf) | 0.4 to 0.5 |

## Piling

| | Fixed treatment (CCA & ACA) |
|---|---|
| Reported volume treated in 1978 (1,000 cu. ft.) | 943 |
| Percent of arsenically treated wood | 1.0 |
| Amount of preservative (million pounds) | 0.17 |
| Application methods | Pressure |
| Pests controlled | Wood-destroying fungi, insects, & marine borers |
| Application rate (pcf) | 0.8 to 2.5 |

## Crossing Plank

| | |
|---|---|
| Reported volume treated in 1978 (1,000 cu. ft.) | 70 |
| Percent of As-treated wood | 0.08 |
| Amount of preservative (million pounds) | 0.04 |
| Application methods | Pressure |
| Pests controlled | Wood-destroying fungi & insects |
| Application rate (pcf) | 0.6 |

## Highway Posts

| | Fixed treatment (CCA & ACA) |
|---|---|
| Reported volume treated in 1978 (1,000 cu. ft.) | 599 |
| Percent of arsenically treated wood | 0.64 |
| Volume treated, adjusted for under-reporting (1,000 cu. ft.) | 425 |
| Amount of preservative (million pounds) | 0.24 |

| | |
|---|---|
| Application methods | Pressure |
| Pests controlled | Wood-destroying fungi & insects |
| Application rate (pcf) | 0.4 to 0.6 |

## Mine Ties

| | |
|---|---|
| Reported volume treated in 1978 (1,000 cu. ft.) | 69 |
| Percent of arsenically treated wood | 0.07 |
| Volume treated, adjusted for under-reporting (1,000 cu. ft.) | 59 |
| Amount of preservative (million pounds) | 0.04 |
| Application methods | Pressure & non-pressure |
| Pests controlled | Wood-destroying fungi & insects |
| Application rate (pcf) | 0.4 to 0.6 |

## Mine Timbers

| | Fixed treatment (CCA & ACA) |
|---|---|
| Reported volume treated in 1978 (1,000 cu. ft.) | 1,602 |
| Percent of arsenically treated wood | 1.7 |
| Amount of preservative (million pounds) | 0.78 |
| Application methods | Pressure & non-pressure |
| Pests controlled | Wood-destroying fungi & insects & marine organisms |
| Application rate (pcf) | 0.4 to 0.6 |

## Plywood (AWPA Data Only)

| | |
|---|---|
| Reported volume treated in 1978 (1,000 cu. ft.) | 1,393 |
| Percent of arsenically treated wood | 1.5 |
| Volume treated, adjusted for under-reporting (1,000 cu. ft.) | 1,480 |
| Amount of preservative (million pounds) | 1.55 |

| | |
|---|---|
| Application methods | Pressure |
| Pests controlled | Wood-destroying fungi, insects & marine organisms |
| Application rate (pcf) | 0.25 to 2.5 |

### Other

| | Fixed treatment (CCA & ACA) |
|---|---|
| Reported volume treated in 1978 (1,000 cu. ft) | 3,883 |
| Percent of arsenically treated wood | 4.2 |
| Amount of preservative (million pounds) | 1.55 |
| Application methods | Pressure |
| Pests controlled | Wood-destroying fungi & insects |
| Application rate (pcf) | 0.4 |

## Commercial Field Treatments

Virtually all arsenic salt treatment of wood is accomplished at industrial plants, most by pressure processes, as described by Fuller et al. (1977). Industry sources indicate that a small amount (2,000 to 3,000 gallons of 3% solution/year) is sold for field treatment of surfaces cut in fabrication and that this is normally used by qualified pesticide applicators. The only supplier of solutions for field treatment has recently reduced the container size from 1 gallon to 1/2 gallon. This step was taken to minimize the problem of leftover or unused material.

## Non-Commercial Treatments

Arsenical wood preservatives are not available for home or farm use.

# Exposure Analysis

## Qualitative Exposure of Humans at Application Site

### Commercial Pressure Treatments

Much of the information presented below was obtained from American Wood Preservers Institute (AWPI, 1975) and American Wood Preservers' Association (AWPA, 1977).

Arsenical wood preservatives are produced for sale to wood treaters as concentrates in paste and liquid forms except for FCAP, which is supplied in powder form. The commercial concentrates are diluted at the treating plant to working strengths of 0.75 to 6.0%.

All of the arsenical wood preservative concentrates are sold only as industrial chemical products. They are not offered for distribution, sale, or use by the consuming public. However, a limited quantity of low-concentration, brush-on solution is made for carpenters for the sole use of treating cut ends of lumber at the job site.

## Methods of Application

All of the arsenical wood preservative concentrates, whether in paste, powder, or liquid form, must be diluted to working strengths of 0.75 to 6.0% prior to treatment. The extent of dilution will vary, depending upon the wood species, type of wood product, and the anticipated exposure or end use. The AWPA has issued standards which set forth the chemical retentions deemed necessary for a quality product based on the foregoing variables (AWPA, current).

1. CCA.--The pastes are shipped in sealed drums and pails. The liquid concentrate is normally shipped by tank truck, but some is shipped in drums, especially to the very small plants and to overseas locations such as Hawaii and Puerto Rico.

CCA concentrate is classified by the Department of Transportation under the Hazardous Transport Act as a Class B Poison-Corrosive. Since the arsenical liquid concentrates are hazardous, the tank trucks are used solely for carrying this material. Only drivers who are skilled in safe handling of arsenicals are assigned to such shipments.

2. ACA.--ACA paste is shipped in sealed drums to the treating plants where it is combined with ammonia in an aerated mixing reactor. The reaction with ammonia oxidizes all of the arsenic trioxide in the ACA concentrate to pentavalent arsenic.

3. FCAP.--FCAP is a powder formulation. This material is no longer made in the United States.

Chemical retentions are described as pounds of total chemical solids (on a comparative oxide basis) per cubic foot of wood. AWPA standards require treaters to analyze every treatment batch (charge) for solution penetration and chemical retention. Since the arsenic content of the arsenical preservatives varies, wood treated with different preservatives to identical total chemical retentions will not contain the same amount of arsenic. Modification of treating solutions can be accomplished to obtain retentions of 0.25 to 2.5 pcf of wood.

When untreated wood is ready for treatment, it is loaded onto trams which are pushed into the treating cylinder. The cylinder door is bolted shut and a vacuum is pulled to remove air from the cylinder and the wood. Treating solution is pumped into the cylinder while the cylinder is still under a vacuum. Cylinder pressure is then raised to 150 psi by either air pressure or use of a hydraulic pressure pump. The total treating time will vary, depending upon the species of wood, the commodity being treated, and the desired chemical retention. The treating cycle may be modified to achieve different results, but in all instances the treating process remains a closed system as shown in Figure 14 (Henry, 1973). At the end of the treating cycle, the excess solution not retained by the wood is pumped out of the cylinder and back to storage. The door of the cylinder is then opened and the treated wood pulled from the cylinder.

Poles and pilings are normally air seasoned in the yard before being shipped. If piling are to be dual-treated with creosote, air seasoning to a specific moisture content is necessary.

Lumber and plywood can be kiln dried after treatment or shipped without such processing. If lumber or plywood is to be kiln dried, it must be stickered in order to assure proper drying. (Stickering is a process whereby separators are placed between each plank to provide free air space.)

Increment boring cores are taken from the treated wood for use as samples to determine preservative penetration and retention. Penetration is usually determined by spraying a copper or arsenic indicator onto the core sample. Retention is normally determined by classical "wet analysis," X-ray, or atomic absorption spectometry.

The two major species treated with arsenical preservatives are southern pine and Douglas-fir, but several other western softwoods and eastern hardwoods are also treated with arsenical preservatives. ACA is especially well suited for treating the less treatable Douglas-fir.

### Treater Exposure

The preservative concentrates are diluted at the treating plant for working strength treating solutions. The dilution process is a simple mixing operation in which the concentrate is diluted with water. ACA requires additional consideration because a third chemical is added at the treating plant.

Liquid concentrates in bulk storage are the easiest and safest to handle. Some of the more modern plants have a completely closed system operation in which the liquid concentrate and water are metered into a mix tank, thoroughly mixed, and then pumped to storage. In other plants, liquid concentrate is pumped from storage into a 55-gallon drum on a scale to obtain the proper amount. The liquid concentrate is pumped into the mix tank, water added, the mixture agitated, and the diluted solution pumped to storage.

CCA pastes shipped in drums require special handling because the paste is not pourable. The drums are inverted on a grating over a mixing vat, after which water is sprayed through permanently placed nozzle heads into the drums until they are empty. The diluted solution is then pumped to storage.

ACA pastes are handled in two ways: The drums are either emptied into a screw conveyor which carries the paste into the reactor or the paste is dumped directly into the reactor. The paste is reacted with ammonia in an aerated reactor which is equipped with a scrubber to control ammonia fumes. The mixture is diluted and pumped to storage.

Although not used to a great extent, closed system drum emptying systems are available and can be used for both CCA and ACA pastes.

The method of handling the treated wood depends upon the product treated. Poles and piling are normally moved by cranes (sling cables or bucket grapples) or lift trucks with forks designed for moving round stock. Treated lumber and plywood are moved by lift trucks and, if shipped without air or kiln drying, are normally not handled by man. As previously noted, lumber and plywood that is to be kiln dried must be stickered. This operation may be partly or wholly mechanized, or it may be done by hand. The operation of removing stickers from dried lumber and plywood is similar to that of stickering the wood. Workers handling the treated wood are supplied with personal protective equipment such as rubber gloves, boots, apron, and face shields or goggles. The treating solution is at a much lower concentration than

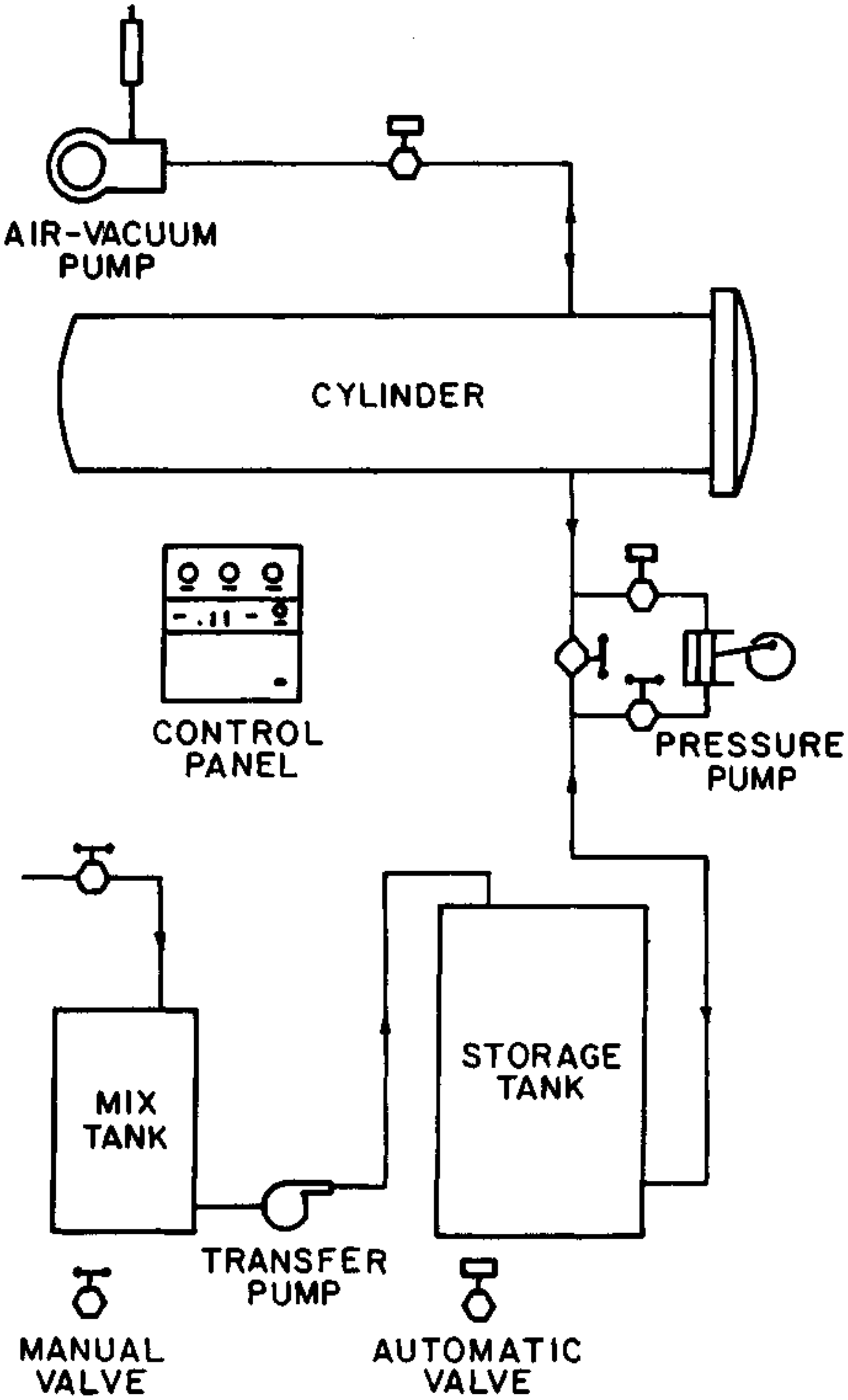

Figure 14. Schematic drawing of an automated pressure treating plant.

the concentrates shipped to the treater and, therefore, does not pose the same exposure as the concentrates.

Several treaters have operations which require sawing of treated wood. The sawdust contains fixed arsenates and small amounts of insoluble deposits from the wood surface. Proper treating solution quality control will reduce surface deposits and in reference to CCA, salt-free formulations have reduced surface deposits. Monitoring data have shown that handling and sawing arsenical treated wood exposes the workers to arsenate particles, but no significant amount is in respirable form. The Minnesota State OSHA took samples of air from a fence building operation which included handling, hammering, and sawing ACA treated wood. Total As in the air ranged from 0.01 to 0.033 mg/cubic meter and a TWA of 0.01 to 0.024 mg/cubic meter (State of Minnesota, 1974). One test has shown that the respirable fraction of As in the air from sawing CCA-C lumber was only 5.3% or 0.00053 to 0.00175 mg/cubic meter (Williams, 1975).

Maintenance workers repairing the cylinder, pumps, and valves and cleaning the cylinders and storage tanks may have contact with the treating solution or sludge. Again, it must be noted that the treating solution is a low concentration; therefore, it does not pose the same exposure potential as the concentrates. For a treating solution with approximately 0.56% As, both oral (rats) and dermal (rabbits) $LD_{50}$ values are in the 4,000 mg/kg range. Men working in these areas follow strict safety rules and are supplied with personal protective equipment.

## Commercial Thermal and Dip Treatments

Very little material is treated with arsenicals by non-pressure processes and is limited to a few very small plants that treat wood by the diffusion process. No data are available on the qualitative exposure in these operations.

## Commercial Groundline Treatments

Arsenical salts are not used for commercial groundline treatments.

## Non-Commercial Spray, Dip, or Brush Treatments

An Assessment Team survey disclosed that there are no known commercial thermal and dip treatments of wood with As compounds. This survey included chemical producers, formulators, sellers, university and Forest Service personnel (Smith, 1979). There are also no known groundline treatments of utility poles with As compounds. Neither are there any known non-commercial spray or dip treatments (large enough supplies of chemicals cannot be purchased from the manufacturers or formulators to accomplish this type of treatment).

A 7% CCA solution, in one-half-gallon containers, is sold for use as a brush-on treatment of cut surfaces of lumber. Its use is limited as the treatment is usually not necessary for 1- to 2-inch southern yellow pine (Bartholomew, 1978). Careful application using protective gloves to apply the liquid will limit exposure to As.

# Quantitative Exposure of Humans at Application Site (Commercial Pressure Treatments Only)

There are approximately 325 wood-preserving plants in the United States that can treat with arsenical preservatives (Ernst and Ernst, 1976; and AWPB, 1979). Some of these also treat with creosote or penta. It is estimated by the team that the total number of workers of all types in the 325 plants is probably much less than 2,000, with a smaller proportion of them working only in the treating areas. In the plants treating with arsenical alone, there are usually only four or five people directly exposed to the preservatives. The cylinder operator and unloader and the stackers of treated wood receive the greatest exposure. There is little exposure to workers of all types in ACA and CCA treating plants (Arsenault, 1975a). There is even less exposure today (1978) because of OSHA regulations, cessation of production of FCAP dusts, general awareness of industry, and precautions taken to prevent exposure.

## Qualitative Exposure of Humans at Point of End Use

In general, handling clean, dry arsenically treated wood is free from any hazard attributable to the preservative (Arsenault, 1975a; and Camarano, 1973). However, some exposure can occur when the wood contains surface deposits or is cut during installation. The degree of exposure varies for the various products and this is discussed below.

### Poles

Treated poles are almost always handled by machinery and not by hand because of their sheer size and bulk. If any worker is exposed to the treated surface of a pole, it would be the lineman or pole rigger. By the time the lineman is exposed to the pole, it usually will have dried in storage for several weeks or months, been transported, handled several times during loading, unloading, and erection and partially weathered. Each factor plus the fact that the pentavalent As is tightly bound to the wood makes the pole surface an unlikely source of exposure to the lineman.

### Lumber, Timbers, and Plywood

These products are handled extensively by carpenters during the construction process. Exposure to As can occur by breathing the sawdust particles that are of respirable size which results from cutting the wood. In addition, if the wood has surface deposits this can contribute to the potential exposure level. If appropriate respirators are worn during this operation, the exposure can be adequately controlled.

### Fence Posts

Fence posts are normally not modified by cutting during installation, so exposure is limited to any respirable surface deposits that may be present.

### Piling

Treated piling is generally handled mechanically, so exposure during transportation and installation is minimal. Some limited exposure can occur from surface deposits, if these are present.

## Quantitative Exposure of Humans at Point of End Use

The permanency of arsenates in arsenically treated wood is discussed in Fate of Arsenic in the Environment which follows this discussion. This basic insoluble characteristic of As in arsenically treated wood explains the durability of treated wood and the limited release of arsenates into the environment. It also explains the safe handling characteristics of arsenically treated wood.

## Carpenters

Since arsenically treated wood is such a versatile building product, it is often used by carpenters. Arsenically treated wood can be handled in a safe manner with minimal risk. Two studies are cited in support of this statement: 1.) Hawaii carpenters study (Budy and Rashad, 1976); 2.) Report of a home building plant (Lock Homes) in Wisconsin (Wisconsin, 1977).

The most pertinent epidemiological study is a retrospective analysis of cancer mortality among carpenters in Hawaii who were working with treated wood. Budy and Rashad (1976) conducted this study at the Pacific Biomedical Research Center of the University of Hawaii. The study was undertaken to analyze the mortality experience of carpenters in Hawaii before and after the introduction of the arsenical wood preservatives, FCAP and CCA, both of which contain arsenates. A cohort exposed to a specific chemical compound is, of course, the ideal group for the analysis of the carcinogenic effect of that compound. Since arsenical wood preservatives are chemically different from other arsenicals previously studied, such as those in smelters, this study was an ideal case-control study. The specific chemical compound constituted the exposure without influences from sulfur or other known carcinogens.

The Hawaii study statistically compared the mortality experience (the death certificates) of 227 carpenters who died between June 1947 and May 1951 (Group A) with a group of 293 carpenters who died between January 1970 and December 1973 (Group B).

Group A carpenters were not significantly exposed to arsenically treated wood. Group B carpenters were exposed to a significant amount of dust from wood treated with FCAP and CCA. Both Group A and Group B carpenters were exposed to dust from untreated wood.

The amount of dust that carpenters can be exposed to in handling and sawing operations with CCA-treated wood is shown in the following table (Arsenault, 1975a).

| | mg As/m$^3$ |
|---|---|
| Handling CCA-treated lumber | 0.0018-0.002 |
| Handling CCA-treated plywood | 0.01-0.22 |
| Power hand saw (worker personal monitor) | 0.071 |
| Area near power hand saw | 0.015-0.097 |
| Sawing studs and assembly of panels | 0.012-0.038 |

From the above typical exposures it is obvious that the carpenters in Group B were exposed to a significant amount of arsenically treated wood dust that could be ingested and inhaled (although only about 5% of the dust particles are small enough to be respirable).

The Hawaii study concluded that exposure to dust from arsenically treated wood is not associated with increased risk of total cancer, lung cancer, or lymphatic cancer. In terms of collection of death certificates, completeness of the study with respect to the population involved, coding of death certificates, matching of controls in the exposed and unexposed groups, and method of statistical analysis, the Hawaii study stands on its own as an ideal analysis of a population exposed to arsenate compounds without the concomitant exposure to other known chemicals in the workplace. The Hawaii study suffers from certain limitations (AWPI, 1975), just as any epidemiological study does, but these data constitute the best epidemiological evidence available on arsenate wood preservative exposure and arsenical compounds used in the wood preserving industry. Dr. Sauer (1976) concludes that "this study does seem to us to be the best presently available, and to possess definite merit."

## Other Industrial Users

Exposure in the many industries that use arsenically treated wood is limited almost exclusively to that of handling the treated wood. Some examples are utility linemen erecting treated poles and agricultural workers handling tomato stakes and grape stakes. Handling of arsenically treated wood is free from hazard attributable to the preservative (Arsenault, 1975; and Camarano, 1973).

Another exposure situation (Wisconsin, 1977) for carpenters involves sawing operations. The greatest exposure would be the carpenters working with treated wood routinely. Carpenters were studied at a plant where prefabricated homes were being constructed. Air levels of As were monitored and urine levels (108 units, 136 micrograms/liter) determined. It was concluded that:

1. No detectable airborne arsenic concentrations were found in the breathing zone of the radial saw operator, or the workers assembling the treated wood foundation.
2. No detectable airborne arsenic concentrations were found in the general atmosphere of other employees in the plant during the sawing and assembly operations.
3. The amount detected in the breathing zone of the off bearer during the sawing operations represents a trace amount which, due to the lower limit of sensitivity of the procedure, borders on a "none detected" concentration.
4. The 8-hour time-weighted average concentration for the off bearer is well below the existing OSHA permissible limits established in 29 CFR 1910.1018(c) (OSHA, 1978).
5. The results of the airborne arsenic monitoring from the days of the study would also meet the new proposed OSHA permissible exposure limit of 10 micrograms As/cubic meter.
6. The arsenic concentrations detected in the urine samples of the two workers appear to be within the normal range for persons with no known arsenic exposure, and when all possible environmental variables are not accounted for.

## General Public

The do-it-yourself homeowner working with arsenically treated wood is exposed to a limited amount of sawdust and handling. Since arsenically treated wood is more expensive than untreated wood, the homeowner normally uses treated wood only for such specialized outdoor uses as patio decks, planter boxes, and fences. Obviously, this is a very limited exposure. The treated wood does not emit vapors; therefore, the completed project cannot be considered as a source of exposure.

Residents of houses in Hawaii and other tropical environments constructed with arsenically treated wood have shown no ill effects (Budy and Rashad, 1976). Data from the University of Hawaii show that the As residue in dust taken from houses built almost entirely with arsenically treated wood (pressure treated) averaged 14.6 micrograms As/g of dust as compared to 10.4 micrograms As/g of dust from untreated houses.

The authors concluded that the value from homes built of treated wood was "not appreciably higher" (Klemmer, et al., 1975) than the mean value for dusts from untreated homes. They further mentioned, "It is logical to assume that a portion of the arsenic found in Hawaii house dusts is derived from soil brought into the home." Recent work by the National Bureau of Standards (NBS) (Sleater and Berger, 1977) has shown that, based on preliminary data, air in basements of houses built with the All Weather Wood Foundation (AWWF) contained 0.012 microgram As/cubic meter to 0.031 microgram As/cubic meter as compared to masonry foundation basements which contained 0.0072 microgram As/cubic meter to 0.011 microgram As/cubic meter (Sleater and Berger, 1977). Therefore, air quality was not significantly different. The figures for the AWWF compared favorably to ambient air quality, which averaged 0.01 microgram As/cubic meter in the 1964-1965 survey. Air quality data on urban and non-urban air in this survey ranged up to 2.5 micrograms As/cubic meter (Sullivan, 1969). The AWWF is growing in use in the continental United States, as well as other countries, and has repeatedly been shown to be a safe use of arsenically treated wood (AWPI, 1977). Wood, when properly treated, has little or no As residue on the surface. However, some treating plants do not filter the solution being used which results in a sludge deposit on the wood surface at the top of the bundle. Wood inside the bundle would not ordinarily be coated with this sludge. This deposit is very insoluble, and contains the treating chemicals in the approximate ratios contained in the treating solution. It is probably a complex mixture of copper hydroxide, copper arsenate, chromium hydroxide, and chromium arsenate. Since it is insoluble, little would be available for dermal uptake. In addition to sludge, a crystalline sodium sulfate may form on the wood's surface if sodium dichromate and copper sulfate are used as the starting material instead of chromic acid and basic copper carbonate. Again, little exposure to As would be expected from this deposit (Best, 1979).

In an effort to determine exposure to arsenates from handling CCA treated wood, several "hand-wipe" tests have been conducted to estimate potential surface availability of the preservative. In the initial tests, damp sponges were wiped over plywood treated to 0.6 pcf CCA, the type of treated wood used to construct an All Weather Wood Foundation. The average As pickup was 0.0002583 mg/square centimeter based on 12 samples. This value was found to be affected by tiny slivers of wood picked up by the sponge. In order to get a more realistic exposure value, a true hand-wipe test was performed.

In this test, both wet and dry hands were wiped over CCA-C treated southern pine plywood. Tests were run on recently treated and dried plywood, treated plywood 2 years old, and treated plywood which had been hosed with water to remove surface dust. The wet hand-wipe on 0.0929 square meter (1 square foot) of unwashed plywood removed less than 1/3 the amount of As consumed daily in the average diet, and washing reduced even these amounts substantially (Arsenault, 1975).

Johanson and Dale (1973) have reported on As removed from the surface of pole sections which had been scrubbed vigorously. This scrub test simulated exterior leaching rather than exposure which could be related to simple handling of treated wood. Even though there was more As removed by this method as compared to the hand-wipe method (0.61 mg/100 square centimeters vs. 0.032 mg/100 square centimeters), after three to four scrubbings very little As was available.

In a test designed to estimate the potential As pickup by food from treated wood, it was concluded that Tanalith-C (CCA-C) was clearly not a hazard (Richardson and Jaffe, 1956). Pads of filter paper were soaked in water and placed on the treated wood surface for 48 hours and then analyzed for As. The pads were found to contain 0.003 mg As/6.4516 square centimeters.

Tests have also been performed to measure As in sump water from the basements of an As-treated wood foundation building. Measurements were taken immediately after construction, after 3 months, and after 6 months. With the exception of the initial reading, the As concentration was below 0.1 ppm, the level permissible for discharge to ground water and for use as irrigation water (Arsenault, 1975a).

The Alberta, Canada, Occupational Health and Safety Division investigated the AWWF and concluded (Boway and Hosern, 1976):

> "From our evaluation of the literature regarding the environmental effects of wood preservatives, we do not think that its usage presents any significant health hazard to the occupants, nor any contamination threat to the vegetation, soil, or the water system. Occupational exposure, either from applying the preservative in the plant or from cutting the finished wood, presents no problem because of the nature of the reacted chemical and the work procedure. We support the Building Standards Branch ruling on Preserved Wood Foundations and, if the CSA standards are adhered to, then there will be no health or ecological risk."

In a study commissioned by the EPA, Burrus and Sargent (1976) reported that:

> "Atmospheric emissions resulting from the manufacture of wood preservatives is considered negligible. With regard to the uses of arsenically-preserved wood, however, it is reasonable to assume that after a sufficient period of time (decades and, in some applications, centuries) deterioration of the wood would release the arsenic to the environment. Such release would be very slow since the preservative compounds bind tightly to the wood fibers. The amount of arsenic moving into the environment by this method is too slow to pose a pollution hazard to air, water, or soil, and at the expected slow rate of release, concentration of soluble arsenic in adjacent soil and water would be low enough for the arsenic to become readily bound into insoluble species in soils and sediments."

This study went on to consider various alternative policy positions available to the EPA. With respect to the alternative of banning use of arsenical wood preservatives, the report concluded (Burrus and Sargent, 1976):

> "This alternative was rejected because there is no apparent health hazard to the consumer via vaporization, leaching, or other mechanism."

### Exposure to Animals at Point of End Use

Animals that may be exposed to treated wood are usually domestic farm animals and pets. Animals would have similar exposure to the surfaces of the treated wood as that of humans living in buildings constructed of treated wood. Some horses are prone to "cribbing" or biting off bits or chunks of wood from their stalls. They are not known to ingest this wood, thus limiting the exposure to As.

## Fate of Arsenic in the Environment

Since As is an element, it is not a degradable entity such as penta or creosote. It does undergo changes in chemical identity and in valence state. Arsenic may be leached from treated wood, or applied as a herbicide, fungicide, insecticide, growth regulator, or soil sterilant. However, once it reaches the environment, it becomes indistinguishable from As which is present naturally.

For these reasons, this section will discuss the fate of As in the environment in general terms as well as that specifically applicable to the wood preservatives. The fate of As that is unique to a particular application or use will be discussed in Volume II.

## Arsenic in Air

> "Natural and human activities produce a persistent low-level concentration of arsenic in the atmosphere. However, elevated concentrations are found near certain human activities. To assess the importance of the contributions of some of these activities, it is necessary to estimate the background concentrations for locations in which these activities are not present.
>
> "The National Air Sampling Network (NASN) routinely monitors suspended particulate concentration levels in urban and non-urban areas, generally reporting them as quarterly composites for stations in the network. The composite, which pools all samples collected during the quarter, assists in generating sufficient material for laboratory analysis.
>
> "Average annual arsenic concentrations for locations ranged from 0.000 to 0.083 microgram/cubic meter. The average annual concentration for all NASN locations was 0.003 microgram/cubic meter. The average annual concentration for the eight smelter sites was 0.030 microgram/cubic meter. Hence, concentrations increase by an order of magnitude for urban over rural and another order of magnitude for smelter cities over urban (Suta, 1978)."

### Arsenic in Air from Treated Wood

Arsenic in air from the use of treated wood originates in three ways: (1) from the sawing of treated wood, (2) from metabolism to volatile compounds, and (3) air entrainment of surface deposits.

The Department of Health and Social Services for the State of Wisconsin (Wisconsin, 1977) examined the air content in a home building plant which used CCA-treated plywood. Air concentrations varied from 0.001 mg/cubic meter to 0.003 mg/cubic meter in the breathing zone of off-bearer during the sawing operations. The "8-hour time-weighted average concentration for the off-bearer would be approximately 0.0015 mg/cubic meter," well below the current OSHA standard. No arsenic was detected in the breathing air of other workers involved with the sawing operation or the construction of walls treated with CCA.

The NBS (Sleater and Berger, 1977) conducted air sampling tests in basements of homes built with the All-Weather Wood Foundations. They found levels of 0.002 to 0.019 microgram As/cubic meter in an exposed masonry basement. In homes with finished basement rooms, the levels were 0.002 to 0.031 microgram As/cubic meter with an average of 0.008 microgram As/cubic meter for wooden foundations; in masonry basements which were covered the level was 0.008 microgram As/cubic meter. These results indicate that the As air levels in basements constructed from treated wood were not statistically higher than those constructed of masonry. The NBS values were much lower than those reported in an earlier study by the National Concrete Masonry Association (NCMA) for two of the same dwellings. No background As levels were reported by NCMA and thus their analysis might be in error (Sleater and Berger, 1977).

Wood treated with As but not with copper and chromium might contribute to atmospheric As particularly in a closed environment. Merrill and French (1964) reported that Lenzites trabea and L. saepiaria gave a garlic odor when grown on an agar media containing $As_2O_3$. Both L. trabea and L. saepiaria are wood-rotting fungi commonly found in wooden buildings. The methods used in this study could not detect any evolved arsenicals. Although the formation of alkylarsines from As in treated wood is theoretically possible, the presence of copper and/or chromium in the preservative prevents the reaction by controlling the microorganism capable of this metabolic conversion.

## Arsenic in Air from Pesticide Application

Only two studies have been found relative to As in air as a result of pesticide usage. One involved lead arsenate spraying on apples and the other in air around a cotton gin after the cotton was defoliated or desiccated with arsenicals.

Neal, et al. (1941) reported As air concentrations for a number of operations during the use of lead arsenate in apple orchards (Table 45).

Table 45.--Concentration of arsenic in air

| Operation | Average | Range |
|---|---|---|
| | mg As/$m^3$ | |
| Mixing insecticide | 18,500 | 200-110,700 |
| Burning containers | 166,700 | 48,600-261,200 |
| Spraying orchard | 1,400 | 400-4,800 |
| Thinning fruit | 800 | 100-3,200 |
| Picking fruit | 8,800 | 2,600-19,000 |
| Dumping fruit | 100-600 | 20-1,900 |
| Sorting and packing | 60 | 30-80 |

A wide range of air concentrations is evident depending on the operation. Applications of 30 to 90 pounds As/acre/yr were applied during this study. Since lead arsenate is no longer used on apples, this source of contamination no longer exists.

Seasonal variation of atmospheric As in Texas was reported during a 3-year period as air concentrations ranged from 0.001 mg/cubic meter to 0.085 mg/cubic meter (Attrep, et al., 1975). Concentrations were elevated from September to February, a period when cotton is ginned. The As found is a result of using arsenic acid desiccant or cacodylic acid, an organic arsenical defoliant. Average ambient air As content was 0.018 mg/cubic meter during this 3-year period. It was estimated that "6 grams of arsenic are released during the ginning on one bale (500 pounds) of cotton."

Burning of cotton trash from a gin is also a source of atmospheric As (HEW, 1967). At a distance of 46 to 91 m downwind from a west Texas cotton gin, concentrations of 0.600 to 141.0 mg/cubic meter were detected. Arsenic emissions from incineration, however, were not reported. In 1966, 37% of the gins incinerated their trash. "Adverse effects on trees and vegetation in areas downwind from cotton gin were observed." Texas Air Quality Control Board regulations since 1966 have changed these levels since burning is by permit only in remote, non-populated areas.

## Arsenic in Air from Smelters and Mining Operations

Air As levels have usually been highest in communities where smelters are located. During the refining of ore (copper, lead, zinc, or gold), heat decomposes the minerals and volatile $As_2O_3$ is emitted. The arsenical gases are cooled, condensed, and refined. The quantities of As in non-ferrous ores vary. Western ores generally are highest in As. The arsenical concentrates after smelting may be sent to the ASARCO smelter at Tacoma, Wash., where they are refined further.

Air concentrations in and around the Tacoma smelters have been reported by a number of researchers (McClannan and Rossano, 1975; Nelson, 1977; Wagner, 1976; and Milham and Strong, 1974). Monthly averages during 1975 ranged from 0.5 to 2.5 micrograms/cubic meter at the property line and dropped to 0.26 to 1.46 micrograms/cubic meter at a distance of 2,000 feet. Values continued to drop to 0.02 to 0.13 micrograms/cubic meter at 8 miles from the smelter (Nelson, 1977).

Arsenic air levels within the smelter are a function of the ore being processed. The higher the As content in the ore, the higher the As in the smelter air (Wagner, 1976). Values ranged from <1.0 microgram/cubic meter for a smelter processing 0.003% As ore to 130 micrograms/cubic meter for a smelter processing 1% As ore.

Arsenic can be re-entrained into the atmosphere from traffic traveling on unpaved roads (McClannan and Rossano, 1975), but the levels are about one/tenth those present from the smelter operation itself.

It has been calculated that the ASARCO smelter in Tacoma has emitted 200 tons $As_2O_3$ per year (Milham and Strong, 1974) although levels should decrease as pollution controls are upgraded under EPA guidelines.

Atmospheric As is lower at other smelters. Anaconda, Mont., had As levels of 0.18 to 2.5 micrograms/cubic meter (Wagner, 1976) and averages <0.5 microgram/cubic meter. A lead smelter in El Paso, Tex., had quarterly averages of 1.40 micrograms/cubic meter in 1974 (HEW, 1968). A Utah smelter had ambient air levels for 0 to 12 ppm As depending on sampling time (Wullstein and Snyder, 1971).

## Arsenic in Air from Coal-Fired Plants

Several studies have examined the mass balance of As in coal-fired steam plants and the resulting losses. Highest concentrations of As were found in the precipitator (Bolton, et al., 1973; and Lyon and Emery, 1975). However, there was a loss of 52 to 64% of the As indicating formation of a volatile gas which escaped the precipitator. Coutant, et al. (1975) likewise found As distribution through the combustion system as a function of temperature. They concluded that "although lead and arsenic display characteristics of volatility in the combustion system, only small percentages of these elements are emitted from the stack." Arsenic is enriched in downstream fly ashes (Kaakinen, et al., 1975).

The smaller sized fly ash is most likely to escape control measures and will also contain the highest residues on a weight/weight basis (Natusch, et al., 1974). Some As might escape the power plant in the vapor phase as $As_2O_3$ (Davison, et al., 1974). Emissions from power plants may account for the higher urban air levels recorded when compared to air in rural areas of the country. A summary of As in air and dust is presented in Table 46.

## Arsenic in Dust

Arsenic in dust can be present from several sources. House dusts in an area around a smelter were among the highest reported in the literature (McClannan and Rossano, 1975). Values ranged from 77 to 4,461 ppm As and were a function of distance from the Tacoma smelter. Milham and Strong (1974) likewise found dust samples at 2 miles from the smelter contained 70 ppm As and increased to 1,300 ppm As from 0 to 0.4 mile from the stack. These findings were used by the Puget Sound Air Pollution Control Board to set an emission standard for As designed to reduce environmental contamination.

House dusts in Hawaii were examined for As since arsenical herbicides and wood preservatives are extensively used in Hawaii (Klemmer, et al., 1975). Results were classified according to whether As had been used for termite control. Values varied from 1.1 to 1,080 ppm As but no correlation was found between levels in the dust and As treatment for termite control.

House dusts in CCA-treated wooden foundation buildings with exposed plywood had levels up to 1,267 ppm As and averaged 229 ppm (Sleater and Berger, 1977). When the walls had been covered, the respective values were 53 and 20 ppm As. A home with masonry walls had dust levels of 27 and 18 ppm As for uncovered and covered walls, respectively.

Atmospheric dust samples from Munich, Germany (Schramel, et al., 1974) revealed variations with site and month of the sample taken. Yearly averages ranged from 8.0 to 53 ppm As. Monthly values ranged from 1.0 to 297 ppm As. However, monthly trends for the various sampling stations were not consistent.

Dust samples at four sampling stations in Japan indicated air concentrations from 0.025 microgram As/cubic meter to 0.19 microgram As/cubic meter (Mamuro, et al., 1970). Only two 1-month periods were examined in the first study. In the latter, values ranged from 0.01 microgram As/cubic meter to 0.079 microgram As/cubic meter in monthly samples from four sites taken over a year's period. The four stations were from areas with different degrees of pollution. Atmospheric As levels did not correlate with the pollution of other elements at any given site.

## Arsenic in Water

Naturally occurring As appears in all water samples as evidenced in Table 47. In some cases, the As is below normal detection limits which vary according to the method used. Arsenic levels are generally quite low. About 4% of the analyses in the United States shows As at more than 50 ppb, the maximum permissible concentration in drinking water (HEW, 1962).

Table 46.--Arsenic in air and dust

| Locality | Arsenic Concentration | | Reference |
|---|---|---|---|
| | Air | Dust | |
| | Microgram/m$^3$ As | ppm As | |
| United States: | | | |
| Maryland | 0.005-0.012 | -- | Aras et al., 1973 |
| Washington, D.C. | 0.02 | -- | Aras et al., 1973 |
| Miscellaneous | 0.01-2.50 | -- | Sullivan, 1969 |
| Tacoma, Wash. | -- | 1,300[a] | Millam & Strong, 1974 |
| | | 70[b] | Millam & Strong, 1974 |
| | | 77-4,641 | McClannan & Rossano, 1975 |
| U.S. general[c] | | 680-1,700 | Natusch et al., 1974 |
| Hawaii | | 11-1,080 | Klemmer et al., 1975 |
| Australia | -- | 10-12[d] | Commissioner of Public Health, 1930 |
| Czechoslovakia | -- | 14.0[e] | Bencko et al., 1968 |
| | | 750-3,800[a] | Porazik et al., 1966 |
| England | 0.041-0.078 | -- | Goulden et al., 1952 |
| Japan | 0.012-0.066 | -- | Mamuro et al., 1972 |
| | -- | 0.012-0.19[f] | Mamuro et al., 1972a |
| Mexico | 0.005 | -- | Navarrete et al., 1974 |
| Russia: | | | |
| Rostov | 0.8-6.0 | -- | Bespalov et al., 1969 |
| 3,000-5,000m from copper smelter | 58-160 | -- | Rozenshtein, 1969 |
| 300-4,000m from power plant | 3.8-24.8 | -- | Rozenshtein, 1969 |
| Germany | -- | 1.0-297 | Schramel et al., 1974 |

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[a] Dust from copper smelter.

[b] Dust remote from copper smelter.

[c] Fly ash.

[d] Dust from cattle dipping.

[e] Near power plant.

[f] Airborne.

Table 47.--Arsenic in fresh water

| Water | Arsenic Concentration | Reference |
|---|---|---|
| | Micrograms/liter (ppb) | |
| United States, lakes: | | |
| New York, Chautauqua | 3.5-35.6 | Lis & Hopke, 1973 |
| Michigan | 0.5-2.4 | Seydel, 1972 |
| Superior | 0.1-1.6 | Seydel, 1972 |
| Wisconsin | 4.0-117 | Chamberlain & Shapiro, 1969 |
| California, Searles | 198,000-243,000 | White *et al.*, 1963 |
| California | 0.0-100[a]<br>0.0-2,000[b] | Livingston, 1963<br>Livingston, 1963 |
| Florida, Echols | 3.58 | Braman & Foreback, 1973 |
| Florida, Magdelene | 1.75 | Braman & Foreback, 1973 |
| Connecticut, Linsley Pond | 2.3-2.6 | Cowgill, 1974 |
| Cedar Lake | 1.6-13.9 | Cowgill, 1974 |
| United States, rivers: | | |
| Hillsborough | 0.25 | Braman & Foreback, 1973 |
| Withlacoochee | 0.42 | Braman & Foreback, 1973 |
| Fox (introduced) | 100-6,000 | Brown *et al.*, 1973 |
| Yellowstone | 4.5 | Ellis, 1934 |
| Narrow | 0.90 | Ray & Johnson, 1972 |
| Providence | 0.75-0.90 | Ray & Johnson, 1972 |
| Seekonk | 2.48-3.45 | Ray & Johnson, 1972 |
| Sugar Creek (industrial discharge) | <10-1,100 | Durum *et al.*, 1971; & Wilder, 1972 |
| Columbia | 1.6 | Onishi, 1969 |
| Columbia | 0.21-86.9 | Silker, 1964 |
| Schuylkill | 30-180 | Kopp & Kroner, 1967 |
| New Mexico, variety | 0.55-192 | Gladney & Owens, 1976 |
| Variety | <10-140 | Durum *et al.*, 1971 |
| United States, canals: | | |
| Florida | <10-20 | Grantham & Sherwood, 1968 |
| United States, well water: | | |
| California | 10-2,000 | Goldsmith *et al.*, 1972 |
| Florida | 0.68 | Braman & Foreback, 1973 |
| Minnesota (introduced) | 11,800-21,000 | Feinglass, 1973 |
| Washington | 5.0-6.0 | Fairhall, 1941 |
| Oregon | 0.00-1,700 | Goldblatt *et al.*, 1963 |
| Oregon | 0.00-2,150 | Morton *et al.*, 1976 |
| Georgia | 0.00-70 | Sandhu *et al.*, 1975 |
| United States, Puget Sound | 1.5-1,200 | Crecelius et al., 1975; & Crecelius & Carpenter, 1974 |

Table 47.--Arsenic in fresh water--continued

| Water | Arsenic Concentration | Reference |
|---|---|---|
| | Micrograms/liter (ppb) | |
| United States, rainwater: | | |
| Rhode Island | 0.82 | Ray & Johnson, 1972 |
| Washington, Seattle | 17 | Crecelius *et al*., 1975 |
| Argentina, Cordoba, drinking water | 480-1,490 | Guatelli & de Germicola, 1970 |
| | trace-300 | Bado, 1939 |
| Bosnia, Shebrenica, spring | 4,607 | Ivancevic & Tomic, 1956 |
| Canada, well water | 0.5-15 | Goulden & Brooksbank, 1974 |
| | <2.3-7,500 | Wyllie, 1937 |
| Chile | 800 | Borgono & Greiber, 1972 |
| Italy, Modena Province: | | |
| Groundwater | 3.0-5.0 | Vivoli & Beneventi, 1970 |
| Subsurface | <0.4-21 | Clemente *et al*., 1974 |
| Japan: | | |
| Rain | 0.01-13.9 | Kanamori & Sugawara, 1965 |
| Rivers (40) | 0.25-7.7 | Kanamori & Sugawara, 1965 |
| Aomori Prefecture | 30-3,950 | Noguchi & Nakagawa, 1970 |
| Lakes | 0.16-1.9 | Onishi, 1969 |
| Well, Nagoya Univ. | 11.0 | Sugawara & Kanamori, 1964 |
| Germany: | | |
| Elbe River | 20-25 | Onishi, 1969 |
| Rhine River | 3.1 | Kölle *et al*., 1971 |
| Main River | 3.6 | Lieser & Neitzert, 1976 |
| Logo Maggiore | 2.5 | Lieser & Neitzert, 1976 |
| Greece, lakes | 1.1-54.5 | Onishi, 1969 |
| Formosa, well water | 800 | Fan & Yang, 1969 |
| New Zealand, rivers: | | |
| Waikato River[c] | 5-100 | Lancaster *et al*., 1971 |
| Waiotapu Valley | trace-276,000 | Grimmett & McIntosh, 1939 |
| Postugal | 0.0-1.0 | Livingston, 1963 |

Table 47.--Arsenic in fresh water--continued

| Water | Arsenic Concentration | Reference |
|---|---|---|
| | Micrograms/liter (ppb) | |
| Yagnob, Daiyee River, suspended | 100-300 | Kvashnevskaya & Shablovskaya, 1963 |
| Sweden: | | |
| Rivers | 0.2-0.4 | Onishi, 1969 |
| Glacial ice | 2.0-3.8 | Weiss & Bertine, 1973 |
| Antarctica | 0.60-0.75 | White *et al.*, 1963 |
| Spring water,[d] California, Kamchatka, U.S.S.R., New Zealand | 130-1,000 | White *et al.*, 1963 |
| Oil- and gas-field waters, California, Louisiana, Hungary | 0.0-5,800 | White *et al.*, 1963 |
| Thermal waters, Wyoming, Nevada, California, Alaska, Iceland | 20-3,800 | White *et al.*, 1963 |
| Spring waters,[e] U.S.S.R., Wyoming, Algeria, Iceland | 30-500 | White *et al.*, 1963 |

[a] Dissolved solids, <2,000 ppm.

[b] Dissolved solids, >2,000 ppm.

[c] High in bicarbonate; of geothermal origin.

[d] High in bicarbonate and boron.

[e] Deposit travertine.

There are some sites where the arsenic levels are high naturally: Searles Lake, Calif.; wells in California and Oregon; Bosnia; Canada; Aomori Prefecture, Japan; New Zealand rivers, and various springs and thermal waters. But for the most part, drinking water As levels are not above the maximum allowable level of 50 ppb. Arsenic in seawater normally ranges from 1 to 6 ppb.

## Arsenic in Water from Wood Preservatives

The CCA pressure treatment forces the preservative into the cellular structure of the wood. Within this cell structure, the As forms very insoluble compounds. Factors which affect the penetration and retention within the wood will affect its leachability.

Douglas-fir, ponderosa pine, and southern yellow pine had high leachability at 2 to 2.5% preservative solutions, but greatly reduced leachability when the concentration of the treating solution was doubled (Dahlgren, 1975). Neither drying temperatures nor the time between treatment and drying affected the leachability of As.

Leaching in saltwater is more rapid than in fresh water. Loss of As is shown to lag behind that of copper and chromium and is related to the excess chromium in the preservative formula. Leaching increased as the salinity increased (Irvine and Dahlgren, 1976).

The formulation may affect the leachability of the preservative. Wood treated with ammonical solutions of copper, zinc, and As lost 35 to 67% of the As when the metal oxide to arsenic oxide ratio was less than 1.25. When the ratio was greater than 1.25, only 1 to 15% was lost under a severe accelerated leaching test (Rak, 1976).

Tests have been made for As leaching from AWWF as measured in the sump-pump waters. Arsenault (1975) reported an initial As level of 110 ppb As in the sump pit at the completion of construction of a house in Atlanta, Ga. After 3 months, the level declined to 80 ppb and in another 3 months, to 20 ppb As.

A more recent examination of water from sump pumps in AWWF basements was made in Rapid City, S. Dak., in 1978 (McNamara, 1978). Twelve homes were tested, varying in length of time the basements were completed (3 to 60 months). In homes with no sump pumps operating and debris in the pit, values ranged from 5 to 22 ppb As. In houses which had sump pumps operating and were being lived in, residue levels were <1 to 10 ppb As.

## Arsenic in Water from Pesticide Applications

Several episodes of As appearing in water as a result of pesticide contamination or application have appeared in the literature over the years.

Feinglass (1973) reported on 13 people who were exposed to well water which was contaminated by an arsenical grasshopper bait. The bait had been stored on the ground and the well was drilled through a layer containing the bait. The well water had levels of 11,800 to 21,000 ppb As. No permanent adverse health effects were observed.

Water in the Wenatchee, Wash., area contained from only 5 to 6 ppb As (Fairhall, 1941), even though the soil in Washington was estimated to have received as much as 7,000,000 pounds of lead arsenate in a single year. Most of this chemical was applied in the Wenatchee-Yakima areas.

Sodium arsenite was used for aquatic weed control for many years. As a result, As levels in some lakes has increased. However, it becomes difficult to assess all inputs when other sources of pollution are present. Arsenic levels in treated Lake Chautauqua averaged 15.1 ppb As 13 years after treatment stopped (Lis and Hopke, 1973). Arsenic content in water at application time varied from 1,100 to 14,600 ppb As. Sodium arsenite is not used for aquatic weed control at the present time.

Richardson, et al. (1978) examined runoff water from cotton fields after arsenic acid was applied at 6.6 kg/ha. The highest residues were 250 ppm and were a function of time and tillage operations after application. Levels were reduced to 10 to

20 ppb after two to three runoff events. Most of the As was associated with the sediment from erosion.

## Arsenic in Water from Industrial Discharge

Industrial sources for As in water are quite varied. Widespread low levels have been reported in rainwater (Cawse and Peirson, 1972; Ray and Johnson, 1972; and Kanamori and Sugawara, 1965). Rain near smelters, however, may be quite high. Crecelius (1975) reported levels in Seattle rainwater of 17 ppb compared to <0.1 to 5.4 ppb As in areas not containing smelters.

Dumping of arsenic-rich slag and liquid discharges into the Puget Sound has elevated As levels in the vicinity of the ASARCO smelter at Tacoma (Crecelius and Carpenter, 1974; and Crecelius, 1975). Arsenic content in water decreases rapidly with distance from the smelter, however, with values ranging from 1,200 ppb As at the smelter to 1 to 2 ppb 2 miles downstream.

At a zinc smelter in Blackwell, Okla., samples were collected from ponds, creeks, roadside ditches, stock tanks, public water supplies, and the Chickaskia River. All samples contained less than 10 ppb As (Benenati, 1974).

Sources need not be caused by manufacturing and processing activities, however. Elevated As levels in drainage from an abandoned mine were found at Moreton Harbor, Newfoundland (Penrose, et al., 1975). At the point of drainage, 5.3 ppb were observed. The concentration dropped rapidly to 1 ppb. Streams in southwest England receive drainage from past mining and smelting of arsenical and associated metalliferous ores (Aston, et al., 1975). Levels >250 ppb are found in these streams.

An episode involving As discharge from a manufacturing plant occurred at Sugar Creek in North Carolina in 1971. Large amounts of As were discharged into a sewage treatment plant in Charlotte, N.C. Water levels of 1,100 ppb were found in the water of Sugar Creek. The As was being moved downstream in both the dissolved and suspended state (Wilder, 1972).

Arsenic levels in Lake Michigan average 1.6 ppb As (Seydel, 1972) and are higher than those in Lake Superior. Klein (1975) assessed the importance of various sources of inputs of As into Lake Michigan. He concluded that introduced sources are likely to be most important for As. Aerosol deposition is the major source.

Low As levels in river water were the result of using detergents containing As (Tanner, et al., 1973; and Colasanti and Hopke, 1974). Arsenic levels ranged from 5 to 51 ppm As in the detergent itself. Angino, et al. (1970) found that water treated with cold lime contained As at 0.4 ppb. Water at the intake contained 2.6 to 3.6 ppb before treatment. The As in water returned to the Kansas River after sewage treatment ranged from 1.5 to 2.1 ppb. Angino felt that As in detergents added significant quantities of As to the river system; others have felt that there was little danger (Pattison, 1970; and Sollins, 1970).

## Fate of Arsenic in Water

### Adsorption from Water

Arsenic in water is quickly removed by reaction or adsorption to sediments. Several factors are responsible for the removal of arsenite from water by lake sediments (Huang and Liaw, 1979). The adsorption maximum of the lake sediments was reduced sevenfold after removal of the sesquioxides (iron and aluminum hydrous oxides), carbonates, and organic matter. Some adsorption still occurred after removal of the above materials and was attributed to adsorption to the external surfaces of various clays.

Concentration of As in water appears to be a factor in the rate of adsorption. At water concentration of 10 ppb As, 11% was left in the water at 5 days, and 9% after 11 days. When 1,000 ppb As were added, 46% remained in solution at 5 days but only 17% at 11 days (Woolson, et al., 1976).

Naturally occurring As from hot springs concentrates in sediments to 300 ppm As (Reay, 1973). Arsenic is moved downriver as suspended particulate matter and deposited in the ocean.

Industrial arsenical wastes, likewise, may concentrate in sediments downstream from the site of contamination (Wilder, 1972). Levels of 35 ppm As were found in stream-bed materials and 500 ppm on suspended sediments. During periods of low stream flow, most As is transported in the dissolved state and reacts with stream-bed materials, thereby decreasing As levels in water. During periods of high flow, the sediments are carried along by the water movement and most As is moved downstream on suspended sediments. Arsenic, whether from natural sources or human activity, moves to the ocean ultimately where sedimentation occurs. Ferguson and Gavis (1972) concluded that "there is no substantial imbalance between natural weathering and deposition of arsenic at present."

A summary of As in sediments is presented in Table 48.

### Metabolism in Water and Aquatic Organisms

Metabolism of As involves several reactions; namely, oxidation, reduction, and methylation. The latter two processes are biologically mediated while the oxidation may or may not be.

Arsenate, methylarsonic acid, and dimethylarsinic acid were found in natural fresh waters which had received no As applications (Braman and Foreback, 1973). In addition to the above, arsenite was detected in seawater. Trimethylarsine (or the oxide) was found only in fresh water.

Bacteria, fungi, aquatic plants, and/or animals are responsible for the conversions of inorganic As to the organic forms. Bacteria can methylate As both anaerobically (McBride and Wolfe, 1971) and aerobically (Challenger and Higginbottom, 1935). Marine bacteria are known to reduce arsenate to arsenite under laboratory conditions (Johnson, 1972). Johnson and Braman (1975) "hypothesize that some member(s) of the Sargassum community is producing the alkyl-arsenic" since it is not present in rainwater and alkyl arsenicals as well as arsenite and arsenate are found in members of this community.

Table 48.--Arsenic in sediments

| Locality | Arsenic Concentration | Reference |
|---|---|---|
| | ppm | |
| UNITED STATES: | | |
| New York, Chautauqua | 6.0-70.0 | Lis & Hopke, 1973 |
| | 0.5-306.0; $\bar{x}$=22.1 | Ruppert et al., 1974; Hopke et al., 1976 |
| Texas | 3.0 | Ahr, 1973 |
| | 0.8-8.0 | Presley & Culp, 1972 |
| Winyah Bay | 8.0-12.0 | Johnson, 1970 |
| Lake Erie | 0.16-8.0 | Walters, Jr. et al., 1974 |
| Lake Michigan | 5.0-30.0 | Ruch et al., 1970 |
| | 7.2-28.8 | Seydel, 1972 |
| | 0.2-8.5 | Marsh & Minear, 1973 |
| Lake Superior | 2.8-5.4 | Seydel, 1972 |
| Lakes, Wisconsin | 0.1-45.0 | Shukla et al., 1972 |
| Sugar Creek (contaminated) | 4,470-66,700 | Wilder, 1972 |
| Puget Sound | 2.9-10,000 | Crecelius et al., 1975 |
| Washington, rivers | | |
| Skagit | 15-34 | Crecelius et al., 1975; & Crecelius & Carpenter, 1974 |
| Stillaguamish | 17-48 | Crecelius et al., 1975; & Crecelius & Carpenter, 1974 |
| Snohomish | 22-74 | Crecelius et al., 1975; & Crecelius & Carpenter, 1974 |
| Duwamish | 15-40 | Crecelius et al., 1975; & Crecelius & Carpenter, 1974 |
| Puyallup | 2.6-7.5 | Crecelius et al., 1975; & Crecelius & Carpenter, 1974 |
| Nisqually | 4.5-12 | Crecelius et al., 1975; & Crecelius & Carpenter, 1974 |
| Dosewallips | 7.4 | Crecelius et al., 1975; & Crecelius & Carpenter, 1974 |
| Duckabush | 6.8 | Crecelius et al., 1975; & Crecelius & Carpenter, 1974 |
| JAPAN | | |
| Minamata | 0.0-93.4 | Kanamori & Sugawara, 1965 |
| | 4.7-60 | Hamaguchi et al., 1960 |
| NETHERLANDS | | |
| Rhine Delta | ND-310 | de Groot et al., 1969 |

Table 48.--Arsenic in sediments--continued

| Locality | Arsenic Concentration | Reference |
|---|---|---|
| | ppm | |
| NEW ZEALAND | | |
| Waiotapu Valley muds | 51-14,250 | Grimmett & McIntosh, 1939 |
| Various sediments | 2-550 | Reay, 1972 |
| Marine | 6.6 | Portmann & Riley, 1964 |
| | 8-110 | De Goeij *et al*., 1975 |
| Pelagic | 40 | Van Itallie, 1932 |
| ENGLAND | <2-5,000 | Thornton *et al*., 1975<br>Leatherland & Burton, 1974<br>Aston *et al*., 1975 |
| CANADA | 9.1-2,600 | Penrose *et al*., 1975 |

ND = Not detected.

In order to better understand the mechanism of As transformations of the pelagic *Sargassum* community, Blake and Johnson (1976) measured the As changes in a flow-through system. Arsenic additions had no measurable effect on the metabolism of the community, but when the "steady state" distribution of arsenate/arsenite was altered, there was a rapid response to re-establish the ambient arsenite/arsenate ratio of 0.13.

Arsenic is taken in by aquatic organisms, metabolized, and some is excreted. Arsenate accumulates to various degrees in different organisms, with accumulation ratios in fresh water for algae, daphnids, *Gambusia*, and crayfish of 34, 5, 127, and 5, respectively (Woolson, *et al*., 1976). Residues were characterized by gel filtration chromatography following chemical fractionation. Arsenic was found in all fractions. The distribution between the sugar/transient intermediates, lipid, nucleic acid, and protein fractions varied with the organism. The lowest members of the food chain (algae and daphnids) contained their greatest percentage in sugar/transient intermediates fraction; *Gambusia* in the lipid fraction; and crayfish about equal percentages in all but the protein (4%) fraction. Gel filtration of the sugar/transient intermediates and nucleic acid fractions indicated the presence of at least three compounds of different molecular weights from arsenate in the various organisms.

Inorganic As is converted to an organic form by fish only when it is ingested (Lunde, 1972; and Penrose, 1975). The implication is that intestinal microorganisms carry out at least the first stage of As conversion. Greysole and flounder appeared to form a tetramethylarsonium compound (Penrose, *et al*., 1977) when extracted with trichloroacetic acid and benzene. Detection was with mass spectroscopy and NMR. A phospholipid which migrated on TLC with phosphatidylethanolamine was found in *Daphnia magna* grown in $^{74}$As-sodium arsenate. The experimental results are not inconsistent with the presence of an arsenocholine moiety in the lipids (Irgolic, *et al*., 1977).

A phospholipid formed by marine algae grown in $^{74}$As-arsenate was isolated and identified (Cooney, et al., 1978). The arsenical compound was identified as trimethylarsonium lactic acid after hydrolysis which would derive from O-phosphatidyltrimethylarsonium lactic acid. Its accumulation in marine algae and animals and its probable function as a detoxicated form of As appears related to its structural similarities rather than differences. Andreae and Klumpp (1979) isolated 12 soluble organoarsenic compounds formed by pure cultures of marine phytoplankton species which were bacteria free. All species released substantial amounts of methylarsonate and dimethylarsinate into their environment. The production of arsenite was also common, and especially conspicuous with two species of Coccolithophores. These findings explain at least in part the common occurrence of these As compounds in the aquatic environment. Water of the Salton Sea in California contained 90% of its As in the methylated forms, an extreme case relative to seawater.

### Plant Uptake of Arsenic from Water

Arsenic content of plants grown in contact with fresh or marine water is presented in Table 49. Marine algae (seaweed) contain quite variable amounts of As, depending on the species that is present naturally.

Fresh-water algae generally do not contain levels above 10 ppm As dry weight. However, there is one exception noted in the literature involving submerged and emergent aquatic plants growing in high As water from a geothermal power plant in the Waikato River of New Zealand. The plants grew adequately and Reay (1972) concluded that "the aquatic plants examined appear to be more tolerant to arsenic than several other plants."

### Animal Uptake of Arsenic from Water

All animal life in the aquatic environment contains As which is acquired from the water or from the consumption of As-containing food. In experimental studies, As content of animals seems to reach a steady-state level when exposed to a constant source of As. When the source is removed, As levels in the organism decline (Woolson, et al., 1976).

The As is incorporated or metabolized in fish to organic compounds, some of which are quite complex. Simple methylated arsenicals are formed and excreted into the water (Andreae and Klumpp, 1979). More complex water-soluble and lipid-soluble compounds are also formed.

Residues in fresh water fish are normally lower than those in marine fish. Filter feeders normally contain the most As. "However, the arsenic contained in the organisms is apparently not toxic to animals or humans, and is readily excreted" (Woolson, 1975). Residues in aquatic animal life are presented in Table 50.

Arsenic does not appear to biomagnify through the food chain, but does bioaccumulate directly from water. Organisms lower in the food chain normally contain the highest residues (Woolson, 1975).

# Arsenic Residues in Soil

## Soil Residues from Treated Wood

Arsenic reaches soil from treated wood as a result of leaching, primarily from the wood's surface. Once in the soil, the As behaves as that available from any source and will be discussed later in this chapter.

Table 49.--Arsenic content of aquatic plants

| Part or Product | Treatment[a] | Arsenic Concentration, (dry wt.) Treated | Nontreated | References |
|---|---|---|---|---|
| | | - - - - ppm | - - - - | |
| Phytoplankton | -- | -- | 5.8 | Seydel, 1972 |
| Zooplankton | -- | -- | 6.2 | Seydel, 1972 |
| MARINE ALGAE, SEAWEED: | | | | |
| *Macrocystis pyrifera* | -- | -- | 4.0-60.0 | Gorgy *et al.*, 1948;<br>Williams & Whetstone, 1940;<br>Wilson & Fields, 1941 |
| *Chondrus crispus* | -- | -- | 3.8-18.0 | Chapman, 1926; Jones, 1922;<br>Leatherland & Burton, 1974 |
| *Laminaria digitata* lamina | -- | -- | 107-109 | Lunde, 1970 |
| *Laminaria digitata* | -- | -- | 47.0-93.8 | Jones, 1922; &<br>Leatherland & Burton, 1974 |
| *Laminaria digitata*, oil | -- | -- | 221.0 | Lunde, 1972a |
| *Laminaria digitata*, fatty acid | -- | -- | 36.0 | Lunde, 1972a |
| *Laminaria sacchrina* | -- | -- | 45.0[b]-52.5 | Jones, 1922; &<br>Leatherland & Burton, 1974 |
| *Laminaria saccharina*, oil | -- | -- | 155 | Lunde, 1972a |
| *Laminaria saccharina*, fatty acid | -- | -- | 7.5-52.5 | Jones, 1922; &<br>Leatherland & Burton, 1974; &<br>Lunde, 1972a |
| *Halidrys siliquosa* | -- | -- | 26.0-30.0 | Jones, 1922;<br>Leatherland & Burton, 1974 & |
| *Fucus nodosus* | -- | -- | 45.0 | Jones, 1922 |
| *Entarompha compressa* | -- | -- | 11.2 | Jones, 1922 |
| *Ahnfelitia plicata* | -- | -- | 39.0 | Leatherland & Burton, 1974 |
| *Fucus vesiculosus* | -- | -- | 24-65 | Jones, 1922 & Lunde, 1970 |
| *Fucus vesiculosus*, oil | -- | -- | 35.0 | Lunde, 1972a |
| *Fucus vesiculosus*, fatty acid | -- | -- | 5.1 | Lunde, 1972 |
| *Fucus serratus* | -- | -- | 28-67.5 | Jones, 1922 & Lunde, 1972b |
| *Fucus serratus*, fatty acid | -- | -- | 6.1 | Lunde, 1972a |
| *Fucus* sp. | MP | 17.3 | 12.1 | Penrose *et al.*, 1977 |
| *Piocamium coccineum* | -- | -- | 7.5 | Jones, 1922 |
| *Ulva latissima* | -- | -- | 6.0 | Jones, 1922 |
| *Gigartina mammillosa* | -- | -- | 4.5-17.2 | Jones 1922; & Lunde 1970 |
| *Laminaria hyperborea*, oil | -- | -- | 197 | Lunde, 1972a |
| *Laminaria hyperborea*, fatty acid | -- | -- | 16 | Lunde, 1972a |
| *Ascophyllum nodosum* | -- | 17.2 | 9.8 | Penrose *et al.*, 1977 |
| *Ascophyllum nodosum*, oil | -- | -- | 7.8-49.0 | Lunde, 1972a |
| *Ascophyllum nodosum*, fatty acid | -- | -- | 5.2-21.0 | Lunde, 1972a |
| *Fucus spiralis* | -- | -- | 15-34 | Lunde, 1970 |
| *Fucus spiralis*, oil | -- | -- | 5.7 | Lunde, 1972a |
| *Fucus spiralis*, fatty acid | -- | -- | 5.0 | Lunde, 1972a |
| *Pelvetia canaliculata* | -- | -- | 15-22 | Lunde, 1970 |
| *Pelvetia canaliculata*, oil | -- | -- | 10.8 | Lunde, 1972a |
| *Pelvetia canaliculata*, fatty acid | -- | -- | 7.3 | Lunde, 1972a |
| *Sargassum fluitans* | -- | -- | 19.5[b] | Johnson & Braman, 1975 |
| *Sargassum filipendula* | -- | -- | 5.8[b] | Johnson & Braman, 1975 |
| *Sargassum* sp. | -- | -- | 4.2-12.7[b] | Johnson & Braman, 1975 |

Table 49.--Arsenic content of aquatic plants--continued

| Part or Product | Treatment[a] | Arsenic Concentration, (dry wt.) | | References |
|---|---|---|---|---|
| | | Treated | Nontreated | |
| | | - - - - *ppm* - - - - | | |
| FRESH WATER ALGAE: | | | | |
| Algae | -- | -- | 0.5-12.0 | Cardiff, 1937;<br>Marcelot, 1913;<br>Williams & Whetstone, 1940 |
| *Algae*, *Odegodeum* | CA | 4.5-71.4 | -- | Isensee *et al.*, 1973 |
| | CA | 2-12 | -- | Schuth *et al.*, 1974 |
| | As | 269 | -- | Woolson *et al.*, 1976 |
| *Sceletonema costatum*, oil | -- | -- | 1.3 | Lunde, 1972b |
| *Chlorella ovalis*, oil | -- | -- | 0.7 | Lunde, 1972b |
| *Chlorella pyrenoidosa*, oil | -- | -- | 0.5 | Lunde, 1972b |
| *Phaedactylum tricornutum*, oil | -- | -- | 3.6-4.8 | Lunde, 1972b |
| *Oscillatoria rubescens*, oil | -- | -- | 0.4-0.5 | Lunde, 1972b |
| *Pterygophera californica* | -- | -- | 12.0 | Williams & Whetstone, 1940 |
| *Agarium fimbuetum* | -- | -- | 4.0 | Williams & Whetstone, 1940 |
| *Rhodemia pertusa* | -- | -- | 1.0 | Williams & Whetstone, 1940 |
| *Casteria castata* | -- | -- | 1.0 | Williams & Whetstone, 1940 |
| MOSS: | | | | |
| *Hylocomium splendens* | SP | <4-9 | <4 | LeBlanc *et al.*, 1974 |
| *Pleurozium schreberi* | SP | <1-10 | 2-3 | LeBlanc *et al.*, 1974 |
| AQUATIC PLANTS, NEW ZEALAND: | | | | |
| *Ceratophyllum demursum* | GTA | 20-1,060 | 1.4 | Lancaster *et al.*, 1971; & Reay, 1973; & Reay, 1972 |
| *Lagarosiphon major* | GTA | 29-1,450 | -- | Lancaster *et al.*, 1971; & Reay, 1973; & Reay, 1972 |
| *Elodea canadensis* | GTA | 307-700 | 3.0 | Lancaster *et al.*, 1971; & Reay, 1972 |
| *Potamoteton* sp. | GTA | 45-436 | <6.0 | Lancaster *et al.*, 1971; & Reay, 1972 |
| *Lemna* sp. | GTA | 30 | 2.5 | Lancaster *et al.*, 1971; & Reay, 1972 |
| *Nitella hookeri* A. Braun | GTA | 182 | 13.0 | Lancaster *et al.*, 1971; & Reay, 1972 |
| *Enteromorpha nana* | GTA | 14-40 | -- | Lancaster *et al.*, 1971; & Reay, 1973; & Reay, 1972 |
| *Compsopogon hookeri* | GTA | 550 | -- | Reay, 1973; & Reay, 1972 |
| *Typha orientalis* Presi | GTA | 8 | -- | Lancaster *et al.*, 1971; & Reay, 1972 |
| *Egeria densa* | GTA | 266-310 | -- | |
| *Atriplex confertifolia* | -- | -- | 3.2 | Headden, 1910 |
| *Myriophyllum propinquum* | GTA | 456 | -- | Lancaster *et al.*, 1971 |
| LINSLEY POND, CONN. | | | | Cowgill, 1974 |
| *Ceratophyllum demersum* | -- | -- | 5.6-26.0 | |
| *Potamogeton praelongus* | -- | -- | 9.9 | |
| *Potamogeton crispus* | -- | -- | 4.0-4.8 | |
| *Nuphar advena* | -- | -- | 2.5-3.6 | |
| *Fontederia cordata* | -- | -- | 2.3-3.5 | |
| *Nyphaea odorata* | -- | -- | 2.4-3.2 | |
| *Decodon verticillatus* | -- | -- | 2.8-3.3 | |

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[a] MP = mine pollution CA = cadocylic acid SP = smelter pollution GTA = geothermal area
As = arsenate.

[b] Wet weight.

Table 50.--Arsenic content of aquatic animal life

| Animal | Exposure[a] | Arsenic Concentration (fresh wt) |  | References |
|---|---|---|---|---|
|  |  | Exposed | Normal |  |
|  |  | - - - - ppm As | - - - - |  |
| SHRIMP | -- | -- | 1.27-41.6 | Cardiff, 1937; Chapman, 1926; Coulson et al., 1935; Luzanski, 1935; & Johnson & Braman, 1975 |
| English potted | -- | -- | 8.2-18.8 | Chapman, 1926 |
| Edible portion | -- | -- | 0.95-31.2 | Coulson et al., 1934 |
| Canned | -- | -- | 0.08 | Dick & Pugsley, 1950 |
| B.C. (muscle) | -- | -- | 3.9 | Reinke et al., 1975 |
| Asian (sp. unknown) | -- | -- | 0.4-2.7 | Zook et al., 1976 |
| Alaskan (mixed sp.) | -- | -- | 0.9-5.1 | Zook et al., 1976 |
| brown (Penaeus aztecus) | -- | -- | 3.1-5.2 | Zook et al., 1976 |
| brown | -- | -- | 1.77-23.75 |  |
| Mexican (sp. unknown) | -- | -- | 0.5-2.9 | Zook et al., 1976 |
| white (Penaeus setiferus) | -- | -- | 1.7-7.7 | Zook et al., 1976 |
| pink (Pandalus borealis) | -- | -- | 3.6-15.8 | Zook et al., 1976 & Kennedy, 1976 |
| Pandalus borealis, oil | -- | -- | 10.1 | Lunde, 1972 |
| Pandalus borealis, fatty acid | -- | -- | 4.8 | Lunde, 1972 |
|  | -- | -- | 13.0-42.0[b] | Lunde, 1973a; & Luzanski, 1936 |
| Pandulus montagui | -- | -- | 4.0-19.6 | Kennedy, 1976 |
| Palamon serratus, cooked | -- | -- | 1.0-2.7 | Costa & Da Fonseca, 1967 |
| Parpapeneus longirostris | -- | -- | 1.7-38.2 | Costa & Da Fonseca, 1967 |
| CRAB | -- | -- | 27.0-52.5 | Chapman, 1926 |
| Dressed | -- | -- | 18.8-62.6 | Chapman, 1926 |
| Canned | -- | -- | 0.71 | Dick & Pugsley, 1950 |
| Muscle | -- | -- | 3.7-6.1 | Hoover et al., 1974; & Reinke et al., 1975 |
|  | 1 | ≤7.95 | -- | Thumann, 1940; & Thumann, 1941 |
| (CancerMagister) | -- | -- | 2.2-37.8 | LeBlanc & Jackson, 1973 |
| blue (Callinectes sapidus) | -- | -- | 0.5-1.8 | Zook et al., 1976 |
| body meat; | -- | -- | 3.81-35.62 | Zook et al., 1976 |
| king (Paralithodes camschatica) | -- | -- | 2.6-7.0 | Zook et al., 1976 |
| king (Paralithodes camschatica) leg meat | -- | -- | 2.3-6.7 | Zook et al., 1976 |
| Carcinus maenas, cooked | -- | -- | 2.5-7.0 | Costa & Da Fonseca, 1967 |
| Cancer pagurus, cooked | -- | -- | 2.1-33.4 | Costa & Da Fonseca, 1967 |
| CLAM, minced | -- | -- | 0.85 | Cardiff, 1937 |
|  | -- | -- | 1.42-2.56 | Cardiff, 1937; & White, 1933 |
| Canned | -- | -- | 0.36 | Dick & Pugsley, 1950 |
| Pecten maximum | -- | -- | 11.6 | Lunde, 1968a |
| N-liquor | -- | -- | 18.6 | Lunde, 1968a |
| Oil | -- | -- | 4.8 | Lunde, 1972 |
| Fatty acid | -- | -- | 1.9 | Lunde, 1972 |
| (Macoma sp.; Clinocardium sp.) | -- | -- | <0.5-15.6 | LeBlanc & Jackson, 1973 |
| hard (Mercenaria mercenaria) | -- | -- | 1.0-2.5 | Zook et al., 1976 |
| soft (Mya arenaria) | -- | -- | 0.6-2.1 | Zook et al., 1976 |
| surf (Spisula solidissima) | -- | -- | 1.2-2.2 | Zook et al., 1976 |
| all species | -- | -- | 0.90-12.72 | Zook et al., 1976 |
| Eualus macilentus | -- | -- | 2.6-12.7 | Kennedy, 1976 |
| S. septemcarinata | -- | -- | 3.9-22.7 | Kennedy, 1976 |
| PRAUNS | -- | -- | 34.1 | Cardiff, 1937 |
| Dublin Bay | -- | -- | 27.0-130.5 | Chapman, 1926 |
| American tinned | -- | -- | 10.5-30.0 | Chapman, 1926 |
| Japanese tinned | -- | -- | 15.0-63.8 | Chapman, 1926 |

Table 50.--Arsenic content of aquatic animal life--continued

| Animal | Exposure[a] | Arsenic Concentration (fresh wt) | | References |
|---|---|---|---|---|
| | | Exposed | Normal | |
| | | - - - - ppm As - - - - | | |
| OYSTER | -- | -- | 0.3-3.7 | Cardiff, 1937; Cox, 1925; Hiltner & Wickmann, 1919; Mackay et al., 1975b; & White, 1933 |
| English | -- | -- | 2.2-7.5 | Chapman, 1926 |
| Portuguese | -- | -- | 24.8-52.5 | Chapman, 1926 |
| American tinned | -- | -- | 0.4-0.8 | Chapman, 1926 |
| Canned | -- | -- | 0.22 | Dick & Pugsley, 1950 |
| Smoked | -- | -- | 1.00 | Dick & Pugsley, 1950 |
| Ostrea edulis | -- | -- | 2.6-8.2[b] | Leatherland & Burton, 1974; & Lunde, 1968a |
| Ostrea edulis, N-liquor | -- | -- | 9.8 | Lunde, 1968a |
| Gryphea angulata | -- | -- | 1.2-3.6 | Costa & Da Fonseca, 1967 |
| N-liquor | -- | -- | 17.0 | Lunde, 1968a |
| Loligo vulgaris, raw | -- | -- | 0.8-7.5 | Costa & Da Fonseca, 1967 |
| Loligo vulgaris, cooked | -- | -- | 0.4-3.3 | Costa & Da Fonseca, 1967 |
| Fatty acid | -- | -- | 0.7 | Lunde, 1972 |
| Crassostrea virginica | -- | -- | 0.6-2.5 | Zook et al., 1976 |
| Crassostrea virginica | -- | -- | 0.45-42.75 | Zook et al., 1976 |
| Crassostrea commercialis | -- | -- | 0.3-3.4 | Mackay et al., 1975a |
| LOBSTER | | | | |
| (Homarus vulgarus) | -- | -- | 2.27-54.5 | Cardiff, 1937; Chapman, 1926; Costa & Da Fonseca, 1967; & Del Vecchio et al., 1962 |
| Canned | -- | -- | 0.94 | Dick & Pugsley, 1950 |
| Fillet | -- | -- | 5.3 | Lunde, 1968a |
| Fillet, N-liquor | -- | -- | 14.0 | Lunde, 1968a |
| Cooked | -- | -- | 10.8-17.2 | Costa & Da Fonseca, 1967 |
| Muscle | -- | -- | 0.022 | Barnard, 1911 |
| Whole | -- | -- | 0.453 | Barnard, 1911 |
| Tail | -- | -- | 40.5 | Reinke et al., 1975 |
| Norwegian, cooked (Nephrops norvegicus) | -- | -- | 7.2-19.4 | Costa & Da Fonseca, 1967 |
| Spiny (Panulirus borealis) | -- | -- | 3.2-9.6 | Zook et al., 1976 |
| (Homerus americanus) | 2 | 3.8 | 7.6 | Penrose et al., 1975 |
| SCALLOP | -- | -- | 27.0-63.8 | Cardiff, 1937; & Chapman, 1926 |
| SCALLOP, sea | -- | -- | 0.39-33.56 | Zook et al., 1976 |
| Aequipecten irradians | -- | -- | 0.5-1.1 | Zook et al., 1976 |
| Aequipecten gibbus | -- | -- | 3.5-5.0 | Zook et al., 1976 |
| Placopecten magellanicus | -- | -- | 1.3-2.4 | Zook et al., 1976 |
| MUSSEL | -- | -- | 2.58-89.2 | Cardiff, 1937; Chapman, 1926; Del Vecchio et al., 1962; & Lunde, 1973a |
| Mytilus edulis | -- | -- | 0.08-8.0 | Costa & Da Fonseca, 1967; Del Vecchio et al., 1962; Gorgy et al., 1948; Lunde 1968a; Luzanski, 1935; & Luzanski, 1936 |
| Mytilus edulis | 2 | 5.3 | 1.6 | Penrose et al., 1975 |
| | -- | -- | 9.5-15.0[b] | Leatherland & Burton, 1974 |
| Whole | -- | -- | 0.0[b] | Lunde, 1973a |
| N-liquor | -- | -- | 9.7 | Lunde, 1968a |
| Oil | -- | -- | 18.0 | Lunde, 1972 |
| Fatty acid | -- | -- | 22.0 | Lunde, 1972 |
| Mytilus edulis, whole | 1 | 0.04-3.73 | 0.01 | Del Vecchio et al., 1962; & Sautet et al., 1964 |
| Mytilus Magellonicus | -- | -- | 10.5-26.1[b] | Moyana, 1956 |

Table 50.--Arsenic content of aquatic animal life--continued

| Animal | Exposure[a] | Arsenic Concentration (fresh wt) | | References |
|---|---|---|---|---|
| | | Exposed | Normal | |
| | | - - - - *ppm As* - - - - | | |
| COCKLE | | | | |
| *Caridum edule* | -- | -- | 5.1-8.4 | Leatherland & Burton, 1974 |
| | -- | -- | 12.8-30.0 | Cardiff, 1937; & Chapman, 1926 |
| | -- | -- | 1.3-2.4 | Costa & Da Fonseca, 1967 |
| Tapes decussatus | -- | -- | 3.7-6.6 | Costa & Da Fonseca, 1967 |
| WHELK | -- | -- | 9.0-30.0 | Chapman, 1926 |
| French edible small | -- | -- | 0.4 | Chapman, 1926 |
| *Buccinum undatum* | -- | -- | 11.4[b] | Leatherland & Burton, 1974 |
| PERIWINKLE | | | | |
| *Littorina littorea* | -- | -- | 12[b] | Leatherland & Burton, 1974 |
| | | | 14.0-19.0[b] | Leatherland & Burton, 1974 |
| *Littorina littorea*, oil | -- | -- | 84.0 | Lunde, 1972 |
| *Littorina littorea*, | 2 | 11.5 | 4.0 | Penrose *et al*., 1975 |
| fatty acid | -- | -- | 32.0 | Lunde, 1972 |
| Cooked | -- | -- | 3.6-6.3 | Costa & Da Fonseca, 1967 |
| CRAWFISH | | | | |
| *Palinurus vulgaris*, cooked | -- | -- | 12.0-54.6 | Costa & Da Fonseca, 1967 |
| *Palinurus vulgaris*, | -- | -- | 15.0-33.8 | Chapman, 1926 |
| *Astacus pallipes* | -- | -- | 0.8-1.5 | Chapman, 1926 |
| SQUID | | | | |
| *Ommastrephes sagittatus* | -- | -- | 6.5 | Lunde, 1968a |
| STARFISH | | | | |
| (*Asterias rubens*) | -- | -- | 10[b] | Leatherland & Burton, 1974 |
| Oil | -- | -- | 9.1 | Lunde, 1972 |
| Fatty acid | -- | -- | 7.5 | Lunde, 1972 |
| CUTTLEFISH | | | | |
| *Sepia officinalis*, gills | -- | -- | 198[b] | Leatherland & Burton, 1974 |
| *Sepia officinalis*, mantle | -- | -- | 73[b] | Leatherland & Burton, 1974 |
| *Sepia officinalis*, raw | -- | -- | 6.2-11.5 | Costa & Da Fonseca, 1967 |
| *Sepia officinalis*, cooked | -- | -- | 0.8-6.8 | Costa & Da Fonseca, 1967 |
| ANCHOVY | -- | -- | 7.1-10.7 | Lunde, 1973 |
| OCTOPUS | | | | |
| *Octopus bimoculatus*, tentacles | -- | -- | 0.12 | Gorgy *et al*., 1948 |
| *Octopus vulgaris*, raw | -- | -- | 2.6-40.3 | Costa & Da Fonseca, 1967 |
| cooked | -- | -- | 3.0-31.- | Costa & Da Fonseca, 1967 |
| COD (*Gadus morrhua*) | -- | -- | 0.3-24.3[b] | Cardiff, 1937; Lunde, 1973 Zook *et al*., 1976; & Kennedy, 1976 |
| Fillet | -- | -- | 2.2 | Lunde, 1968a |
| Fillet, N-liquor | -- | -- | 13.0 | Lunde, 1968a |
| Muscle | -- | -- | 0.4-0.8 | Sadolin, 1928 |
| Liver | -- | -- | 0.7-3.2 | Sadolin, 1928 |
| Liver, oil | -- | -- | 1.4-10.0 | Cardiff, 1937; Holmes & Remmington, 1934; Lunde, 1972; Luzanski, 1936; & Sadolin, 1928 |
| *Olphiodon elongatus* | -- | -- | 0.3 | LeBlanc & Jackson, 1973 |

Table 50.--Arsenic content of aquatic animal life--continued

| Animal | Exposure[a] | Arsenic Concentration (fresh wt) | | References |
|---|---|---|---|---|
| | | Exposed | Normal | |
| | | - - - - ppm As - - - - | | |
| BLACK MARLIN | | | | |
| Muscle | -- | -- | 0.1-1.65 | Mackay et al., 1975 |
| Liver | -- | -- | 0.1-2.75 | Mackay et al., 1975 |
| TUNA | -- | -- | 0.71-4.6 | Cardiff, 1937; & Orvini et al., 1974 |
| TUNNY (Thunnus thynnus) | -- | -- | 9.6[b] | Lunde, 1973a |
| yellowfin (T. albacares) | -- | -- | 0.1-0.9 | Zook et al., 1976 |
| HADDOCK (Melanogrammus eaglefinus) | -- | -- | 1.8-10.8[b] | Cardiff, 1937; Lunde, 1973a; Zook et al., 1976; & Reinke et al., 1975 |
| MULLET, red | -- | -- | 1.54 | Barela & Pezzeri, 1966 |
| DOGFISH | -- | -- | 0.53 | Barela & Pezzeri, 1966 |
| PLAICE | -- | -- | 4.5-7.5 | Chapman, 1926 |
| Fillet, oil (Pleuronectes platessa) | -- | -- | 6.1 | Lunde, 1972 |
| Fillet, fatty acid | -- | -- | 5.2 | Lunde, 1972 |
| R. hippoglossoides | -- | -- | 0.2-1.5 | Kennedy, 1976 |
| H. platessoides | -- | -- | 1.4-11.7 | Kennedy, 1976 |
| SOLE (Solea solea) | -- | -- | 5.2 | Chapman, 1926 |
| (Microstomus pacificus) | 2 | 1.3-1.5 | 3.1 | De Goeij et al., 1975 |
| Psettichtys melanostictus, Parophrys vetulus | -- | -- | 0.6-11.5 | LeBlanc & Jackson, 1973 |
| DAB | -- | -- | 2.2-3.0 | Chapman, 1926 |
| CAVIAR, Russian | -- | -- | 3.8 | Chapman, 1926 |
| PIKE (Esox lucius) | -- | -- | 0.8 | Chapman, 1926 |
| PILE | 1 | 0.0 | 0.0-0.11 | Thumann, 1940; & Thumann, 1941 |
| PERCH (Perca fluviatilis) | -- | -- | 0.6 | Chapman, 1926 |
| TENCH | -- | -- | 0.4 | Chapman, 1926 |
| BREAM | -- | -- | 0.4 | Chapman, 1926 |
| ROACH | -- | -- | 0.4 | Chapman, 1926 |
| | 1 | <0.09 | -- | Thumann, 1940; & Thumann, 1941 |
| TROUT, viscera | 2 | 5.3 | -- | Ellis, 1934 |
| Muscle | 2 | 2.4 | -- | Ellis, 1934 |
| | -- | -- | 0.069-0.149 | Pratt et al., 1972 |
| WHITEFISH, viscera | 2 | 3.6 | -- | Ellis, 1934 |
| Muscle | 2 | 2.7 | -- | Ellis, 1934 |
| SUCKER | | | | |
| Spotted, whole | -- | -- | 0.062-0.253 | Ellis et al., 1941; & Pratt et al., 1972 |
| White | -- | -- | 0.11 | Pillay et al., 1974 |

Table 50.--Arsenic content of aquatic animal life--continued

| Animal | Exposure[a] | Arsenic Concentration (fresh wt) | | References |
|---|---|---|---|---|
| | | Exposed | Normal | |
| | | - - - - ppm As - - - - | | |
| SHINER, golden | -- | -- | 0.55-1.95 | Ellis *et al.*, 1941 |
| BASS | | | | |
| Black, liver, oil | -- | -- | 7.37-77.31 | Ellis *et all*, 1941 |
| Black, large-mouth (*Micropterus salmoides*) | 1 | 0.07-0.93 | 0.01-1.86 | Ellis *et al.*, 1941 Pratt *et al.*, 1972; & Wiebe *et al.*, 1931 |
| White | -- | -- | 0.28-0.48 | Ellis *et al.*, 1941; & Pillay *et al.*, 1974 |
| CARP | -- | -- | 0.055-0.51 | Ellis *et al.*, 1941; Pillay *et al.*, 1974; Pratt *et al.*, 1972 Thumann, 1940; & Thumann, 1941 |
| CUNNER, (*Tautogolabarus adspersus*) | 2 | 0.6 | -- | Penrose *et al.*, 1976 |
| BLENNY (sp. unknown) | 2 | 0.4-0.8 | -- | Penrose *et al.*, 1976 |
| *LEPAS*, tissue | -- | -- | 7.6 | Johnson & Braman, 1975 |
| whole | -- | -- | 3.6 | Johnson & Braman, 1975 |
| *PORTUNUS*, whole | -- | -- | 5.5-6.5 | Johnson & Braman, 1975 |
| FILE FISH | -- | -- | 2.6 | Johnson & Braman, 1975 |
| KINGFISH | -- | -- | 8.86 | Schroeder & Balassa, 1966 |
| CATFISH | -- | -- | 0.07-0.298 | Pillay *et al.*, 1974; & Pratt *et al.*, 1972 |
| channel (*Ictalurus punctatus*) | -- | -- | 0.0-3.1 | Zook *et al.*, 1976 |
| (I. sp.) | -- | -- | 0.12-2.2 | Zook *et al.*, 1976 |
| HERRING, FILLET (*Clupera harengus*) | -- | -- | 1.4-3.8 | Lunde, 1968a; & Reinke *et al.*, 1975 |
| N-liquor | -- | -- | 6.4-24.0 | Lunde, 1968a; & Lunde, 1969 |
| Meal | -- | -- | 2.7-6.9[b] | Lunde, 1968a; Lunde, 1973a; & Bjornstad *et al.*, 1974 |
| Oil | -- | -- | 3.1-20.2 | Lunde, 1972; Lunde, 1973; Lunde, 1973b; & Sadolin, 1928 |
| Muscle | -- | -- | 2.0 | Sadolin, 1928 |
| MACKEREL (*Scomber scomber*) | -- | -- | 0.027-9.2[b] | Lunde, 1973a |
| Meal | -- | -- | 2.7-3.8 | Lunde, 1968 |
| Fillet, N-liquor | -- | -- | 3.2-17.0 | Lunde, 1968a; & Lunde, 1969 |
| Fillet | -- | -- | 1.5-3.5 | Leatherland & Burton, 1974; Lunde, 1968a; & Reinke *et al.*, 1975 |
| Fillet, oil | -- | -- | 8.2 | Lunde, 1972 |
| Fillet, fatty acid | -- | -- | 4.1 | Lunde, 1972 |
| Liver, oil | -- | -- | 13.0 | Lunde, 1972 |
| Liver, fatty acid | -- | -- | 6.2 | Lunde, 1972 |
| Oil | -- | -- | 4.3-15.0 | Lunde, 1973; & Lunde, 1973b |

Table 50.--Arsenic content of aquatic animal life--continued

| Animal | Exposure[a] | Arsenic Concentration (fresh wt) | | References |
|---|---|---|---|---|
| | | Exposed | Normal | |
| | | - - - - ppm As - - - - | | |
| CAPELIN | | | | |
| Meal | -- | -- | 2.6-19.1 | Lunde, 1968; & Lunde, 1973a |
| N-liquor | -- | -- | 10.3 | Lunde, 1969 |
| Oil (*Mallotus villosus*) | -- | -- | 5.2-23.2 | Lunde, 1972; Lunde, 1973; & Lunde, 1973b |
| Fatty acid | -- | -- | 6.3 | Lunde, 1972 |
| POUT | | | | |
| Norway, meal | -- | -- | 3.9 | Lunde, 1968 |
| Norway, oil | -- | -- | 11.8 | Lunde, 1973b |
| WHALE (*Balaenoptera physalus*) | -- | -- | 0.4 | Lunde, 1968a |
| N-liquor | -- | -- | 0.9 | Lunde, 1968a |
| COALFISH (*Pollachius virens*) | -- | -- | 7.2[b] | Lunde, 1973a |
| FLOUNDER (*Limanda ferruginea*) | -- | -- | 2.1-10.3 | Zook *et al.*, 1976 |
| Witch, muscle | -- | -- | 24.0 | Penrose *et al.*, 1977 |
| HAKE (*Merluccius productus*) | -- | -- | 0.2-1.0 | Zook *et al.*, 1976 |
| (*M. bilinearis*) | -- | -- | 2.3-5.4 | Zook *et al.*, 1976 |
| HALIBUT (*Hippoglossus stenolepis*) | -- | -- | 0.8-3.9 | Zook *et al.*, 1976 |
| HALIBUT | -- | -- | 1.8 | Reinke *et al.*, 1975 |
| PERCH (*Sebastes marinus*) | -- | -- | 0.4-3.2 | Zook *et al.*, 1976; & Kennedy, 1976 |
| POLLOCK (*Pollachius virens*) | -- | -- | 1.1-4.7 | Zook *et al.*, 1976 |
| ROCKFISH | -- | -- | 0.1-0.6 | Zook *et al.*, 1976 |
| (*Sebastes* sp.) | -- | -- | <0.3-2.6 | LeBlanc & Jackson, 1973 |
| SNAPPER, red (*Lutjanus campechanus*) | -- | -- | 0.2-1.0 | Zook *et al.*, 1976 |
| SALMON SOCKEYE (*Oncorhynchus nerka*) | -- | -- | 0.2-0.4 | Zook *et al.*, 1976 |
| (O. sp.) | -- | -- | <0.4 | LeBlanc & Jackson, 1973 |
| SHARK (*Hexanchus griseus*) | -- | -- | <0.4-5.9 | LeBlanc & Jackson, 1973 |
| DOGFISH (*Squalus acanthias*) | -- | -- | 1.5-5.6 | LeBlanc & Jackson, 1973 |
| SKATE (*Raja* sp.) | -- | -- | 16.2 | LeBlanc & Jackson, 1973 |
| RATFISH (*Hydiolagus colliet*) | -- | -- | 0.4-103 | LeBlanc & Jackson, 1973 |
| STEELHEAD (*Salmo* gairdneri | -- | -- | <0.4 | LeBlanc & Jackson, 1973 |
| Eggs | 1 | 1.0-4.8 | <0.1-0.2 | Dabrowski, 1976 |
| GREENLING (*Hexagrammos* sp.) | -- | -- | <0.4-0.8 | LeBlanc & Jackson, 1973 |
| SUNFISH (*Lepomis Cyanellus*) | 1 | 15-250 | 1-15 | Sorensen, 1976 |
| *PAGELLUS ERYTHRINUS* | 2 | 5.1-19 | 1.5-8.8 | Papadopoulou *et al.*, 1973 |

Table 50.--Arsenic content of aquatic animal life--continued

| Animal | Exposure[a] | Arsenic Concentration (fresh wt) | | References |
|---|---|---|---|---|
| | | Exposed | Normal | |
| | | - - - - ppm As - - - - | | |
| NORTH ATLANTIC FINFISH | | | | |
| Catfish (*Bagre marinus*) | -- | -- | <1.0[b] | Windom *et al.*, 1973 |
| Eel (*Anguilla rostrata*) | -- | -- | <1.0[b] | Windom *et al.*, 1973 |
| Flounder (*Paralichthys lethostigma*) | -- | -- | <1.0[b] | Windom *et al.*, 1973 |
| *Decapterus punctatus* | -- | -- | 1.8[b] | Windom *et al.*, 1973 |
| Eel (*Conger* sp.) | -- | -- | <1.0[b] | Windom *et al.*, 1973 |
| Anchovy (*Anchova mitchelli*) | -- | -- | 2.1[b] | Windom *et al.*, 1973 |
| Mullet (*Mugil cephalus*) | -- | -- | <1.1[b] | Windom *et al.*, 1973 |
| *Hygophum hygomi* | -- | -- | <1.0[b] | Windom *et al.*, 1973 |
| *Ceratoscopelus warmingil* | -- | -- | <1.0[b] | Windom *et al.*, 1973 |
| *Notoscopelus caudispinous* | -- | -- | <1.0[b] | Windom *et al.*, 1973 |
| *Lobianchia dofleini* | -- | -- | <1.0[b] | Windom *et al.*, 1973 |
| *Lepidophanes indicus* | -- | -- | <1.0[b] | Windom *et al.*, 1973 |
| *Diaphus mollis* | -- | -- | <1.0[b] | Windom *et al.*, 1973 |
| *Lampanyctus pusillus* | -- | -- | 1.0[b] | Windom *et al.*, 1973 |
| *Ophichthus ocellatus* | -- | -- | 1.0[b] | Windom *et al.*, 1973 |
| *Ophichthus gomesi* | -- | -- | 1.0[b] | Windom *et al.*, 1973 |
| *Morone saxatilis* | -- | -- | 1.8[b] | Windom *et al.*, 1973 |
| Sea trout (*Cynoscion nebulosus*) | -- | -- | 2.5[b] | Windom *et al.*, 1973 |
| *Euthynus alletteratus* | -- | -- | 1.1[b] | Windom *et al.*, 1973 |
| *Scomberomorus maculatus* | -- | -- | 1.8[b] | Windom *et al.*, 1973 |
| *Centropristes striatus* | -- | -- | 6.4[b] | Windom *et al.*, 1973 |
| COASTAL ORGANISMS: | | | | |
| ENGLAND | | | | |
| *Halichondria panicea* | -- | -- | 2.8[b] | Leatherland & Burton, 1974 |
| *Tealia felina* | -- | -- | 72.0[b] | Leatherland & Burton, 1974 |
| *Nereis diversicolor* | -- | -- | 5.2[b] | Leatherland & Burton, 1974 |
| *Palaemon elegans* | -- | -- | 16.0[b] | Leatherland & Burton, 1974 |
| *Patella vulgata* | -- | -- | 11-24[b] | Leatherland & Burton, 1974 |
| *Crepidula fornicata* | -- | -- | 8.1-13.0[b] | Leatherland & Burton, 1974 |
| *Nucella lapillus* | -- | -- | 16.0-38.0[b] | Leatherland & Burton, 1974 |
| *Styela clava* | -- | -- | 4.8[b] | Leatherland & Burton, 1974 |
| *Botryllus schlosseri* | -- | -- | 6.6[b] | Leatherland & Burton, 1974 |
| *Anguilla anguilla*, muscle | -- | -- | 1.7[b] | Leatherland & Burton, 1974 |
| *Marone labras*, muscle | -- | -- | 7.1[b] | Leatherland & Burton, 1974 |
| *Platichthys* flesus, muscle | -- | -- | 8.7[b] | Leatherland & Burton, 1974 |
| SHELLFISH, PORTUGAL | | | | |
| Rock shell (*Murex trunculus*) cooked | -- | -- | 14.6-26.4 | Costa & Da Fonseca, 1967 |
| *Donax trunculus* | -- | -- | 1.8-3.7 | Costa & Da Fonseca, 1967 |
| *Solen marginatus*, | -- | -- | 1.9-4.2 | Costa & Da Fonseca, 1967 |
| cooked | -- | -- | 1.4-2.7 | Costa & Da Fonseca, 1967 |
| *Aristeus antennatus* | -- | -- | 4.4-19.6 | Costa & Da Fonseca, 1967 |
| *Aolliceps cornucopia*, cooked | -- | -- | 1.2-8.6 | Costa & Da Fonseca, 1967 |

Table 50.--Arsenic content of aquatic animal life--continued

| Animal | Exposure[a] | Arsenic Concentration (fresh wt) | | References |
|---|---|---|---|---|
| | | Exposed | Normal | |
| | | - - - - ppm As - - - - | | |
| MISCELLANEOUS | | | | |
| Sand dollars (*Echinarachinius parma*) | -- | -- | 1.5-10.8[b] | Penrose *et al.*, 1975 |
| Sea urchins (*S. droebachiensis*) | 2 | 5.8[b] | 2.5[b] | Penrose *et al.*, 1975 |
| Bluegills (*Lepomis macrochirus*) | -- | -- | 0.52 | Ellis *et al.*, 1941 |
| | 1 | 0.09-11.6 | -- | |
| Gar, long-nosed | -- | -- | 0.35-0.40 | Ellis *et al.*, 1941 |
| Shad, gizzard | -- | -- | 0.13-1.47 | Ellis *et al.*, 1941; & Pillay *et al.*, 1974 |
| Small-mouthed buffalo | -- | -- | 0.05-2.75 | Ellis *et al.*, 1941 |
| Brook silversides | -- | -- | 0.30-1.26 | Ellis *et al.*, 1941 |
| Drum, freshwater | -- | -- | 0.09 | Pillay *et al.*, 1974 |
| Salmon, coho | -- | -- | 0.09 | Pillay *et al.*, 1974 |
| Minnows | -- | -- | 0.14-1.95 | Ellis *et al.*, 1941 |
| Pickerel | -- | -- | 0.13-0.73 | Ellis *et al.*, 1941 |
| Black bullhead | -- | -- | 0.22 | Ellis *et al.*, 1941 |
| Horned dace | -- | -- | 0.42-0.65 | Ellis *et al.*, 1941 |
| *Gambusia* | 1 | 0.07-101.9 | -- | Isensee *et al.*, 1973; & Woolson *et al.*, 1976 |
| Snail | 1 | 0.61-68.3 | -- | Isensee *et al.*, 1973 |
| Crustacean, planktonic | -- | -- | 3.2-5.5 | Ellis *et al.*, 1941 |
| Sea star (*Pisoster ochraceus*) | -- | -- | 1.26[b] | Gorgy *et al.*, 1948 |
| Fish, muscle | -- | -- | 3.06-6.8 | Hoover *et al.*, 1974 |
| *Daphnia magna* | 1 | 3.6-254 | -- | Isensee *et al.*, 1973; & Woolson *et al.*, 1976 |
| *Procambarus* sp. | 1 | 2.8-4.3 | -- | Woolson *et al.*, 1976; & Schuth *et al.*, 1974 |
| Zooplankton | -- | -- | 0.9-8.9 | Kennedy, 1976 |

[a] 1 = fed arsenic; 2 = pollution.

[b] Dry weight.

Arsenault (1975) reported on residues in the soil around treated poles. The North Carolina poles were in place for 32 years and the Florida samples for 7 or 26 years. The former were treated with CCA-A and the latter with CCA-B or CCA-A, respectively. Residues decreased with distance from the post or pole and averaged 53.0 ppm at 0 to 5.0 cm from the post and 30 cm deep. At a distance 28 to 33 cm from the post, residues declined to 16.3 ppm As with control levels of 14.2 ppm As. In posts at Orange Park, Fla., CCA-B-treated posts had higher soil residues than those treated with CCA-A. Residues again declined with distance of the samples from the post. Stakes treated with CCA-C 5 years before sampling had soil residues at 2.5 cm from the stake of 9.3 ppm As. The average at 15 cm was 8.9 ppm As. All values were within the range normally expected in soil (Arsenault, 1975). Lower soil residues were found with CCA-C treatments than with types A or B because type C forms more insoluble compounds in the wood than the other formulations.

In another study in Mississippi, soil was sampled beneath and adjacent to stakes treated with CCA-type I, type II, or ACA. The stakes were in place for about 30 years. Residues at 0 to 15 cm beneath the stake were highest with CCA-II and ACA (108.1 and 79.4 ppm As, respectively). Only type II-treated stakes had elevated residues at the 15 to 30 cm depth. Residues adjacent to the stake were 73.2, 183.2, and 220.9 ppm As for CCA-Type I, II, and ACA, respectively, in 15 cm cores. At 15 cm from the stakes, residues had declined to 1.3, 6.0, and 7.2 ppm As. Background levels were 1.3 ppm As (De Groot, et al., 1979).

Soil As levels adjacent to CCA-treated wooden foundations varied from 2 to 331 ppm As and averaged 41 ppm As (Sleater and Berger, 1977). The two highest levels had total soil As/Cr ratios of 6.3:1 and 9.1:1. Most soils had ratios less than 0.5:1 while treated wood has a ratio of about 0.5:1. This might indicate some other source for As than the treated wood, perhaps a pesticide treatment or contaminated fill dirt.

From these results, one can conclude that there is little environmental hazard from the leaching of As from arsenically treated wood. The As which does leach from the wood is limited to a very short distance around the post, stake, pole, or wall.

## Residues from Recommended Field Pesticide Application

The increase of As residues in soil is commonly reported from the past use of lead arsenate in orchard areas in this country. Annual applications historically have ranged from 34 to 100 kg As/ha. At present, little lead arsenate is applied. The amounts annually applied have often been so large that normal metabolic transformations have been unable to limit the buildup of these residues over the years. As a result of these high application rates, soil residues have increased and are summarized in Table 51. Residues as great as 2,553 ppm As have been reported, but 100 to 200 ppm As are more common.

Residues from the use of sodium arsenite to kill potato vines prior to harvest are much lower, averaging in the 20 to 50 ppm As range. Toxicity at these levels to subsequent crops has not been reported while orchard soils have become phytotoxic in some cases. Other uses where application rates are much lower seldom involve large soil residues.

Results of the National Soils Monitoring Program indicate that As was found in 99.3% of 1,726 samples analyzed (Wiersma, et al., 1972). Residues ranged from 0.2 to 107 ppm As with a mean of 6.3. "It is probable that most of (the) As (reported) was from natural sources, although agricultural sources cannot be ruled out . . . ."

Table 51.--Arsenic accumulation from recommended field pesticide applications

| Pesticide Applied | Total Application | Residue Found | Background | Reference |
|---|---|---|---|---|
| | | - - - - - - - ppm As | - - - - - - - | |
| Lead arsenate | -- | x = 47.7; 25.5-138.0 | 2.51-5.00 | Headden, 1910 |
| Lead arsenate | -- | 0.68-1.34 (soluble) | | |
| Lead arsenate | -- | 60(0-3 inches) | 7 | Williams & Whetstone, 1940 |
| Lead arsenate | | 140-240 | -- | |
| Lead arsenate | | 9.8-124.4 | trace 7.9 | Bishop & Chisholm, 1962 |
| Lead arsenate | | 0.4-9.0 (water soluble) | | |
| Lead arsenate | | 30-145 | | Thompson & Batjer, 1950 |
| | | 0.51-1.82 (soluble) | | |
| Lead arsenate | 504 kg As/ha | 276 (54.7% left after 16 years | | Chisholm & MacPhee, 1972 |
| Lead arsenate | -- | 4-2,553 | 13 | Woolson _et_ _al_., 1971 |
| Calcium arsenate | | 1-40 (Maine) | 9 | Woolson _et_ _al_., 1971 |
| | | 0-7 (Florida) | -- | Woolson _et_ _al_., 1971 |
| Sodium arsenite | | 18-28 (Florida) | 8 | Woolson _et_ _al_., 1971 |
| | | 14-193 (Wisconsin) | 1 | Woolson _et_ _al_., 1971 |
| Lead arsenate | | 0-427 | | Benson, 1976 |
| Lead arsenate | 2500 kg a.i./ha | 9.6-102.2 (0-2") | | Aten _et_ _al_., 1980 |
| | | 26.3-100.8 (2-4") | | |
| Sodium arsenite | 7-20 kg As/year | 10.5-21.8 (increase after 5 years) | | Murphy & Goven, 1966 |
| Sodium arsenite | 0-96 kg As/ha | 2.2-25.9 | | Steevens _et_ _al_., 1972 |
| Calcium arsenate | -- | 1-5 | 4 | Small & McCants, 1961 |
| Lead arsenate | | 10-121 | 1-9 | Miles, 1968 |
| Lead arsenate | | 17-439 | 3-14 | Jones & Hatch, 1945 |
| Lead arsenate | | 106-830 | 6-13 | Benson, 1953 |
| Lead arsenate | | 48 | 4-13 | Vandecaveye _et_ _al_., 1936 |

Residues above the average (and the number of samples analyzed) were found in Arizona (6.58, 8), Arkansas (8.98, 47), Illinois (8.05, 142), Indiana (7.88, 75), Iowa (7.51, 152), Kentucky (8.41, 31), Maine (16.01, 8), Massachusetts (9.75, 2), New Jersey (11.72, 5), New York (9.38, 35), North Dakota (8.5, 158), Ohio (11.23, 69), Pennsylvania (10.8, 29), Rhode Island (21.3, 1), and Tennessee (8.05, 27).

Values in noncropland in the same study averaged 5.01 ppm As and ranged from 0.33 to 54.17 ppm As. Above average values were found in Arizona (6.63, 44), Idaho (7.73, 26), Iowa (7.08, 7), Maine (5.14, 8), Maryland (8.43, 3), Washington (6.94, 21), and West Virginia (5.16, 6). Levels for noncropland in Maine were about 30% of those in crop areas. Other residues are not very different.

Residues from experimentally applied arsenicals are summarized in Table 52. Total applications have been as high as 2,690 kg As/ha. In all cases, residues have declined. The loss of As from soil has ranged from 0.020%/day to 0.193%/day of the total As present. The average loss for the studies cited is 0.073, which translates into 26%/year. The mechanism behind this loss will be discussed under soil metabolisms later in this chapter.

## Soil Levels from Anthropogenic Sources

Soil As may occur as a result of burning coal and smelting ore as emission sources. It has been well documented that small-diameter particulate matter escapes most stack scrubbers and precipitators (Kaakinen, et al., 1975). Balance studies indicate that approximately 50% of the As entering into the combustion system is lost to the atmosphere (Bolton, et al., 1973; Lyon and Emery, 1975). In an attempt to examine As residues in soil from the burning of coal, soil samples were collected on a north-south transect up to 20 miles from the Allen steam plant. Samples to the north contained 10.0 and 11.5 ppm total As and 7.4 and 7.6 south of the plant. Since winds are generally south to north, the results indicate a slight accumulation of As downwind from the plant.

Wiersma, et al. (1972) and Carey, et al. (1976) compared soil levels in urban and cropland soils as part of their reports on the National Soils Monitoring Program (Table 53).

They concluded that the geometric means tended to separate the cities into two general classes--those with greater than 5 ppm total soil As and those with levels less than 2 ppm As. The variations in total As are probably attributable to differences in geological conditions or possible contamination from industrial or combustion sources. In only five cases were levels lower in cities than in cropland where As may have been applied. In the other 12, levels were higher in the cities. However, the higher soil concentrations cannot be accurately ascribed to human activities. Natural As levels are dependent on parent material and most urban soil profiles are disturbed by such actions as construction, removal of topsoil, or use of fill from other areas.

Soil As levels in the vicinity of Zn, Ag, or Cu smelters have been measured. Soil levels surrounding the Tacoma, Wash., smelter of ASARCO were highest in the immediate vicinity of the stack (380 ppm) and the closest points on Vashon (93 to 186 ppm) and Maury Islands (100 to 338 ppm As) (Crecelius, et al., 1975). The islands are at least 4 km to the north-northeast of the smelter. The prevailing winds are from the south-southwest. Soils to the south-southwest did have elevated (<1-89 ppm) As levels, but not as high as those samples collected downwind. Soil levels decrease with distance from the stack.

Table 52.--Arsenic soil residues after experimental treatment

| Arsenical Applied | Total Application | Years After Application | Residue Initial[a] | Final | Reference |
|---|---|---|---|---|---|
| | kg As/ha | Yrs | - - - ppm As | - - - | |
| $NaAsO_2$ | 253 | 10 | 99 | 16 | Tammes & de Lint, 1969 |
| | 101 | 10 | 36 | 9 | |
| | 51 | 10 | 14 | 4 | |
| $NaAsO_2$ | 720 | 2 | 250 | 150 | Jacobs *et al.*, 1970 |
| | 180 | 2 | 73 | 63 | |
| | 90 | 2 | 23 | 26 | |
| | 45 | 2 | 11 | 19 | |
| | 0 | 2 | 3 | 3 | |
| $Ca_3(AsO_4)_2$ | -- | -- | 21-135 | | Woolson *et al.*, 1971 |
| $NaAsO_2$ | 720 | 0.33 | 250 | 193 | Woolson *et al.*, 1971 |
| | 180 | 0.33 | 73 | 48 | |
| | 90 | 0.33 | 23 | 40 | |
| | 45 | 0.33 | 11 | 14 | |
| | 0 | -- | 3 | 1 | |
| $NaAsO_2$ | 2,690 | 14 | -- | 318-435 | Isensee *et al.*, 1973a |
| $NaAsO_2$ | 115 | 7 | 4.6[b] | 62 | Woolson & Isensee, 1979 |
| | 32 | 7 | 4.6[b] | 20 | |
| | 16 | 7 | 4.6[b] | 6 | |

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[a] Residue after application.

[b] Residue before application.

Table 53.--Arsenic levels reported in the national soils monitoring program

| State | Urban | Cropland | Significance[a] |
|---|---|---|---|
| California | 7.1 | 5.2 | |
| New Jersey | 11.2 | 6.8 | |
| Florida | 2.3 | 0.8 | |
| Wisconsin | 14.4 | 3.8 | |
| Utah | 15.7 | 4.8 | |
| Connecticut | 8.5 | 10.0 | |
| Maine | 4.0 | 7.7 | X |
| South Carolina | 2.1 | 1.4 | NS |
| Wyoming | 0.6 | 0.3 | NS |
| Michigan | 3.7 | 3.4 | NS |
| Mississippi | 5.5 | 5.0 | NS |
| Tennessee | 5.8 | 6.9 | NS |
| Alabama | 0.8 | 0.3 | NS |
| Pennsylvania | 8.5 | 7.2 | NS |
| Virginia | 1.2 | 1.2 | NS |
| Missouri | 2.2 | 4.1 | X |
| Iowa | 7.0 | 2.4 | XX |
| Delaware | 3.5 | 4.3 | NS |

[a] X = 95% confidence; XX = 99% confidence that levels are different between areas; and NS = not significant.

Arsenic accumulation in soil from smelter operations around Salt Lake City was examined by Wullstein and Snyder (1971). Surface soil levels were 110 and 740 ppm As. A downwind site on the north end of the Oquirrh Mountains was considered to be under more or less constant influence of local smelter emissions. Control samples west of the smelter area averaged 10 ppm As.

Soil As levels around an urban secondary lead smelter were as high as 533 ppm As and averaged 70 for 40 samples up to 600 meters from the smelter (Linzon, et al., 1976). Soil levels were much less in the vicinity of a battery manufacturer in the same area and ranged from 3.3 to 30.8 ppm with an average of 9.0 ppm. The As level for a control area was 9.5 ppm.

A smelter in East Helena, Mont., was found to be a source of soil As in a limited area. "Soil samples collected from the upper 10 cm layer within 1.6 km of the smelter stack contain up to 150 ppm As and commonly contain more than 50 ppm. The As content decreases systematically away from the stack for a distance of 8 to 16 km . . . ." (Miesch and Huffman, 1972). Other soils in the Helena Valley area contained 25 to 50 ppm total As as a result of emission sources (Hindawi and Neely, 1972).

Arsenic contents are also a reflection of the soil's parent material composition. Colbourn, et al. (1975) reported soil levels near a smelter of up to 2,500 ppm As. Soils remote from the smelter, however, contained up to 95 ppm As, a reflection on the parent material from which the soil formed. Some soils are naturally high in As. Rhodesian soils associated with gold deposits or reefs usually contain between 300 to 5,000 ppm As (Wild, 1974).

Gold smelters are also a source of As emissions as the ores contain arsenosulfides. Soil 300 m from the smelter stack had contents of 147 ppm and levels declined to a constant 11 ppm at distances greater than 8 km (Amasa, 1975). Tailings from gold mines are also a source of As. Surface concentrations in the Getchell study area (Nevada) ranged from 169 to 6,138 ppm As while 0- to 15-cm cores ranged from 52 to 644 ppm As. Highest concentrations were closest to the tailings with levels declining rapidly with distance from the pile. Levels up to 800 ppm were found at various depths down to 60 cm at the most heavily contaminated site (Comanor, et al., 1974). Tailings from abandoned As mines can contaminate the surrounding soil (Rocovich and West, 1975). Soil levels from a mine in Virginia ranged from 100 to 41,200 ppm As. Plants were growing even on these high As containing soils.

Another potential source of soil As involves the land disposal of fly ash or municipal sludge. Fly ash contained 139 ppm As while Milwaukee sludge contained 22.8 ppm As (Furr, et al., 1976, and 1976a). The addition of 10% fly ash or sludge mixed with soil resulted in no significant increase in plant As concentrations.

## Fate of Arsenic in Soil

### Sorption Products and Their Chemical Nature

Arsenic, both arsenate and arsenite, forms very insoluble complexes in soil systems. They react with the hydrous oxides coating clay particles or with cations in solution. Many studies have examined the nature of this adsorption and the factors which affect it.

Autoradiography, electron microscopy, and electron probe microanalysis were used to measure the location of added arsenate on the soil component. In Kent sand (<2 micron fraction was 80% Kaolinite, 1 to 5% interstratified vermiculite, 5% iron oxide) arsenate was retained by the goethite particles which also held the native phosphorus (Fordham and Norrish, 1974). Mica minerals, as they are weathered, strongly sorb arsenate (Stewart, et al., 1975). The sorption is a function of the spacing in the clay lattice and the amount of the hydroxyaluminum present on the clay surfaces.

Retention of As was proportional to sesquioxide content and decreased as the amorphous Fe and Al compounds were removed (Jacobs, et al., 1970). Most As was bound to the Fe fraction with lesser amounts bound to Al (Woolson, et al., 1971). Water-soluble As was least prevalent and the amount bound to Ca was slightly higher.

Ion products for arsenate in two soils revealed that equilibrium solutions from both soils were undersaturated with respect to Fe, Al, and Ca, and that Pb and Mn arsenate were stable, i.e., saturated (Hess and Blanchar, 1976). Arsenate and phosphate are bound to the same sites and also form a coprecipitate with Al in soils (Fassbender, 1975).

Arsenic becomes bound more tightly with time after application. The rate of fixation is a function of soil type (i.e., available reactive sites) and the amount of As added. Clay soils which are high in Fe and Al and low application rates will favor very fast binding times. Conversely, soils with low adsorption capacities and high levels of application will increase the binding time (Woolson, et al., 1973). In extreme cases the time necessary to reach equilibrium conditions will vary from hours to about 20 weeks.

Arsenite fixation is affected by the presence of arsenate in the soil (Misra and Tiwari, 1963). The formation of arsenite in soil is a function of pH and Eh. At normal soil pH values (4.5 to 8.0), reduction in soil occurs at Eh values of 0.4 to 0.3 volt. The same Eh values are approximately correct for As in solution (Bohn, 1976). As the Eh of the soil is reduced, the amount of soluble As increases. Whether this As is arsenate or arsenite is not known. The Nernst equation for a moderately oxidized soil (+200 mv) predicts an arsenite/arsenate ratio of $2.19 \times 10^{-11}$ at pH 8.0 (Deuel and Swoboda, 1972). Soil has Eh values in the range of 0.3 volt only when they are flooded.

## Desorption of Arsenic from Soil

Arsenic and phosphorus are in the same periodic family and have similar chemical and physical properties. Since they adsorb on soil components in an analogous manner, they should be competitive for sorption sites. Arsenate solutions have been used to extract phosphate from soils (Barrow, 1974). Lithium arsenate was more effective than sodium arsenate; however, arsenate did not prevent the sorption of some phosphate from solution. In an experiment designed to simulate high-phosphate additions to orchard soils containing high As residues, 77% of the total As present was removed by $KH_2PO_4$ (Woolson, 1973). The relative distribution of chemical forms changed during the leaching process. The more water soluble aluminum-arsenate declined from 39 to 19% of the amount remaining while the percentage of the less water soluble Fe-arsenate increased. The more water-soluble forms leach into the subsoil and are sorbed lower in the profile.

## Leaching of Arsenic from Soil

Arsenic generally is sorbed tightly to the soil surface and is moved deeper into the profile only by mixing due to tillage. However, if sufficient As is present and the sorptive capacity of the soil is low, As can be moved into the subsoil by leaching. Significant movement in agricultural soils only occurs on sandy soils.

Tammes and de Lint (1969) observed some movement of As into the subsoil from a sandy loam. High concentrations were found down to 60 cm in soils next to tailings from a gold mine (Comanor, et al., 1974). The soil adsorption sites were likely completely saturated since surface levels of 6,138 ppm As were found. Residual As levels were found down to 46 cm from a surface application of 2,690 kg/ha As applied as sodium arsenite 14 years previously (Isensee, et al., 1973). Levels declined from 318 ppm As in the 0 to 8 cm layer to 42 ppm As at 38 to 46 cm. When 2,690 kg/ha of sodium chlorate were added at the same time, levels declined from 435 ppm As in the 0 to 8 cm layer to 27 ppm As in the 38 to 46 cm layer.

The rate of application as well as volume of water passing through the soil affect the movement of As at high application rates. No As appeared in filtrates when soil was treated with 760 or 6,080 ppm As and leached with 1 liter of water. Arsenic did appear in the filtrate at the 6,080 ppm As rate leached with 5 liters of water. The depth of movement of As added at high levels in the soil columns was related to both treatment rate and elution volume on Chenango silt loam soil (Arnott and Leaf, 1967).

Arsenic moves more readily in sandy soils. Even so, no detectable increase in As below the 23 cm level was seen at rates up to 180 kg As/ha applied as sodium arsenite to Plainfield sand. At 720 kg As/ha, a significant increase in As levels was observed in the 23 to 53 cm layer 3 years after application (Steevens, et al., 1972). However, these data are not representative of typical field applications due to the high amount of As added.

## Transformation of Arsenic in Soil

Transformation of As in soil involves two reactions--oxidation/reduction, and methylation. The oxidation/reduction reactions can be a combination of chemical and microbiological processes. Chemical redox reactions are governed by the iron and pH levels (Keaton and Kardos, 1940). High iron levels favor the oxidation of arsenite to arsenate. Aluminum does not affect the redox reactions. However, the redox potential in soils is independent of any individual oxidant or reductant. Because soil is so complex and very few individual oxidants or reductants can be identified, the redox potential must be considered as representing a complex unit.

Microbial redox reactions also occur. A strain of Alcaligenes isolated from soil possessed the ability to oxidize arsenite to arsenate. Response of the arsenite-oxidizing enzyme system to respiratory inhibitors suggests that electrons are transferred via cytochrome C and cytochrome oxidase to oxygen (Osborne and Ehrlich, 1976).

On the other hand, isolates of Pichia guillermondii and Micrococcus sp. obtained from soil were reported to convert arsenate to arsenite (Bautista and Alexander, 1972). The capacity to reduce a number of anions including arsenate was found to be common to some soil microorganisms. One problem with this study, however, was the means of detecting arsenite. The conversion of arsenate to arsenite was determined by the decoloration of iodine. The gas, $H_2S$, will also decolor iodine and, since sulfate was present in the medium, it may have been the reducing agent, not arsenite. A more specific test for arsenite would have been helpful.

The formation of alkylarsines in the environment has been reported. Dimethylarsine and trimethylarsine were detected in air above grass which had been sprayed with sodium arsenite (Braman, 1975). Woolson (1977) went a step further and isolated dimethylarsine in air from sodium arsenate-treated soil. Only small amounts of trimethylarsine (1% and 1.8% of the added arsenate after 160 days under aerobic and anaerobic conditions, respectively) were also detected.

Arsenic in soil can influence microbial reactions. In soil comtaminated from smelter emission sources, soil residue levels of 100 to 245 ppm As decreased the rate of nitrification. No other metal measurements were made, however, so the causative agent cannot be clearly established (Wullstein and Snyder, 1971).

# Arsenic in Plants

Market basket surveys by FDA have examined vegetables not grown on As-treated soils for As contents over a period of many years. Mahaffey, et al. (1975) estimated a total As consumption in a typical diet at 7.7 micrograms As/capita/day. Twenty percent (1.51 micrograms As) came from grain, cereal, and potatoes each day. Grains and cereal products had 0.023 ppm As while potatoes had 0.0025 ppm As. Leafy, root, and legume vegetables, fruits, and garden fruits contained no detectable As levels. Daily intake levels for As have declined from 48 micrograms As/day in 1965 to 1970 to 7.6 in 1973, but increased to 16.0 in 1974. A change in the analytical method caused this apparent decline in arsenic consumption. A further change in the analysis method shows the current level of arsenic in the U.S. diet is about 60 micrograms per person per day (Horwitz, 1980). A 60-kg woman will consume 0.27 microgram As/kg/day from food.

Canada has examined As levels in its food supply over a number of years (Smith, et al., 1972; Smith, et al., 1973; and Smith, et al., 1975). In no year was the consumption greater than 35 micrograms As/person/day. Average As contents for the 4-year period were: cereals, 0.011 mg/kg; potatoes, 0.010 mg/kg; leafy vegetables, 0.008 mg/kg; legumes, 0.010 mg/kg; roots, 0.014 mg/kg; garden fruits, 0.011 mg/kg; and fruits, 0.010 mg/kg.

Arsenic levels in English plant materials are: cereals, 0.18 mg/kg; root vegetables, 0.08 mg/kg; fruits and preserves, 0.07 mg/kg; the total As dietary intake was estimated to be 100 micrograms/day (Hamilton and Minski, 1972/73). The Japanese daily intake is reported to be between 70 to 170 microgram As/day (Nakao, 1960). The higher intake in the Japanese to the U.S. diet may be due to a higher consumption of seafood.

## Arsenic Concentrations in Plants

### Arsenic Residues from Use of Wood Preservatives

One study was conducted relative to As uptake in plants growing adjacent to treated wood (Levi, et al., 1974). Grapes (*Vitis rotundifolia* Michx. cv. Magnolia) were planted 3 inches from CCA-treated southern pine posts. Arsenic contents in all samples of fruit and leaves were below 0.05 ppm As (the detection limit), indicating that As uptake by plants growing in soil close to treated stakes and poles is minimal.

### Plant Arsenic Residues from Application of Pesticides

Residues from field applications of arsenical pesticides can arise from normal applications to uncontaminated soil, or from soil which has been highly contaminated from past use of high applications of arsenicals. A listing of experimental studies which determined plant As concentrations is presented in Table 54. The soil type (where known) or some general characteristic of the soil will provide an estimate of the availability of the soil As residues for plant uptake. Data on individual plant parts have been presented where available.

Table 54.--Arsenic residues in plants from pesticidal and experimental applications of arsenical compounds

| Chemical Applied | As Level | Type |  | Plant |  | FW-Fresh Weight DW-Dry Weight | Reference |
|---|---|---|---|---|---|---|---|
|  |  | Soil | Study F-Field/ E-Experimental | Part | As Level |  |  |
|  | ppm |  |  |  | ppm |  |  |
| Lead arsenate | 0.17-141.0 | Lima silt loam | F | Tomato stem | 0.35-01.08 | DW | Aten *et* al. 1980 |
|  |  | ......do...... | F | Tomato, leaf | 0.66-2.95 | DW | .......do....... |
|  |  | ......do...... | F | Tomato, fruit | 0.01-0.02 | DW | .......do....... |
|  |  | ......do...... | F | Green bean stem | 0.50-1.93 | DW | .......do....... |
|  |  | ......do...... | F | Green bean, leaf | 1.37-3.17 | DW | .......do....... |
|  |  | ......do...... | F | Green bean, pod | 0.03-0.17 | DW | .......do....... |
|  | 3.0 | Melbourne clay loam | F | Green bean vines | 0.18 | DW | Jones and Hatch, 1945 |
|  | 66.5 | ........do......... | F | Green bean vines | 1.82 | DW | .........do.......... |
|  | 3.0 | ........do......... | F | carrot roots | 0.32 | DW | .........do.......... |
|  | 66.5 | ........do......... | F | carrot roots | 0.18 | DW | .........do.......... |
|  | 3.0 | ........do......... | F | peas | 0.06 | DW | .........do.......... |
|  | 66.5 | ........do......... | F | peas | 0.10 | DW | .........do.......... |
|  | 3.0 | ........do......... | F | vetch hay | 1.22 | DW | .........do.......... |
|  | 66.5 | ........do......... | F | vetch hay | 1.93 | DW | .........do.......... |
|  | 2.0 | Hood silt | F | eggplant (peeled) | 6.16 | DW | .........do.......... |
|  | 40.3 | ...do.... | F | eggplant (peeled) | 19.76 | DW | .........do.......... |
|  | 2.0 | ...do.... | F | onion | 0.36 | DW | .........do.......... |
|  | 40.3 | ...do... | F | onion | 0.36 | DW | .........do.......... |
|  | 2.0 | ...do.... | F | peas | 0.40 | DW | .........do.......... |
|  | 40.3 | ...do.... | F | peas | 0.49 | DW | .........do.......... |
|  | 2.0 | ...do.... | F | pepper | 0.40 | DW | .........do.......... |
|  | 40.3 | ...do.... | F | pepper | 0.47 | DW | .........do.......... |
|  | 4.6 | Meyer clay adobe | F | clover, white | 3.66 | DW | .........do.......... |
|  | 96.0 | .......do....... | F | clover, white | 6.26 | DW | .........do.......... |
|  | 4.6 | .......do....... | F | corn plant | 0.71 | DW | .........do.......... |
|  | 96.0 | .......do....... | F | corn plant | 2.77 | DW | .........do.......... |
|  | 4.6 | .......do....... | F | peas | 0.04 | DW | .........do.......... |
|  | 96.0 | .......do....... | F | peas | 0.04 | DW | .........do.......... |
|  | 4.6 | .......do....... | F | tomato plant | 6.78 | DW | .........do.......... |
|  | 96.0 | .......do....... | F | tomato plant | 11.52 | DW | .........do.......... |
|  | 4.0 | Neal silty clay loam | F | alfalfa hay | 1.98 | DW | .........do.......... |
|  | 115.0 | .........do......... | F | alfalfa hay | 3.98 | DW | .........do.......... |
|  | 4.0 | .........do......... | F | beet tops | 1.47 | DW | .........do.......... |
|  |  | .........do......... | F | beet, roots | .34 | DW | .........do.......... |
|  | 115.5 | .........do......... | F | beet, tops | 1.29 | DW | .........do.......... |
|  |  | .........do......... | F | beet, roots | 20.30 | DW | .........do.......... |
|  | 4.0 | .........do......... | F | kale | 0.27 | DW | .........do.......... |
|  | 115.5 | .........do......... | F | kale | 0.99 | DW | .........do.......... |
|  | 4.0 | .........do......... | F | lettuce | 0.12 | DW | .........do.......... |
|  | 115.5 | .........do......... | F | lettuce | 0.32 | DW | .........do.......... |
|  | 4.0 | .........do......... | F | tomato | 0.08 | DW | .........do.......... |
|  | 115.5 | .........do......... | F | tomato | 0.10 | DW | .........do.......... |

Table 54.--Arsenic residues in plants from pesticidal and experimental applications of arsenical compounds--continued

| Chemical Applied | As Level | Type |  | Plant |  | FW-Fresh Weight DW-Dry Weight | Reference |
|---|---|---|---|---|---|---|---|
|  |  | Soil | Study F-Field/ E-Experimental | Part | As Level |  |  |
|  | ppm |  |  |  | ppm |  |  |
| Lead arsenate | 24.5 | Berwick sandy loam | F | green beans | 0.01-0.02 | FW | Chisholm, 1972 |
|  |  | ........do........ | F | potato flesh | <0.01 | FW | ......do...... |
|  |  | ........do........ | F | potato, peel | 0.02 | FW | ......do...... |
|  |  | ........do........ | F | carrot | <0.01 | FW | ......do...... |
|  |  | ........do........ | F | corn | <0.01 | FW | ......do...... |
|  | 122.5 | ........do........ | F | green bean | 0.03-0.04 | FW | ......do...... |
|  |  | ........do........ | F | potato flesh | .03 | FW | ......do...... |
|  |  | ........do........ | F | potato, peel | 0.13 | FW | ......do...... |
|  |  | ........do........ | F | carrot | 0.03 | FW | ......do...... |
|  |  | ........do........ | F | corn | 0.02 | FW | ......do...... |
|  | 9.4 | Somerset sandy loam | F | green beans | <0.01 | FW | ......do...... |
|  |  | ........do......... | F | potato flesh | <0.01 | FW | ......do...... |
|  |  | ........do......... | F | potato, peel | <0.01 | FW | ......do...... |
|  |  | ........do......... | F | carrot | <0.01 | FW | ......do...... |
|  |  | ........do......... | F | turnip flesh | <0.01 | FW | ......do...... |
|  |  | ........do......... | F | turnip, peel | <0.01 | FW | ......do...... |
|  |  | ........do......... | F | swiss chard | <0.01 | FW | ......do...... |
|  |  | ........do......... | F | corn | <0.01 | FW | ......do...... |
|  | 53.6 | ........do......... | F | green bean | 0.01 | FW | ......do...... |
|  |  | ........do......... | F | potato flesh | 0.02 | FW | ......do...... |
|  |  | ........do......... | F | potato peel | 0.25 | FW | ......do...... |
|  |  | ........do......... | F | carrot | 0.03 | FW | ......do...... |
|  |  | ........do......... | F | turnip flesh | 0.02 | FW | ......do...... |
|  |  | ........do......... | F | turnip peel | 0.17 | FW | ......do...... |
|  |  | ........do......... | F | swiss chard | 0.05 | FW | ......do...... |
|  |  | ........do........ | F | corn | 0.01 | FW | ......do...... |
|  | 122 | Berwick sandy loam | F | oat seed | 0.74-1.03 | DW | Chisholm and MacPhee, 1972 |
|  |  | ........do......... | F | grass | 0.88-1.48 | DW | ...........do........... |
|  |  | ........do......... | F | clover | 1.32 | DW | ...........do........... |
|  |  | ........do......... | F | hay | 1.26-2.65 | DW | ...........do........... |
|  |  | ........do......... | F | beans | 0.13-0.25 | DW | ...........do........... |
|  |  | ........do......... | F | leaves | 0.25-4.58 | DW | ...........do........... |
|  |  | ........do......... | F | tomato | 0.09 | DW | ...........do........... |
|  |  | ........do......... | F | carrot flesh | 0.10 | DW | ...........do........... |
|  |  | ........do......... | F | carrot peel | 1.47 | DW | ...........do........... |
|  |  | ........do......... | F | potato flesh | 0.06 | DW | ...........do........... |
|  |  | ........do......... | F | potato peel | 0.92 | DW | ...........do........... |
|  |  | ........do......... | F | swiss chard | 0.27 | DW | ...........do........... |
|  |  | ........do......... | F | beet tops | 0.21 | DW | ...........do........... |
|  |  | ........do......... | F | onion | 0.16 | DW | ...........do........... |

Table 54.--Arsenic residues in plants from pesticidal and experimental applications of arsenical compounds--continued

| Chemical Applied | As Level | Type: Soil | Type: Study F-Field/ E-Experimental | Plant: Part | Plant: As Level | FW-Fresh Weight DW-Dry Weight | Reference |
|---|---|---|---|---|---|---|---|
| | ppm | | | | ppm | | |
| Lead arsenate | 92 | Sassafras sandy loam | F | common mustard, tops | <1 | DW | Williams and Whetstone, 1940 |
| | | .........do......... | F | common mustard, roots | 34 | DW | ............do........... |
| | | .........do......... | F | dandelion | 7 | DW | ............do........... |
| | | .........do......... | F | wild leek | 8 | DW | ............do........... |
| | | .........do......... | F | buckhorn plantain | 16 | DW | ............do........... |
| | | .........do......... | F | sourgrass | 18 | DW | ............do........... |
| | | .........do......... | F | daisy | 12 | DW | ............do........... |
| | | .........do......... | F | milkweed | 1 | DW | ............do........... |
| | 130 | Sassafras sandy loam | F | rhododendron leaves | 2 | DW | ............do........... |
| | | .........do......... | F | sour dock, tops | 1 | DW | ............do........... |
| | | .........do......... | F | sour dock, roots | 7 | DW | ............do........... |
| | | .........do......... | F | burdock, leaves | <1 | DW | ............do........... |
| | 270 | Sassafras sandy loam | F | orchard grass | 2 | DW | ............do........... |
| | | .........do......... | F | baptisia, false indigo | 1 | DW | ............do........... |
| | | .........do......... | F | wild carrot, tops | <1 | DW | ............do........... |
| | | .........do......... | F | wild carrot, root | 2 | DW | ............do........... |
| | | .........do......... | F | iris, roots | 10 | DW | ............do........... |
| | 60 | Hagerstown silt loam | F | clover, leaves | 12 | DW | ............do........... |
| | | Hagerstown silt loam | F | alfalfa | 14 | DW | ............do........... |
| | 240 | sandy soil (Washington) | F | alfalfa | 860 | DW | ............do........... |
| | | ..........do........... | F | string bean, leaves | 10 | DW | ............do........... |
| | | ..........do........... | F | beet, tops | 10 | DW | ............do........... |
| | | ..........do........... | F | cucumber, vines, leaves | 12 | DW | ............do........... |
| | | ..........do........... | F | corn, leaves | 5 | DW | ............do........... |
| Calcium arsenate | 5.7-7.0 | mixed soils | F | blueberry leaves | 0.02-0.03 | DW | Anastasia and Kender, 1973 |
| | 9.6-37.8 | mixed soils | F | blueberry leaves | 0.23-1.20 | DW | Anastasia and Kender, 1973 |
| | 20 | soil | E | rice, hulled | 0.02 | DW | Tsutsumi and Takahashi, 1974 |
| | 20 | soil | E | .......do....... | 0.13 | DW | .............do............. |
| | 50 | soil | E | .......do....... | 0.16 | DW | .............do............. |
| | 125 | soil | E | .......do....... | 0.56 | DW | .............do............. |
| Sodium arsenate | 0 | Hagerstown silt clay loam | E | corn plant | 3.0 | DW | Woolson *et al.*, 1973 |
| | 100 | Hagerstown silt clay loam | E | corn plant | 1.8 | DW | Woolson *et al.*, 1973 |
| | 1,000 | Hagerstown silt clay loam | E | corn plant | 8.5 | DW | Woolson *et al.*, 1973 |
| | 0 | soil | E | rice, hulled | 0.02 | DW | Tsutsumi and Takahashi 1974 |
| | 20 | soil | E | rice, hulled | 0.11 | DW | Tsutsumi and Takahashi 1974 |
| | 50 | soil | E | rice, hulled | 0.40 | DW | Tsutsumi and Takahashi 1974 |
| | 20,80 | Plainfield sand | E | corn plant | 3-16 | DW | Jacobs and Keeney 1970 |
| | 20,80 | Waupun silt loam | E | corn plant | 1-5 | DW | Jacobs and Keeney 1970 |

Table 54.--Arsenic residues in plants from pesticidal and experimental applications of arsenical compounds--continued

| Chemical Applied | As Level | Type | | Plant | | FW-Fresh Weight DW-Dry Weight | Reference |
|---|---|---|---|---|---|---|---|
| | | Soil | Study F-Field/ E-Experimental | Part | As Level | | |
| | ppm | | | | ppm | | |
| Sodium arsenate | 1.2-4.5 | Lakeland loamy sand | E | green bean | 0.4 | DW | Woolson, 1973 |
| | | Hagerstown silty clay loam, Christiana clay loam | E | lima bean | 0.5 | DW | .....do...... |
| | | | E | cabbage | 0.4 | DW | .....do...... |
| | | | E | tomato | 0.5 | DW | .....do...... |
| | 6.2 | available As and plant residue at 50% growth reduction | E | green bean | 4.2 | DW | .....do...... |
| | 10.9 | ..........do.......... | E | lima bean | 1.0 | DW | .....do...... |
| | 10.6 | ..........do.......... | E | spinach | 10.0 | DW | .....do...... |
| | 48.3 | ..........do.......... | E | cabbage | 1.5 | DW | .....do...... |
| | 25.4 | ..........do.......... | E | tomato | 0.7 | DW | .....do...... |
| | 19.0 | ..........do.......... | E | radish | 76.0 | DW | .....do...... |
| Potassium arsenate | 0 | solution culture | E | lemon, leaves | 0.10-0.15 | DW | Liebig *et al.*, 1959 |
| | | .......do....... | E | lemon, stems | 0.0-0.05 | DW | ........do......... |
| | | .......do....... | E | lemon, roots | 0.15 | DW | ........do......... |
| | 1.6-1.8 | .......do....... | E | lemon, leaves | 0.75-6.97 | DW | ........do......... |
| | | .......do....... | E | lemon, stems | 0.45-0.65 | DW | ........do......... |
| | | .......do....... | E | lemon, roots | 113 | DW | ........do......... |
| | 4.3-4.4 | .......do....... | E | lemon, leaves | 0.80-11.20 | DW | ........do......... |
| | | .......do....... | E | lemon, stems | 0.80-2.05 | DW | ........do......... |
| | | .......do....... | E | lemon, roots | 261 | DW | ........do......... |
| | 7.9-8.1 | .......do....... | E | lemon, leaves | 1.05-4.10 | DW | ........do......... |
| | | .......do....... | E | lemon, roots | 1,200 | DW | ........do......... |
| rsenic trioxide | 0 | seed bed | E | white spruce, leaf | 2.1 | DW | Rosehart and Lee, 1973 |
| | | ...do... | E | white spruce, branch | 2.1 | DW | ..........do.......... |
| | | ...do... | E | white spruce, trunk | 2.4 | DW | ..........do.......... |
| | | ...do... | E | white spruce, root | 1.0 | DW | ..........do.......... |
| | 1,000 | ...do... | E | white spruce, leaf | 2.9 | DW | ..........do.......... |
| | | ...do... | E | white spruce, branch | 14.3 | DW | ..........do.......... |
| | | ...do... | E | white spruce, trunk | 0.3 | DW | ..........do.......... |
| | | ...do... | E | white spruce, root | 59.5 | DW | ..........do.......... |
| | 2,000 | ...do... | E | white spruce, leaf | 2.1 | DW | ..........do.......... |
| | | ...do... | E | white spruce, branch | 3.0 | DW | ..........do.......... |
| | | ...do... | E | white spruce, trunk | 55 | DW | ..........do.......... |
| | | ...do... | E | white spruce, root | 130 | DW | ..........do.......... |
| | 0-28 | Amarillo fine sandy loam | E | cotton | 0.2-4.0 | DW | Deuel and Swoboda, 1972 |
| | | Amarillo fine sandy loam | E | soybean | 0.6-2.5 | DW | ..........do........... |
| | 0-112 | Houston black clay | E | cotton | 0.4-3.0 | DW | ..........do........... |
| | | Houston black clay | E | soybean | 0.5-1.2 | DW | ..........do........... |

Table 54.--Arsenic residues in plants from pesticidal and experimental applications of arsenical compounds--continued

| Chemical Applied | As Level | Type | | Plant | | FW-Fresh Weight DW-Dry Weight | Reference |
|---|---|---|---|---|---|---|---|
| | | Soil | Study F-Field/ E-Experimental | Part | As Level | | |
| | ppm | | | | ppm | | |
| Arsenic trioxide | 56-84 | Amarillo fine sandy loam | E | cotton | 8.0-9.2 | DW | Deuel and Swoboda, 1972 |
| | 56 | Amarillo fine sandy loam | E | soybean | 6.5 | DW | ..........do.......... |
| | 168-280 | Houston black clay | E | cotton | 4.0-12.2 | DW | ..........do.......... |
| | | Houston black clay | E | soybean | 3.0-13.8 | DW | ..........do.......... |
| Sodium arsenite | 6.0-17.4 | sandy loams | F | potato, flesh | 0.2-0.4 | DW | Steevens *et al.*, 1972 |
| | | sandy loams | F | potato, peel | 0.5-1.8 | DW | .........do......... |
| | 5.4-25.9 | silt loams | F | potato, flesh | <0.1-0.4 | DW | .........do......... |
| | | silt loams | F | potato, peel | 0.2-0.5 | DW | .........do......... |
| | 2.2-14.9 | loamy sands | F | potato, flesh | <0.1-0.6 | DW | .........do......... |
| | | loamy sands | F | potato, peel | 0.4-2.3 | DW | .........do......... |
| | 3 | Plainfield sand | E | potato, flesh | 0.0 | DW | Jacobs *et al.*, 1970 |
| | | ......do....... | E | potato, peel | 0.4-1.4 | DW | ........do........ |
| | 11 | ......do....... | E | potato, flesh | 0.0-<0.1 | DW | ........do........ |
| | | ......do....... | E | potato, peel | 2.9-8.1 | DW | ........do........ |
| | 23 | ......do....... | E | potato, flesh | 0.0-0.1 | DW | ........do........ |
| | | ......do....... | E | potato, peel | 6.6-26.9 | DW | ........do........ |
| | 73 | ......do....... | E | potato, flesh | <0.1-0.4 | DW | ........do........ |
| | | ......do....... | E | potato, peel | 13.3-46.9 | DW | ........do........ |
| | 250 | ......do....... | E | potato, flesh | <0.1-0.5 | DW | ........do........ |
| | | ......do....... | E | potato, peel | 31.4-83.0 | DW | ........do........ |
| | 3 | Plainfield sand | E | snap beans | 0.0 | DW | ........do........ |
| | 19 | ......do....... | E | ....do.... | 0.0 | DW | ........do........ |
| | 26 | ......do....... | E | ....do.... | 0.3-0.8 | DW | ........do........ |
| | 63 | ......do....... | E | ....do.... | 0.6-1.5 | DW | ........do........ |
| | 150 | ......do....... | E | ....do.... | no growth | -- | ........do........ |
| | 0 | Maine potato soil | F | potato | 0.01-0.02 | ? | Murphy and Goven, 1966 |
| | 3-9 | Maine potato soil | F | potato | 0.02-0.05 | ? | Murphy and Goven, 1966 |
| | 0 | soil | E | rice, hulled | 0.02 | DW | Tsutsumi and Takahashi, 1974 |
| | 20 | soil | E | .....do..... | 0.13 | DW | ...........do........... |
| | 50 | soil | E | .....do..... | 0.12 | DW | ...........do........... |
| | 1-8 | soil | E | .....do..... | 0.2-3.1 | ? | ...........do........... |
| | 3.0-3.6 | Plainfield sand | E | potato, flesh | 0.0-0.1 | DW | Steevens *et al.*, 1972 |
| | | ......do....... | E | potato, peel | 1.0-2.4 | DW | .........do......... |
| | 11.0-14.1 | ......do....... | E | potato, flesh | <0.1-0.1 | DW | .........do......... |
| | | ......do....... | E | potato, peel | 4.6-5.2 | DW | .........do......... |
| | 23.0-27.0 | ......do....... | E | potato, flesh | <0.1-0.1 | DW | .........do......... |
| | | ......do....... | E | potato, peel | 9.8-12.9 | DW | .........do......... |
| | 45.0-73.0 | ......do....... | E | potato, flesh | 0.2-0.5 | DW | .........do......... |
| | | ......do....... | E | potato, peel | 22.2-27.3 | DW | .........do......... |

Table 54.--Arsenic residues in plants from pesticidal and experimental applications of arsenical compounds--continued

| Chemical Applied | As Level | Type | | Plant | | FW-Fresh Weight DW-Dry Weight | Reference |
|---|---|---|---|---|---|---|---|
| | | Soil | Study F-Field/ E-Experimental | Part | As Level | | |
| | ppm | | | | ppm | | |
| Sodium arsenite | 100.0-250.0 | Plainfield sand | E | Potato, flesh | 0.3-0.6 | DW | Steevens et al., 1972 |
| | | Plainfield sand | E | potato, peel | 47.9-53.7 | DW | Steevens et al., 1972 |
| | 11.4 | red soil (Hawaii) | E | tomato plant | 0.68 | DW | Clements and Munson, 1947 |
| | 619 | .......do....... | E | .....do..... | 3.72 | DW | ..........do........... |
| | 1,151 | .......do....... | E | .....do..... | 6.84 | DW | ..........do........... |
| | 1,531 | .......do....... | E | .....do..... | 15.12 | DW | ..........do........... |
| | 2,291 | .......do....... | E | .....do..... | 40.05 | DW | ..........do........... |
| | 19.0 | black soil (Hawaii) | E | tomato plant | 0.61 | DW | ..........do........... |
| | 391 | ........do........ | E | .....do..... | 2.81 | DW | ..........do........... |
| | 695 | ........do........ | E | .....do..... | 8.44 | DW | ..........do........... |
| | 1,531 | ........do........ | E | .....do..... | 23.18 | DW | ..........do........... |
| | 2,291 | ........do........ | E | .....do..... | 38.00 | DW | ..........do........... |
| | 11.4 | red soil (Hawaii) | E | Sudan grass | 1.14 | DW | ..........do........... |
| | 65 | .......do....... | E | ....do..... | 2.28 | DW | ..........do........... |
| | 239 | .......do....... | E | ....do..... | 4.94 | DW | ..........do........... |
| | 391 | .......do....... | E | ....do..... | 9.35 | DW | ..........do........... |
| | 771 | .......do....... | E | ....do..... | 35.04 | DW | ..........do........... |
| | 11.4 | black soil (Hawaii) | E | Sudan grass | 0.99 | DW | ..........do........... |
| | 163 | ........do........ | E | ....do..... | 4.10 | DW | ..........do........... |
| | 467 | ........do........ | E | ....do..... | 9.80 | DW | ..........do........... |
| | 695 | ........do........ | E | ....do..... | 18.70 | DW | ..........do........... |
| | 1,531 | ........do........ | E | ....do..... | 42.64 | DW | ..........do........... |
| | 1,911 | ........do........ | E | ....do..... | 65.74 | DW | ..........do........... |
| | 11.4 | red soil (Hawaii) | E | bean plant | 1.14 | DW | ..........do........... |
| | 315 | ........do....... | E | ....do.... | 5.24 | DW | ..........do........... |
| | 1,151 | ........do....... | E | ....do.... | 11.93 | DW | ..........do........... |
| | 1,911 | ........do....... | E | ....do.... | 24.85 | DW | ..........do........... |
| | 2,291 | ........do....... | E | ....do.... | 35.34 | DW | ..........do........... |
| Potassium arsenite | 0.81-0.87 | solution culture | E | lemon, leaves | 0.65-4.55 | DW | Liebig et al., 1959 |
| | | .......do....... | E | lemon, stem | 0.35-0.45 | DW | ........do......... |
| | | .......do....... | E | lemon, root | 20 | DW | ........do......... |
| | 1.40-1.60 | .......do....... | E | lemon, leaves | 0.50-7.45 | DW | ........do......... |
| | | .......do....... | E | lemon, stem | 0.30-1.05 | DW | ........do......... |
| | | .......do....... | E | lemon, root | 130 | DW | ........do......... |
| | 3.20-3.30 | .......do....... | E | lemon, leaves | 0.55-6.10 | DW | ........do......... |
| | | .......do....... | E | lemon, stem | 0.60-1.50 | DW | ........do......... |
| | | .......do....... | E | lemon, root | 611 | DW | ........do......... |

Several generalizations can be made from the data presented:

1. Plants grown on sands and sandy loams have higher residues at equivalent soil levels than those grown on heavier-textured soils.
2. Fruit has lower levels than leaves, stems, or roots.
3. Roots contain the highest levels.
4. The skin of root crops has higher residues than the inner flesh.
5. Residues are low unless the plant growth is severely affected.
6. Crops are different in their sensitivity and uptake of As.

Plant residues from current recommended applications to soil of lead and calcium arsenate will be quite small since the higher applications are no longer allowed under USDA and EPA regulations. Residues currently in the soil may present some problems due to phytotoxicity to sensitive crops where rotation is practical, but this is not reflected in As residues in the plants since accumulation is low. Studies by Aten, et al. (1980), Jones and Hatch (1945), Chisholm (1972), Chisholm and MacPhee (1972), and others indicate that soil levels in excess of 200 to 300 ppm As are necessary to reach edible plant levels of 1 ppm As on a fresh-weight basis. A couple of exceptions do occur, however: Eggplant and beet roots (Jones and Hatch, 1945) contain 19.76 and 20.30 ppm As on a dry-weight basis when grown on soil containing 40.3 and 115.5 ppm As, respectively. These two values, however, appear out of line with values reported for other crops, indicating perhaps an ability for these two crops to accumulate As more readily than do other crops.

The peels of root crops, potatoes, beets, carrots, or turnips, contain much higher residues than do the flesh when grown on As-contaminated soil. The levels in the peel rise as the soil levels rise, but flesh content rises very little if any (Jacobs, et al., 1970; Steevens, et al., 1972; and Chisholm, 1972).

Several studies have been conducted with sodium arsenite, arsenic trioxide, and sodium arsenate to observe the response of plants (growth and content) to elevated levels of As in the soil environment (Table 55). Many of these studies used rates higher than those normally observed from agricultural uses. Non-toxic levels up to 2,291 ppm As have been added to some soils. Several studies used levels over 200 ppm As with no decrease in plant growth and little As uptake. These studies, like the actual field studies, indicate little danger from root uptake of As.

## Plant Content from Arsenic Sources Other Than Pesticides

There are several instances where plants may receive As exposure as a result of human activities other than from direct pesticidal application. Highest reported plant As contents have generally been associated with the mining and smelting of metals where the plant receives the As as a result of atmospheric emissions or the land disposal of the mine tailings. A much lower exposure, but with a wider geographic distribution, is that resulting from the combustion of fossil fuels, specifically coal. Plants generally do not accumulate significant amounts of As from this source.

Some of the highest plant contents have resulted from plants growing in soils having high As levels in the vicinity of smelters. Some of the plant As may be present from aerial deposition but most is present from root uptake. Plant contents are proportional to the soil levels (Table 56). Levels up to 6,640 ppm As have been observed.

Table 55.--Phytotoxic response of plants to soil arsenic

| Arsenic Source | Arsenic Level | Soil | Crop | Percent of Check[a] | Reference |
|---|---|---|---|---|---|
| | ppm | | | | |
| Calcium arsenate | 94 | Cecil sandy clay loam | Vetch | 94.6 | Cooper *et al*., 1931 |
| | 283 | .........do......... | Vetch | 65.8 | ........do........ |
| | 1,131 | .........do......... | Vetch | 11.3 | ........do........ |
| | 94 | .........do......... | Oats | 75.8 | ........do........ |
| | 283 | .........do......... | Oats | 58.6 | ........do........ |
| | 1,131 | .........do......... | Oats | 18.0 | ........do........ |
| | 283 | .........do......... | Barley | 90.0 | ........do........ |
| | 377 | .........do......... | Barley | 52.8 | ........do........ |
| | 1,131 | .........do......... | Barley | 34.0 | ........do........ |
| | 283 | .........do......... | Wheat | 130.0 | ........do........ |
| | 565 | .........do......... | Wheat | 66.1 | ........do........ |
| | 1,131 | .........do......... | Wheat | 72.1 | ........do........ |
| | 141 | .........do......... | Rye | 164.5 | ........do........ |
| | 1,131 | .........do......... | Rye | 105.8 | ........do........ |
| | 47 | Greenville clay loam | Cowpeas | 64.0 | ........do........ |
| | 377 | .........do........ | Cowpeas | 18.0 | ........do........ |
| | 47 | .........do........ | Soybeans | 73.5 | ........do........ |
| | 377 | .........do........ | Soybeans | 6.1 | ........do........ |
| | 94 | .........do........ | Corn | 93.9 | ........do........ |
| | 377 | .........do........ | Corn | 37.3 | ........do........ |
| | 47 | Greenville sandy loam | Cowpeas | 105.6 | ........do........ |
| | 94 | .........do......... | Cowpeas | 90.6 | ........do........ |
| | 377 | .........do......... | Cowpeas | 18.9 | ........do........ |
| | 47 | .........do......... | Soybeans | 113.0 | ........do........ |
| | 94 | .........do......... | Soybeans | 95.6 | ........do........ |
| | 377 | .........do......... | Soybeans | 21.7 | ........do........ |
| | 47 | .........do......... | Corn | 64.9 | ........do........ |
| | 283 | .........do......... | Corn | 7.2 | ........do........ |
| | 377 | .........do......... | Corn | -0- | ........do........ |
| | 47 | .........do......... | Sorghum | 111.3 | ........do........ |
| | 141 | .........do......... | Sorghum | 98.6 | ........do........ |
| | 377 | .........do......... | Sorghum | 47.9 | ........do........ |
| | 141 | Cecil clay loam | Vetch hay | 1-03.9 | Cooper *et al*., 1932 |
| | 283 | ......do....... | Vetch hay | 76.4 | ........do........ |
| | 942 | ......do....... | Vetch hay | 36.5 | ........do........ |
| | 94 | ......do....... | Oat grain | 103.8 | ........do........ |
| | 141 | ......do....... | Oat grain | 79.1 | ........do........ |
| | 1,131 | ......do....... | Oat grain | 46.0 | ........do........ |
| | 188 | ......do....... | Barley grain | 109.3 | ........do........ |
| | 942 | ......do....... | Barley grain | 187.0 | ........do........ |
| | 1,131 | ......do....... | Barley grain | 94.7 | ........do........ |
| | 94 | ......do....... | Wheat grain | 109.2 | ........do........ |

Table 55.--Phytotoxic response of plants to soil arsenic--continued

| Arsenic Source | Arsenic Level | Soil | Crop | Percent of Check[a] | Reference |
|---|---|---|---|---|---|
| | ppm | | | | |
| Calcium arsenate | 1,131 | Cecil clay loam | Wheat grain | 102.4 | Cooper et al., 1932 |
| | 94 | ......do....... | Rye grain | 108.3 | ........do......... |
| | 1,131 | ......do....... | Rye grain | 120.7 | ........do......... |
| | 94 | Davidson clay loam | Corn | 100.6 | ........do......... |
| | 471 | .......do......... | Corn | 123.8 | ........do......... |
| | 94 | .......do......... | Sorghum | 95.1 | ........do......... |
| | 471 | .......do......... | Sorghum | 134.6 | ........do......... |
| | 94 | .......do......... | Soybeans | 102.5 | ........do......... |
| | 188 | .......do......... | Soybeans | 142.8 | ........do......... |
| | 471 | .......do......... | Soybeans | 122.2 | ........do......... |
| | 94 | .......do......... | Cotton | 107.9 | ........do......... |
| | 471 | .......do......... | Cotton | 137.6 | ........do......... |
| | 94 | .......do......... | Cowpeas | 138.4 | ........do......... |
| | 471 | .......do......... | Cowpeas | 71.7 | ........do......... |
| | 99 | .......do......... | Kentucky bluegrass | 73.3* | Engel and Callahan, 1967 |
| | 99 | .......do......... | Kentucky bluegrass | 80.3* | ...........do........... |
| | 99 | .......do......... | Kentucky bluegrass | 85.8* | ...........do........... |
| | 0.44Kg/100m$^2$ | Colwood sand loam | Annual bluegrass | 71.9 | Carrow et al., 1975 |
| | 1.76 | .......do........ | Annual bluegrass | 4.7 | ........do......... |
| | 3.53 | .......do........ | Annual bluegrass | -0- | ........do......... |
| | 0.44 | .......do........ | Merion Ky. bluegrass | 62.5 | ........do......... |
| | 1.76 | .......do........ | Merion Ky. bluegrass | 12.5 | ........do......... |
| | 3.53 | .......do........ | Merion Ky. bluegrass | -0- | ........do......... |
| | 0.44 | .......do........ | Penncross bentgrass | 66.7 | ........do......... |
| | 1.76 | .......do........ | Penncross bentgrass | 20.3 | ........do......... |
| | 3.53 | .......do........ | Penncross bentgrass | 4.3 | ........do......... |
| | 0.44 | .......do........ | Cohansey bentgrass | 92.1 | ........do......... |
| | 3.53 | .......do........ | Cohansey bentgrass | 58.7 | ........do......... |
| | 1.76 | Kawkawlin sandy loam | Annual bluegrass | 34.4 | ........do......... |
| | 3.53 | Kawkawlin sandy loam | Annual bluegrass | 1.1 | ........do......... |
| | 20 | Pot culture | Rice plants | 103.0 | Tsutsumi and Takahashi, 1974 |
| | 50 | ....do..... | Rice plants | 109.2 | .............do............. |
| | 625 | ....do..... | Rice plants | 40.1 | .............do............. |
| | 50 | ....do..... | Rice grain | 98.2 | .............do............. |
| | 125 | ....do..... | Rice grain | 67.4 | .............do............. |
| | 625 | ....do..... | Rice grain | -0- | .............do............. |
| Lead arsenate | <25 | Washington soil | Apple trees | No reduction | Benson, 1968 |
| | 25-50 | ......do....... | Apple trees | No reduction | .....do..... |
| | | ......do....... | Apricot | May damage | .....do..... |
| | | ......do....... | Peach | May damage | .....do..... |

Table 55.--Phytotoxic response of plants to soil arsenic--continued

| Arsenic Source | Arsenic Level | Soil | Crop | Percent of Check[a] | Reference |
|---|---|---|---|---|---|
| | ppm | | | | |
| Lead arsenate | 50-100 | Washington soil | Apricot | (Survival is doubtful) | Benson, 1968 |
| | | ......do....... | Peach | (Survival is doubtful) | .....do..... |
| | | ......do....... | Apple | May damage | .....do..... |
| | >100 | ......do....... | Apple | Growth doubtful | .....do..... |
| | 122 | Berwick sandy loam | Green beans | 65-97 | Chisholm and McPhee, 1972 |
| | | ........do........ | Beet root | 126 | ...........do........... |
| | | ........do........ | Potato | 121 | ...........do........... |
| | | ........do........ | Oat (grain + straw) | 148* | ...........do........... |
| | 106 | Cherry | Corn plant | 37 | Woolson *et al.*, 1971a |
| | 2,553 | Birchmont | ....do.... | 34 | .........do......... |
| | 445 | Loepp | ....do.... | 24 | .........do......... |
| | 81 | Cahaba fine sandy loam | ....do.... | 90 | .........do......... |
| | 53 | Norfolk sandy loam | ....do.... | 104 | .........do......... |
| | 96 | Memphis silt loam | ....do.... | 113 | .........do......... |
| | 94 | Orangeburg fine sandy loam | ....do.... | 80 | .........do......... |
| | 16 | Chesterfield silt loam | ....do.... | 128 | .........do......... |
| | 80 | ..........do.......... | ....do.... | 85 | .........do......... |
| | 120 | ..........do.......... | ....do.... | 65 | .........do......... |
| | 24 | ..........do.......... | ....do.... | 126 | .........do......... |
| | 28 | ..........do.......... | ....do.... | 115 | .........do......... |
| | 138 | Greenleaf silt loam | ....do.... | 68 | .........do......... |
| | 170 | ........do......... | ....do.... | 31 | .........do......... |
| | 204 | ........do......... | ....do.... | 34 | .........do......... |
| | 162 | ........do......... | ....do.... | 28 | .........do......... |
| | 162 | ........do......... | ....do.... | 20 | .........do......... |
| | 54 | Yakima cobbly loam | ....do.... | 40 | .........do......... |
| | 81 | Ritzville silt loam | ....do.... | 75 | .........do......... |
| | 82 | Yakima cobbly loam | ....do.... | 108 | .........do......... |
| | 16 | Ritzville silt loam | ....do.... | 112 | .........do......... |
| | 103 | Coker clay adobe | ....do.... | 157 | .........do......... |
| | 76 | Coker clay adobe | ....do.... | 128 | .........do......... |
| | 74 | Medford gravely clay | ....do.... | 105 | .........do......... |
| | 80 | Medford gravely clay | ....do.... | 96 | .........do......... |
| | 67 | Agate gravely loam | ....do.... | 105 | .........do......... |
| | 315 | Burnt Fork cobbly loam | ....do.... | 72 | .........do......... |
| | 319 | Newfane sand | ....do.... | 58 | .........do......... |
| | 122 | Hilton silt loam | ....do.... | 92 | .........do......... |
| | 252 | Dunkirk silt loam | ....do.... | 68 | .........do......... |
| | 90 | Lockport silty clay loam | ....do.... | 60 | .........do......... |
| | 625 | Dunkirk silt loam | ....do.... | 18 | .........do......... |
| | 92 | A loess soil | ....do.... | 88 | .........do......... |

Table 55.--Phytotoxic response of plants to soil arsenic--continued

| Arsenic Source | Arsenic Level | Soil | Crop | Percent of Check[a] | Reference |
|---|---|---|---|---|---|
| | ppm | | | | |
| Lead arsenate | 250 | A loess soil | Corn plant | 38 | Woolson *et al*., 1971a |
| | 88 | .....do..... | ....do.... | 79 | .........do.......... |
| | 56 | .....do..... | ....do.... | 89 | .........do.......... |
| | 125 | .....do..... | ....do.... | 145 | .........do.......... |
| | 143 | Hagerstown clay loam | ....do.... | 58 | .........do.......... |
| | 238 | Litz shaly loam | ....do.... | 108 | .........do.......... |
| Sodium arsenate | 10 | Hagerstown silty clay loam | Corn plant | 122* | Woolson, 1972 |
| | 100 | Hagerstown silty clay loam | Corn plant | 106 | Woolson, 1972 |
| | 500 | Hagerstown silty clay loam | Corn plant | 32* | Woolson, 1972 |
| | 1 | Crowley silt loam | Rice | 74.1 | Oh and Sedberry, 1974 |
| | 8 | Crowley lilt loam | Rice | 48.1 | Oh and Sedberry, 1974 |
| | 20 | Plainfield sand | Corn plant | 90 | Jacobs and Keeney, 1970 |
| | 80 | Plainfield sand | ....do.... | 5* | ..........do........... |
| | 20 | Waupun silt loam | ....do.... | 95 | ..........do........... |
| | 80 | Waupun silt loam | ....do.... | 45* | ..........do........... |
| | 10 | Hagerstown silty clay loam | ....do.... | 81.6 | Woolson *et al*., 1973 |
| | 100 | ............do........... | ....do.... | 105.6 | .........do......... |
| | 1,000 | ............do........... | ....do.... | 57.6* | .........do......... |
| | 10 | ............do........... | ....do.... | 103 | .........do......... |
| | 100 | ............do........... | ....do.... | 96 | .........do......... |
| | 1,000 | ............do........... | ....do.... | 10* | .........do......... |
| | 10 | Lakeland loamy sand | ....do.... | 97 | .........do......... |
| | 100 | ........do......... | ....do.... | 55* | .........do......... |
| | 10 | ........do......... | Oats | 94 | .........do......... |
| | 100 | ........do......... | .do. | 2* | .........do......... |
| | 10 | Hagerstown silty clay loam | .do. | 78 | .........do......... |
| | 100 | Hagerstown silty clay loam | .do. | 19* | .........do......... |
| | 1,000 | Hagerstown silty clay loam | .do. | 0* | .........do......... |
| | 1.9 | Solution, phosphorus = 10 ppm | Tomato | 125.9 | Clements and Munson, 1947 |
| | 11.4 | .............do............. | ..do.. | 37.0 | ...........do........... |
| | 19 | .............do............. | ..do.. | 22.2 | ...........do........... |
| | 30.4 | .............do............. | ..do.. | 7.4 | ...........do........... |
| | 0.8 | .............do............. | Sudan grass | 57.5 | ...........do........... |
| | 3.8 | .............do............. | Sudan grass | 27.5 | ...........do........... |
| | 19 | .............do............. | Sudan grass | 5.0 | ...........do........... |
| | 0.38 | .............do............. | Bean | 76.0 | ...........do........... |
| | 1.9 | .............do............. | Bean | 22.0 | ...........do........... |
| | 56.2 | Red soil (Hawaii) | Tomato | 102.9 | ...........do........... |
| | 467 | .......do........ | ..do.. | 88.3 | ...........do........... |
| | 771 | .......do........ | ..do.. | 49.2 | ...........do........... |
| | 2,291 | .......do........ | ..do.. | 21.1 | ...........do........... |

Table 55.--Phytotoxic response of plants to soil arsenic--continued

| Arsenic Source | Arsenic Level | Soil | Crop | Percent of Check$^a$ | Reference |
|---|---|---|---|---|---|
| | ppm | | | | |
| Sodium arsenate | 239 | Black soil (Hawaii) | Tomato | 101.8 | Clements and Munson, 1947 |
| | 2,291 | Black soil (Hawaii) | Tomato | 84.3 | ...........do........... |
| | 79 | Red soil (Hawaii) | Sudan grass | 105.7 | ...........do........... |
| | 239 | .......do........ | ....do..... | 77.7 | ...........do........... |
| | 619 | .......do........ | ....do..... | 6.4 | ...........do........... |
| | 2,291 | .......do........ | ....do..... | 1.0 | ...........do........... |
| | 87 | Black soil (Hawaii) | ....do..... | 98.6 | ...........do........... |
| | 695 | Black soil (Hawaii) | ....do..... | 66.3 | ...........do........... |
| | 1,151 | Black soil (Hawaii) | ....do..... | 28.3 | ...........do........... |
| | 2,291 | Black soil (Hawaii) | ....do..... | 1.9 | ...........do........... |
| | 315 | Red soil (Hawaii) | Bean | 87.2 | ...........do........... |
| | 543 | .......do........ | .do. | 45.7 | ...........do........... |
| | 771 | .......do........ | .do. | 17.3 | ...........do........... |
| | 2,291 | .......do........ | .do. | 6.2 | ...........do........... |
| | 20 | Pot culture | Rice plants | 101.0 | Tsutsumi and Takahashi, 1974 |
| | 50 | ....do..... | ....do..... | 107.6 | ............do............ |
| | 125 | ....do..... | ....do..... | 104.0 | ............do............ |
| | 625 | ....do..... | ....do..... | 42.9 | ............do............ |
| | 50 | ....do..... | Rice straw | 89.2 | ............do............ |
| | 125 | ....do..... | Rice straw | 56.4 | ............do............ |
| | 625 | ....do..... | Rice straw | 2.7 | ............do............ |
| | 20 | ....do..... | Rice grain | 98.8 | ............do............ |
| | 50 | ....do..... | ....do.... | 75.6 | ............do............ |
| | 125 | ....do..... | ....do.... | 40.7 | ............do............ |
| | 625 | ....do..... | ....do.... | -0- | ............do............ |
| Sodium arsenite | 14 | Plainfield sand | Corn plant | 82 | Woolson et al., 1971a |
| | 40 | ......do....... | ....do.... | 61 | .........do......... |
| | 48 | ......do....... | ....do.... | 45 | .........do......... |
| | 193 | ......do....... | ....do.... | 4 | .........do......... |
| | 302 | Matapeake silt loam | ....do.... | 90 | Isensee et al., 1973a |
| | 378 | ........do......... | ....do.... | 30 | Isensee et al., 1973a |
| | 27 | Plainfield sand | Peas | 102.8 | Steevens et al., 1972 |
| | 45 | ......do....... | Peas | 60.1* | .........do......... |
| | 100 | ......do....... | Peas | 5.1* | .........do......... |
| | 27 | ......do....... | Potatoes | 99.4 | .........do......... |
| | 45 | ......do....... | ...do... | 82.9* | .........do......... |
| | 100 | ......do....... | ...do... | 24.8* | .........do......... |
| | 11 | ......do....... | ...do... | 108.6 | Jacobs et al., 1970 |
| | 23 | ......do....... | ...do... | 102.0 | Jacobs et al., 1970 |

Table 55.--Phytotoxic response of plants to soil arsenic--continued

| Arsenic Source | Arsenic Level | Soil | Crop | Percent of Check[a] | Reference |
|---|---|---|---|---|---|
| | ppm | | | | |
| Sodium arsenite | 73 | Plainfield sand | Potatoes | 78.7 | Jacobs *et al.*, 1970 |
| | 250 | ......do....... | Potatoes | 24.4* | ........do......... |
| | 19 | ......do....... | Peas | 90.4 | ........do......... |
| | 26 | ......do....... | .do. | 68.2 | ........do......... |
| | 63 | ......do....... | .do. | 45.9* | ........do......... |
| | 150 | ......do....... | .do. | 5.1* | ........do......... |
| | 19 | ......do....... | Snap beans | 88.8 | ........do......... |
| | 26 | ......do....... | ....do.... | 45.6* | ........do......... |
| | 63 | ......do....... | ....do.... | 24.9* | ........do......... |
| | 150 | ......do....... | ....do.... | -0-* | ........do......... |
| | 19 | ......do....... | Sweet corn | 103.1 | ........do......... |
| | 26 | ......do....... | Sweet corn | 90.7 | ........do......... |
| | 63 | Plainfield sand | Sweet corn | 46.5* | ........do......... |
| | 150 | Plainfield sand | Sweet corn | -0-* | ........do......... |
| | 700 | Planting beds | White spruce | 44.8 | Rosehart and Lee, 1973 |
| | 1,780 | Planting beds | White spruce | 54.0 | Rosehart and Lee, 1973 |
| | 44 | Planting beds | White spruce | 36.5 | Rosehart and Lee, 1973 |
| | 17.1 | Colton loamy sand | Blueberry | 86.1 | Anastasia and Kender, 1973 |
| | 43.8 | .......do........ | ...do.... | 82.1 | ............do........... |
| | 69.5 | .......do........ | ...do.... | 69.6* | ............do........... |
| | 84.5 | .......do........ | ...do.... | 55.3* | ............do........... |
| | 31.4 | Amarillo fine sandy loam | Cotton | 47.8* | Deuel & Swoboda, 1972 |
| | 110 | ...........do.......... | Cotton | 11.0* | .........do......... |
| | 157 | ...........do.......... | Cotton | 5.2* | .........do......... |
| | 15.7 | ...........do.......... | Soybean | 54.8* | .........do......... |
| | 31.4 | ...........do.......... | Soybean | 33.7* | .........do......... |
| | 62.7 | ...........do.......... | Soybean | 3.5* | .........do......... |
| | 157 | Houston Black clay | Cotton | 60.4* | .........do......... |
| | 314 | ........do........ | Cotton | 47.2* | .........do......... |
| | 94 | ........do........ | Soybean | 59.8* | .........do......... |
| | 188 | ........do........ | Soybean | 16.0* | .........do......... |
| | 314 | ........do........ | Soybean | 2.4* | .........do......... |
| | 1,520 | Chenango silt loam | Monterey pine | 41.8 | Arnott and Leaf, 1967 |
| | 2,280 | ........do........ | .....do...... | 38.2 | .........do......... |
| | 3,040 | ........do........ | .....do...... | 40.0 | .........do......... |
| | 3,800 | ........do........ | .....do...... | -0- | .........do......... |

[a] 100% = no reduction in growth relative to a control.

* Indicates a significant change in growth.

Table 56.--Arsenic contents in plants grown on soil with elevated As levels from antropogenic sources

| Source of As | Soil As Level | Crop | Residue | Moisture[a] | Reference |
|---|---|---|---|---|---|
| | ppm As | | ppm As | | |
| Zinc smelter | 3.1-6.2 | barley | 0.072-0.162 | ? | Singh and Steinnes, 1976 |
| Copper smelter | 25-50 | garden crops | 0.0-3.3 | FW | Hindawi and Neeley, 1972 |
| | | small grain | 0.0-0.9 | FW | |
| | | alfalfa | 0.4-5.7 | FW | |
| | | pasture grass | 2.5-12.0 | FW | |
| Gold smelter | 11-147 | cassava | 0.6-2.6 | DW | Amasa, 1975 |
| | | sugar cane | 14.8 | DW | |
| | | orange | 2.3 | DW | |
| | | plantain | 0.6 | DW | |
| | | fern | 1,100-4,700 | DW | |
| | | grass | 11.6-20.9 | DW | |
| | | palm tree | 2,875 | DW | |
| Mine and smelter wastes | 8,500-26,500 | *Agrostis tenuis* Sibth. | 3-3,470 | DW | Porter and Peterson, 1975 |
| | | *Jasione montana* (L.) | 6,640 | DW | |
| | | *Calluna vulgaris* (L.) Hull | 4,130 | DW | |
| | | *Agrostis stolonifera* (L.) | 1,350 | DW | |
| | | *Holcus lanatus* (L.) | 560 | DW | |
| | | *Agrostis canina* (L.) | 460 | DW | |

Table 56.--Arsenic contents in plants grown on soil with elevated As levels from antropogenic sources--continued

| Source of As | Soil As Level | Crop | Residue | Moisture[a] | Reference |
|---|---|---|---|---|---|
| | ppm As | | ppm As | | |
| | Low As sites | *Calluna vulgaris* (L.) Hull | 0.33 | DW | Porter and Peterson, 1975 |
| | | *Agrostis tenuis* Sibth. | 0.28 | DW | |
| Gold deposits | 300-5,000 | wide variety | 0.33-242.0 | in ash | Wild, 1974 |
| Holland Marsh, Canada | 0.5-1.6 | carrot shoot | 0.62 | DW | Chattopadhyay *et al.*, 1972 |
| | | carrot root | 0.54 | DW | |
| | | celery shoot | 0.75 | DW | |
| | | celery root | 1.00 | DW | |
| Manure | 15-30 in manure | corn | 0.04-0.06 | DW | Liebhardt, 1976 |
| Sludge | 22.8 in sludge | 7 crops | no increase | DW | Furr *et al.*, 1976 |
| Fly ash | 139 in ash | beans | 0.01-0.2 | DW | Furr *et al.*, 1976a |
| | | onion | 0.1-0.03 | DW | |
| | | potato | 0.1-0.1 | DW | |
| | | tomato | 0.1-0.1 | DW | |
| | | cabbage | 0.1-0.2 | DW | |
| | | carrot | 0.1-0.2 | DW | |
| | | millet | 0.2-1.0 | DW | |

[a] FW - Fresh Weight, DW - Dry Weight.

As emissions of As from coal-burning plants are reduced under air-quality controls, the amount of fly ash to be disposed of will increase. Disposal on agricultural land as a soil amendment is possible. Before this can be considered, however, the trace metal contents must be considered. A slight increase in the As content of crops grown on fly-ash-amended soil was observed (Furr, et al., 1976a; and Furr, et al., 1978a). The highest residue observed was 1.0 ppm As on a dry-weight basis in millet. All food crops were less than 0.5 ppm As (dry weight), a level generally considered insignificant.

Manure disposal likewise does not seem to pose a problem of As uptake in crops grown on amended soils (Morrison, 1969; and Liebhardt, 1976). Sludge disposal on agricultural land does not increase As levels in the crops significantly. Other metals in sludge may present problems, however (Furr, et al., 1976).

## Phytotoxicity of Soil Arsenic

The phytotoxicity of a given soil-arsenic level is a function of soil type, the plant grown, nutrient status, and environmental stress. The literature was searched and plant responses to As levels are tabulated in Table 55. The responses are separated based on the applied arsenical. Intermediate As levels were frequently deleted if they were not significantly different from those tabulated.

Wood treated with CCA is frequently used in the construction of greenhouse benches and flats or trays. Kaufert and Loerch (1955) tested CCA and other wood treatments for phytotoxicity to plants grown in treated flats. Growth responses varied from trace to severe damage in the first year. CCA had light injury to tomato plants the first year, trace injury the second year, and none after that. Some other preservatives still showed phytotoxicity in the fourth growing season after application.

As stated earlier, As is more phytotoxic at a given level in sandy soils than in heavier-textured soils. The average As level calculated from the table for a growth decrease in sands, sandy loams, and loamy sands is 94 ppm As. The corresponding value for clay loams and silt loams is 432 ppm As. These values are calculated only from the studies that provided a statistical treatment. Any particular soil may deviate from these values. The average decrease in growth was 32% for each of the above soil textures.

Many studies have shown differences in the sensitivity of plants to As. For instance, Cooper, et al. (1931) observed responses of 11.3, 18.0, 34.0, 72.1, and 105.8% of control for vetch, oats, barley, wheat, and rye, respectively, grown on Cecil sandy clay loam containing 1,131 ppm As. Similar differences in plant response are seen in studies by Cooper, et al. (1932), Carrow, et al. (1975), Clements and Munson (1947), Steevens, et al. (1972), Jacobs, et al. (1970), Deuel and Swoboda (1972), and Woolson (1973).

Woolson (1973) took plant response to a variety of crops, different As levels and soils, and calculated regression equations based on plant response and "available" (soluble in dilute HCl and $H_2SO_4$) As levels in soil. Different plant sensitivities can be seen in that it takes 6.2, 10.9, 10.6, 48.3, 25.4, and 19.0 ppm available As to reduce growth 50% for green beans, lima beans, spinach, cabbage, tomatoes, and radishes respectively. Green beans are most sensitive and cabbage the least sensitive of the crops tested. If one assumes that one-tenth of the total As present is available (Woolson, et al., 1971a), levels needed to reduce growth 50% would range from 62 to 483 ppm As for these crops.

The effects of soil amendments on phytotoxicity have been examined by a number of researchers. The addition of 750 pounds of sulfur per acre to Crowley clay loam which had received $Ca_3(AsO_4)_2$ for bollworm control improved rice straw weight by 22% and head weight from a total of 0.9 g to 10.3 g per pot (Epps and Sturgis, 1939). Sulfur was also found to decrease the amount of As taken into the crop.

Iron salts have been used by several researchers in attempts to overcome As toxicity. Cooper, et al. (1931) treated soil, containing $Ca_3(AsO_4)_2$ applied to control the cotton bollworm, with 382 kg/ha iron sulfate, 112 kg/ha manganese sulfate, or 2,240 kg/ha limestone, and varying amounts of fertilizer. Iron sulfate increased cowpea yield by 42%, while manganese and lime did not have much effect. When superphosphate was added to the soil (90 kg/ha P) yield was reduced to 49% of the unfertilized plot. The addition of iron sulfate returned the yield to 94% of the unfertilized plot.

Iron and aluminum sulfate were added to Plainfield sand containing various levels of As (Steevens, et al., 1972). Aluminum sulfate did not have much effect on yields of peas or potatoes. Iron sulfate (4.21 metric tons/ha) improved growth at all As levels for peas, but only at the 220 kg As/ha level for potatoes.

While added aluminum may not attenuate As toxicity, naturally occurring aluminum does appear to affect the toxicity of As, especially at high levels. Woolson, et al. (1971a) added 670 ppm As to a series of soils with a varying reactive aluminum content. Corn growth followed the aluminum content quite closely. In addition to the high aluminum contents, most of the soils were sandy which makes plant growth at 670 ppm As all the more unique.

Phosphorus added at 10, 100, and 1,000 ppm P to two soils containing 10, 100, or 1,000 ppm As increased corn growth on the Hagerstown silty clay loam as the phosphorus increased relative to the As treatments alone, but not on the Lakeland loamy sand (Woolson, et al., 1973). Differences in the number of reactive iron and aluminum sorption sites between the soils are thought to explain the observed phenomena. The heavier soils fixed much more As and P than the loamy sand. Thus, as the P is added to the sandy loam, the sorption sites were close to saturation. The same behavior was observed by Jacobs and Keeney (1970) with corn grown on Plainfield sand and Waupun silt loam. Phosphorus increased As toxicity at 80 ppm As while growth on the silt loam improved as P increased. The latter was probably due to less uptake of As by higher P levels in solution. P addition increased As content in the plant especially at the high rate on the Plainfield sand. The P addition increased $NH_4OAc$ extractable As more than 100% in the Plainfield when compared to the Waupun soil.

Turf-grass growth improved with the addition of 4 $kg/100m^2$ P to soil containing up to 3.53 $kg/100m^2$ As (Carrow, et al., 1975). Weights averaged over four species increased from 0.10 to 0.46 g/pot at the high P rate.

The effects of different fertilizer materials and combinations on the growth of corn have been examined (Woolson, 1972). At 10 and 100 ppm As, a combination of N, P, and K gave the best growth. The addition of lime at 500 ppm As improved growth. The best source for each fertilizer element was found to be $NH_4NO_3$ for N, $Ca(H_2PO_4)_2$ for P, $K_2SO_4$ for K, $CaCO_3$ for pH control. These materials were selected based on plant growth, available As, and As in the plant.

The effect of zinc (Zn) on As toxicity cannot be explained as readily as that for P, Fe, Al, or Ca. Thompson and Batjer (1950) added Zn (10 pounds $ZnSO_4$/tree) to soil containing peach trees. The soil had received lead arsenate and contained from 30 to 145 ppm As. The addition of Zn plus high N almost completely eliminated defoliation caused by As. Ferrous sulfate plus either medium or high N was almost as good when the soil pH was 6.6. At a high pH (8.1), the ferrous sulfate treatment was not as effective.

The addition of Zn (36.6 ppm Zn) improved the growth of rice by 76% for As levels of 1 to 8 ppm As. The As content was also raised somewhat by the Zn addition (Oh and Sedberry, Jr., 1974).

## Metabolism of Arsenic in Plants

### Arsenate/Arsenite Conversions

The oxidation/reduction interconversion of arsenite/arsenate are important since arsenite is about 10 times more phytotoxic to plants as well as being more water soluble. Conditions and organisms which affect the relative proportions in the soil environment are necessary informational inputs in order to understand the bioenvironmental cycle of As.

Several researchers have examined the oxidation of arsenite to arsenate by microorganisms isolated from soil. Osborne and Ehrlich (1976) isolated a Alcaligenes sp. organism from soil which oxidizes arsenite to arsenate. The capability is an acquired trait and the arsenite-oxidizing enzyme system is formed by growth-dependent induction. The optimum pH was found to be 7.0. Essentially quantitative conversion of arsenite to arsenate was observed with a Michaelis constant (Km) of $15.4 \times 10^{-4}$. Various inhibitors destroyed the ability of the microbe to oxidize arsenite. "The results of the inhibition experiments and the spectral evidence suggest that the following electron transport chain may be involved in arsenite oxidation by the organism."

$$AsO_2 \xrightarrow{\text{oxido-reductase}} \text{cytochrome c} \rightarrow \begin{array}{c}\text{cytochrome}\\ \text{oxidase}\end{array} \rightarrow O_2$$

to arsenate (Philips and Taylor, 1976). Oxidation is "brought about by an induced enzyme and/or electron acceptor which is formed only when cells are grown in the presence of arsenite and that lack of arsenite oxidation could not be accounted for by lack of permeability of the cell to arsenite." They conclude that "although the mechanism of induction is still unknown, this study suggests the possibility that some factor, i.e., some secondary metabolite produced largely in the stationary phase, is essential for synthesis of an enzyme or a specific cytochrome associated with arsenite oxidation."

Bautista and Alexander (1972) reported on the reduction of arsenate to arsenite by Pichia quillermondii and Micrococcus sp. obtained from soil. They detected the conversion of arsenate to arsenite by iodine decoloration. Hydrogen sulfide will also decolor iodine. Their nutrient media contained sulfate which could also be reduced to $H_2S$. The experiment does not prove conclusively that arsenate is converted to arsenite in the soil by these two microorganisms.

### Formation of Alkylarsines

The formation of alkylarsines has been proposed as part of a natural cycle of As in nature (Wood, 1974; McBride and Wolfe, 1971; Sandberg and Allen, 1975; Woolson, 1976, and 1977). The formation occurs biologically from several starting materials--arsenite, arsenate, methanearsonic acid, and dimethylarsinic acid, and proceeds to dimethylarsine or trimethylarsine.

Several strains of Aspergillus, 10 strains of Scopulariopsis, and 14 strains of Aspergillus sydowi produced arsenical gases (Thom and Raper, 1932). They also isolated organisms from a South Carolina soil which had been treated with calcium arsenate. Species of Penicillium, Aspergillus, Fusarium, and Paecilomyces were active in the production of arsenical gases as well as several species of Actinomyces and bacteria.

The production of a volatile arsenical gas from arsenate occurred only at concentrations of 113 to 452 ppm As (Zussman, et al., 1961). Arsenite would not act as a substrate. The organism responsible for the unknown arsine formation was Trichophyton rubrum, a dermatophyte.

Woolson (1977), however, did identify the arsenical compound being evolved from soil as predominantly dimethylarsine with a small amount of trimethylarsine formed also. The organism responsible for the compound formation was neither isolated nor identified.

Scopulariopsis brevicaulis Sacc. and several species of Penicillium and Aspergillus were tested for the production of volatile arsenicals starting with various sources of As (Bird et al., 1948). Two species of Aspergillus and S. brevicaulis gave $(CH_3)_3$ As starting with $As_2O_3$. S. brevicaulis was the only organism giving arsenical gases when $Na_2HAsO_4$ was the starting material.

S. brevicaulis, Candida humicola, and Gliocladium roseum grown aerobically methylated a range of As compounds (Cullen, et al., 1977). In order to examine the mechanism of methylation, they added L-methionine- methyl-$d_3$ to the cultures. The $CD_3$ label was incorporated intact into the alkylarsine indicating that S-adenosylmethionine or some related sulphonium compound is involved in the biological process. They isolated trimethylarsine.

## Arsenic in Animals

### Environmental Levels

Arsenic levels in wildlife are generally quite low unless the animal has consumed vegetation which was recently sprayed with an arsenical. Such instances will be discussed later in this chapter.

The U.S. Department of Interior has jurisdiction for monitoring residues of metals, pesticides, and industrial chemicals in wildlife. As part of this program, Martin and Nickerson (1973) examined As levels in starlings gathered from 53 preselected sites throughout the contiguous United States in November and December 1971. The highest level was found in a sample from Lansing, Mich., at 0.21 ppm As. All remaining samples had levels of 0.04 ppm or less with no As detected in eight of the samples. "Arsenic residues in urban soil samples around the country have been reported as high as 74.5 ppm (Wiersma, et al., 1972), but apparently this As is unavailable to starlings or is ingested in a form which is not retained in the body of this species."

A similar study was conducted in 1973 (White, et al., 1977). Residues were higher than in the previous study with samples collected in urban areas (0.171 ppm As) analyzing higher than those collected in rural areas (0.139 ppm As). "This overall increase of residues in starlings may reflect an increase in the use of arsenic-containing compounds as insecticides or herbicides on lawns." Industrial or combustion sources rather than pesticidal contamination are more likely sources. Different methodologies for As determination may also cause differences between years due to differences in loss during sample preparation.

Another measure of environmental quality which has been examined is the analysis of various materials in tissue and eggs of brown pelicans. Egg shell thinning as a result of pollutants, especially the organochlorinated hydrocarbon insecticides, has caused serious population declines. Analysis of eggs and liver tissue for As and other metals was made on collected samples. The mean for eggs collected in South Carolina during 1971-1972 was 0.31 ppm As (fresh weight) with a range of 0.17 to 0.66 ppm As. Samples from Florida averaged 0.10 and ranged from 0.07 to 0.18 ppm As. Liver levels for pelicans found dead were 0.23, 0.47, 0.54, and 1.02 ppm As (fresh weight), while levels for those shot were 0.29, 0.36, 0.63, and 0.89 ppm As. "It is possible that differences in metal residues reflect local differences in contamination of pelican foods." However, the levels found indicate no extensive contamination of the pelicans' food (Blus, et al., 1977).

The effect of sodium arsenite (100 mg/kg as a single oral dose) on eggshell thickness in mallard ducks was examined experimentally (Haegele and Tucker, 1974). Sodium arsenite caused short-term eggshell thinning which returned to normal by the fifth day after treatment. The "shell thinning" appears to be associated with reduced food consumption caused by sublethal intoxication and could be termed "toxic thinning." Reduced food consumption itself causes eggshell thinning.

A listing of toxic oral doses for a variety of arsenicals and wildlife species is presented in Table 57. The levels are much higher than what is observed in nature. Consumption of sprayed foliage or drinking from pesticide spills is the only likely means of wildlife consuming the required toxic dose.

## Effects of Arsenic in Water

Arsenic is present in all water with concentrations varying according to locale and inputs. Marine organisms normally contain higher levels of As than do comparable fresh-water species (Woolson, 1975). The effects of varying As water levels on a variety of aquatic animals will be discussed in this section.

The tolerances of a number of marine and non-marine fungi and bacteria to a copper-chrome-arsenate preservative and its constituents have been investigated (Irvine and Jones, 1975). Most of the fungi had minimum inhibitory concentration (MIC) values of 179 to 636 mg As/liter. In the presence of the CCA preservative, most marine fungi had MIC values of 0.1 to 0.2%, while non-marine fungi had values of 0.0125 to 0.025%. Bacterial isolates were generally more tolerant than the fungi species studied with MIC values of 636 to 795 mg As/liter and 0.1 to 0.5% CCA preservative.

Table 57.--Toxic oral doses of some arsenic compounds in wildlife

| Compound | Animal | Toxic Dose[a] (as arsenic) | Comment | Reference |
|---|---|---|---|---|
| Calcium arsenate | Wild rabbit | 23.5 mg/kg | Dead at 3 days | Chappellier and Raucourt, 1936 |
| | Hare | 21.3 mg/kg | Lived | |
| Copper acetoarsenite | Wild rabbit | 10.5 mg/kg | Dead at 50 hr | |
| | Hare | 10.5 mg/kg | Dead at 74 hr | |
| | Cowbird | 99.8 ppm | 50% mortality in 11 days | Safety of Paris, Green, 1969 |
| | Bobwhite quail | 480 ppm | $LC_{50}$ | Heath *et al.*, 1972 |
| | Japanese quail | 1,204 ppm | $LC_{50}$ | |
| | Ring-necked pheasant | 1,403 ppm | $LC_{50}$ | |
| | Mallard | >5,000 ppm | 20% mortality at 5,000 ppm | |
| Lead arsenate | Gray partridge | 300 mg/kg | Approximate fatal dose | Chappellier and Raucourt, 1936 |
| | Hare | 40.4 mg/kg | Dead at 60 hr | |
| | Wild rabbit | 40.4 mg/kg | Dead at 52 hr | |
| | Japanese quail | 4,185 ppm | $LC_{50}$ | Hill *et al.*, 1975 |
| | Ring-necked pheasant | 4,989 ppm | $LC_{50}$ | |
| | Mallard | >5,000 ppm | No mortality | |
| Sodium arsenite | White-tailed deer | 923 mg | Yearling doe died in 12 hr | Boyce and Verme, 1954 |
| | Mallard | 1,000 ppm | 50% mortality in 6 days | U.S. Dept. Int., 1964 |
| | Mallard | 500 ppm | 50% mortality in 32 days | |
| | Mallard hen | 323 mg/kg | $LD_{50}$ | Tucker and Crabtree, 1970 |

[a] mg/kg = dose per unit body weight; ppm = concentration of arsenic in the diet; mg = total dose.

The organism Philodina roseola, or rotifer, is a common aquatic species in the United States and is an excellent fish food. Environmental conditions which adversely affect its survival could affect fish populations. The median tolerated level for arsenate in water was determined (Schaefer and Pipes, 1973) to be 96.3 mg/liter at 15° C and 82.8 mg/liter at 20° C. The range of measured life span $TL_m$ values were 6.0 to 13.0 mg/liter. Temperature affects the $TL_m$ concentration, but not the life span. Few river waters or drinking water supplies contain more than 0.05 mg/liter which would seem to indicate that they are safe for the rotifer.

The green sunfish accumulates arsenate in proportion to exposure time, temperature, and concentration (Sorensen, 1976). Levels in the sunfish were highest in the liver and lowest in the muscle. Temperature quotient ($Q_{10}$) values for As uptake in liver tissue have a mean of 4.5, higher than Lepomis genus, but similar to a marine yeast (Button and Dunker, 1971). The elevated levels suggest that elevated heat and high metal concentrations act synergistically in heavy metal uptake.

In another experiment, Sorensen (1976a) found that As levels ranged from 0 to 100 ppm As, 400 to 700 ppm As, and 550 to 650 ppm As in Lepomis tissue after exposure to 100, 500, or 1,000 ppm As in the water. Arsenic was eliminated from tissue after removal to As-free water.

Survival of immature bluegills was related to the total amount of sodium arsenite added to experimental ponds (Gilderhus, 1966). Survival varied from 90% in the control pools to 18% in pools which received 1.2 ppm $NaAsO_2$ weekly for a total treatment of 19.20 ppm $NaAsO_2$ or 11.04 ppm As. Fish contained up to 11.70 ppm As, but only 1.3 ppm were in the flesh; most appeared in the gills and digestive tract (17.6 ppm As) or the liver (11.6 ppm As).

Treatments totaling 4.0 ppm or more resulted in substantially reduced bottom fauna numbers. Fewer species were present at higher concentrations. Mayfly nymphs were absent at 4.0, 4.8, 6.4, and 19.2 ppm $NaAsO_2$ levels. The four lowest concentrations, 0.4, 0.64, 1.2, and 1.6 ppm, had somewhat greater populations of bottom fauna than the control.

Rotifer populations were reduced at the two highest levels but were higher than the control at lower application levels. Cladocera were severely reduced at water levels above 0.4 ppm $NaAsO_2$. "The total numbers of the microcrustaceans which are valuable fish foods appeared to be greatly reduced in all pools which received totals of 4.0 ppm ($NaAsO_2$) or more."

Dabrowski (1976) examined the effect of sodium arsenate and arsenic trioxide on the development of rainbow trout embryos. Survival of embryos improved as the arsenate level increased although all were lower than the control. No definite relationship was found between egg survival and $As^{+3}$ concentration although arsenic trioxide caused a higher mortality of eggs. Arsenic content increased with incubation time for both arsenicals. The eggs contain a maximum of 4.3 to 4.7 ppm As (dry weight) at 50 ppm As from either source. Arsenite is probably in the pentavalent form after 40 days since $As^{+3}$ is rapidly converted into $As^{+5}$ when water is aerated (Clement and Faust, 1973).

Water hardness did not affect the toxicity of sodium arsenite when bluegills were treated (Inglis and Davis, 1972). The $LC_{50}$ value was 26.7 ppm As.

The mud snail, Nassarius obsoletus (Say), is an important marine scavenger along the Atlantic coastline. Sodium arsenite depressed oxygen consumption at levels greater than 2.0 ppm (MacInnes and Thurberg, 1973). At normal oceanic As levels, respiration in this marine gastropod will be normal.

Oysters have also been examined for adverse effects of arsenite as well as other metals. Arsenite was relatively non-toxic to the American oyster, Crassostrea virginica with an $LC_{50}$ value of 7.5 ppm As. In contrast, the $LC_{50}$ for mercury was 0.0056 ppm Hg. (Calabrese, et al., 1973).

The toxicity of various As compounds is tabulated in Table 58 for a variety of aquatic fish and shellfish. In general, the concentrations needed to cause an adverse effect are much higher than that observed in natural waters.

## Effects of Arsenic from Air

Arsenic may settle onto plants and soils from emission sources and be consumed by animals. Animals in the Helena, Mont., valley are exposed to air pollution from a copper smelter. Horses appear to be especially susceptible to the effects of pollution. As a result, horse-mane hair was sampled in an area around the smelter. Horse hair on animals grazing in pastures closest to the smelter had the highest levels: 5.9, 5.6 and 1.0 ppm As at one site; 2.3, 1.6 and 0.0 at a second site--both 1.6 km from the stack. Other sites had values of 0.34, 0.0, 0.2, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, and 0.0 ppm As. The horses at the two highest As sites correspond to higher ranked Cd and Pb concentrations. Lewis (1972) concluded that "the arsenic levels that were detected are indicative of exposure to arsenic; however, the toxicologic significance of these levels remains unclear. Arsenic concentrations tend to increase with increasing zinc, cadmium, and lead levels in hair."

Various animal food products were obtained within 3.2 km of the smelter and analyzed. The following values (ppm As) were obtained: rabbit muscle, 0.6; beef liver, 0.2; beef muscle, 0.05; chicken muscle, trace; whole milk, trace; swine heart, trace; sausage, trace. In general, the levels do not indicate a serious pollution problem from incorporation of As and there is little danger to the general population from consumption of these products.

In a study to determine the suitability of fly ash as a selenium supplement for farm animals, Furr, et al. (1978) also analyzed for As. The fly ash contained 195 ppm As and was incorporated at 1, 2.5, 5, and 7.5% by weight into complete rations for lambs. The ration appeared quite acceptable based on average daily weight gain. None of the elements except selenium showed an increase (above the controls) in tissues from the sheep fed the fly ash ration.

## Effects of Arsenic in Plants

A case of misuse of an arsenical and a resulting deer kill occurred in 1971. Arsenic acid, labeled for use on Bermudagrass lawns, was aerially sprayed on a field of Johnsongrass to prepare the field for planting soybeans. Eleven dead deer were found in or near the field shortly thereafter. The deer were analyzed for As in their liver (19 ppm As), kidney (18 ppm As), and rumen contents (22 ppm As). The arsenic acid did not control the Johnsongrass (Swiggart, et al., 1972).

Table 58.--Toxicity of various arsenic compounds to freshwater and marine fish and shellfish[a]

| Compound | Test Organism | Habitat[b] | Test Conditions[c] | Concentration | Remarks | Reference |
|---|---|---|---|---|---|---|
| | | | | ppm As | | |
| Arsenic (form unspecified) | Bluegill (*Lepomis machrochirus*) | F | FW | 15 | Toxic | Warrick *et al*., 1948 |
| | Large-mouth bass (*Micropterus salmoides*) | F | FW | 6.0 | Survived 232 hr | Warrick *et al*., 1948 |
| | | | | 10.0 | 87% survival | |
| | Crappie (*Pomoxis* sp.) | F | FW | 15 | Toxic | Warrick *et al*., 1948 |
| | Pike perch | -- | FW | 0.7-1.1 | Tolerated, 48 days | Meinck *et al*., 1956 |
| | | | | 1.1-2.2 | Lethal in 2 days | |
| | "Minnow" | -- | FW | 17.8 | Toxic | Burgess, 1957 |
| | Carp (*Cyrprinus carpio*) | F | FW | 3.1 | Toxic, 4-6 days | Meinck *et al*., 1956 |
| | | | | 2.2 | Tolerated, 13 days | |
| | "Eel" | -- | FW | 3.1 | Toxic, 3 days | Meinck *et al*., 1956 |
| | "Bleak" | -- | FW | 2.2 | Toxic, 3 days | Meinck *et al*., 1956 |
| | | | | 1.1-1.5 | Tolerated, 11 days | |
| Arsenic (form unspecified) | "Fish" | -- | FW | 0.76 | Tolerated | Brown, 1951 |
| Arsenic trioxide | Sea lamprey (*Petromyzon marinus*), larvae | A | SB,FW,LS | 5.0 | No effect,24hr;12.8C | Applegate *et al*., 1957 |
| | Rainbow trout (*Salmo gairdneri*) | A,F | SB,FW,LS | 5.0 | No effect,24hr;12.8C | Applegate *et al*., 1957 |
| | Bluegill (*Lepomis machrochirus*) | F | SB,FW,LS | 5.0 | No effect,24hr;12.8C | Applegate *et al*., 1957 |
| | Pink salmon (*Oncorhynchus gorbuscha*) | A | SB,SW,LS | 9.5 | Initial concentration total kill in 7 days | Holland *et al*., 1960 |
| | | | | 2.6-5.3 | Indicated tolerance concentration 10 days of exposure plus observation | |
| Sodium arsenate | Blue mussel (*Mytilus edulis*) | S | SW | 16 | Lethal in 3-16 days | Ellis, 1940 |
| | "Minnow" (*Phoxinus phoxinus*) | F | SB,FW,LS | 250 | Toxic, 16 hr mean; loss of equilib. | Grindley, 1946 |
| | "Minnow" (*Phoxinus phoxinus*) | F | -- | 234 | Lethal, 16-20C | Jones, 1962 |
| | Green sunfish (*Lepomis cyanellus*) | F | LS | 30 | Lethal in 527 hr. | Sorensen, 1976 |
| | | | | 60 | Lethal in 210 hr. | Sorensen, 1976 |
| | | F | LS | 100 | Lethal in 46 hr. | Sorensen, 1976a |
| | | | | 500 | Lethal in 17 hr. | Sorensen, 1976a |
| | | | | 1,000 | Lethal in 12 hr. | Sorensen, 1976a |
| Sodium arsenite | Mud snail (*Nassarius obsoletus*) | S | SW,LS | 2 | Depressed oxygen consumption in 72 hr. | MacInnes and Thurberg, 1973 |
| | "Minnow" (*Phoxinus phoxinus*) | F | SB,FW,LS | 20 | Toxic, 36hr mean; loss of equilib. | Grindley, 1946 |
| | "Minnow" (*Phoxinus phoxinus*) | -- | -- | 20 | Lethal or deleterious, 36hr. | Rudd and Genelly, 1956 |
| | Fathead minnow (*Pimephales promelas*) | F | FW,FS (pond) | 4.0 | No observed effect | Eipper, 1959 |
| | American Oyster (*Crassostrea virginica*), eggs | S | SW,LS | 7.5 | 48hr. TLM[d]; 26C | Calabrese *et al*., 1973 |
| | Spottail shiner (*Notropis hudsonius*) | F | SB,FW,LS | 45 | 25 hr. TLM; sublethal effects | Boschetti and McLoughlin, 1957 |
| | | | | 29 | 48 hr. TLM; fin damage, diarrhea, scale damage, and hemorrhaging around fins | Boschetti and McLoughlin, 1957 |
| | | | | 27 | 72 hr. TLM | Boschetti and McLoughlin, 1957 |

Table 58.--Toxicity of various arsenic compounds to freshwater and marine fish and shellfish[a]--continued

| Compound | Test Organism | Habitat[b] | Test Conditions[c] | Concentration | Remarks | Reference |
|---|---|---|---|---|---|---|
| | | | | ppm As | | |
| Sodium arsenite | Golden shiner (*Notemigonus crysoleucas*) | F | FW,FS (pond) | 4.0 | No observed effect | Eipper, 1959 |
| | Bluegill (*Lepomis macrochirus*)<br>..............do.............. | F | FW,FS (pond) | 4.0 | Numbers reduced by 42%; monthly applications | Lawrence, 1958 |
| | ..............do.............. | F | SB,FW,LS | 26.7 | 96 hr. TLM | Inglis and Davis, 1972 |
| | ..............do.............. | F | FW,FS (pond) | 4.0 | No observed effect | Eipper, 1959 |
| | ..............do.............. | F | FW | 35.0 | 96hr TLM;12C | Gilderhus, 1966 |
| | ..............do.............. | F | -- | 44 | 48hr TLM;23.9C | Crosby and Tucker, 1966 |
| | ..............do.............. | F | FW,LS | 44 | 48hr TLM;24C | Cope, 1966 |
| | ..............do.............. | F | SB,FW,LS | 0.5<br>0.7 | 48hr TLM<br>24hr TLM | Hughes and Davis, 1967 |
| | ..............do.............. | F | SB,FW,LS | 5.0 | No harmful effects; 24 hr;12.8C | Applegate *et al*., 1957 |
| | Large-mouth bass (*Micropterus salmoides*) | F | FW,FS (pond) | 4.0 | No observed effect | Eipper, 1959 |
| | Channel catfish (*Ictalurus punctatus*) | F | SB,FW,LS | 47.9<br>25.9 | 24 hr TLM:25C<br>48, 72, and 96 hr TLM; 25C | Clemens and Sneed, 1959<br>Clemens and Sneed, 1959 |
| | ............do............ | F | FW | 15 | 48 and 72 hr TLM | Clemens and Sneed, 1959 |
| | ............do............ | | | 27.6 | 24 hr TLM | |
| | Rainbow trout (*Salmo gairdneri*) | A,F | FW | 25.6 | 96 hr TLM;12C | Gilderhus, 1966 |
| | ..............do.............. | A,F | -- | 60 | 48 hr TLM;12.8C | Crosby and Tucker, 1966 |
| | ..............do.............. | A,F | FW,LS | 36.5 | 48 hr TLM;13C | Cope, 1966 |
| | ..............do.............. | A,F | FW | 20 | Lethal or deleterious, 36 hr | Rudd and Genelly, 1956 |
| | ..............do.............. | A,F | SB,FW,LS | 5.0 | No harmful effects, 24 hr;12.8C | Applegate *et al*., 1957 |
| | Goldfish (*Carassius auratus*) | F | FW | 34.0 | 96 hr TLM;12C | Gilderhus, 1966 |
| | Chum salmon (*Oncorhynchus keta*) | A | SB,SW,LS | 11.0 | 48 hr TLM | Alderdice and Brett, 1957 |
| | Pink salmon (*Oncorhynchus gorbuscha*) | A | SB,SW,LS | 5.0 | Initial concentration, 54% kill in 10 days | Holland *et al*., 1960 |
| | Sea lamprey (*Petromyzon marinus*) larvae | A | SB,FW,LS | 5.0 | No harmful effects, 24 hr;12.8C | Applegate *et al*., 1957 |

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[a] Most of these data from Toxicity of Power Plant Chemicals to Aquatic Life.

[b] A = anadromous; F = freshwater; S = seawater.

[c] SB = static bioassay; FW = freshwater; SW = seawater; LS = laboratory study; FS = field study.

[d] TLM = median tolerance limit (concentration necessary to kill half the test animals) in a specified period.

## Beneficial Effects of Arsenic in Animals

The first attempt to establish As as an essential element was by Hove, et al. (1938) who found that a milk diet fortified with iron, copper, and manganese furnishing as little as 2 micrograms As/day had no significant effect on growth, hemoglobin concentration, and red blood cell number or fragility in rats. They did observe, however, that a supplement of 5 micrograms per day of dietary arsenic as $As_2O_3$ delayed the rate of fall of hemoglobin level in rats fed whole milk without mineral supplementation subsequent to being fed the mineral-supplemented milk diet. Skinner and McHargue (1946) reported that rats responded to As supplements by exhibiting increased levels of hemoglobin when fed a diet composed basically of skim milk powder and sucrose and adequately supplemented with iron and copper. In contrast, rats fed a diet composed basically of whole milk and glucose did not respond to As supplementation. Schroeder and Balassa (1966) found that rats and mice grew and developed normally when fed diets containing as little as 0.053 microgram As/g. They observed, however, that additional As via the drinking water improved the appearance of the skin and hair.

Recently studies from two independent laboratories have renewed interest in the possibility that As is an essential nutrient. To date, findings showed that dietary As deprivation adversely affected rats, chicks, minipigs, and goats. In the RPAR position document those studies were mentioned just briefly. Further details of those studies are probably warranted and thus are given in the following.

While investigating the essentiality of nickel, Nielsen, et al. (1978) observed that from third-generation pregnant rats, fed a diet based on skimmed milk powder, whether nickel-deficient or -supplemented, perinatal death of pups was 90%. A group of 10 nickel-supplemented third-generation dams were rebred and five were given a supplement of 4.0 microgram As as sodium arsenate and 0.5 microgram As as sodium arsenite per gram of diet. The perinatal loss of pups was reduced to one-half in the group receiving the As supplement. In the As-supplemented group, most of the deaths occurred in one litter, apparently due to maternal neglect--not due to nutritional imbalances. At weaning (24 days) mean body weight was 26 g for the six surviving As-deprived pups and 42 g for the 26 surviving As-supplemented pups. Furthermore, in the group receiving 4.5 micrograms As/g of diet, all pups appeared normal and there was no evidence of teratology. Only the As-deprived pups exhibited an unhealthy appearance.

The essentiality of As for rats was tested in two additional experiments (Nielsen, et al., 1975). The offspring of Sprague-Dawley dams fed an As-deficient (30 nanograms/g) diet from day 3 of gestation were examined for deficiency signs. Controls received 4.5 micrograms As/g of diet. During the suckling period, pups did not differ in mortality or appearance. Possibly, perinatal mortality was not elevated and growth was not depressed because the dams had not been on the As-deficient regimen for a sufficient time. After weaning, the growth was slower in the As-deprived than in the supplemented offspring. At 40 to 44 days, control males weighed significantly more than As-deprived males. At this time the deprived rats appeared less thrifty than the supplemented rats; their coats were rougher, and yellowish. Other signs of As deprivation were elevated erythrocyte osmotic fragility, elevated spleen iron, and splenomegaly.

Some of the signs of As deprivation found in minipigs and goats were similar to those found in rats. Anke, et al. (1976, and 1978) fed an As-deficient diet (less than 50 nanogram/g) to growing minipigs and goats that were allowed to reproduce. Controls were supplemented with 350 nanograms As/g of diet. Arsenic deprivation apparently did not adversely affect the growing animals. The first signs of As deprivation appeared in $F_1$ offspring, and the most obvious signs in $F_2$ offspring. Birth weight and growth were depressed. Mortality was higher for As-deficient than for supplemented piglets and kids. Some adult, first-generation, As-deprived goats died and those that died during lactation exhibited histologically damaged cardiac muscle. Other signs of deficiency included depressed levels of skeletal ash and elevated levels of copper and manganese in several organs.

Arsenic metabolism in rats is different than in most other species. Thus, Nielsen used the chick as an experimental animal in studies of As nutrition and metabolism. Data obtained to date strongly suggest that As is an essential nutrient for growing chicks (Nielsen and Shuler, 1978). In four experiments, day-old cockerel chicks were fed a diet based on skimmed milk powder and acid-washed ground corn that was supplemented with arginine (20 g/kg). The basal diet contained about 20 nanograms As/g in experiments 1 and 2, 35 nanograms/g in experiment 3, and 45 nanograms/g in experiment 4. Controls were fed a supplemental 1.0 microgram As/g of diet as sodium arsenate. In the first three experiments, the As-deprived chicks weighed significantly less than controls at 28 days. Chicks fed the basal diet containing 45 nanogram As/g grew as well as controls. Chicks fed the basal diet containing 20 nanogram As/g had larger, darker livers than controls. When the basal diet contained 35 nanograms As/g, the elevation in size of livers was less but still significant. When the basal diet contained 45 nanograms As/g, liver weight was not elevated. The As-deprived chicks exhibited extremely elevated levels of zinc in the liver except in experiment 4 in which the basal diet contained 45 nanograms As/g. Other possible signs of As deprivation that were shown only in experiment 3, and therefore need confirmation, were: depressed plasma alkaline phosphatase, depressed white blood cell count, and elevated erythrocyte osmotic fragility.

Many of the As deprivation signs seen in chicks were similar to zinc deprivation signs. Furthermore, signs of As deprivation were more obvious and appeared sooner when high levels of arginine, a zinc antagonist (Coleman, et al., 1971), was added to the diet. At present, Nielsen is conducting a study designed to ascertain whether As is necessary for the efficient utilization of zinc. In an experiment in progress, the interaction between Zn and As is being investigated with cockerel chicks in a two-way, two by two, factorially-designed experiment. Supplements to the basal diet were zinc (as zinc acetate) at 0 and 50 micrograms/g and As (as sodium arsenate) at 0 and 2 micrograms/g. The basal diet contained 50 micrograms Zn/g and approximately 7 nanograms As/g. At 4 weeks, chicks fed the basal diet developed classical signs of zinc deficiency: depressed growth, "frizzled" feathers, enlarged hocks, shortening and thickening of the legs, stiff gait, and dermatitis on the shank skin. Feeding chicks a supplemental 50 micrograms Zn/g of diet, or 2 micrograms As/g of diet, prevented those abnormalities from appearing. Preliminary data also indicate that the chicks showing abnormalities similar to those found in zinc deficiency (As-deprived) had elevated levels of zinc in bones. The findings strongly suggest that even though the chicks were receiving adequate zinc in the diet, the lack of As in the diet prevented efficient utilization of that zinc. In other words, As may be required in the diet for normal zinc metabolism.

The previously described findings show that even though As nutrition does not now appear to be of concern, it does not preclude its nutritional significance in the future. It is unfortunate that As has been synonymous with poison for centuries, and recent reports have associated As with some forms of cancer. This has resulted in a relatively common state of mind, called "arsenophobia" by Frost (1975), that condemns any compound or form of As. That attitude apparently rejects the possibility that As might be similar to other trace elements (e.g., nickel) that can be detrimental at high dietary levels and in certain forms, may be carcinogenic, but in other forms and in physiological amounts are essential nutrients. Accumulating evidence strongly suggests that As might be of nutritional importance. Thus, concerns about practices which contribute As to the environment and ultimately to the food supply at ppb or low ppm levels are probably unnecessary and may be detrimental because they might lead to efforts for a zero-base exposure to As, or for elimination of as much As as possible from dietary sources for animals and humans. The consequence of eliminating an essential nutrient from the diet is obvious.

## Summary of Biological Analysis of Inorganic Arsenicals

Industry-based statistics grossly understate the volume of arsenically treated wood produced each year and the number of plants using As-containing formulations. Better data have recently been obtained and incorporated in this report.

Arsenic treatments provide excellent protection with a surface that is clean, odorless, non-oily, and paintable. They are the dominant treatment for lumber.

Other available waterborne salt treatments do not provide the protection that can be expected of the arsenicals.

The characteristics of the arsenicals make them particularly suitable and accepted for use in and around residential construction.

The production of lumber treated with arsenicals is growing rapidly for three major reasons:

1. The largest use, for residential accessories such as decks and landscaping, is growing rapidly.
2. The naturally durable woods once commonly used for these purposes are no longer available, from a practical standpoint, to fill more than a small and declining portion of the demand.
3. New systems where arsenically treated wood offers substantial advantages over conventional materials and methods, such as the wood foundation, are being developed and effectively promoted.

There are approximately 325 wood-preserving plants in the United States that treat with arsenical preservatives. Some of these also treat with creosote or penta. It is estimated by the team that the total number of workers of all types in the 325 plants is probably much less than 2,000, with a smaller proportion of them working only in As treating sections. In each plant treating with As compounds alone, there are likely only four or five total people employed. The cylinder operator and unloader and the stackers of treated wood receive the greatest exposure. However, there is little exposure to workers of all types in ACA and CCA treating plants (Arsenault, 1975a). There is even less exposure today because of OSHA regulations, cessation of production of FCAP dusts, general awareness of industry, and precautions taken to prevent exposure.

Treated poles, because of their sheer size and bulk, are almost always handled by machinery and not by hand. If any handler is exposed to the treated surface of a pole, it would be the lineman or pole rigger. By the time the lineman is exposed to the pole, it usually will have dried in storage for several weeks or months and will have been transported; handled several times during loading, unloading, and erection; and weathered during this period of time. Each factor, plus the fact that the pentavalent As is tightly bound to the wood, makes the pole surface unlikely to be a significant source of exposure to the lineman.

Handling of arsenically treated wood is free from hazard attributable to the preservative.

The do-it-yourself homeowner working with arsenically treated wood (lumber, timbers, plywood, fence posts, and piling) is exposed through sawdust and handling to a limited amount of As. The homeowners use of treated wood is confined to specialized outdoor uses such as decks, fences, and planter boxes.

Wipe tests show limited exposure to As by handling treated wood or plywood. A study showed there is no apparent health hazard to the consumer via vaporization, leaching, or other mechanism.

Animals that may be exposed to treated wood include farm animals and pets. Animals would have similar exposure to the surfaces of the treated wood as that of humans living in buildings constructed of treated wood. Some horses are prone to "cribbing" or biting off bits or chunks of wood from their stalls. They are not known to ingest this wood, thus limiting the exposure to As in this manner. Lower As levels are found in aquatic animals, with shrimp and lobster containing higher levels than fish. Marine organisms contain higher levels than those in fresh water.

The environmental effects of As in air, water, or soil at concentrations normally found from arsenical pesticides as currently used are insignificant. Detrimental effects to plants and animals have occurred in the soil of apple orchards and in isolated instances of pesticide misuse. However, there is growing evidence that As may be an essential element at low levels in animals.

Arsenic can be found in all components of the environment naturally or as a result of human activity. Levels are generally quite low except around smelters or where large applications of lead arsenate were made over many years (a use no longer permitted).

No problems have been found in the literature relative to the environment from wood preservative use. Soil levels around treated wood are higher than normal, but no problems have been associated with these concentrations. Current use patterns for the other arsenicals, likewise, indicate very little environmental problems.

Arsenate, the form present in aerobic soils, is bound tightly to soil components and becomes unavailable for plant uptake or leaching. Arsenic in water is sorbed by sediments and becomes unavailable to aquatic plants or animals. Arsenic can be metabolized to alkyl arsenicals which are lost from soil as dimethyl- or trimethylarsines. Since As is lost from the soil, an equilibrium will be reached where the amount lost will be equal to the amount applied. For most uses, the equilibrium soil concentration in the 0 to 15 cm layer will be $\leq$ 21 ppm As. The exception to the above statement is the use of calcium arsenate on turf where a higher treatment is used to create toxicity to germinating annual bluegrass seed.

Phytotoxicity has been observed in apple orchards treated with large amounts of lead arsenate, but plant residues are generally low. Other instances of phytotoxic As levels are rare.

Arsenic does occur naturally in aquatic organisms. Marine algae and seaweed contain appreciable amounts of As bound in organic compounds.

All of the arsenical wood preservative concentrates, whether in paste, powder, or liquid form, are sold as industrial chemical products and must be diluted to working strengths of 0.75 to 6.0% prior to treatment. All dilutions are done in completely closed systems and the solutions are pumped into treating cylinders and returned to storage after treatment. They are not offered for distribution, sale, or use by the consuming public. However, CCA solution is available for brush on application in special use situations.

The method of handling the treated wood depends upon the product treated. Little or no treated wood is handled while it is wet. Treated wood to be kiln-dried is allowed to drip and air-dry before it is stacked and stickered by workmen wearing personal protective equipment.

An Assessment Team survey disclosed that there are no known commercial thermal and dip treatments of wood with As compounds. This survey included chemical producers, formulators, sellers, university and Forest Service personnel (Smith, 1979). There are also no known groundline treatments of utility poles with As compounds. Neither are there any known non-commercial spray or dip treatments (large enough supplies of chemicals cannot be purchased from the manufacturers or formulators to accomplish this type of treatment).

# CHAPTER 5: CREOSOTE, CREOSOTE-COAL-TAR SOLUTIONS, AND CREOSOTE-PETROLEUM SOLUTIONS

# CHAPTER 5: CREOSOTE, CREOSOTE-COAL-TAR SOLUTIONS, AND CREOSOTE-PETROLEUM SOLUTIONS

## Introduction

Creosote is the oldest of the major wood preservatives, having received extensive use as a coating for ship timber prior to 1800. Its modern use in pressure treatments had its origin in the early 1800's when Rueping patented the first pressure-vacuum treating process. Wide-scale use of creosote as a wood preservative in the United States began around 1870 when a pressure-treating plant was constructed in Pascagoula, Miss., to produce railroad ties. The importance of creosote as a preservative for crossties has continued, so that today creosote-treated crossties account for one-third of all pressure-treated wood production. The total volume of wood treated with creosote is almost equal to the volume treated with all other preservatives combined. The quantity of creosote used annually (about 1.2 billion pounds) is such that it would not be possible either now or in the foreseeable future for other preservatives to replace it.

## Use Patterns and Efficacy

In 1976, approximately 118 million gallons of creosote and coal tar were used in the commercial treatment of wood in the United States (Ernst and Ernst, 1977). The preservatives were used as straight creosote, creosote-coal tar solution, creosote-petroleum solution, and creosote-pentachlorophenol solution. The usage of each of these preservatives by region is shown in Table 59.

Ninety-eight percent of creosote and its solutions used for treatment of wood was applied in "closed-system," pressure-treatment processes, and the other almost 2% in commercial non-pressure treatments (AWPI, 1977a).

von Rumker, et al. (1975) estimated that only 0.2% of creosote produced was sold to individuals for farm and home treatment of wood. Thus, in 1976 approximately 2 million pounds of creosote were used by individuals. Finally, a further 0.5 million pounds were used for commercial groundline treatment of poles (Levi, 1978).

The following section shows the use patterns for creosote-containing preservatives applied by various methods, rates of application, and pests controlled.

Creosote and its solutions are used to prevent attack by wood-destroying fungi, wood-destroying insects, and certain marine borers. Wood-destroying fungi utilize the carbohydrate and lignin components of wood. As decay proceeds wood loses its strength, finally becoming useless as a structural material. Creosote can prevent attack by these fungi.

Wood-destroying insects include subterranean, dampwood and drywood termites; anobiid, lyctid and bostrichid beetles; flat and round-headed borers; and carpenter ants. These insects build galleries in the wood either for shelter or to obtain food. Termites, lyctid beetles, and carpenter ants can rapidly destroy wood in service. The other insects destroy wood more slowly, but can still cause serious economic losses if left uncontrolled. Creosote can prevent attack by these insects.

Marine borers include crustacean and molluscan borers. The major crustacean is Limnoria, which attacks the surface of wood. It forms, in time, the characteristic hour-glass shape seen at the water line of improperly preserved piling. Molluscs

Table 59.--Amount of creosote and its solutions used for commercial pressure and non-pressure treatment of wood in the United States in 1976[a]

| Preservative | North-east | North Central | South-east | South Central | Rocky Mt. | Pacific | Total |
|---|---|---|---|---|---|---|---|
| | - - - - - - - - - - | - 1,000 Pounds of | Preservative Solution | - - - - - - - - - - | | | |
| Straight creosote | 61,610 | 11,740 | 99,360 | 203,940 | 2,650 | 35,470 | 414,770 |
| Creosote content of:<br>creosote- coal tar | 50,900 | 118,370 | 87,220 | 114,380 | 4,830 | 19,470 | 395,160 |
| Creosote-petroleum solution | 4,720 | 44,060 | 2,290 | 41,480 | 21,950 | 21,890 | 136,380 |
| Creosote-penta and other | 20 | 0 | 1,120 | 900 | 0 | 10 | 2,050 |
| Total creosote | 117,250 | 174,160 | 189,990 | 360,700 | 29,430 | 76,830 | 948,370 |
| Coal tar in creosote-coal tar solution | 33,930 | 70,960 | 55,450 | 58,190 | 4,650 | 7,910 | 231,100 |
| Total creosote and coal tar | 151,180 | 245,120 | 245,440 | 418,890 | 34,080 | 84,740 | 1,179,470 |

[a] Source: Ernst and Ernst, 1977.

include shipworms (Teredo and Bankia), which form galleries deep into the interior of the wood, and pholads (Martesia) which form galleries just below the surface. Both Limnora and shipworms can cause rapid failure of improperly treated timber in salt water. Creosote will prevent attack by all of these organisms except the warm water Limnoria species, L. tripunctata. A modified creosote containing an increased proportion of naphthalene shows promise in preventing Limnoria attack (Webb and Fish, 1978).

Approximately 35% of the total creosote and coal tar used in wood preservation is applied as a straight creosote. This performs very well and is used for all types of wood products treated with creosote and its solutions. In many situations, creosote is blended with either coal tar or petroleum oils and the resulting solution used for pressure treatment of wood. Creosote-coal tar solutions reduce the tendency of treated wood to split in service, are cheaper than straight creosote in some areas, and have greater tendency than straight creosote to bleed to the surface of treated wood. They are used primarily in the eastern United States for the treatment of railroad ties. The percentage of coal tar ranges up to 50%. Creosote-petroleum solutions have similar qualities to creosote-coal tar solutions except that they are not as effective in preventing attack by wood-destroying organisms. Creosote-petroleum solutions are used primarily in the central and western United States for the treatment of railroad ties. Mixtures of 50-50 or 70-30 petroleum and creosote are generally used.

Creosote-pentachlorophenol was developed as a highly effective preservative against wood-destroying organisms which could be applied at lower retentions than creosote alone. Unfortunately, the preservative is highly corrosive to treatment plant equipment when any water is present. This has almost eliminated the commercial use of the preservative. Some plants in the southeast and south central regions of the United States still use the preservative for the treatment of primary poles and lumber and timbers.

## Commercial Pressure and Non-Pressure Treatments

The volumes of various wood products treated commercially with creosote, creosote-coal tar, and creosote-petroleum are shown in Table 60. All statistics in this and other tables in this section are from the 1976 AWPA Wood Preservation Statistics (Ernst and Ernst, 1977). The percentage of each product type treated with creosote and its solution, and the percentage of creosoted wood in each product type are also shown. Almost 75% of creosoted wood products are crossties and switch ties. In addition, creosote and its solutions are used almost exclusively for the treatment of ties. Other uses of creosote in descending order of importance are for poles, lumber, and piling. Piling is the only product other than ties where creosote is the major preservative used for treatment.

The total usage of creosote and its solutions has decreased significantly in the last 10 years (Table 61). However, this has not been the case for ties, the most important market for creosote. The volume of treated tie material has increased over the last 3 years. This trend should continue because the production of crossties during the recent past has fallen far short of the number needed to maintain track in good condition. It has been estimated that approximately 33 million ties are needed annually for maintenance alone (Thompson, 1978), whereas, in 1976 only 28 million ties were treated.

Table 60.--Usage of creosote and its solutions for commercial pressure and non-pressure treatment by product and preservative in the United States in 1976[a]

| | Cross-ties | Switch Ties | Piling | Poles | Cross-arms | Lumber and Timbers | Posts | Other | Total |
|---|---|---|---|---|---|---|---|---|---|
| | - - - - - - - - | - - - - - | - - - - | - - - | 1,000 cu. ft | - - - - | - - - - | - - - - | - - - - |
| Creosote and Creosote-coal tar | 68,528 | 4,419 | 7,411 | 14,483 | 78 | 8,914 | 1,891 | 2,444 | 108,168 |
| Creosote-petroleum | 26,637 | 1,299 | 62 | 88 | 0 | 758 | 822 | 347 | 30,013 |
| Total | 95,165 | 5,718 | 7,473 | 14,571 | 78 | 9,672 | 2,713 | 2,791 | 138,181 |
| Percent of product treated with creosote and its solutions | 99+ | 99+ | 90 | 30 | 4 | 12 | 20 | 31 | |
| Percent of all creosoted wood used for each product | 68 | 4 | 5 | 11 | 1 | 7 | 2 | 2 | 100 |

[a] Source: Ernst and Ernst, 1977.

Table 61.--Wood products treated with creosote and its solutions in the United States in 1966, and 1972-76[a]

| Preservative | Year | Cross-ties | Switch Ties | Piling | Poles | Cross-arms | Lumber and Timbers | Fence Posts | Other | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1,000 cu. ft. | | | | | | | | |
| Creosote and creosote-coal tar | 1966 | 49,001 | 5,417 | 18,663 | 42,821 | 868 | 16,473 | 7,234 | 3,313 | 143,790 |
| | 1972 | 60,610 | 4,702 | 13,362 | 26,056 | 373 | 11,869 | 6,591 | 1,890 | 125,453 |
| | 1973 | 47,907 | 3,778 | 12,198 | 25,521 | 350 | 10,590 | 4,427 | 1,676 | 106,447 |
| | 1974 | 54,864 | 5,128 | 12,471 | 28,910 | 437 | 11,275 | 4,599 | 2,283 | 119,967 |
| | 1975 | 66,107 | 5,513 | 8,096 | 14,174 | 93 | 12,076 | 2,483 | 1,933 | 110,475 |
| | 1976 | 68,528 | 4,419 | 7,411 | 14,483 | 78 | 8,914 | 1,891 | 2,444 | 108,168 |
| Creosote-petroleum | 1966 | 20,852 | 2,312 | 429 | 832 | 81 | 2,709 | 2,495 | 438 | 30,148 |
| | 1972 | 25,070 | 1,215 | 200 | 376 | 2 | 1,020 | 752 | 254 | 28,889 |
| | 1973 | 19,526 | 1,221 | 178 | 193 | 0 | 1,269 | 867 | 264 | 23,518 |
| | 1974 | 20,656 | 1,325 | 297 | 161 | D[b] | 1,405 | 971 | 162 | 24,977[c] |
| | 1975 | 26,551 | 2,413 | 433 | 673 | 0 | 968 | 745 | 269 | 32,052 |
| | 1976 | 26,637 | 1,299 | 62 | 88 | 0 | 758 | 822 | 347 | 30,013 |
| Total creosote and its solutions (inc. creo/penta) | 1966 | 69,855 | 7,729 | 19,107 | 52,133 | 968 | 20,482 | 9,961 | 3,751 | 183,986 |
| | 1972 | 85,680 | 5,917 | 13,562 | 27,560 | 375 | 12,972 | 7,343 | 2,144 | 155,553 |
| | 1973 | 67,433 | 4,999 | 12,376 | 26,334 | 352 | 11,863 | 5,294 | 1,940 | 130,591 |
| | 1974 | 75,520 | 6,453 | 12,768 | 29,071[d] | 437[e] | 12,680 | 5,570 | 2,445 | 144,944[f] |
| | 1975 | 92,658 | 7,926 | 8,529[d] | 14,847[d] | 93 | 13,044 | 3,228[d] | 2,202 | 143,403 |
| | 1976 | 95,165 | 5,718 | 7,473[d] | 14,571[d] | 78 | 9,672[d] | 2,826 | 2,791 | 139,004 |

[a] Source: Ernst and Ernst, 1977.

[b] D = Value not shown to avoid disclosure of individual company data.

[c] This excludes volume of crossarms treated to avoid disclosure of company data.

[d] This excludes volume treated with creosote/penta to avoid disclosure of company data.

[e] This excludes volume treated with creosote/petroleum to avoid disclosure of company data.

[f] This excludes volume of poles treated with creosote/penta and crossarms treated with creosote/petroleum to avoid disclosure of company data.

Information on wood products treated with creosote, the amount of preservative used by product, and application rates is presented below.

## Crossties and Switch Ties

| | Creosote and creosote-coal tar | Creosote-petroleum |
|---|---|---|
| Volume treated (1,000 cu. ft.) | 72,947 | 27,936 |
| Percentage of total volume treated | 72 | 28 |
| Amount of preservative (million pounds) | 583 | 168 |
| Application methods | pressure | |
| Pests controlled | wood-destroying fungi & insects | |
| Application rate (pcf) | 6 to 10 | |

## Poles

| | Creosote and creosote-coal tar | Creosote-petroleum |
|---|---|---|
| Volume treated (1,000 cu. ft.) | 14,483 | 88 |
| Percentage of total volume treated | 29 | 0.5 |
| Amount of preservative (million pounds) | 130 | 1 |
| Application methods | pressure and thermal | |
| Pests controlled | wood-destroying fungi & insects | |
| Application rate (pcf) | 6 to 16 | |

## Lumber and Timbers

| | Creosote and creosote-coal tar | Creosote-petroleum |
|---|---|---|
| Volume treated (1,000 cu. ft.) | 8,914 | 758 |
| Percentage of total volume treated[a] | 11 | 1 |
| Amount of preservative (million pounds) | 89 | 8 |
| Application methods | pressure | |
| Pests controlled | wood-destroying fungi, insects & marine borers | |
| Application rate (pcf) | 5 to 25 | |

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[a] Including fire retardants.

## Piling

| | Creosote and creosote-coal tar | Creosote-petroleum |
|---|---|---|
| Volume treated (1,000 cu. ft.) | 7,411 | 62 |
| Percentage of total volume treated | 89 | 1 |
| Amount of preservative (million pounds) | 89 | 0.7 |
| Application methods | pressure | |
| Pests controlled | wood-destroying fungi, insects & marine borers | |
| Application rate (pcf) | 6 to 20 | |

## Fence Posts

| | Creosote and creosote-coal tar | Creosote-petroleum |
|---|---|---|
| Volume treated (1,000 cu. ft.) | 1,891 | 822 |
| Percentage of total volume treated | 15 | 6 |
| Amount of preservative (million pounds) | 11 | 0.5 |
| Application methods | pressure, thermal & soak | |
| Pests controlled | wood-destroying fungi & insects | |
| Application rate (pcf) | 6 to 10 | |

## Mine Ties and Timbers

| | Creosote and creosote-coal tar | | Creosote-petroleum | |
|---|---|---|---|---|
| | Mine ties | Mine timbers | Mine ties | Mine timbers |
| Volume treated (1,000 cu.ft.) | 253 | D[a] | 0 | 0 |
| Percentage of total volume treated | 53 | D[a] | 0 | 0 |
| Amount of preservative (million pounds) | 4 | D[a] | 0 | 0 |
| Application method | pressure | | | |
| Pests controlled | wood-destroying fungi & insects | | | |
| Application rate (pcf) | 6 to 10 | | | |

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[a] D = Value not shown to avoid disclosure of individual company data.

## Crossarms

| | Creosote and creosote-coal tar | Creosote-petroleum |
|---|---|---|
| Volume treated (1,000 cu. ft.) | 78 | 0 |
| Percentage of total volume treated | 4 | 0 |
| Amount of preservative (million pounds) | 0.5 | 0 |
| Application methods | pressure | |
| Pests controlled | wood-destroying fungi & insects | |
| Application rate (pcf) | 4 to 10 | |

## Wood Block Flooring[a]

| | Creosote and creosote-coal tar | Creosote-petroleum |
|---|---|---|
| Volume treated (1,000 cu. ft.) | 999 | 0 |
| Percentage of total volume treated | 93 | 0 |
| Amount of preservative (million pounds) | 3 | 0 |
| Application methods | pressure | |
| Pests controlled | wood-destroying fungi & insects | |
| Application rate (pcf) | 6 to 8 | |

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[a] Figures quoted are for 1975.

### Commercial Field Treatments (Groundline and Other Treatments)

Commercial groundline treatments are used to control attack by wood-destroying fungi and insects in poles and piling in service. Approximately 0.5 million pounds of creosote were used in 1977 in preservative formulations containing creosote, pentachlorophenol, fluorides, and borax. Groundline treatments are applied either in bandages or are troweled onto the surface of wood to be treated and then covered with a plastic or other protective film.

### Non-Commercial Brush, Dip, and Spray Treatments

Only about 0.2% (or 2 million pounds) of the creosote sold for treatment of wood in 1976 was sold to individuals for home or farm use. Creosote is used by the individual for either prevention or control of wood-destroying fungi and insects. Generally, brush, dip and spray treatments are ineffective for prevention or control of attack of wood in ground contact. However, these treatments when applied to dry sound wood will reduce the rate of attack of wood above ground. Hot and cold soak treatments, when properly applied, will protect wood to be used in ground contact.

Products containing neutral oils are also used to a limited extent as a wood preservative. These products are usually composed of neutral oils alone or in combination with petroleum distillates, creslyic acid, or coal tar. The effectiveness of these products in protecting wood against termites and decay is questionable, particularly in the case of ground-contact service.

# Exposure Analysis

## Qualitative Exposure of Humans at Application Site

Qualitative exposure of employees at the application site for the various application methods is summarized in Table 62.

### Commercial Pressure Treatments

Approximately 98% of the creosote used by the wood-preserving industry is consumed by commercial pressure treating plants and is applied in closed systems. One hundred eighty-eight such operations in the United States use roughly 1 billion pounds of creosote annually and employ about 5,000 people, 4,000 of whom are production workers and receive some level of exposure to creosote by inhalation of vapors or through skin contact.

Opportunity for exposure--either by inhalation or through skin contact--varies with work position. As a general rule, exposure through skin contact is not a serious problem because of in-plant safety requirements regarding the use of protective clothing and lotions. The fact that creosote causes a burning sensation in contact with the skin is in itself fortuitous, since this response normally results in an early visit to the wash facilities, where the creosote is removed. Skin sensitivity to creosote varies widely, but generally is most intense among workers with light complexions and least intense among those with dark complexions.

The transfer of creosote from incoming tanker or rail car to plant storage facilities is the first operation involving creosote where worker exposure is a consideration. Method and frequency of delivery is dependent upon plant size and location. Larger plants may receive several rail car loads weekly, while smaller plants may require only a single road tanker delivery during the same period.

Transfer of the preservative, whether from rail car or tanker, is normally through a closed system and is supervised by treatment-room personnel or other qualified workers. Exposure is limited, consisting of low to moderate exposure by inhalation.

Once the creosote has been transferred to storage, several groups of personnel are exposed to preservative at the various stages of the pressure-treatment process. Bundles of wood to be treated are loaded into the treatment cyclinder by tractor or switch engine drivers. Treating room personnel operate pumps and valves to determine the duration and form of the pressure process. After treatment, the wood is handled by inspectors who take borings from the wood to check the quality of treatment, and by operators of forklifts or front end loaders who unload and stack the wood. All of these personnel may potentially be exposed to inhalation of relatively high concentrations of preservative for short periods of time when the treatment cylinder is opened at the end of the treating cycle. However, the duration of exposure is very short, with individual treatment cylinders being opened only once or twice per working shift. The intensity of skin contact for all these groups is minimal for reasons previously discussed. Both intensity and duration of exposure may be increased above normal levels when equipment failure requires that a worker enter a retort to make repairs.

Once the treated wood has been removed from the cylinder and stacked, it is handled by operators of forklifts, cranes, or other types of equipment, who are

Table 62.--Summary of exposures to creosote-type preservatives at application site

| Application Method | Amount Used | Personnel Exposed | | Intensity of Potential Exposure[a] | |
|---|---|---|---|---|---|
| | | Job Description | Number | Skin Contact | Inhalation |
| | Million Pounds | | | | |
| Commercial pressure treatment | 1,000 | Forklift, switch engine, etc. operators. | 4,000 | 5 | 2 |
| | | Treating room personnel. | | 5 | 2 |
| | | Handlers and inspectors of treated wood. | | 5 | 3 |
| | | Maintenance workers. | | 2 | 2 |
| | | Non-production workers | 1,000 | 5 | 4 |
| Commercial thermal and dip treatment | 20 | Forklift, switch engine, etc. operators. | 100 | 5 | 1 |
| | | Treating equipment operator. | | 5 | 1 |
| | | Handlers and inspectors of treated wood. | | 5 | 1 |
| | | Maintenance workers. | | 5 | 1 |
| | | Non-production workers. | 25 | 5 | 4 |
| Commercial groundline treatment | 0.5 | Applicators | 300 | 5 | 5 |
| Non-commercial brush, dip, spray and soak treatment | 2 | Applicators (homeowners, farmers) | >50,000 | 2-5[b] | 2-4[b] |

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[a] 1 = consistent high exposure; 2 = occasional high exposure; 3 = consistent moderate exposure; 4 = occasional moderate exposure; 5 = minimal exposure.

[b] This application method will normally be used at most only once or twice a year by individual applicators. Thus, high exposure is very infrequent and for most of the year there is no exposure.

responsible for restacking and shipping it. These workers receive consistent moderate exposure from inhalation of creosote vapors emitted from the freshly treated wood. Exposure from skin contact is insignificant.

The final group to come in close contact with preservative or treated wood is maintenance workers who are responsible for clean-up and repair work. They may receive occasionally high exposure from inhalation and skin contact, particularly when cleaning the treating cylinder and repairing equipment.

Non-production workers at creosote pressure treatment plants receive occasional moderate exposure from inhalation of preservative and essentially no exposure from skin contact.

## Commercial Thermal and Dip Treatments

An estimated 20 million pounds of creosote are consumed annually in the United States by non-pressure operations. Such operations are more common on the West Coast where some lodgepole pine and western red cedar poles are still butt-treated by the thermal process. Other plants, both in the East and the West, use non-pressure processes to treat lumber, fence posts, and various other products. These plants differ from pressure operations in two primary respects: their small number and the greater opportunity for inhalation.

There are about 22 such plants in the United States that use creosote in this manner. They employ an estimated 100 people, most of whom are involved at one time or another in the production process. With the exception of thermal plants that are part of larger operations that include pressure-treating facilities--a not uncommon situation on the West Coast--many of these plants are family owned and operated.

The greater opportunity for, and intensity of exposure of, operating personnel at non-pressure facilities that employ creosote stems from the fact that open tanks are used in the treating process. Because ordinary creosote is likely to solidify when cold, the treating operation normally involves heating creosote. Poles are placed in open tanks and hot creosote pumped into the required depth. After the requisite time, usually a few hours, the hot creosote is replaced with creosote that is about 100° F cooler and allowed to remain a few hours.

Personnel who work near the tanks of hot creosote may be expected to receive consistently high exposure to creosote fumes. Included among these would be workers who load and unload the tanks, as well as any equipment operators involved in the transfer of treated stock and handlers and inspectors concerned with assessing treatment quality.

## Commercial Groundline Treatments

Several multicomponent preservatives containing creosote are registered for control of decay and termites in poles in service. Other preservatives used in combination with creosote include sodium fluoride and pentachlorophenol. The preservatives can be formulated as liquids applied by brush; as grease-like formulations applied by brush, paddle, scoop, caulking gun or other mechanical applicator; or as impregnants in wrapping or bandages applied around the pole at and below ground level. Approximately 500 thousand pounds of creosote are used annually for this purpose and about 300 people are involved in some aspect of groundline treatment.

Inspection and treatment of poles are carried out by small crews, with one person usually responsible for preservative application. Skin contact is minimal for these workers because of the use of protective clothing and rigorous hygiene. Groundline treatments are applied in open air at ambient temperatures; therefore, applicators undergo minimal inhalation of creosote vapors in the preservative formulations.

### Non-Commercial Brush, Dip, Spray, and Soak Treatments

Several creosote preservatives are registered for sale to homeowners, farmers, etc., for treatment of wood to prevent or control decay and insect attack. Preservatives can be applied to the products before installation or while in use by brushing, dipping, spraying, or soaking. The preservatives may be used as either hot or cold solutions. An estimated 50,000 people apply about 2 million pounds of creosote annually by these methods. A relatively small volume of neutral-oil products is now sold for brush, dip and spray applications.

Individual applicators normally use creosote only once or twice a year for home or farm application. Thus, the total exposure time to either skin contact or inhalation is minimal. When the preservative is being applied, exposure depends on the adequacy of label instructions and how well they are followed. Inhalation will range from occasional moderate exposure to occasional high exposure, depending on ventilation in the area where the creosote is applied and on whether the preservative is heated or used cold. Skin contact ranges from minimal to occasionally high, depending upon whether or not adequate protective clothing is worn and rigorous hygiene is used.

Non-commercial treatments applied by brushing, dipping, and spraying present the greatest possibility for creosote exposure of any of the treatment methods that have been described. This statement is based both on the number of applicators involved--probably in excess of 50,000 per year--and their lack of product knowledge. Expected minor injuries resulting from improper or careless use of creosote-containing products include skin and eye irritations, both of which can be avoided by the use of protective apparel, including goggles.

The possibility for such injuries notwithstanding, the number of actual injuries reported is very small, indeed. Thus, for example, the total number of health-related episodes involving creosote that is on file in the Pesticide Episode Review System for the years 1967-1976 is 42 (EPA, 1976). Of this number, which includes both commercial and non-commercial uses of this product, 22 were related to the dip-, spray-, and brush-type treatments. Most of these involved carpenters, homeowners, and construction workers. There were no fatalities. On the contrary, the episodes described were all related to skin or eye injury and all were apparently of a superficial nature. No data were collected on possible chronic health effects resulting from the use of penta and creosote.

## Quantitative Exposure of Humans at Application Site (Commercial Pressure Treatments Only)

Direct exposure to creosote and its solutions is a consideration within a relatively small population of workers involved in the processing, transporting, and installation of treated wood products. Within this population, workers at the treating plant level would appear to have the most problems in duration and type of exposure.

Definitive data on exposure levels obtained by air-monitoring surveys are limited both in quantity and scope. The most comprehensive study of worker exposure was conducted by Koppers Company (Webb, 1978) and by Koppers Company in cooperation with NIOSH (1977, 1977a). Additionally, three of the larger wood-preserving companies have sponsored air-monitoring surveys at selected plants. Results of all of the latter studies have not been released.

The sampling procedure followed in the NIOSH and Koppers Company studies, and recommended by NIOSH (1977) for the determination of employee exposure to coal-tar products, employs a combination of glass-filter and silver-membrane filter in a cassette equipped with an air-sampling pump with a capacity of 1.6 liters per minute. A filter cassette and pump are attached to each employee for whom it is desired to determine exposure level and left in place for a full 8-hour shift. A measure of exposure is obtained by determining the weight of cyclohexane- or benzene-extractable materials removed from the filters using ultrasonic extraction equipment. The weight of extracted materials is assumed to be numerically equal to the weight of coal-tar products captured by the system of filters. It is perhaps significant that only the particulate polycyclic organic materials (PPOM) are collected by this procedure. Vapor-phase polynuclear aromatic compounds are not included in the sample. However, data on the composition of the vapor phase were obtained by equipping workers with a conventional filter for PPOM collection followed by a tube of activated carbon to trap vapors which passed through the filter (Detrick, 1979).

The largest reliably detectable concentration of PPOM using the procedure described above is 0.1 mg/cubic meter. This value is the permissible exposure limit recommended by NIOSH. The permissible limit adopted by OSHA is 0.2 mg/cubic meter.

Results of the NIOSH monitoring study, which was conducted at Koppers Company's Little Rock, Ark., plant, are given in Table 63. It is obvious from the negative values obtained when the filter weight gains were adjusted by subtracting the values for the blanks that some problems were encountered in this study. This result was attributable to the introduction of interferences by extracting a cellulose pad used as a backup for the filter system. However, the NIOSH data, after adjusting for blank values, are in surprisingly good agreement with data collected by Koppers Company at the time of the NIOSH study (Table 64) and in a separate air-monitoring survey, also conducted at the Little Rock plant (Table 65). Likewise, a study sponsored by Kerr-McGee Chemical Company involving three work stations provided results that are well correlated with those obtained by NIOSH and Koppers Company (Table 66). Exposure data for naphthalene and Stoddard solvent are also presented.

The range and average PPOM values for the major work stations for which monitoring data are available are presented in Table 67. Basically, these data show that average employee exposure to coal-tar volatiles is within the permissible level of 0.1 mg/cubic meter recommended by NIOSH. The range of values includes this level in the case of only two work stations--the treating operator and the locomotive switchman. However, the range for only the latter station exceeds the permissible exposure limit of 0.2 mg/cubic meter set by OSHA.

The composition of the vapor-phase fractions collected with a carbon filter, along with the corresponding benzene-soluble particulate matter collected at the same time on a conventional filter, is shown in Table 68 for four work positions. Naphthalene, methylnaphthalene, and acenaphthene were the only components of creosote present in amounts that could be measured reliably. The sum of the quantities of these chemicals ranged from 0.54 to 2.0 mg/cubic meter, depending upon work station. Fluorene and phenanthrene-anthracene were detected in trace, but not quantifiable,

Table 63.--Results of air-monitoring study conducted at Koppers Company's Little Rock plant: February 24-25, 1976 by the National Institute for Occupational Safety and Health

| Operation | Filter Loading[a] | Air Volume in Samples | Concentration of PPOM[b] |
|---|---|---|---|
| | Microgram | $m^3$ | $mg/m^3$ |
| Treating operator | 32.5 | 0.49 | 0.07 |
| | 62.5 | 0.49 | 0.13 |
| Doorman | -47.5 | 0.53 | -- |
| | -17.5 | 0.51 | -- |
| Locomotive operator | 12.5 | 0.49 | 0.03 |
| | 52.5 | 0.56 | 0.09 |
| Locomotive switchman | -37.5 | 0.73 | -- |
| | -57.5 | 0.57 | -- |
| | 137.5 | 0.50 | 0.28 |
| | 42.5 | 0.50 | 0.08 |
| Treating area[c] | 52.5 | 0.44 | 0.12 |

[a] Adjusted for blanks.

[b] OSHA permissible limit is 0.2 $mg/m^3$. PPOM = particulate polycyclic organic materials.

[c] Stationary sampling device.

Table 64.--Results of air monitoring study conducted by Koppers Company concurrently with the National Institute for Occupational Safety and Health study: February 24-25, 1976

| Operation | Concentration of PPOM[a] |
|---|---|
| | $mg/m^3$ |
| Treating operator | 0.10 |
| Locomotive switchman | 0.07 |
| | 0.07 |
| Locomotive operator | 0.07 |

[a] PPOM = particulate polycyclic organic materials.

Table 65.--Results of air monitoring study conducted by Koppers Company: June 26-27, 1977

| Operation | Total Particulate Matter | Concentration of PPOM[a] |
|---|---|---|
| | mg/$m^3$ | mg/$m^3$ |
| Doorman | 0.17<br>0.68 | 0.02<br>0.07[b] |
| Treating operator | 0.43<br>0.30 | 0.05<br>0.01 |
| Switchman | 0.25<br>0.13<br>0.07 | 0.03<br>0.02<br>0.002 |
| Locomotive operator | 0.18<br>0.20 | 0.05<br>0.01 |
| Sample boring | 0.42 | 0.04 |
| Air cleanup | 0.30 | 0.02 |

[a] OSHA permissible limit is 0.2 mg/$m^3$. PPOM = particulate polycyclic organic materials.

[b] Doorman entered retort to retrieve stuck tram.

Table 66.--Results of air monitoring study conducted by Kerr-McGee Chemical Company: September 20, 1977

| Operation | PPOM[a] | Concentration[b] | |
|---|---|---|---|
| | | Naphthalene | Stoddard Solvent |
| | | - - - - - - - - mg/$m^3$ - - - - - - - - | |
| Treating operator | 0.20 | 2.2 | 29.3 |
| Sample boring | 0.05 | | -- |
| Shipping supervisor | 0.06 | | |
| Fireman | -- | 0.5 | 0.8 |
| Switchman | -- | 0.7 | 0.5 |
| Cranecrew laborer | -- | 3.1<br>1.6 | -- |

[a] PPOM = particulate polycyclic organic materials.

[b] OSHA permissible limits for PPOM, naphthalene, and stoddard solvent are 0.2, 50, and 2,950 mg/$m^3$, respectively.

Table 67.--Summary of exposure data for coal tar pitch volatiles for studies conducted by the National Institute for Occupational Safety and Health, Koppers Company, and Kerr-McGee Chemical Company

| Operation | PPOM[a] Range | PPOM Average |
|---|---|---|
| | ---------- mg/$m^3$ ---------- | |
| Treating operator | 0.01 - 0.20 | 0.09 |
| Doorman | 0.02 - 0.07 | 0.04 |
| Locomotive operator | 0.01 - 0.09 | 0.04 |
| Locomotive switchman | <.01 - 0.28 | 0.08 |
| Sample borer | 0.04 - 0.05 | 0.04 |
| Shipping supervisor | -- | 0.06 |

[a] PPOM = particulate polycyclic organic materials.

Table 68.--Measure of exposure of selected workers to vapor-phase and particulate polycyclic organic materials at a wood preserving plant[a]

| | Switchman | Switchman | Test Borer | Load-Out Individual |
|---|---|---|---|---|
| | -------------- | -------------- mg/$m^3$ | -------------- | -------------- |
| Carbon Tube | | | | |
| Benzene[b] | 0.012 | 0.010 | 0.012 | 0.008 |
| Toluene[b] | 0.032 | 0.045 | 0.032 | 0.034 |
| Xylene/Ethylbenzene[b] | 6.3 | 11.6 | 6.5 | 7.9 |
| Naphthalene | 0.47 | 0.77 | 1.7 | 1.5 |
| Methylnaphthalenes | 0.037 | 0.041 | 0.25 | 0.32 |
| Acenaphthene | 0.036 | 0.018 | 0.068 | 0.11 |
| Fluorene | 0.01 | 0.01 | 0.01 | 0.01 |
| Phenanthrene/anthracene | | | | |
| Filter: | | | | |
| Benzene soluble particulate | 0.10 | 0.07 | 0.04 | 0.02 |
| Total particulate matter | 0.21 | 0.16 | 0.16 | 0.08 |

[a] Adapted from Detrick (1979).

[b] These constituents are found in the vapor drying solvent and are not present in creosote/coal tar solutions.

amounts. Values for benzene-soluble particulates (PPOM) ranged from 0.02 to 0.10 mg/cubic meter.

Benzene-soluble particulate matter was present in sufficient quantities in one instance (switchman) to permit a determination of its composition. The analytical data showed that creosote components with vapor pressures equal to or smaller than that of fluorene are largely collected on the conventional filter, while components with higher vapor pressures are not. It is the former components that are reported to be carcinogenic.

Related to employee exposure, results of examinations of the genetic activity of coal-tar creosote and creosote-coal tar solutions were negative in a series of studies conducted by Litton Bionetics, Ltd., under the sponsorship of Koppers Company. Both test materials were examined for mutagenic activity in a series of *in vitro* microbial assays employing *Salmonella* and *Saccharomyces* indicator organisms (Litton Bionetics, Ltd., 1978, 1978a). They were tested directly and in the presence of liver microsomal enzyme preparations from rats over a dose range of 0.001 microliter to 5 microliters per plate. The low dose in all cases was below the level that induced toxic effects. Toxicity was demonstrated with all strains of test organisms, except one, at dose levels of 1 microliter per plate and higher. Both nonactivation and activation test results were all negative (Tables 69 and 70).

Similar results were reported following an evaluation of coal tar creosote in a battery of microbial assays in which essentially the same test procedure was followed (Litton Bionetics, Ltd., 1978b). The test organisms used were a diploid strain (DS) of *Saccharomyces cerevisiae*, DNA polymerase deficient and efficient strains of *Escherichia coli*, a DNA repair-deficient strain of *E. coli* (WR2UVrA), and recombination deficient and proficient strains (M45 rec$^-$ and H 17 rec$^+$) of *Bacillus subtilis*. The range of doses was from 0.01 microliter to 10 microliters per plate. Creosote did not exhibit mutagenic activity with $WP_2$UVrA or DS either in the presence or absence of a metabolic activation system. No DNA-modifying effects or recombinagenic effects were observed with the polymerase deficient or *Bacillus* strains, respectively (Tables 71 and 72).

Additional work conducted by the same laboratory (Litton Bionetics Ltd., 1978c) on unscheduled DNA synthesis in human WI-38 cells gave positive results. These results indicated that coal-tar creosote was capable of inducing DNA damage, although the level of activity was considered to be weak (Table 73).

## Qualitative Exposure of Humans at Point of End Use

Exposure at point of end use occurs on installation of the treated product, during inspection and maintenance, and through casual contact. Each of these exposure points is considered separately for the various end uses of creosote-treated wood (Table 74).

### Crossties

The major end use for creosote is pressure treatment of crossties. It is used alone, with coal tar, or with petroleum. Crossties are installed mechanically by railroad companies. Crews have minimal exposure to skin contact because of the automatic nature of the installation process and requirements for use of protective clothing. There is consistent moderate inhalation of creosote from freshly treated ties. Crossties for use on sidings at industrial and commercial sites are sometimes installed manually. Where this is done, there is consistent moderate inhalation of

Table 69.--Results of examination of a creosote/coal tar solution for mutagenic activity

A. Name or Code Designation of the Test Compound: Creosote/Coal Tar Solution, Type C, (Not Less Than 60% Creosote) Conforming to AWPA Standard P2.
B. Solvent: DMSO
C. Test Initiation Date: Nov. 18, 1977
Note: Concentrations Are Given in Microliter or Microgram Per Plate.

| Test | Species | Tissue | TA-1535 |  | TA-1537 |  | TA-1538 |  | TA-98 |  | TA-100 |  | D4[a] |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
|  |  |  | - - - - - - - - - - - - - Revertants per Plate - - - - - - - - - - - - - |  |  |  |  |  |  |  |  |  |  |  |
| Nonactivation |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Solvent control | -- | -- | 16 |  | 11 |  | 19 |  | 44 |  | 195 |  | 41 |  |
| Positive control | -- | -- | 604 |  | 444 |  | 847 |  | 894 |  | 559 |  | 906 |  |
| Test compound |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 0.001000 microliter | -- | -- | 25 |  | 11 |  | 17 |  | 24 |  | 141 |  | 22 |  |
| 0.010000 microliter | -- | -- | 22 |  | 17 |  | 15 |  | 21 |  | 203 |  | 38 |  |
| 0.100000 microliter | -- | -- | 13 |  | 6 |  | 7 |  | 17 |  | 176 |  | 31 |  |
| 1.000000 microliter | -- | -- | 0 |  | 0 |  | 0 |  | 6 |  | 77 |  | 26 |  |
| 5.000000 microliters | -- | -- | 0 |  | 0 |  | 0 |  | 0 |  | 24 |  | 3 |  |
| Activation |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Solvent control | Rat | Liver | 15 |  | 13 |  | 17 |  | 35 |  | 236 |  | 43 |  |
| Positive control | Rat | Liver | 169 |  | 208 |  | 416 |  | 507 |  | >1,000 |  | 78 |  |
| Test compound |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 0.001000 microliter | Rat | Liver | 18 |  | 6 |  | 15 |  | 25 |  | 301 |  | 40 |  |
| 0.010000 microliter | Rat | Liver | 32 |  | 14 |  | 20 |  | 42 |  | 252 |  | 48 |  |
| 0.100000 microliter | Rat | Liver | 20 |  | 18 |  | 31 |  | 45 |  | 209 |  | 39 |  |
| 1.000000 microliter | Rat | Liver | 8 |  | 4 |  | 5 |  | 14 |  | 120 |  | 40 |  |
| 5.000000 microliters | Rat | Liver | 0 |  | 0 |  | 0 |  | 4 |  | 41 |  | 2 |  |

[a] Thy convertants per plate.

-- Indicates test was not done.

Table 70.--Results of examination of coal tar creosote for mutagenic activity

A. Name or Code Designation of the Test Compound: Coal Tar Creosote, Conforming to AWPA Standard P1.
B. Solvent: DMSO
C. Test Initiation Date: Nov. 18, 1977
Note: Concentrations Are Given in Microliter or Microgram Per Plate.

| Test | Species | Tissue | TA-1535 | | TA-1537 | | TA-1538 | | TA-98 | | TA-100 | | D4[a] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| | | | Revertants per Plate | | | | | | | | | | | |
| **Nonactivation** | | | | | | | | | | | | | | |
| Solvent control | -- | -- | 16 | | 11 | | 19 | | 44 | | 195 | | 41 | |
| Positive control | -- | -- | 604 | | 444 | | 847 | | 894 | | 559 | | 906 | |
| Test compound | | | | | | | | | | | | | | |
| 0.001000 microliter | -- | -- | 21 | | 6 | | 8 | | 30 | | 216 | | 79 | |
| 0.010000 microliter | -- | -- | 20 | | 5 | | 18 | | 31 | | 225 | | 45 | |
| 0.100000 microliter | -- | -- | 24 | | 8 | | 4 | | 23 | | 160 | | 41 | |
| 1.000000 microliter | -- | -- | 0 | | 0 | | 0 | | 8 | | 58 | | 36 | |
| 5.000000 microliters | -- | -- | 0 | | 0 | | 0 | | 0 | | 13 | | 10 | |
| **Activation** | | | | | | | | | | | | | | |
| Solvent control | Rat | Liver | 15 | | 13 | | 17 | | 35 | | 236 | 260 | 43 | |
| Positive control | Rat | Liver | 169 | | 208 | | 416 | | 507 | | >1,000 | 913 | 78 | |
| Test compound | | | | | | | | | | | | | | |
| 0.001000 microliter | Rat | Liver | 19 | | 15 | | 17 | | 39 | | 270 | 272 | 37 | |
| 0.010000 microliter | Rat | Liver | 19 | | 18 | | 18 | | 48 | | 403 | 203 | 66 | |
| 0.100000 microliter | Rat | Liter | 15 | | 12 | | 18 | | 37 | | 269 | 250 | 45 | |
| 5.000000 microliters | Rat | Liter | 5 | | 11 | | 6 | | 24 | | 102 | 161 | 42 | |
| | Rat | Liter | 0 | | 0 | | 2 | | 1 | | 74 | 7 | 6 | |

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[a] Thy convertants per plate.

-- Indicates test was not done.

Table 71.--Results of examination of mutagenic activity of selected strains of *Escherichia coli* and *Bacillus subtilis* exposed to coal tar creosote

Client: Koppers
Compound: Coal tar creosote #7702
Date: March 10, 1978

| Test | $WP_2uvrA^-$ | Zone of Inhibition | | | |
|---|---|---|---|---|---|
| | | $PolA^+$ | $PolA^-$ | $Rec^+$(H17) | $Rec^-$(M45) |
| | Revertants/Plate | mm | | | |
| Nonactivation: | | | | | |
| Concentration | | | | | |
| Solvent Control[a] | 16 | 0 | 0 | 0 | 0 |
| Positive Control[b] | 1,707 | 40 | 60 | 46 | 59 |
| Test Compound | | | | | |
| 0.01 microliter | 18 | 0 | 0 | 0 | 0 |
| 0.1 microliter | 22 | 0 | 0 | 0 | 0 |
| 1.0 microliter | 11 | 0 | 0 | 0 | 0 |
| 5.0 microliters | 19 | 0 | 0 | 0 | 0 |
| 10.0 microliters | 16 | 0 | 0 | 0 | 0 |
| Activation: | | | | | |
| Solvent Control[a] | 23 | 0 | 0 | 0 | 0 |
| Positive Control[c] | 41 | 11 | 21 | 13 | 25 |
| Test Compound | | | | | |
| 0.01 microliter | 13 | 0 | 0 | 0 | 0 |
| 0.1 microliter | 32 | 0 | 0 | 0 | 0 |
| 1.0 microliter | 28 | 0 | 0 | 0 | 0 |
| 5.0 microliters | 30 | 0 | 0 | 0 | 0 |
| 10.0 microliters | 10 | 0 | 0 | 0 | 0 |

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[a] 50 microliters of Dimethylsulfoxide.

[b] 10 microliters of 100% Methylmethanesulfonate.

[c] 2.5 micrograms of 2-Anthramine for $WP_2uvrA^-$ and 100 microliter of 100% Dimethylnitrosamine for all others.

Table 72.--Results of examination of DNA modifying effects of creosote on selected test organisms

Client: Koppers
Compound: Coal tar creosote #7702
Date: March 10, 1978

| Nonactivation:<br>Concentration | Survival | Pink/White Colonies | Red/White Colonies | Pink/Red Colonies | Pink/Red Colonies | Red Colonies | Pink Colonies | Total Events Per $10^4$ Survivors |
|---|---|---|---|---|---|---|---|---|
| | Percent | | | | | | | |
| Solvent Control (DMSO 50 microliter) | 100 | 8 | 4 | 0 | 0 | 4 | 2 | 18 |
| Positive Control (EMS 1,240 micromoles) | 65 | 170 | 54 | 4 | 14 | 94 | 172 | 508 |
| Test Compound | | | | | | | | |
| 0.01 microliter | 100 | 1 | 5 | 0 | 0 | 4 | 0 | 10 |
| 0.1 microliter | 100 | 3 | 6 | 0 | 0 | 7 | 2 | 18 |
| 1.0 microliter | 100 | 2 | 5 | 0 | 0 | 4 | 1 | 12 |
| 5.0 microliters | 9 | 2 | 0 | 0 | 0 | 1 | 1 | 4 |
| 10.0 microliters | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Activation: | | | | | | | | |
| Solvent Control (DMSO 50 microliter) | 100 | 5 | 2 | 0 | 1 | 3 | 5 | 16 |
| Positive Control (DMN 675 micromoles) | 74 | 65 | 35 | 8 | 15 | 5 | 3 | 131 |
| Test Compound | | | | | | | | |
| 0.01 microliter | 100 | 2 | 2 | 0 | 0 | 4 | 0 | 8 |
| 0.1 microliter | 100 | 5 | 1 | 0 | 0 | 1 | 0 | 7 |
| 1.0 microliter | 100 | 2 | 2 | 0 | 0 | 0 | 0 | 4 |
| 5.0 microliters | 36 | 2 | 1 | 0 | 1 | 3 | 0 | 7 |
| 10.0 microliters | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 73.--Results of assay of unscheduled DNA synthesis in human WI-38 cells

| Test | Concentration | DNA | DNA | Control |
|---|---|---|---|---|
| | Microliters/ml | Micrograms/ml | DPM/Micrograms | Percent |
| Nonactivation | | | | |
| Solvent control | -- | 19.64 | 26 | 100 |
| MNNG | 5[b] | 14.19 | 146 | 562 |
| CTC #7702[a] | 0.00075 | 18.48 | 36 | 138 |
| CTC #7702 | 0.001 | 23.10 | 36 | 138 |
| CTC #7702 | 0.0025 | 22.44 | 39 | 150 |
| CTC #7702 | 0.005 | 23.26 | 49 | 188 |
| Activation | | | | |
| Solvent control | -- | 27.88 | 24 | 100 |
| BaP | 10[b] | 12.87 | 40 | 167 |
| CTC #7702 | 0.00075 | 15.84 | 36 | 150 |
| CTC #7702 | 0.001 | 19.96 | 32 | 133 |
| CTC #7702 | 0.0025 | 26.40 | 34 | 142 |
| CTC #7702 | 0.005 | 22.28 | 42 | 175 |

[a] CTC #7702 = Coal tar creosote conforming to AWPA Standard P1.

[b] Micrograms/ml.

creosote during tie installation. Skin contact can range from occasionally high to minimal depending upon whether workers wear protective clothing. Most ties are installed by train crews, the members of which routinely wear protective clothing.

Railroad companies routinely inspect ties in service. Inspection usually involves a visual appraisal of the condition of the ties and sometimes sounding with a hammer. There are minimal skin contact and inhalation during inspection.

Railroad personnel, industrial and commercial workers, and, to a lesser extent, members of the general public will have casual contact with treated crossties from time to time. Skin contact and inhalation are minimal in these situations.

Crossties are also used in landscaping. Exposure for landscape contractors involved in the sale and installation of freshly treated ties will be consistently moderate for inhalation, and minimal to occasionally high for skin contact, depending upon how thoroughly safety precautions are followed in handling the ties. For old ties there is minimal inhalation and skin contact.

## Poles

Poles are usually installed mechanically, but require some manual contact for attachment of fittings. Exposure to inhalation is consistently moderate. Skin

Table 74.--Summary of qualitative exposures to products treated with creosote-type preservatives at point of end use

| Product | Volume Treated In 1976 | Exposed At | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Installation | | | Inspection, Maintenance | | | Casual Contact | | |
| | | Number Exposed[a] | Intensity of Exposure[b] | | Number Exposed[a] | Intensity of Exposure[b] | | Number Exposed[a] | Intensity of Exposure[b] | |
| | | | Skin Contact | Inhalation | | Skin Contact | Inhalation | | Skin Contact | Inhalation |
| | 1,000 cu. ft. | | | | | | | | | |
| Crossties[c] | 95,165 | B | 5 | 3 | B | 5 | 5 | C | 5[d] | 5 |
| Poles | 14,571 | B | 5 | 3 | B | 5 | 5 | C | 5[d] | 5 |
| Lumber and timbers--outdoors or in well ventilated buildings[e] | 9,672 | C | 2-5 | 3 | C | 5 | 5 | C | 5[d] | 5 |
| Lumber and timbers--in enclosed, poorly ventilated buildings | | A | 2-5 | 3 | A | 5 | 3 | A | 5[d] | 5 |
| Switch ties and crossing planks | 6,198 | B | 2-5 | 3 | B | 5 | 5 | C | 5[d] | 5 |
| Piling--foundation | 5,769 | B | 5 | 3 | NA[f] | -- | -- | NA[f] | -- | -- |
| Piling--marine | 1,642 | B | 5 | 3 | C | 5 | 5 | C | 5[d] | 5 |
| Fence posts | 2,826 | C | 2-5 | 3 | C | 5 | 5 | C | 5[d] | 5 |
| Mine ties and timbers | 254 | B | 2-5 | 3 | B | 5 | 5 | C | 5[d] | 5 |
| Crossarms | 78 | B | 5 | 3 | B | 5 | 5 | NA[f] | -- | -- |
| Block flooring | 999 | A | 5 | 3 | B | 5 | 3 | B | 5 | 3 |

[a] A = <1,000; B = 1,000 to 10,000; C = >10,000.

[b] 1 = consistent high exposure; 2 = occasional high exposure; 3 = consistent moderate exposure; 4 = occasional moderate exposure; 5 = minimal exposure.

[c] Most crossties are installed mechanically: For exposure data for hand-installed ties see switch ties and crossing planks.

[d] Wood products pressure treated with some creosote formulations have a tendency to bleed leaving concentrated deposits of creosote/coal tar on the surface of the wood. Casual contact with such products causes occasional moderate exposure to skin contact.

[e] Includes pressure treated bridge timbers, piers, retaining walls, fencing, shelters, and pole barns.

[f] NA - not applicable.

contact is minimal because personnel use protective clothing and follow approved hygiene procedures.

Inspection of poles is routinely made at groundline and involves removal of earth around the pole, visual inspection, sounding with a hammer, and boring of the pole. A visual inspection is made of the above-ground portion of the pole and, where warranted, the pole is climbed for detailed inspection. Poles are also climbed routinely for maintenance. Personnel responsible for inspection and maintenance wear protective clothing. Inhalation and skin contact are minimal. This also applies to casual contact.

## Lumber, Timbers

### Outdoors or In Well-Ventilated Buildings

Considerable manual contact is involved in the installation of lumber and timbers in structures such as bridges, piers, retaining walls, fencing, shelters, and pole barns. Persons installing the material will range from homeowners, who may handle the treated wood only once a year, to contractors, who work with the material routinely. Exposure to inhalation will be moderate when working with treated wood. Exposure to skin contact will vary from minimal for individuals who use protective clothing to occasionally high for those who do not use gloves, etc. The latter situation will usually be the case with irregular users of creosote-treated wood such as farmers or homeowners.

Intensity of skin contact and inhalation during inspection, maintenance, and casual contact with treated lumber and timbers is minimal.

### Enclosed or In Poorly Ventilated Buildings

Exposure during installation of lumber and timbers in enclosed spaces is similar to that for lumber and timbers outdoors. The major difference between the two categories is in exposure during inspection, maintenance, and casual contact. There is minimal exposure to skin contact, but consistent moderate exposure to inhalation where creosoted materials are used in enclosed areas. Exposure diminishes as the treated products age.

## Switch Ties and Crossing Planks

Switch ties and crossing planks are usually installed manually, not mechanically. Installation may involve handling, cutting, drilling, and attachment of fittings. Inhalation is consistently moderate. Skin contact can range from occasionally high exposure for personnel who install ties infrequently and do not wear protective clothing to minimal exposure for those who install ties routinely and wear protective clothing.

Intensity of skin contact and inhalation during inspection, maintenance, and casual contact with switch ties and crossing planks is minimal.

## Piling

### Foundation Piling

Personnel have little physical contact with foundation piles during driving. There is minimal exposure to skin contact when protective clothing is worn. There is consistent moderate exposure to inhalation of creosote from freshly treated material.

Once the piles have been driven below ground, they are no longer a source of exposure to skin contact or inhalation.

### Marine and Fresh Water Piling

Exposure during installation is similar to that for foundation piling. Exposure to skin contact and inhalation is minimal during inspection, maintenance, and casual contact.

## Fence Posts

Installation of creosote-treated fence posts is usually manual. It may be done by contractors who install posts routinely or by homeowners or farmers, etc. who install posts infrequently. In both cases inhalation will be consistently moderate during installation. Skin contact will be minimal for contractors because they normally wear protective clothing. For farmers, homeowners, etc., skin contact will range from occasionally high to minimal dependent on whether or not protective clothing is used.

Fence posts are usually inspected visually, pushed, or probed at ground level. Skin contact and inhalation are minimal. There is also minimal exposure during casual contact.

## Mine Ties and Timbers

Exposure intensity for these products is similar to that for switch ties and crossing planks.

## Crossarms

Installation of crossarms involves considerable manual contact. There is consistent moderate inhalation and minimal skin contact, thanks to protective clothing and rigorous hygiene.

There is minimal skin contact and inhalation during inspection and maintenance. The placement of crossarms on poles prevents casual contact by the public.

## Block Flooring

Installation of block flooring involves considerable manual contact. There is minimal skin contact during installation, inspection, maintenance, and casual contact because of the use of protective clothing. There is consistent moderate inhalation of creosote during installation. Exposure diminishes as treated products age, and because pitch is poured over the treated wood in place.

## Quantitative Exposure of Humans at Point of End Use

The Assessment Team is not aware of any definitive quantitative data on exposure of human subjects to creosote at the point of end use.

## Exposure to Animals at Point of End Use

Definitive studies of the effect of creosote on terrestrial fauna have been limited. Apparently there are no recorded cases of either wild or domestic animals having been injured by contact with or ingestion of creosote, except in research designed to ascertain the type and extent of injuries induced by this material. Creosote and several of its constituents are toxic to aquatic fauna, and there are instances of fish kills resulting from contamination of streams and lakes with creosote or process wastewater from creosoting operations.

Studies conducted by Bionomics, Inc. and Truslow Farms, Inc., under the sponsorship of Koppers Company, provide some insight into the effect of creosote on fish and birds (Webb, 1975). Exposure of rainbow trout and bluegill to marine grade creosote gave $TL_{50}$ values as follows:

| | $TL_{50}$ (mg/liter) | | No effect |
|---|---|---|---|
| | 24 hr. | 96 hr. | level (mg/liter) |
| Rainbow trout | >0.24 | 0.20 | 0.08 |
| Bluegills | >1.00 | >1.00 | 0.18 |

Subsequent work provided these additional estimates of $TL_{50}$ for rainbow trout exposed to creosote:

| | | |
|---|---|---|
| 24 hours | (mg/liter) | 2.16 |
| 96 hours | (mg/liter) | 0.56 |
| No effect | (mg/liter) | 0.32 |

Comparable data for the two species of fish exposed to a creosote-coal tar solution were as follows:

| | $TL_{50}$ (mg/liter) | | No effect |
|---|---|---|---|
| | 24 hr. | 96 hr. | level (mg/liter) |
| Rainbow trout | 4.42 | 0.88 | 0.49 |
| Bluegills | 3.72 | 0.99 | 0.75 |

The work on birds involved mallard ducks and consisted of observing the effects of a gradient series of dosage levels of 60/40 creosote-coal tar solution added to the birds' ration. Dieldrin was included in the study as a positive control; the negative control consisted of the basal diet alone.

Ducks exposed to the highest concentration of creosote-coal tar, 4,640 ppm, sustained a mortality rate of 20%. The survivors of this dosage level lost weight and displayed other symptoms of ill health. Birds exposed to dosage levels of 215, 464, 1,000, and 2,150 ppm showed no symptoms of toxicity throughout the study, although there was a dose-related reduction in body weight given. The latter effect apparently was due to initial rejection of the ration containing the creosote.

Partial to total group mortality occurred over a period of 8 days at all dosage levels of dieldrin. Mortality on the eighth day by dosage level was as follows:

| Dose (ppm) | Mortality % |
|---|---|
| 100 | 30 |
| 159 | 40 |
| 251 | 80 |
| 398 | 80 |
| 631 | 100 |

Calculated $LD_{50}$ values for creosote-coal tar and dieldrin were as follows:

| | |
|---|---|
| Creosote | 10,539 ppm |
| Dieldrin | 164 ppm |

## Fate of Creosote, Creosote-Coal Tar, and Creosote Petroleum Solutions in the Environment

Creosote and solutions of creosote-petroleum and creosote-coal tar, unlike most pesticides, are not sprayed or otherwise widely distributed over large land areas. Both creosote and its solutions are forced into wood in closed retorts, thereby reducing to a minimum the opportunity for environmental pollution during the actual treating process. Furthermore, current EPA regulations pertaining to wastewater discharges (EPA, 1974) and spill prevention and countermeasure systems (EPA, 1973) have as their purpose to prevent the preservatives from entering the environment in harmful quantities either by the discharge of effluents or by accidental spills.

The amount of creosote that enters the environment is relatively small. It consists of that discharged as part of the effluent from those wood-preserving plants that are permitted a discharge of pollution, including components of creosote, under the EPA effluent guidelines and standards for the industry that were promulgated in 1974 and became effective July 1, 1977 (EPA, 1974). Then, too, creosote in small quantities enters the environment as an exudate and vapor form from treated wood products in service. Each of these two avenues of environmental pollution is discussed briefly here in terms of the quantities of creosote involved and its fate in the environment.

### Fate at Application Site

Approximately 200 of the estimated 400 commercial wood-preserving plants in the United States use creosote and/or its solutions in the preservative treatment of wood. Of this number, approximately 40 discharge wastewater pollutants to publicly owned treatment works (POTW), and are thus classified as indirect dischargers. Among the remaining plants, an additional 40 condition wood by the Boulton process, do not discharge to a POTW, and consequently, have achieved a zero discharge, as required by applicable effluent guidelines for best practical treatment and control technology.

The remaining 120 plants, which employ steam conditioning to prepare stock for preservative treatment, are permitted a discharge under existing effluent guidelines, and either have or potentially have a discharge of wastewater pollutants. However, approximately 30 of these 120 plants have achieved total or near total elimination of discharges by wastewater evaporation, soil irrigation, incineration, or a combination of these methods. Thus, it would appear that a maximum of only about 90 of the plants that are using creosote and are permitted to discharge wastewater pollutants under current standards actually have a discharge. In fact, both a survey of the industry conducted in 1974-1975 (Thompson, 1975) and data collected from over 200 plants of all types by EPA in 1977 (EPA, 1977) revealed less than 20 plants in the industry that discharge directly to the environment.

Plants discharging directly to the environment are required to meet specific discharge criteria (EPA, 1974), among which are included concentration limitations of 2.40 mg/liter and 45 mg/liter for total phenols and oil and grease, respectively. Assuming that all 90 plants discussed above discharge an average of 5,000 gallons per day of wastewater of creosote origin and, further, that all discharges meet the criteria set by EPA, the total weight of phenol and oil and grease released to the environment daily from wood-preserving operations in the United States employing creosote would be 9.0 and 68 pounds, respectively. These quantities are scheduled to be reduced to 0.56 and 48 pounds, respectively, under best available treatment and control technology beginning July 1, 1983.

The foregoing data do not adequately address the question of the quantity of those components in creosote for which there is evidence of a health hazard and that are released into the environment with the wastewater discharges from wood-preserving operations. However, an estimate of the amount of various components in creosote that enter the environment from this source can be obtained by assuming that the permissible oil and grease discharge discussed above is equivalent to creosote and prorating this value among components on the basis of the percentage composition that each is of the whole. Data of Lorenz and Gjovik (1972) on the composition of creosote provide the basis for these estimates, which are shown in Table 75.

While these estimates are based on the questionable assumption that all of the individual components are associated with the oil phase and none with the water phase of the wastewater, they do place in perspective the quantity of the various creosote components released to the environment by the industry. The actual amount released is probably considerably smaller than indicated in Table 75, since most current discharge data indicate that a much smaller number of plants is discharging directly to the environment than the 90 on which these estimates are based.

More definitive estimates of pollution loadings from creosote wood-preserving operations are provided by analytical data for priority pollutants in raw and treated wastewater from three plants sampled in 1978 in conjunction with EPA's review of the best treatment standards (EPA, 1977).[3] The average results for each of several priority pollutants associated with creosote are given in Table 76 for wastewaters before and after biological treatment. Also included in this table are estimates of total daily discharge of pollutants by the industry. As indicated in the table, the amount of discharge for most pollutants is less than 0.5 pounds per day.

The fate of creosote in the environment is unknown. However, the available evidence indicates that certain of its components are rapidly biodegraded. Dust and Thompson (1973) monitored total phenol content of water collected at various soil depths following irrigation of land with untreated creosote wastewater applied at the rate of 3,500 gallons/acre/day. Removal of phenols equaled or exceeded 99% at

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[3] Six plants were sampled, but data are included only for the three plants that have on-site biological treatment facilities.

Table 75.--Daily discharge of creosote wastewater pollutants by the wood-preserving industry

| Creosote Component | Composition of Whole Creosote | Allowable Discharge[a] | |
|---|---|---|---|
| | | 1977 | 1983 |
| | Percent | Pounds/day | |
| Naphthalene | 3.0 | 5.0 | 1.4 |
| 2-Methylnaphthalene | 1.2 | 2.0 | .6 |
| 1-Methylnaphthalene | .9 | 1.5 | .4 |
| Biphenyl | .8 | 1.3 | .4 |
| Dimethylnaphthalenes | 2.0 | 3.4 | 1.0 |
| Acenaphthene | 9.0 | 15.1 | 4.3 |
| Dibenzofuran | 5.0 | 8.4 | 2.4 |
| Fluorene | 10.0 | 16.8 | 4.8 |
| Methylfluorenes | 3.0 | 5.0 | 1.4 |
| Phenanthrene | 21.0 | 35.3 | 10.0 |
| Anthracene | 2.0 | 3.4 | 1.0 |
| Carbazole | 2.0 | 3.4 | 1.0 |
| Methylphenanthrenes | 3.0 | 5.0 | 1.4 |
| Methylanthracenes | 4.0 | 6.7 | 1.9 |
| Fluoranthene | 10.0 | 16.8 | 4.8 |
| Pyrene | 8.5 | 14.2 | 4.0 |
| Benzofluorenes | 2.0 | 3.4 | 1.0 |
| Chrysene | 3.0 | 5.0 | 1.4 |

[a] Discharges are based on a flow rate of 5,000 gal/day per plant, 90 plants, and discharge limitations on oil and grease of 45 mg/liter in 1977 and 13 mg/liter in 1983.

all soil depths within the range of 1 to 4 feet. Seasonal variations in removal efficiencies were negligible. Similar results have been reported by Fisher (1971). Satisfactory removal of phenols from creosote wastewater has also been achieved by trickling filters and activated-sludge units (EPA, 1976a).

## Fate at Point of End Use

Losses of creosote from treated wood may occur by exudation of whole oil, leaching by rainwater, or volatilization of some of the lighter fractions. By whatever means creosote enters the environment from treated wood products, the available evidence suggests that the process is generally extremely slow. Poles, piling, and timbers properly treated with creosote can reasonably be expected to provide satisfactory service for 30 to 50 years, depending upon service conditions. Numerous studies have shown that the amount of creosote retained by products after 20 to 40 years of exterior service is adequate to provide continued protection for many additional years.

Table 76.--Concentration of priority pollutants in cresote wastewater and estimate of daily discharge of each by the wood-preserving industry

| Priority Pollutant | Average Concentration | | Daily Discharge[a] |
|---|---|---|---|
| | Raw Wastewater | Treated Wastewater | |
| | - - - Micrograms/liter - - - | | Pounds |
| Benzene | 1,872 | 16 | <0.06 |
| Phenol | 43,667 | Tr | 0.01 |
| Phenanthrene/anthracene | -- | -- | -- |
| Total phenols | 23,905 | 140 | 0.52 |
| Ethylbenzene | 1,160 | <10 | <0.04 |
| Toluene | 2,333 | <58 | <0.22 |
| 2 Nitrophenol | <1,500 | <31 | <0.12 |
| 2,4 Dimethylphenol | 4,257 | <67 | <0.25 |
| Fluoranthene | 8,267 | 607 | 2.27 |
| Benzo(b)fluoranthene | 650 | 89 | 0.33 |
| Benzo(k)fluoranthene | 1,950 | 101 | 0.38 |
| Pyrene | 6,267 | 444 | 1.66 |
| Benzo(a)pyrene | 1,473 | 125 | 0.47 |
| Indeno (1,2,3-CD) pyrene | 1,990 | 54 | 0.20 |
| Benzo (g,h,i) perylene | 107 | 4 | 0.01 |
| Anthracene | 19,167 | <483 | <1.80 |
| Benzo(a)anthracene | 2,900 | 65 | 0.24 |
| Dibenzo (a,h) anthracene | 143 | <4 | <0.01 |
| Naphthalene | 29,150 | <78 | <0.29 |
| Acenaphthene | 7,100 | <149 | 0.56 |
| Acenaphthylene | 553 | <78 | <0.29 |
| Fluorene | 5,367 | <103 | <0.38 |
| Bis (2-ethylhexyl) phthalate | <800 | <66 | <0.25 |
| Phenanthrene | 6,167 | 471 | 1.76 |
| Chrysene | 777 | 96 | 0.36 |

[a] Based on a total treated wastewater discharge of 450,000 gal/day.

The very fact that creosote has been widely used commercially as a preservative in wood products for 125 years with little or no evidence of adverse health or environmental effects strongly indicates that its effects on man and his environment are minimal at worst. There are, for example, 1 billion crossties treated with creosote in the United States that collectively contain approximately 30 billion pounds of creosote or one of its solutions (Howe and Koch, 1976). It is reasonable to suppose that, because of the opportunity for exposure of animal life, including man, to a product of such wide distribution, evidence of adverse health or environmental effects would have surfaced long ago.

von Rumker, et al. (1975) generally agree with the foregoing assessment, stating in part that the evidence available indicates that the environmental hazards of creosote are minimal. They cited reports of several researchers that showed that the retention of creosote in products in service did not change significantly during periods of up to 40 years. Loss of polycyclic aromatic compounds by vaporization from creosote-treated wood was compared by these authors to the emission of similar compounds in greater quantities by pine forests.

Baechler and Alpen (1964) reported retentions of 18.4 to 25.3 pcf of residual creosote in Douglas-fir marine piling after 25 years of service. Earlier work by Baechler and Roth (1960, 1961) showed retentions of 19 to 20 pounds of creosote in piling installed in 1900 and removed 59 years later. Other piling failed after only 5 years of service, presumably because of inadequate treatment or mechanical damage which exposed untreated wood.

Residual creosote retentions equal to 74% of current minimum standards were found by Bramhall and Cooper (1972) in marine piling after 40 years of service. The physical characteristics of the oil extracted from these pilings were reported to be practically identical to current standards, thus indicating that the major components of the creosote remained intact in the piling.

Hochman (1967) concluded from his work that the loss of creosote from wood in a marine environment varies inversely with the void volume of the wood when saturated with water. Both Hochman (1967) and Sweeney, et al. (1956) believed that creosote is forced from treated wood when the wood becomes saturated following immersion in water. These workers presented as evidence in support of this hypothesis results from salt water exposure of wood test panels. Some creosote may indeed be forced from wood containing high retentions of this preservative. Some reduction in the dimensions of cell lumens occurs when wood is saturated with water containing certain salts, including sodium chloride.

Both Hochman (1967) and Sweeney, et al. (1956) reported rapid losses of creosote from test panels exposed to sea water. It would be unwise to attempt to extrapolate their results to full-size members.

Some loss of creosote does occur from treated wood in a marine environment. However, there is evidence that such losses can be controlled in part by choice of the grade and type of creosote-coal tar solution used, by the method used to condition stock preparatory to treatment, and by making appropriate adjustments in such variables as temperature and pressure during the treating process (Josephson, 1977). Those components of loss attributable to species and variation in anatomical and physical properties within species are less subject to control.

Data available on the effect of creosote loss from marine structures on the aquatic environment are very limited. A report by Dunn and Stich (1975) indicated that mussels in the vicinity of creosoted piling contained higher concentrations of benzo(a)pyrene than those further removed from the piling. However, no conclusive evidence was presented that the creosote was the source of this chemical.

Basu and Saxena (1978) reported that the concentration of polynuclear aromatic hydrocarbons in drinking water for ten United States cities ranged from 0.9 to 15 nanograms/liter. These values are well below the World Health Organization recommended value of 200 nanograms/liter. Raw water values ranged from 4.7 to over 600 nanograms/liter. The differences between the two sets of values are indicative of the efficiency with which this chemical species is removed by standard water treating practices employed by municipalities. It is uncertain whether the reduction effected by treatment was due to removal or transformation to other chemical species.

Lee, et al. (1978) found that the concentration of seven polynuclear aromatic hydrocarbons--including naphthalene, anthracene, fluoranthene, benz(a)anthracene and benzo(a)pyrene--resulting from a controlled oil spill decreased exponentially from

74.4 to <0.2 microgram/liter after 10 days. The value decreased further to below the level of detection by the 17th day. The higher molecular weight compounds, particularly benzo(a)-pyrene and benzo(a)anthracene, were susceptible to photooxidation, with up to half of the former chemical being photooxidized. The remainder apparently became incorporated in bottom sediments. Microbial degradation of the naphthalene occurred at the rate of 5% per day.

Losses of liquid creosote from wood in terrestrial service are generally regarded to have no adverse effects on the environment. Creosote lost by exudation apparently does not migrate more than a few inches into the soil and is rapidly biodegraded. Indeed, in a study conducted at Mississippi State Univ. (1975) on the movement of preservatives radially and vertically from treated poles, none of the major components of creosote was ever isolated from soil samples collected to a depth of 6 inches within the range of 2 to 24 inches from the pole. It was assumed that those components which entered the soil during the 5-year duration of the study were oxidized by soil microorganisms.

Information supportive of the thesis that PNA's are biodegradable was presented previously in this chapter and specifically by the data in Table 76. These data indicate that the primary and secondary treatment efficiency in creosote wastewater exceeds 90% for most priority pollutants. A study by Dust and Thompson (1973), while not providing definitive data on PNA reductions achieved by soil irrigation of creosote wastewater, showed a very high removal efficiency for phenols and other organic constituents. The data, which are summarized in Table 77, show that percolation of wastewater through soil results in a reduction in chemical oxygen demand (COD) of 94.9, 95.3, and 97.4% for depths of 1, 2, and 4 feet. Comparable reductions for total phenols were, in order, 98.9, 99.2, and 99.6%. Removal efficiency was only mildly affected by seasonal changes.

By contrast to the foregoing data on biodeterioration of PNA's, evidence is presented in the literature that certain of these chemicals are common and fairly abundant constituents of soils. Blumer (1961), for example, found the 1,2- and 3,4-isomers of benzpyrene in every soil sample collected from rural areas of Massachusetts and Connecticut. Also present in all samples were phenanthrene, fluoranthene, pyrene, chrysene, perylene, and anthanthrene. Evidence of the presence in soils of anthracene, triphenylene, benzanthracene, benzfluorene, and 1,12-benzperlene was also obtained. The concentrations of benzpyrenes ranged from 40 to 1,300 micrograms/kg. Because of the location of the soils some distance from highways and industries, the author concluded that their presence could not be attributed to pollution fallout. Instead, he hypothesized that the chemicals are indigenous to the soils and probably occur as a result of wood pyrolysis and/or the biological breakdown of plant tissue.

## Summary of Biological Analysis of Creosote, Creosote-Coal Tar, and Creosote-Petroleum Solutions

The subject products are largely used in the preservation of wood used in four industries: (1) railroads, (2) utilities, (3) construction, and (4) agriculture. About 99% of creosote used in the preservation of wood is applied by pressure methods in enclosed cylinders, and less than 1% is applied by nonpressure methods. Although total usage of creosote has been declining, it is still used in greater quantity than any other preservative in the United States. Consumption of straight creosote, creosote-coal tar, and creosote/petroleum solutions in 1976 was 41.5, 62.6, and 29.9 million gallons, respectively, for a total usage of 134 million gallons. Of this volume, 94.8 million gallons was creosote. This volume contrasts with about 47 million gallons of 5% penta solution, the next most widely used preservative.

Table 77.--Reduction of chemical oxygen demand (COD) and phenol in wastewater treated by soil irrigation

| Month | Raw Waste | Soil Depth (ft.): | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 4 |
| | COD mg/liter | | | | |
| July | 2,235 | 1,400 | -- | -- | 66 |
| August | 2,030 | 1,150 | -- | -- | 64 |
| September | 2,355 | 1,410 | -- | -- | 90 |
| October | 1,780 | 960 | 150 | -- | 61 |
| November | 2,060 | 1,150 | 170 | 170 | 46 |
| December | 3,810 | 670 | 72 | 91 | 58 |
| January | 2,230 | 940 | 121 | 127 | 64 |
| February | 2,420 | 580 | 144 | 92 | 64 |
| March | 2,460 | 810 | 101 | 102 | 68 |
| April | 2,980 | 2,410 | 126 | -- | 76 |
| Average % removal (weighted) | | 55.0 | 94.9 | 95.3 | 97.4 |
| | Phenol mg/liter | | | | |
| July | 235 | 186 | -- | -- | 1.8 |
| August | 512 | 268 | -- | -- | 0.0 |
| September | 923 | 433 | -- | -- | 0.0 |
| October | 310 | 150 | 4.6 | -- | 2.8 |
| November | 234 | 86 | 7.7 | 3.8 | 0.0 |
| December | 327 | 6 | 1.8 | 9.0 | 3.8 |
| January | 236 | 70 | 1.9 | 3.8 | 0.0 |
| February | 246 | 111 | 4.9 | 2.3 | 1.8 |
| March | 277 | 77 | 2.3 | 1.9 | 1.3 |
| April | 236 | 172 | 1.9 | 0.0 | 0.8 |
| Average % removal (weighted) | | 55.4 | 98.9 | 99.2 | 99.6 |

Only about 2 million pounds, or 0.2%, of creosote is used in noncommercial applications.

Treatment of crossties consumes the largest amount of creosote of all items injected with this preservative, most of it as a mixture with coal tar or petroleum. In 1976, 20,156,000 ties were treated with creosote or in mixture with coal tar, while 7,955,000 were treated with creosote-petroleum. These treatments required about 66% of the total creosote consumed. During the same year the railroads purchased over 65 million board feet of creosoted lumber and large quantities of piling and bridge timbers.

Electric, telephone, and cable TV companies use treated wood poles and many of these are preserved with creosote. Use of treated wood is decreasing by telephone utilities because of underground installation of cable. About 900,000 poles treated with creosote or its mixtures were produced in 1977. This is about 33% of all treated utility poles, the remainder being treated with other preservatives.

Creosote has been in a declining use pattern for utility poles for about the last 25 years and this trend will probably continue. In 1953, 60 million cubic feet of wood as poles were treated with creosote or as mixture with coal tar, while in 1977 this had fallen to 15.6 million cubic feet. Poles treated with penta largely displaced those which would have been creosote treated. Investor-owned electric utilities have been purchasing 36% of their poles over the last 10 years treated with creosote, but it is expected that this portion will decline to 31% during the next 10 years.

Groundline treatments applied to standing poles to replace lost preservative and prolong life may contain creosote. These treatments are offered in a grease or semi-solid form in mixture with one or more of the following: penta, fluorides, borax, and/or arsenates. They are applied to the wood surface largely below groundline and are covered with a protective film to separate preservative from soil. About 50,000 gallons of creosote was used for this purpose in 1977.

Lumber, timbers, piling, mine ties and timbers, block flooring, highway posts, and construction poles treated with creosote are used in construction. About 21 million cubic feet of wood treated with creosote or one of its solutions made up these items in 1976. As far as the proportion of construction materials treated with creosote preservatives is concerned, piling--both marine and foundation--constituted 35% of the total volume included in the construction category. The largest proportion was composed of lumber and timbers at 53%, while construction poles made up 3% of the total. All the other items made up the remaining 9%.

There were over 4 million posts treated with creosote preservatives in 1976, or about 3 million cubic feet of wood. Twenty percent of all fence posts were given preservative treatment with creosote.

Creosote preservatives as a percentage of total preservatives used are as follows for the item shown:

| | |
|---|---|
| Crossties | 99+ |
| Switch ties | 99+ |
| Poles, utility & construction | 28 |
| Piling, marine & foundation | 90 |
| Lumber and timbers | 12 |
| Fence posts | 20 |
| Crossarms | 4 |
| Other | 15 |

Creosote is a broad-spectrum wood preservative that has been used for this purpose for over 100 years in the United States. It is employed mainly to prevent attack by decay fungi and termites, but is also effective against marine borers, except *Limnoria tripunctata*. Although it prevents attack by various wood-inhabiting beetles such as anobiids and lyctids, creosote is not often used with only this aspect of protection in mind.

About 98% of all creosote used in wood preserving is applied in commercial pressure treating plants, which minimizes human contact with the liquid. It is received, transferred, stored, and applied in a closed system where occasional leaks are the only source of any slight human contact with creosote.

It is estimated that about 4,000 people are employed in production of pressure-treated wood with creosote-type preservatives. Some of these are exposed to occasional high amounts (see Table 62) by inhalation or contact. About 100 workers are involved with production of commercial nonpressure treatments. Some of these undergo consistent high inhalation. The greatest number of people exposed to creosote, estimated to be 50,000, are those who apply it on the job--farmers, carpenters, and homeowners. Skin contact and inhalation may be high on occasion; but they are infrequent, perhaps only once to a few times a year.

A relatively small amount of creosote is incorporated in groundline treatments for standing utility poles. Inhalation or skin contact to applicators is minimal.

Air-monitoring studies have been conducted at a few treating plants using creosote-type preservatives. Results of these studies show that average employee exposure to coal-tar volatiles is within the permissible level of 0.1 mg/cubic meter recommended by NIOSH. In only one test, with locomotive switchmen, was the concentration of PPOM found to be above the permissible level of 0.2 mg/cubic meter set by OSHA. When individual compounds resulting from creosote evaporation around treating plants were measured, naphthalene was found to be well within the limit set by OSHA. Compounds with vapor pressures lower than that of fluorene were found only in particulate form. These include the carcinogenic components of creosote.

During handling, storage, and installation of any creosoted items, there may be moderate inhalation of volatiles, especially on hot days with little wind. The largest number of individuals so exposed would be those installing fence posts, lumber and timbers, and railroad material. Once creosoted items are in place, the incidence of human contact is small because most of the wood is used outdoors and is wholly or partly buried in the soil or submerged. There is moderate inhalation in the very few enclosed structures where wood treated with creosote is used.

There are no recorded instances of wild or domestic animals being injured by creosote. However, creosote can be toxic to fish and other marine life where it or wastewater containing creosote pollute lakes or streams. In experiments on rainbow trout and bluegills, the non-effect level was 0.32 mg/liter for creosote and 0.75 mg/liter for creosote-coal tar. Experiments on mallard ducks indicated an $LD_{50}$ of 10,539 ppm for creosote-coal tar.

The amount of creosote as liquid or vapor that enters the environment is relatively small. Estimated liquid discharge from all wood preserving plants using creosote in the United States totals 9 pounds of phenolic compounds and 68 pounds of "oil and grease" per day. Components of creosote discharged in largest amounts are pyrene, anthracene, phenanthrene, and fluoranthene.

The fate of creosote in the environment is not known, but some components are rapidly biodegraded. Phenol removal in soil exceeds 99%.

Creosote may be lost from treated wood by evaporation, exudation, or leaching. Some of the lower distilling fractions are lost very soon after the wood is treated, but the remainder is very slow to be lost. Exuded liquid moves into soil a few inches before biodegradation. Various polynuclear aromatic hydrocarbons have been found to disappear below detectable level in controlled oil spills after 17 days. Photooxidation and microbial degradation by bottom sediments are responsible.

# CHAPTER 6: ALTERNATIVE PRESERVATIVES

# CHAPTER 6: ALTERNATIVE PRESERVATIVES

## Introduction

The majority of all wood products that currently require preservatives are treated with either penta, creosote, or one of the arsenicals. Numerous other chemicals, which exhibit fungicidal and insecticidal properties, are available but are not widely used as wood preservatives because of unfavorable economic and efficacy characteristics or other limitations. In general, a given chemical must have the following properties in order to be considered as a viable wood preservative candidate:

1. Must be effective in preventing the biodeterioration of wood.
2. Must be economically competitive on a cost performance basis with existing preservatives.
3. Must be soluble and stable in a suitable liquid carrier.
4. Must be leach resistant when exposed to outdoor environmental conditions.
5. Must have a low vaporization rate from wood.
6. Must have no undesirable effects on the handling and finishing characteristics of the products.
7. Must penetrate wood uniformly.
8. Must have no excessive influence on the corrosion of metals that are likely to come in contact with the treating solution or treated wood.
9. Must have no detrimental effect on the physical properties of wood.
10. Must be chemically stable in wood contact.
11. Must have acceptable mammalian toxicity characteristics.
12. Must be compatible with environmental requirements.

## General Characteristics of Alternate Preservatives

Although most wood products are treated with the three major wood preservatives, there are several compounds which for some applications are viable substitutes. These are: 1) copper-8-quinolinolate (Cu-8), 2) tributyltin oxide (TBTO), 3) copper naphthenate, 4) acid copper chromate (ACC), and 5) chromated zinc chloride (CZC). These particular compounds are currently registered by the EPA as wood preservatives and also are recognized by AWPA as satisfactory preservatives for certain products. The general characteristics of these compounds which have a bearing on their use as wood preservatives are presented below.

### Copper-8-Quinolinolate

Copper-8-quinolinolate is generally formulated as an oilborne preservative system with a mineral-spirits carrier. However, some of the manufacturers also provide a water-based formulation with this preservative. Because of the copper present, the solution imparts a light brownish-green color to the wood. In the presence of iron, certain formulations having low pH are unstable and, consequently, are not compatible with steel treating vessels. As a result, these formulations cannot currently be used in standard commercial treating plants.

It should be pointed out that there are two basic types of solubilized Cu-8 formulations, one of which appears to be more effective than the others. In this regard, in a report by Duncan (1958) it has been shown that the preservative threshold value against wood-destroying fungi for the standard Cu-8 formulation is 0.12 pcf. On the other hand, recent studies at Mississippi State Univ. (Thompson, 1979) have shown that a modified solubilized Cu-8 formulation has a preservative threshold of 0.04 pcf for the same test organism. Hence, it would appear that the modified Cu-8 formulation is up to three times as effective as the standard formulation based on these laboratory soil block tests. However, additional laboratory and field tests need to be conducted before this improvement in efficacy can be used as justification for reducing treating solution concentrations.

The efficacy of Cu-8 in ground contact applications is influenced by the type of carrier solvent used. For example, in light petroleum solvents, Cu-8 at a retention level of 0.123 pcf has an estimated service life of 7-8 years (Gjovik and Davidson, 1979). On the other hand, when Cu-8 at the same retention level is carried in a heavy petroleum solvent it performs well in ground contact and has exhibited a service life comparable to that of penta used at its normal retention level (Gjovik and Davidson, 1979). Nevertheless, since at the present time virtually all Cu-8 formulations are based on light petroleum solvents or aqueous solutions and the fact that this preservative is not fully effective against termites, this preservative is considered to be unsatisfactory for ground contact.

Based on the laboratory preservative threshold values of approximately 0.12 pcf for Cu-8 and approximately 0.31 pcf for penta (Duncan, 1958), it appears that the former is about 2.5 times as effective as the latter. Using this differential and the fact that penta is used at a concentration of 5% a.i., one can conclude that Cu-8 should be marketed at a concentration of 2% a.i. in order to provide equivalent preservative value used as an alternate.

## Tributyltin Oxide

Tributyltin oxide is an oil-soluble chemical and is generally formulated as an oilborne preservative with mineral-spirits carrier. This preservative is colorless and, consequently, provides a clean treatment for wood. It is stable in solution and can be used in existing treating plant equipment.

Laboratory studies show that TBTO is an effective fungicide for the major wood destroying fungi (Nicholas, 1973a). However, recent studies (Henshaw et al., 1978) have shown that in some cases TBTO undergoes chemical changes in the wood which results in its conversion to dibutyltin oxide (DBTO). Since DTBO is considerably less effective as a wood preservative, this phenomenon would reduce the efficacy of TBTO and require the use of a higher preservative concentration than predicted by laboratory threshold values. Consequently, the team feels that a solution concentration of at least 2% a.i. TBTO should be used in the event this preservative is considered as an alternative for penta in above-ground applications.

Field tests (Gjovik and Davidson, 1979) have shown that TBTO is not very effective in ground contact, so it should not be used in these applications.

## Copper Naphthenate

Copper naphthenate is classified as an oilborne preservative and is formulated either in heavy- or light-petroleum solvents. This chemical is a very viscous compound which has a dark green color and a disagreeable odor. Consequently, when wood is treated it is dark green in color and has a tacky, gummy surface. The treating solutions are stable and can be used in standard wood treating plant equipment. However, it should be pointed out that copper naphthenate solutions are unstable in the presence of moisture, and under these conditions excessive corrosion of metals occurs. Because of this, copper naphthenate can be used only for the treatment of wood products that are dry. As a result, the common practice of pre-steaming southern yellow pine and treatment without additional drying would not be possible.

Furthermore, the common practice of Boultonizing Douglas-fir poles and piles would not be possible with copper naphthenate.

This limitation in the use of copper naphthenate would increase the treatment cost considerably since only dry wood could be used. Furthermore, many plants would have to be modified in order to provide the necessary equipment to dry poles and other wood products that require treatment.

### Acid Copper Chromate

Acid copper chromate is a waterborne preservative system formulated from copper and chromium compounds. This treatment imparts a dark green color to the wood. The preservative is stable and can be used satisfactorily in existing plant equipment. ACC is a fairly good wood preservative but when used in ground contact its performance is erratic in comparison to the arsenical containing preservatives. Consequently, this preservative should not be used in critical applications where early failure would result in high replacement cost or risk to human life.

### Chromated Zinc Chloride

Chromated zinc chloride is a waterborne preservative which is formulated from zinc chloride and chromium compounds. Because of chromium, the treating solution is colored and imparts a green color to the wood. This preservative system is stable and can be used in existing plant equipment even though it is slightly corrosive to steel.

## Recommended Uses for Alternate Preservatives

### Products Treated by Pressure Processes

All of the existing wood preservative systems have characteristics which limit their application to certain wood products. Consequently, the suitability of a given preservative must be determined for each individual type of wood product. This is illustrated in Table 78 which lists the major commodities that are frequently treated with wood preservatives. For each item, the recommended preservatives are shown along with the required retention and approximate estimated service life. Most of the retentions listed were obtained from the AWPA standards (AWPA Book of Standards) and are representative values for the item in question. Field test data were used to establish retentions which are not covered in the AWPA Standards. The service lives represent estimates that were made from all available field and laboratory test data (Davidson, 1977; Gjovik and Davidson, 1979; Gjovik and Davidson 1975; Cockroft, 1974; Krzyzewski, 1976; Krzyzewski, 1977; and Miller and Graham, 1971).

Although the AWPA (current) Standards and all available field service test data were used to compile Table 78, quantitative data are lacking in certain areas. This resulted in the necessity of making estimates for these items in order to complete this table. Despite this weakness, we are confident that the information is sufficiently reliable to make realistic direct comparisons between the various preservatives in order to determine whether or not viable alternates exist. This is the sole purpose of Table 78 and it should not be used for any other purposes.

The reasons for concluding that some preservatives should not be used for certain commodities are not obvious from the table, so this information is presented below.

Table 78.--Preservatives and retentions recommended for various wood products

| Commodity | Creosote-Coal Tar | | Creosote | | Penta | | CCA & ACA | | Cu-8 | | TBTO | | Cu-Naph. | | ACC | | CZC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Retn.[a] | S.L.[b] | Retn. | S.L. | Retn. | S.L. | Retn. | S.L. | Retn. | S.L. | Retn. | S.L. | Retn.[c] | S.L. | Retn. | S.L. | Retn. | S.L. |
| Poles-utility | NR[d] | -- | 9.0 | 35 | 0.45 | 35 | 0.60 | 50 | NR | -- | NR | -- | 0.68 | 35 | NR | -- | NR | -- |
| Poles-residential | NR | -- | NR | -- | NR[e] | -- | 0.80 | Indef[f] | NR | -- | NR | -- | NR | -- | NR | -- | NR | -- |
| Poles-farm & industrial | 9.0 | 35 | 9.0 | 35 | 0.45 | 35 | 0.60 | 50 | NR | -- | NR | -- | 0.68 | -- | NR | -- | NR | -- |
| Poles-recreational & commercial | NR | -- | NR | -- | 0.60 | 35 | 0.60 | 50 | NR | -- | NR | -- | NR | -- | NR | -- | NR | -- |
| Posts-fence | 6.0 | 25 | 6.0 | 25 | 0.30 | 25 | 0.40 | 35 | NR | -- | NR | -- | 0.45 | 35 | 0.50 | 35 | NR | -- |
| Posts-fence, residential & commercial | NR | -- | NR | -- | 0.30 | 25 | 0.40 | 35 | NR | -- | NR | -- | NR | -- | 0.50 | 35 | NR | -- |
| Posts-hwy. and guardrail (sawn) | 12.0 | 30 | 12.0 | 30 | 0.60 | 30 | 0.60 | 30 | NR | -- | NR | -- | 0.90 | 30 | NR | -- | NR | -- |
| Piling-marine | 20.0 | 20 | 20.0 | 20 | NR | -- | 2.5 | 30 | NR | -- | NR | -- | NR | -- | NR | -- | NR | -- |
| Piling-fdn., land and fresh water | 12.0 | Indef | 12.0 | Indef | 0.60 | Indef | 0.80 | Indef | NR | -- | NR | -- | 1.20 | Indef | NR | -- | NR | -- |
| Crossties | 8.0 | 35 | 8.0 | 35 | 0.40 | 25 | NR | -- | NR | -- | NR | -- | 0.60 | 25 | NR | -- | NR | -- |
| Crossarms | NR | -- | 8.0 | 40 | 0.40 | 40 | 0.40 | 40 | NR | -- | NR | -- | 0.60 | 40 | 0.50 | 40 | NR | -- |
| Ind. block flooring | 8.0 | Indef | 8.0 | Indef | NR | -- | NR | -- | NR | -- | NR | -- | NR | -- | NR | -- | NR | -- |
| Cooling tower slats | NR | -- | NR | -- | NR | -- | 0.40 | 20 | NR | -- | NR | -- | NR | -- | 0.50 | 20 | NR | -- |
| Ag. (grape stakes, tomato stakes, mushroom trays, greenhouses) | NR | -- | NR | -- | NR | -- | 0.50 | 30 | NR | -- | NR | -- | 0.75 | 30 | 0.62 | 30 | NR | -- |
| Landscaping, garden timbers, decking | NR | -- | NR | -- | 0.50 | 30 | 0.40 | 30 | NR | -- | NR | -- | NR | -- | 0.50 | 30 | NR | -- |

Table 78.--Preservatives and retentions recommended for various wood products--continued

| Commodity | Creosote-Coal Tar | | Creosote | | Penta | | CCA & ACA | | Cu-8 | | TBTO | | Cu-Naph. | | ACC | | CZC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Retn.[a] | S.L.[b] | Retn. | S.L. | Retn. | S.L. | Retn. | S.L. | Retn. | S.L. | Retn. | S.L. | Retn.[c] | S.L. | Retn. | S.L. | Retn. | S.L. |
| Containers (boxes, crates, etc.) | NR | -- | NR | -- | 0.30 | -- | 0.25 | -- | 0.12 | -- | 0.12 | -- | 0.40 | -- | 0.25 | -- | 0.45 | -- |
| Boat hulls & decks | NR | -- | NR | -- | NR | -- | 0.60 | -- | NR | -- | NR | -- | NR | -- | NR | -- | NR | -- |
| Lbr. & ply. for commercial bldgs. (above-ground only) | NR | -- | NR | -- | 0.30 | Indef | 0.25 | Indef | NR | -- | NR | -- | NR | -- | 0.25 | Indef | 0.45 | Indef |
| Seawalls, wharves, piers, fenders, etc. | 25.0 | 20 | 25.0 | 20 | NR | -- | 2.5 | 30 | NR | -- | NR | -- | NR | -- | NR | -- | NR | -- |
| Bridges & RR crossing planks | 12.0 | 35 | 12.0 | 35 | 0.60 | 35 | 0.60 | 35 | NR | -- | NR | -- | NR | -- | NR | -- | NR | -- |
| Mine ties & timbers | 10.0 | 30 | 10.0 | 30 | 0.50 | 30 | 0.40 | 30 | NR | -- | NR | -- | 0.75 | 30 | 0.50 | 30 | NR | -- |
| House foundations & swimming pools | NR | -- | NR | -- | NR | -- | 0.60 | Indef | NR | -- | NR | -- | NR | -- | NR | -- | NR | -- |
| Farm & ind. bldgs. (above-ground only) | 8.0 | 50 | 8.0 | 50 | 0.40 | 50 | 0.25 | 50 | 0.16 | 35 | 0.16 | 25 | 0.60 | 50 | 0.25 | 35 | 0.45 | 35 |
| Residential (above-ground only) | NR | -- | NR | -- | 0.30 | Indef | 0.25 | Indef | 0.12 | 30 | 0.12 | 30 | NR | -- | 0.25 | Indef | 0.45 | Indef |
| Hwy. sound barriers | NR | -- | NR | -- | 0.60 | 35 | 0.60 | 35 | NR | -- | NR | -- | NR | -- | NR | -- | NR | -- |
| Playground equipment | NR | -- | NR | -- | NR | -- | 0.40 | 30 | NR | -- | NR | -- | NR | -- | 0.50 | 30 | NR | -- |

[a] Retention expressed in pounds per cubic foot (pcf).

[b] Estimated average service life (SL) (years).

[c] Expressed as retentions of Cu metal. Retentions are based on dilutions with a P9 type A oil.

[d] Not recommended.

[e] Would be acceptable for exterior poles at a retention of 0.8 pcf in P9 oil.

[f] Indefinite - more than 50 years.

## Poles, Utility

Cu-8, TBTO, ACC, and CZC are not recommended because they are not satisfactory for ground-contact applications.

## Poles, Residential

Cu-8, TBTO, ACC, and CZC are not recommended because they are unsatisfactory for ground-contact applications. Creosote and penta are not recommended because they impart oily, unpaintable surface characteristics and may create an unacceptable exposure. However, they could be used for poles located in exterior areas.

## Poles, Farm and Industrial

Cu-8, TBTO, ACC, and CZC are not recommended because they are unsatisfactory for ground-contact applications.

## Poles, Recreational and Commercial

Cu-8, TBTO, ACC, and CZC are not recommended because they are unsatisfactory for ground-contact applications. Creosote and penta in P9 (type A) are not recommended because they impart dark, oily surface characteristics. Treatments with penta by the Cellon or methylene chloride processes are acceptable.

## Posts, Farm and Commercial

Cu-8, TBTO, and CZC are not recommended because they are unsatisfactory for ground-contact applications. ACC is acceptable here because this is considered a non-critical application.

## Posts, Residential

Cu-8, TBTO, and CZC are not recommended because they are unsatisfactory for ground-contact applications. Creosote and copper naphthenate are not recommended because they impart dark, oily, and unpaintable surface characteristics. ACC is acceptable in this application because this is considered a non-critical application.

## Posts, Highway and Guard Rail (Sawn)

Cu-8, TBTO, and CZC are not recommended because they are unsatisfactory for ground-contact applications. ACC is not recommended because it is unsatisfactory for ground-contact in critical applications.

## Piling, Marine

Penta, Cu-8, TBTO, copper naphthenate, ACC, and CZC are not recommended because they are unsatisfactory for severe marine exposure.

## Piling, Foundation, Land and Fresh Water

Cu-8, TBTO, and CZC are not recommended because they are unsatisfactory for ground-contact applications. ACC is not recommended because it is unsatisfactory for ground-contact in critical applications.

## Crossties

Cu-8, TBTO, and CZC are not recommended because they are unsatisfactory for ground-contact applications. ACC is not recommended because it is unsatisfactory for ground contact in critical applications. CCA and ACA are not recommended because they do not provide the necessary lubrication properties. For penta treatments, only penta in P9 (type A) oil is recommended as an alternative for creosote in this application.

## Crossarms

Cu-8, TBTO, and CZC are not recommended because this is a critical application.

## Industrial Wood Block Flooring

Creosote is generally used in industrial application because it interacts with the adhesive to form a good bond to the floor and between blocks.

## Cooling Tower Slats

Creosote, penta, Cu-8, TBTO, copper naphthenate, and CZC are not satisfactory for this application since they are not particularly effective against soft rot fungi which are primarily responsible for decay in cooling towers.

## Agricultural Products (Ground Contact)

Creosote and penta are not recommended primarily because of their undesirable phytotoxic properties. Cu-8, TBTO, and CZC are not recommended because they are unsatisfactory for ground-contact applications.

## Agricultural Products (Above-Ground Contact Only)

Creosote and penta are not recommended primarily because of their undesirable phytotoxic properties.

## Landscaping and Garden Timbers and Decking

Cu-8, TBTO, and CZC are not recommended because they are unsatisfactory for ground-contact applications. Creosote, copper naphthenate, and penta in P9 (type A) are not recommended for most uses, but may be acceptable in certain circumstances where the surface characteristics are acceptable.

## Containers (Boxes, Crates, etc.)

Creosote is not recommended because it imparts undesirable surface characteristics.

## Boat Hulls and Decks

Creosote and copper naphthenate are not recommended because they impart oily, unpaintable surface characteristics. Penta is not recommended because it is unsatisfactory for marine uses and also could lead to undesirable exposure to penta vapors in closed spaces. Cu-8, TBTO, ACC, and CZC are not recommended because they are unsatisfactory for marine applications.

## Lumber and Plywood (for Commercial Buildings in Above-Ground Applications)

Creosote and copper naphthenate are not recommended because they impart dark, oily, and unpaintable surface characteristics. Cu-8 and TBTO are not satisfactory because these items are considered to be critical applications.

## Seawalls, Wharves, Piers, Fenders, etc.

Cu-8, TBTO, ACC, and CZC are not satisfactory because this is considered to be a critical application. Penta and copper naphthenate are not recommended except for areas that are not in contact with sea water.

## Bridges and Railroad Crossing Planks

Cu-8, TBTO, ACC, and CZC are not recommended because they are unsatisfactory for ground-contact applications. Copper naphthenate is not recommended because this is considered to be a critical application. However, copper naphthenate would be satisfactory for railroad crossing planks.

## Mine Ties and Timbers

Cu-8, TBTO, and CZC are not recommended because this is considered to be a critical application.

## House Foundations and Swimming Pools

CCA and ACA are recommended since they are the only preservatives that can provide the indefinite service life that is required for this application.

## Residential (Above-Ground Use)

Creosote and copper naphthenate are not recommended because they impart dark, oily, and unpaintable surface characteristics. Penta should be used only in exterior applications.

## Highway Sound Barriers

Creosote and copper naphthenate are not recommended because they impart dark, oily, and unpaintable surface characteristics. Cu-8, TBTO, and CZC are not recommended because they are unsatisfactory for ground-contact applications. ACC is not recommended because it is unsatisfactory for ground contact in critical applications.

## Playground Equipment

Creosote and copper naphthenate are not recommended because they impart undesirable surface characteristics. Penta is not recommended because of potential dermal exposure to the individuals using this equipment. Cu-8, TBTO, and CZC are not recommended because they are unsatisfactory for ground-contact application. However, this could be satisfactory for components that are not exposed to ground contact.

# Products Treated by Non-Pressure Processes

## Particleboard

A small amount of particleboard (170,000 sq ft, on 3/4-in. basis) is currently treated with penta to provide protection against wood destroying insects for use in areas where this is a problem. Since the preservative is applied to the particles during the blending operation, it is imperative that this chemical be compatible with the adhesive. At the present time, penta is the only known preservative that meets the requirement of compatibility and efficacy, so there are no known alternatives. Other preservatives may be satisfactory for this use, but the data to substantiate this are not currently available.

## Millwork

Most millwork is currently treated with 5% penta in a light petroleum solvent. Since treatment is done after the product is completely surfaced, the preservative must be carried in a light petroleum solvent that does not impart surface deposits which will interfere with subsequent finishing. Consequently, the only viable alternate preservatives are TBTO and Cu-8. In order to provide comparable service lives with these preservatives the ready-to-use solution concentrations should be 2.0% for each. The Assessment Team recognizes that these preservatives are not registered for use at the stated concentration.

Since the low pH formulation of Cu-8 is not stable in contact with iron, the existing dip tanks would have to either be modified or replaced before this particular formulation could be used. The other formulations are satisfactory without equipment modification.

## Sapstain Control for Poles and Lumber

Sodium penta at concentrations ranging from 0.5 to 0.9%, in combination with borates, are extensively used to prevent sapstain from degrading freshly cut lumber and poles. The modified Cu-8 formulation at a concentration of 0.054% Cu-8 plus other solubilizing ingredients is a possible alternative for this application (Nagel, 1979; and Wood and Kelso, 1977). However, because of the instability of the low pH Cu-8 when in contact with iron, the application equipment must be modified before this particular formulation can be used. The other formulations may be satisfactory for this application, but data to substantiate this are not currently available.

## Groundline Treatment Chemicals for Poles

A variety of formulations are used by applicators to provide remedial treatment for poles in line. The chemicals generally used in these preservative systems are penta, creosote, sodium fluoride, dinitrophenol, potassium dichromate, and borax. Creosote and penta are the key ingredients. Reasonably effective preservative systems could be prepared if either creosote or penta were not available, but this is not the case if both were unavailable.

## Preservatives for Home and Farm Use

A 5% solution of penta in light petroleum solvent is widely used by homeowners, farmers, etc., for brush, spray, and dip applications of various wood products.

There are several alternative preservative chemicals registered for use at the home and farm level, the most prevalent being: copper naphthenate, Cu-8, zinc naphthenate, TBTO, and creosote (currently under RPAR). One or more products containing these chemicals are available for sale at most lumber and hardware stores.

Cu-8 at concentrations from 0.25% to 0.30% is registered for use on wood items that will be in contact with food, but this chemical is not readily available for home and farm use.

Creosote based formulations discolor wood and make it unpaintable. Copper naphthenate has similar problems but is available as a pigmented stain in various colors. TBTO is also available in various colored stains and as a colorless solution. Zinc naphthenate, as a clear formulation, is available to a limited degree.

Both TBTO and the standard Cu-8 formulation at concentrations of 2.0% are possible alternate preservatives for this use, although they are not registered by EPA at this concentration.

An estimated 2 million pounds (0.2% of total production) of creosote were sold to individuals for home and farm treatment of wood (Chapter 5). The amount of other chemicals used for home and farm application is unknown.

## Trends in the Development of New Wood Preservatives

Over the years, numerous chemicals have been tested as potential wood preservatives. Because of governmental pressures to eliminate and restrict certain pesticides, activity in this area has increased significantly in the past few years.

Despite the large number of chemicals that are potential wood preservatives, only a very small number are commercially available at the present time. There are two basic reasons for this situation. First of all, the requirements that a chemical must have in order to be a satisfactory wood preservative are very stringent and this eliminates most candidates. Second, insufficient research has been conducted over the years to evaluate fully potential compounds.

At the present time the most promising class of compounds that may prove to be viable wood preservatives for certain uses are the alkylammonium compounds (AAC). Due to an active research program at the Forest Research Institute in New Zealand over the past few years, several of the AAC's are now approved in that country for above-ground applications. However, several more years of field testing will be required before it can be determined whether or not they will be satisfactory for ground-contact applications.

Based on the research conducted to date, it is doubtful that any new chemicals will be able to compete with the major preservatives now in use when compared on a cost/performance basis. However, there may be a few that are in the same general cost/performance range and those may prove to be satisfactory for certain uses where improved toxicological properties are desired.

## Summary of Biological Analysis of Alternative Preservatives

The requirements that a chemical must meet in order to be seriously considered as a wood preservative are very stringent. As a result, only a very small number of chemicals are currently available as wood preservatives.

In addition to the three major wood preservatives currently under RPAR, the following chemicals have been approved by AWPA and EPA as wood preservatives:

1) Copper-8-quinolinolate (Cu-8)
2) Tributyltin oxide (TBTO)
3) Copper naphthenate (Cu-Naph)
4) Acid copper chromate (ACC)
5) Chromated zinc chloride (CZC)

Each of the above preservatives has characteristics which limit its use to specific wood products. Consequently, these compounds would provide alternatives for only a small percentage of the total wood preservative uses. Furthermore, for millwork and home and farm uses, TBTO and Cu-8 are recommended at a 2% solution concentration. Since these preservatives are not currently registered by EPA at these use levels, they cannot be considered as viable alternatives until the appropriate product labels are obtained.

# CHAPTER 7: ALTERNATIVES TO TREATED WOOD PRODUCTS (UNTREATED WOOD AND NON-WOOD MATERIALS)

# CHAPTER 7: ALTERNATIVES TO TREATED WOOD PRODUCTS (UNTREATED WOOD AND NON-WOOD MATERIALS)

## Introduction

The purpose of this chapter is to identify structural materials that could serve as substitutes for preservative-treated wood in the event of cancellation of registration or restrictions on the use of pentachlorophenol, inorganic arsenicals, and creosote. This information is provided particularly for use in the economic analysis (Chapter 8) to assess the economic impacts of cancellation.

The primary alternatives to treated wood are concrete, steel, aluminum, plastic, and untreated wood. In the case of treated utility poles, another alternative is underground cable. This is the only "going without" alternative that will be considered; the possibilities, for example, of "going without" railroad services (or going to overhead monorails) are not addressed.

The alternatives listed are all feasible under certain conditions and all are presently being used to a limited extent. They are employed when they offer advantages of cost, aesthetics (form or color), fire resistance, or when there is need to surpass the structural limitations of wood.

More specifically, this section covers technical and biological feasibilities of substitution. The impacts of substitution on economics, energy and environmental factors, and related socioeconomic impacts are covered quantitatively in Chapter 8.

Untreated wood has some important limitations as a substitute for treated wood products. Under many conditions, untreated wood will give centuries of service. However, where conditions permit development of organisms that can degrade wood, protection must be provided to insure satisfactory service life. The principal organisms that degrade wood are fungi, insects, bacteria, and marine borers (USDA, 1974).

Decay-producing fungi may, under conditions that favor their growth, attack either heartwood or sapwood. The heartwoods of common domestic and imported species have varying degrees of natural decay resistance. Untreated sapwood of almost all species has low resistance to decay and a short service life under decay-producing conditions. Decay resistance of heartwood is greatly affected by differences in preservative qualities of wood extractives, the attacking fungus, and conditions of exposure. Considerable difference in service life may be obtained from pieces of wood of the same species, or even from the same tree, used under apparently similar conditions.

Precise ratings of decay resistance of heartwood of different species are impossible because of variability within species, and the variety of conditions to which wood is exposed. Variations in decay resistance of individual trees or wood samples of a species are much greater for most of the "resistant" or "very resistant" species than for the "slightly resistant" or "nonresistant" species.

Where decay hazards exist, heartwood of "resistant" or "very resistant" species generally gives satisfactory service. But heartwood of "moderately" and "slightly" resistant species will usually require preservative treatment. Marketable sizes and shapes of most species generally contain a substantial percentage of sapwood. The supply of "resistant" and "very resistant" heartwood is uncertain and undoubtedly limited. Moreover, even the heartwood of "very resistant" species may require preservative treatment for important structural or other uses where failure would endanger life or require time-consuming and expensive repairs.

Only a limited number of woods grown in the United States offer any natural resistance to termite attack. The close-grained heartwood of redwood has some resistance, especially when used above-ground. Very resinous heartwood of southern pine is practically immune, but wood of this type is not available in large quantities and is not suitable for many uses.

No wood is immune to marine-borer attack, and no commercially important wood of the United States has sufficient marine-borer resistance to justify its use untreated in any important strucuture where borers are active. Heartwood of several foreign species has shown resistance to marine-borer attack, but service records on these woods do not show uniform results and are affected by local conditions.

The great bulk of treated wood materials produced in the United States is used in construction of railroads, utility lines, buildings, and other structures under conditions that are conducive to the development of wood-destroying fungi, insects, and/or marine borers. Failure of the wood materials in these applications would be hazardous to humans and extremely difficult, time-consuming, and expensive to repair. Due to the scarcity and high variability of "naturally-durable" woods, untreated wood cannot be regarded as a practicable substitute for treated wood in these critical applications. If treated wood were not available, the vast majority of users would likely turn to nonwood substitutes rather than to the use of untreated wood.

Even assuming that users of treated wood products would turn to untreated wood substitutes, the difference in average service life under severe exposure conditions (35 years for treated wood vs. 5 years for untreated wood) would result in a doubling of raw material requirements in 5 years and a 6-fold increase (7 times current requirements) in 30 years. The annual needs in 30 years would be more than 1.2 billion cubic feet for railroad ties, poles, and piling, alone. Such usage would put a very serious drain on timber resources and cause significant shortages and increases in prices of all wood products.

For reasons outlined above, the Assessment Team concludes that untreated wood is not a practicable substitute for most treated wood products. Where it is considered to be a practical alternate, untreated wood will be discussed under the appropriate commodities, below.

## Crossties and Switch Ties

Crossties and switch ties are considered together. The economic and social value of crossties and the crosstie industry to the railroads and the Nation is enormous. The magnitude will be quantified in detail in the section on economic analysis of treated wood products (Chapter 8).

Treated wood is, by far, the dominant material used for crossties (Table 79) and practically all wood ties are treated with creosote. Oak and other hardwoods make up over 80% of the wood species used for ties. The structural alternatives to treated wood for ties are concrete and steel, though no significant numbers of steel ties have been used by U.S. railroads to date.

In addition to the new crossties used, 1971-76, about 66 million board feet of treated wood switch and bridge ties were used annually during the period. Less than 0.5% of new crossties used were concrete, and about 95% of the treated wood crossties were used for spot replacements in traditional track maintenance operations.

Table 79.--Estimated number of new crossties used, 1971-1976

| Year | Wood Crossties Used | | | Concrete Ties |
|---|---|---|---|---|
| | Total | For Replacements | In New Track | |
| | - - - - - - - - - - - - - - - - - 1,000 - - - - - - - - - - - - - - - - - | | | |
| 1971 | 24,121 | 23,024 | 1,097 | 215 |
| 1972 | 23,733 | 22,400 | 1,333 | 47 |
| 1973 | 21,208 | 19,962 | 1,246 | 51 |
| 1974 | 22,535 | 20,823 | 1,712 | 84 |
| 1975 | 21,850 | 20,751 | 1,099 | 107 |
| 1976 | 28,748 | 27,146 | 1,602 | 106 |

Source: Forest Service estimates based on Association of American Railroads (1979) Statistics for Class I Railroads. Wood tie replacements = Class I x 1.07 Wood ties on new track = Class I x 1.05

The 27 million wood ties used for replacements in 1976 were spread over some 299,000 miles of track laid on crossties--an average of 91 ties replaced per mile. This 3% replacement rate gives an "indicated" service life of 33+ years for treated wood ties. Similar data for earlier years show that ties were replaced at an average rate of 2.6% in the decade of the 50's (indicated life = 38 years), 1.6% in the 60's (indicated life = 62.5 years), and 2.2% during the period 1970-75 (indicated life = 45.5 years).

The low replacement rates during the 60's and early 70's reflect the general deferment of track maintenance by many U.S. rail lines, and result in an unreasonably high "indicated" service life. Attempts to catch up on the deferred maintenance have increased demands for treated wood ties since 1976. Projected requirements for the period 1979-82 average about 33 million treated wood ties annually--a replacement rate of 3.7%, giving an "indicated" life of 27 years.

Actual life of treated wood ties depends on many factors including weight (gross ton miles), speed of traffic, axle loads, track condition, climate factors, and the quality of ties, treatment, and track maintenance. The Assessment Team believes that many decades of satisfactory service have demonstrated that a 35-year average service life is reasonable for treated wood on all classes of U.S. railroads.

## Concrete Crossties

Concrete crossties are used extensively in Europe and Japan where wood is scarce and traffic and other conditions are generally different than in the United States. Concrete ties have been installed in numerous tests and demonstrations in the United States and Canada over the past 20 years. Performance of concrete ties in these various installations has been reported by Josephson (1977); Fuller, et al. (1977); and DeLeuw, Cather/Parsons (1977).

Early European experience with concrete ties showed them to be costly and unsafe for high-speed operation. More recent installations of concrete ties on European and Japanese railroads have shown good structural integrity and durability for more than a decade, but have not yet been in service for a full life-cycle. Performance of concrete ties in U.S. railroads prior to 1970 was generally poor. Failures consisted of insert pullout, flexural and torsional cracking in the center of the ties and under the rails, spalling of rail seat shoulders, displacement of rail seat pads, and broken clips or bolt fasteners.

The insert pullout and cracking problems were studied by the Portland Cement Association. The American Railway Engineers Association (AREA) in conjunction with the American Concrete Institute (ACI) developed AREA Preliminary Specifications for Concrete Ties and Fastenings (AREA Bulletin 634) which became the basis for continued development and use of concrete ties in the United States. The AREA standards have been upgraded several times, the latest ones being published in AREA Bulletin 655 in 1975 and Bulletin 660 in 1976 (Fuller, et al., 1977).

Several major test sections of 200 to 800 concrete ties, each, designed in accordance with specifications in AREA Bulletin 644 were installed under various operating conditions in 1973-74 on the Alaskan, Chesapeake & Ohio, Sante Fe, and Norfolk & Western railroads. About 3,000 concrete ties meeting AREA requirements are currently being tested at the Department of Transportation's Facility for Accelerated Service Testing (FAST) at Pueblo, Colorado. Other tests of concrete ties are underway on the Florida East Coast, Canadian National, and Black Mesa & Lake Powell railroads. Reports on performance of concrete ties in these installations, to date, indicate that there are some problems, particularly with fasteners, insulators, and tie pads, which have yet to be solved.

In any case, it is apparent that the long-term durability and ultimate service life of concrete-tie systems have not been demonstrated either for the relatively light loadings on foreign lines, or for the heavier freight tonnages and axle loads typical on U.S. railroads. Service life of concrete ties has been variously assumed to be 40 to 50 years or more. The Assessment Team sees no basis for assigning either a longer or a shorter service life to concrete tie systems than has been estimated for treated wood, i.e., 35 years.

Based on an analysis of concrete tie cost and performance for track structures (DeLeuw, Cather/Parsons, 1977), the U.S. Department of Commerce, Federal Railroad Administration selected concrete crossties for use in rebuilding 430 miles of high-speed railroad in its Northeast Corridor Improvement Project. The analysis included three systems of upgrading track based on type of tie and method of installation:

1. Complete rebuilding of track (ties, rail, ballast) using concrete ties with elastic fasteners.

2. Complete rebuilding of track using preplated, treated wood ties with elastic fasteners.

3. Component (traditional spot) replacement of defective ties using treated wood ties and spike fasteners, followed by complete replacement of rail.

The two "complete rebuilding" systems included use of a mechanized track laying system (TLS) while the "component replacement" system used conventional methods for replacing ties and renewing rail. Two conclusions reached in this analysis are pertinent to any evaluation of the substitutability of concrete for treated wood crossties.

1. The cost analysis included the cost for renewing rail in all alternatives. Should rail renewal be deleted from each alternative, the initial cost of upgrading track by the component renewal method would be greatly reduced and the advantage of total-renewal methods in life-cycle costs would be decreased, if not eliminated. This results from the assumption that the TLS requires no additional equipment or labor for rail renewal, while the component replacement method must include the costs of equipment and labor for an independent rail renewal gang.

2. The component replacement method cannot be considered for concrete ties. Experience has shown that concrete ties do not perform satisfactorily when randomly interspersed in wood-tie track. Concrete ties settle more slowly--resulting in an unstable track structure. The greater weight of concrete ties is also an impediment to their installation by conventional maintenance methods and equipment. Most equipment would have to be modified to handle heavier concrete ties.

Since 95% of treated wood ties are used for spot replacements, and the number of ties required for this purpose is increasing, it appears that the potential for substituting concrete ties for treated wood ties is very limited unless conventional methods of maintenance are to be abandoned. If all sections of U.S. railroad track now in need of spot replacements were to be completely rebuilt, the time, cost, and number of ties required to do the job would be greatly increased.

These factors, along with energy, environmental, safety, and other socioeconomic considerations, will be examined in more detail in Chapter 8.

### Steel Crossties

Experience in the use of steel crossties has been scattered and limited. Following World War II, German railroads found steel ties to have less resilience and higher costs (13%) compared to wood. Steel ties also caused problems in insulating track electrical circuits (Josephson, 1977).

Other experience with steel crossties is very limited. The Delaware and Hudson Railroad has used steel ties made from salvaged rail. The steel ties maintained gauge, but created interference with signaling systems. They are currently used by D. & H. only for yard and industrial sidings (Fuller, 1977).

The Federal Railway Administration tested steel ties in its Pueblo, Colorado (FAST) test track but removed them after a short time when fastening problems developed. Steel ties are still in use in industrial side track and narrow-gauge mining track.

Use of steel for ties is technically feasible. However, they are heavier and more costly than wood, tend to rust, and interfere with electric signals. There are little or no data to indicate that steel ties would perform satisfactorily in main-line railroad track. For these reasons, there is little current interest in expanding the use of steel crossties.

## Poles

Poles constitute the second largest use of treated wood. An estimated 64 million cubic feet of poles were treated in 1978 (Micklewright, 1979). Most poles are used in electric transmission and distribution lines, telephone lines, and light standards. Recreational, residential, and farm building construction account for most of the rest of the poles produced. Wood is a major material for poles and all wood poles are treated with preservative. The possible available substitutes for treated wood poles are concrete, steel, aluminum, plastic, and underground cable systems.

Transmission poles may be over 100 feet in length. Distribution poles are usually 50 feet or less in length. Wood for both is always treated. Creosote, pentachlorophenol, and arsenicals are all used for the preservative treatment. Of the poles treated in 1978, 28% were treated with creosote, 65% were treated with penta, and 7% received other treatments including arsenicals.

Southern pine is the most commonly used wood for distribution poles. Supplies have been generally adequate. The ready renewability of Southern pine pole timber leads to expectations that supplies will be adequate for current demand levels and considerable expansion.

Acceptable pole materials must have high durability, hold fastenings, be low in cost, have good bending strength, and be generally available. Treated wood poles offer the advantages of low cost, durability, versatility, good bending strength, good shock resistance, good resiliency, light weight, fasteners hold and are attached easily, good supply of raw material, and good electrical insulation. Disadvantages are primarily the shortage of large sizes, low fire resistance, eventual strength loss due to decay or insects, and aesthetic considerations.

## Concrete Poles

Concrete can be used for distribution poles and light standards. It could be used in residential and farm building construction but generally, is not. Concrete is heavy, strong in compression, but relatively weak in bending strength and low in electrical resistance. It is versatile and can be molded into any shape and size which makes it useful for applications involving heavy compressive loading. Concrete is not preferred for longer, heavily loaded transmission poles and distribution poles.

Hollow-spun poles are lighter than solid concrete and stronger per unit weight, but will fracture fairly easily in shipment and under bending stresses. These cracks may not be visible to the eye but they will allow moisture penetration causing corrosion and spalling. The great weight of concrete also adds to transportation costs. Concrete poles weigh over twice as much, and cost more than twice as much, as treated wood poles of comparable strength and design characteristics. Energy consumed in production of concrete poles is also higher than for treated wood poles.

Concrete poles are less desirable in areas that are inaccessible to mobile, high-reach trucks since the poles cannot be readily climbed by linemen unless steps are provided.

## Steel Poles and Towers

Steel can be used as a substitute for treated wood in transmission poles, distribution poles, light standards, and farm and other construction poles. Steel is versatile, strong, and can be fabricated into any shape. Lattice-steel tower construction is becoming prevalent for transmission lines; however, formed steel is also used and tube steel has had limited use for light standards and distribution lines. In order to have bending strengths comparable to wood poles, tube steel must be sized up to the point where the costs are considerably higher than wood. Energy consumption for the production of steel is also higher than for wood. Corrosion can reduce service life of steel poles unless poles are modified for corrosion resistance (galvanized, etc.). For this reason, also, steel poles are not placed directly in the ground, but rather on a concrete foundation which adds to costs.

## Aluminum Poles

Aluminum is used as a substitute for treated wood in light standards and to a very small extent in lattice tower construction for transmission lines. The inherent weakness (tendency to "buckle") of aluminum has limited it almost exclusively to use in tubular light standards and break-away sign poles. Tubular poles serve in light-duty applications such as light standards, flag poles, and sign poles. However, if they are placed directly in the ground, ground-line corrosion occurs.

Compared to treated wood for which they would substitute, aluminum poles have the disadvantage of requiring more energy for production, and are also electrical conductors. They offer the advantages of being light in weight, can be made with aesthetically pleasing forms and surfaces, and are not subject to decay or insect attack.

## Plastic (Reinforced Fiberglass) Poles

Reinforced plastic poles are becoming widely used for light standards. They are too flexible (lack stiffness) to be used for the heavily-loaded utility pole where the lines, ice, and wind contribute significantly to the load.

Plastic poles are light in weight, easily handled, do not corrode or deteriorate in contact with soil, and can be molded in aesthetically pleasing forms. They are manufactured in lengths up to 35 feet. The material is a non-conductor but does require more energy to produce than wood, and does deteriorate from ultraviolet light. Guy wires can overcome much of the flexibility problem, but these too can be undesirable additions in urban settings.

## Underground Cable

Largely for aesthetic reasons, there has been public pressure on utilities to place new distribution lines underground rather than overhead on poles. Underground installation is now being used as a substitute for overhead distribution lines, particularly in new urban and suburban subdivisions. Underground distribution is not extensively used in rural areas or as an alternative for distribution pole replacement because of its high cost. For high voltage (over 230 KV) transmission lines, underground installation is not yet feasible.

There are some inherent problems with underground distribution lines: (1) cable is extremely difficult and costly to lay in rock or in excessively rocky ground; (2) underground lines do become defective, insulation deteriorates, wires corrode, rodents damage them, and they are broken by accident during subsequent excavation operations; (3) in case of line failure, it is disruptive and expensive to locate, excavate, and repair the lines, particularly in fully-developed and landscaped urban areas; (4) insulation materials are petroleum based and increased use of these materials only puts a greater demand on petroleum supplies; and (5) there is increasing evidence that underground installations have far shorter service life than that established for overhead lines (Edison Electric Institute, 1979).

# Piling

There are three classes of piling: (1) land and fresh water piling are usually round and embedded partly in soil or fresh water and serve as support for bridges, buildings, trestles, wharves, and similar structures; (2) foundation piling are entirely embedded in the ground, are capped with masonry, and usually serves as support for large buildings; and (3) marine piling are partly embedded in bottom soil, are partly exposed to sea water, and generally subject to attack by marine organisms.

Treated wood is used for all three types of piling. Untreated wood is suitable for some applications. A fairly durable tropical species, greenheart, has been used with some success for marine piling. In areas of severe marine borer activity, however, greenheart piling have provided less than 15 years' service. Durability is variable and questionable and, in any case, the supply is insufficient to satisfy the demand as a substitute for treated wood.

Untreated wood may be used for foundation piling where piling are driven completely into the ground to a depth where oxygen is absent. Untreated wood is not an alternative in critical applications where it is likely to be attacked by destructive organisms.

Recent statistics indicate that about 90% of the treated piling are treated with creosote solutions and the remaining 10% is about equally divided between penta and inorganic arsenicals. Dual treatment (arsenical preservatives followed by creosote) is recommended for use where *Limnoria tripunctata* borers are prevalent. Penta is unsuitable for marine use.

Wood piling are generally used for design loads up to 30 tons and in lengths up to 70 feet (Fuller, *et al.*, 1977). They are generally driven into the ground until the required bearing load is attained. Wood piling are often preferred because they are readily available, easy to drive, easily trimmed to required length, and usually cheaper than alternative materials.

The available substitutes for treated wood piling are concrete and steel.

## Concrete Piling

Concrete can serve as a substitute for treated wood piling in the three main use classes. Concrete piling may be precast and prestressed or cast in place. Since concrete can be cast in any form and size, it has the capability of supporting larger loads than are acceptable for wood piling. Precast piling are significantly heavier than those of wood, and thus may require special equipment for handling. Precast piling must be manufactured to accurate size since they are difficult to trim or slice at the construction site. They are not as easy to drive into compacted soil as wood because of their tendency to fracture. Because of the extra labor and other requirements in the handling of concrete piling they are generally more expensive than treated wood and requires special handling to avoid breakage or damage. There is a possibility of corrosion of the reinforcing rods in concrete piling used in a marine environment.

## Steel Piling

Steel can be used as a substitute for treated wood piling. Steel piling are generally used for supporting large loads. They withstand heavy driving better than wood or concrete. Steel piling are available in a variety of shapes including

H-beam, box piles, and sheet piling. The H-beam piling are used when it is necessary to penetrate very hard or rocky strata. They are used extensively in foundation-type applications. Some of the disadvantages of steel piling are: (1) they are often more expensive than comparable treated wood piling; (2) they tend to corrode in salt water or highly acid soil environments; (3) steel does not have friction bearing characteristics comparable to that of wood or concrete; and (4) more energy is required to produce steel piling than treated wood piling.

## Fence Posts

Fence posts are a relatively large-volume commodity and are extremely important to rural areas. Treated wood fence posts have been widely used for many years and are readily available, durable, low in cost, light in weight, and easy to use. In 1978, approximately 20 million cubic feet of fence posts were treated (Micklewright, 1979). About 55% were treated with penta, 23% with creosote solutions, and 22% with arsenicals.

Most treated posts are used in farm fences where they are preferred due to their durability and strength compared to alternative materials. Other applications such as residential, recreation area, and highway fencing are also important. In many applications, aesthetics is the primary consideration in choice of materials. Alternatives to treated wood fence posts are untreated wood, metal, and concrete.

Untreated wood of nondurable species is subject to rapid deterioration from insects and decay. Life expectancy is 1 to 5 years, depending on exposure. It is, therefore, not recommended for this use. Heartwood of cedars, cypress, redwood, locust, and other durable woods is used for fence posts, and should give 5 to 15 years of service. Due to the scarcity and high price of these "durable" woods, however, it is not reasonable to regard them as potential substitutes for the large volumes of treated wood used for this purpose.

Metal fence posts, particularly galvanized steel, are readily available and suitable for some applications. Aesthetics and the purpose or function of the fence are probably the most important determinants in the selection of metal versus wood for fence posts.

Concrete posts are not as readily available. They are heavier than either wood or steel, more difficult to work with, and considerably more expensive. They pose an additional problem in fastening the fence to the posts.

## Crossarms

Crossarms are usually made of wood treated with penta and are preferred due to their strength, durability, high electrical resistance, and ease of attaching conductors. Due to its uncertain durability and the high risk of failures, untreated wood is not suitable for this crucial application. Concrete is not a satisfactory substitute due to its weight, electrical conductivity, and the difficulty of attaching conductors. Metals are less acceptable due to their electrical conductivity, and plastics can be used but are very expensive.

## Lumber, Timbers, Plywood, and Other Treated Products

This group of commodities accounts for more than 30% of all treated wood produced. Use patterns of these materials are not as clearcut as for crossties, poles, piling, and fence posts. These commodities are used in a wide variety of applications, and the practicability of substituting untreated wood or non-wood materials varies with the specific end use.

The available substitutes for treated wood for various end uses are concrete, steel, aluminum, plastic, and untreated wood. Suitability of these alternatives for specific uses is evaluated in Table 80 and discussed below. Crossties, poles, piling, and posts are included in the table for completeness.

### Treated Wood Foundations

Treated wood foundations for houses and other light-frame buildings are treated with inorganic arsenicals. Untreated wood cannot be used for this critical structural application, nor can creosote- or penta-treated wood. The arsenical preservatives used in these structures are durable, nonleachable, nonvolatile, odorless, clean, and paintable. Treated wood foundations were developed as a substitute for masonry block or poured concrete foundations. They have many advantages and their use has grown from practically zero in 1970 to some 20,000 single-family residences in 1978 (about 1.8 million cubic feet of treated wood).

### Swimming Pool Areas

Swimming pool areas are frequently decked with wood, preferably treated with inorganic arsenicals. Wood decks are most often used around above-ground swimming pools and are, therefore, elevated above the ground. Untreated, durable wood can be used for this purpose but would be subject to the same limitations of availability, cost, and reduced durability listed for fence posts. For safety reasons, treated wood should be used for supports in contact with the ground.

### Farm Service Buildings

Farm service buildings such as barns, poultry houses, hog houses, and machine sheds are often framed with lumber or treated poles. In 1975, 600 million board feet of lumber, 300 million square feet of plywood, and 3.3 million poles were used in farm service building construction (Reid and Baumgartner, 1977). When poles (discussed previously) are used to support farm buildings, treated lumber is generally used for framing between poles at or near the ground (skirt boards) to which the siding is attached. Siding can be lumber or plywood, but is most often flat or corrugated sheet metal. When treated poles are used, there is no reason to seek substitute materials for the treated wood framing and siding materials that are used with them.

### Residential, Recreational and Commercial Buildings

Residential, recreational, and commercial buildings may be framed with treated poles in which case treated framing and/or siding materials may be used as in farm buildings. In conventional light-frame construction on concrete slab foundation, crawl space, or basement, wood sills and other structural members at or near the ground should be treated. Probably the greatest use of treated wood in this class of construction is in decks and patios. Generally, all structural wood members that are in ground contact or otherwise exposed to high insect or decay hazards should be treated. Untreated, durable wood is suitable for nonstructural, above-ground uses.

Table 80.--Suitability of alternatives to treated wood

| Product | Treated Wood | Alternative Materials | | | | | |
|---|---|---|---|---|---|---|---|
| | | Concrete | Metal | | Plastic | Untreated Wood | Other |
| | | | Steel | Aluminum | | | |
| Crossties | + | + | + | - | - | - | |
| Poles | | | | | | | |
| Transmission | +(up to 120 ft) | - | + | +(towers) | - | - | Underground cable |
| Distribution | + | + | + | - | - | - | Underground cable |
| Construction and other | + | + | + | + | + | - | |
| Piling | | | | | | | |
| Land and fresh water | + | + | + | - | - | - | |
| Foundation | + | + | + | - | - | +(deeply submerged) | |
| Marine | + | - | - | - | - | - | |
| Fence posts | + | + | + | - | - | +(durable species) | |
| Lumber, timbers, and plywood | | | | | | | |
| Foundations | + | + | - | - | - | - | |
| Swimming pools | + | + | - | - | + | - | |
| Residential construction | + | + | - | - | - | - | |
| Seawalls | + | + | +(mostly fresh water) | - | - | - | |
| Bridges | + | + | + | - | - | - | |
| Mine ties and timbers | + | + | + | - | - | - | |
| Crossarms | + | - | + | - | - | - | |
| Millwork | + | - | - | + | + | -(exterior exposure) | |
| Block flooring | + | - | - | - | - | - | |
| Cooling towers | + | - | - | - | - | - | |
| Greenhouses | + | + | + | + | - | - | |
| Landscape timbers | + | + | - | - | - | - | |
| Sound barriers | + | + | - | - | + | - | |
| Playground equipment | + | + | + | - | - | - | |
| Boxes and crates | +(non-food) | - | - | - | + | + | Corrugated paper |
| Boats | + | - | + | + | + | - | |

"+" indicates material is suitable for the use (no problem).

"-" indicates a characteristic that is unsatisfactory for the use.

Alternatives to treated wood where exposure to insects and decay are severe, are masonry, concrete, and steel.

## Seawalls, Wharves, Piers, Fender Systems, and Marinas

Seawalls, wharves, piers, fender systems, and marinas are often constructed of treated lumber and timbers. Untreated wood may be used for members that will be continuously submerged in fresh water, but treated material is required for all structures exposed above water line or to marine borers in salt water. Steel and concrete structures may require protection from corrosion when used in salt water. The Department of Defense reports that more than $6 million worth of dual-treated (arsenicals plus creosote) lumber and timbers were purchased by the Navy in fiscal years 1977-78 for use in waterfront structures in warm water harbors.

## Highway and Railroad Bridges, and Railroad Crossing Planks

Highway and railroad bridges, and railroad crossing planks, use large volumes of treated lumber and timbers. Crossing planks are almost always treated wood, but wood is no longer of major importance, except for maintenance and repairs, in highway and railroad bridge construction. Concrete and steel have replaced wood due to demand for longer spans carrying heavy loads. Concrete lends itself well to this use.

## Mine Ties and Timbers

Mine ties and timbers can be of treated wood, concrete or steel. Untreated wood is used in mine shafts that are to be used for less than 5 years, but treated material is required wherever the shaft is to be used for more than 5 years. Treated wood can easily be cut to fit the many different sizes and applications found in mines. Steel pins or bolts driven into the overhead rock have replaced some treated wood materials formerly used to prevent collapse of mine shafts.

## Millwork

Millwork is ordinarily treated with water-repellent pentachlorophenol in a mineral spirits-type solvent to provide dimensional stability and protection from discoloration and deterioration by fungi. Untreated wood is used in doors and window units that will not be exposed to moisture. Steel, aluminum, and plastics are used in place of wood millwork but, where wood is desired and is to be exposed to high moisture conditions, treatment is required.

## Industrial Block Flooring

Industrial block flooring made of creosote-treated wood is often used over concrete subfloors in industrial plants. The resilience of the wood floor protects the concrete from impacts of heavy equipment and materials, and provides quiet and comfort underfoot for workers. Creosote increases dimensional stability, protects the wood from deterioration, and reacts with the mastic to help bond the wood block to the concrete. Obviously, concrete is not an alternative to wood block over concrete. An elaborate, costly plastic flooring could probably be designed to provide the insulating and protective qualities of the wood block.

## Cooling Towers

Cooling towers to cool process water in many industrial applications use treated lumber and timbers for structural framing and for slats. Wood used under the high moisture conditions in cooling towers must be treated. Slats must be made of wettable material for proper operation of the cooling tower. Metals may suffer corrosion due to the chemicals which must be added to the cooling water. Plastics lack the necessary strength. Concrete can be, and is, used in place of treated wood in large and different style cooling towers such as used with nuclear power plants.

## Agricultural Uses, Including Greenhouses

Agricultural uses, including greenhouses, include products such as grape stakes, tomato stakes, mushroom trays, storage bins, greenhouses, and shade structures for nurseries. Where wood is used in these applications it must be treated to provide service for more than 1 to 2 years. Untreated, durable species could be used in some applications but are much more expensive and in short supply. Treated wood is preferred for durability, low cost, versatility, and ease of use by workers in these industries. Metal and concrete are used in place of treated wood for some of these applications--generally for larger, much more expensive, permanent structures by larger producers.

Plastics have replaced some treated wood for use in planting trays and seedling containers.

## Landscape and Garden Timbers

Landscape and garden timbers must be treated to provide more than 2 to 3 years of service under the severe conditions to which they are exposed in use. In many metropolitan areas, this use provides a ready market for used or reject railroad ties. Large volumes of wood are also treated specifically for this use. Untreated, durable species (i.e., cedars, redwood) are no doubt used in some areas but would be considerably more expensive and less durable than treated wood. Masonry products and concrete can be used in place of treated wood at higher cost. Aesthetics are an important consideration in selection of materials for landscaping and garden structures.

## Highway Sound Barriers

Highway sound barriers are becoming an important, large-volume use for treated wood. Many effective and aesthetically pleasing designs have been developed. Treatment provides long-lasting, permanent structures that resist damage by vandals and are relatively easy to repair. Untreated wood is not satisfactory due to its short life and high maintenance and replacement costs. Steel and concrete are also used for sound barriers and are satisfactory substitutes for treated wood so long as the barriers have adequate strength and sound-deadening qualities.

## Playground Equipment

Playground equipment is frequently constructed of treated wood which is required for durability and safety in use. Metals can be used in place of treated wood in many items of equipment. Concrete can be used for tables, benches, climbing structures, and similar applications.

### Boxes, Crates, and Shipping Containers

Boxes, crates, and shipping containers are produced in a wide variety of sizes and forms. Treated wood is used for durability, light weight, strength, toughness, and versatility.

Metals and plastic can be, and are, used in place of treated wood for these purposes.

### Boat Hulls and Decks

Boat hulls and decks are made of treated lumber and plywood. Steel, aluminum, and plastic (fiberglass) are used extensively as substitutes for treated wood in these products.

## Summary of Alternatives to Treated Wood Products

The main alternatives to preservatively treated wood are concrete, steel, aluminum, plastic, and untreated wood. All are presently used, to some extent, where treated wood might serve. Untreated wood has important limitations as an alternative since the treated wood is normally used in situations where the biological deterioration of untreated material would be rapid or costs of failure high. Some naturally durable woods exist but the supply is limited and performance uncertain.

Wood ties are the largest market for treated wood. About 95% are used as replacement ties and the balance in new track, with an average service life of 35 years. Concrete ties are widely used in some other countries and have had numerous evaluations in the United States. Successful foreign use which spans less than a full life cycle is based on axle loads much smaller than that common in the United States. U.S. tests before 1970 were failures. The design has been improved but problems still remain. Concrete ties were selected in 1977 for rebuilding 430 miles of track in the northeast; the cost analysis assumed rail replacement, biasing the result. Concrete ties cannot be interspersed as replacements in wood tie track; thus a change to concrete would require replacing virtually all 299,000 miles of U.S. track over a short span of years.

Steel ties have had very limited use and cause problems of insulation on electric circuits, interference with electrical signaling systems, and fastening. There are no data suggesting suitability for mainline service and little interest in steel crosstie use.

Poles are the third largest use for treated wood, mostly for utility service and lighting. Alternatives are concrete, steel, aluminum, plastic, and underground installation. Poles must have a long service life, a good fastening system, low cost, and good bending strength. Treated wood poles possess these characeristics and are both lightweight and good insulators. Concrete poles are weak in bending, heavy, more difficult for linemen to climb, and more expensive. Steel poles are widely used. Aluminum poles are relatively weak and have generally been limited to light duty applications. Reinforced plastic poles are used for lighting standards but are too flexible for utility service. Undergrounding of distribution lines is widespread but has many inherent problems. Untreated wood is not suitable due to short service life.

Necessary characteristics of a piling material depend upon the specific use, but include mechanical strength and long service life. Untreated wood is suited for foundation piling driven below groundwater level but is unsuited for other types of piling. Effective preservative treatments are available for all applications and alternatives available are concrete and steel. Concrete piling may be used in all applications. They can be designed to carry heavier loads than wood but have some installation problems and are generally more expensive. Steel piling are used extensively in foundation applications but may be more expensive, corrode in some environments, and have poor friction-bearing properties compared to wood and concrete.

Treated wood fence posts are widely used with untreated wood, concrete and steel as alternatives. Untreated wood gives an inadequate service life. Steel fence posts are widely used while concrete posts are not, due to cost and installation problems.

Crossarms of treated wood give good service and none of the alternative materials is really satisfactory, for a variety of reasons.

Treated lumber and plywood are used in a wide variety of applications but limited information is available on specific uses or requirements. Concrete, steel, aluminum, plastic and untreated wood may be substituted for some uses.

Treated wood is often used in and around buildings. Wood foundation installations have increased rapidly since introduced about 1970, because of many advantages over concrete. Areas around swimming pools and other outdoor living spaces are often decked with treated wood. These areas could be paved with concrete, but only at ground level. Farm buildings are often built of treated wood but could generally be built of other readily available materials.

Marine construction frequently involves treated wood in addition to piling. Untreated wood is suited when continuously submerged, in fresh water only. Steel and concrete may be substituted if protected from corrosion. Concrete and steel have replaced treated wood in most bridge construction but treated wood is generally used as railroad crossing planks. Concrete could be substituted. Treated wood mine ties and timbers are easily installed and untreated wood is used for short use shafts. Concrete on steel could generally be used but installation would be considerably more difficult and expensive.

Wooden millwork is normally protected by treatment. Other materials could generally be substituted but metals result in major increases in home heat loss. Wood block flooring has unique properties not provided by any alternative. Industrial cooling towers are made of treated wood. They could be made of concrete as are some larger towers, but at serious cost and design penalties. Plastics are too weak for most applications and metals unsuited because of corrosion.

Treated wood is used for a variety of agricultural purposes. Steel, concrete or plastic may be substituted for many, at higher costs. Wooden landscape timbers may be replaced by concrete. Both steel and concrete may be used in place of treated wood for highway sound barriers, for most playground facilities, and containers. Steel, aluminum, and reinforced plastic are used in boat construction, as is treated wood.

All alternatives to treated wood require more energy to manufacture than the treated materials they replace.

# CHAPTER 8: ECONOMIC IMPACT ANALYSIS OF THE LOSS OF WOOD PRESERVATIVES AND TREATED WOOD PRODUCTS

# CHAPTER 8: ECONOMIC IMPACT ANALYSIS OF THE LOSS OF WOOD PRESERVATIVES AND TREATED WOOD PRODUCTS

## Purpose and Scope

Regulations issued pursuant to the Federal Insecticide, Fungicide, and Rodenticide Act provide that an evaluation of the economic, social, and environmental benefits of RPAR'd pesticides may be submitted, and that the Administrator of EPA will weigh the benefits against the risks in determining appropriate regulatory action.

The purpose of this Chapter is to provide up-to-date analyses of benefits from use of creosote, penta, and inorganic arsenicals for the preservative treatment of wood products. To assess benefits, we will look at current production and use of products treated with each of the preservative chemicals, and will consider:

(a) Changes in costs and performance of treated products or structures that would result from a shift to an alternative preservative, to untreated wood, or to non-wood materials.

(b) Supply problems, capital requirements, and economic or social impacts that would result from a shift to an alternative preservative, to untreated wood, or to non-wood materials.

(c) The effects of these changes on producers and processors of wood raw materials, producers of treated wood, and users of treated wood products.

Only the impacts of canceling one or more of the preservative chemicals for use on one or more products (sites) are considered in this assessment. Analyses of regulatory options short of cancellation are not included.

Assessments of the impacts of canceling a preservative for a major use, and shifting to an alternative preservative or to a non-wood substitute, are based on the assumption that sufficient alternative chemicals or materials would be available at current prices. In reality, any major shift to an alternative chemical (e.g., from creosote- to penta-treated crossties) or substitute material (e.g., from treated wood ties to concrete crossties) could result in shortages of materials, a need for substantial capital investment to increase production of alternatives, production delays, and significant shifts in material prices, all of which could have impacts not only on producers and users of treated wood, but throughout the U.S. economy wherever alternative materials might be involved.

Cancellation of one or more preservatives and a resultant shift to non-wood materials for crossties, utility poles, piling, fence posts, or other treated wood products could have other indirect impacts on the economy such as:

(1) A substantial increase in the amount of energy required to mine, process, and manufacture substitute materials, all of which are more energy-intensive than treated wood (Josephson, 1977 and 1979).

(2) Increased air and water pollution and degradation of the landscape (or increased costs of environmental pollution control) associated with production of substitute materials (Josephson, 1977 and 1979).

(3) Increased dependence on imports of non-wood raw materials and energy, with attendant effects on the United States' balance of payments.

(4) Increased costs of goods and services to consumers resulting from use of high-cost substitutes for treated wood--e.g., an increase in electric rates due to increased costs to utility companies from use of concrete or steel poles.

These and other indirect impacts could be significant, and could add substantially to the direct impacts of cancellation and substitution described in this report.

## Pressure Treatments

This section of the report covers the production and use of wood treated by establishments classified in the wood-preserving industry in accordance with the Office of Management and Budget Standard Industrial Classification system. Also included are commercial treating plants owned and operated by other industries (e.g., lumber companies, building material distributors, etc.) in which wood preservation is a secondary activity. The majority of these establishments treat wood products by pressure methods in pressurized retorts. There are, however, a number of plants that treat by thermal or vacuum processes as described in Chapter 2. These are classified in the wood preserving industry and are included here even though they are commonly referred to in industry reports as non-pressure treaters. Their methods and products are distinctly different from soak, dip, spray, or brush applications discussed later in this report under "Non-Pressure Treatments."

### The Wood-Treating Industry

In 1978, we estimate that some 631 wood-preserving plants treated more than 327 million cu. ft. of wood products (Chapter 1, Data Base-Production of Treated Wood Products). These 631 plants include establishments whose primary activity is wood preservation and whose primary product is treated wood, as well as treating plants owned and operated by other industries (e.g., lumber companies, cooling tower manufacturers, building material distributors, etc.) in which wood preservation is a secondary activity. The 1977 Census of Manufactures (U.S. Dept. Comm., 1979) reports 458 establishments classified in the wood preserving industry. Although this number has undoubtedly grown since 1977, it is apparent that a substantial volume of wood is treated in plants operated by firms which the Census classifies in other industries.

The 631 treating plants on which our evaluation of the industry is based were identified through the cooperation of AWPA and various suppliers of treating chemicals and equipment as described in Chapter 1. There are, no doubt, some treating plants that we have not identified. Others that were in production in 1977 may no longer be in business. Although our list of 631 treaters may not be complete or entirely accurate, it is the best available listing of wood-treating establishments that we know of at this time.

The distribution of wood-preserving plants by region and type of treating facilities is shown in Table 81. Of the 601 treating establishments for which we have information, 522 are pressure treaters and 79 are non-pressure plants. Twenty-seven of the pressure treaters also have non-pressure treating facilities. About one-half of the pressure treating facilities (272) are single-cylinder plants, 140 plants have 2 cylinders, and the largest plant has 7 cylinders.

Table 81.--Wood preserving plants in the United States by region and type, 1978

| Region | Pressure | Non-pressure | Pressure and Non-pressure | Type Unknown | Total |
|---|---|---|---|---|---|
| Northeast | 58 | 5 | 1 | 3 | 67 |
| North Central | 71 | 38 | 3 | 5 | 117 |
| Southeast | 140 | 4 | 6 | 3 | 153 |
| South Central | 164 | 5 | 9 | 16 | 194 |
| Rocky Mountain | 19 | 14 | 3 | -- | 36 |
| Pacific | 43 | 13 | 5 | 3 | 64 |
| United States | 495 | 79 | 27 | 30 | 631 |

Most treating plants (423) use only one type of preservative: 221 treat only with waterborne salts, almost all of which are arsenicals; 135 treat only with penta; and 67 treat only with creosote solutions. The other 178 plants use various combinations of 2 or more preservatives. Considering all plants and all combinations:

325 plants treat with waterborne salts
295 plants treat with penta
188 plants treat with creosote solutions

The South and Southeast lead the Nation in number of treating plants (347) and production of treated wood (57% of total). Alabama heads the list with 49 treating plants, followed by Georgia (47), Texas (45), Florida (36), and Louisiana (32). The percentages of wood treated and the leading States in other regions are:

Northeast, 8% of volume treated--Pennsylvania, 22 plants
North Central, 17% of volume treated--Missouri, 43 plants
Rocky Mountain, 5% of volume treated--Idaho and Montana, 12 and 10 plants, respectively
Pacific, 14% of volume treated--Washington, 28 plants

## Trends in Production of Treated Wood

Annual production of all treated wood products (except fire retardants), 1970-1978, is shown in Table 82. Production of products treated with creosote solutions, penta, and inorganic arsenicals is shown in Tables 83, 84, and 85, respectively. Figure 15 shows the trend in total production of treated wood during the 8-year period. The solid line on the chart depicts the trend as indicated by the annual industry surveys. For reasons discussed in Chapter 1 (Data Base), we believe the trend is much more accurately represented by the broken line on the chart. This is substantiated by the fact that the number of treating plants increased by about 50% during the period.

Table 82.--Products treated--all preservatives,[a] 1970-1978[b]

| | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|
| | 1,000 cu. ft. | | | | | | | | |
| Crossties | 79,384 | 87,029 | 85,880 | 67,603 | 75,870 | 93,097 | 95,320 | 93,518 | 106,085 |
| Switch ties | 7,874 | 6,208 | 5,971 | 5,006 | 6,501 | 7,959 | 5,728 | 6,708 | |
| Poles | 76,760 | 74,374 | 74,537 | 75,379 | 73,112 | 49,144 | 53,143 | 52,531 | 64,179 |
| Crossarms | 3,454 | 3,075 | 2,487 | 2,592 | 2,416 | 1,424 | 4,628 | 1,347 | 1,692 |
| Piling | 15,128 | 13,699 | 14,324 | 12,978 | 13,315 | 9,403 | 8,478 | 11,346 | 12,114 |
| Lumber, timbers | 52,105 | 56,303 | 59,700 | 64,762 | 73,692 | 58,135 | 63,626 | 60,396 | 107,579 |
| Plywood[c] | (1,344) | (1,578) | (1,923) | (2,079) | (1,766) | (1,859) | (2,848) | (2,406) | (2,845) |
| Fence posts | 15,106 | 16,669 | 18,175 | 15,168 | 17,304 | 15,311 | 13,769 | 10,735 | 20,105 |
| Other | 5,913 | 6,392 | 5,667 | 5,243 | 6,833 | 5,995 | 11,231 | 14,770 | 18,266 |
| Total | 255,724 | 263,749 | 266,741 | 248,731 | 269,043 | 240,468 | 255,923 | 251,351 | 330,020 |

[a] Material treated with fire retardants not included. CZC and ACC included.

[b] Source: 1970-77--Maloney and Pagliai, 1978; and 1978--Micklewright, 1979.

[c] Plywood volume included in "Other." Volumes shown include fire-retardant treatments.

Note: Columns may not add to totals due to rounding.

Table 83.--Products treated with creosote solutions,[a] 1970-1978[b]

| | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|
| | 1,000 cu. ft. | | | | | | | | |
| Crossties | 78,970 | 86,813 | 85,680 | 67,433 | 75,520 | 92,658 | 95,165 | 91,281 | 103,138 |
| Switch ties | 7,812 | 6,144 | 5,917 | 4,999 | 6,453 | 7,926 | 5,718 | 6,161 | |
| Poles | 37,687 | 32,593 | 27,560 | 26,334 | 29,071 | 14,847 | 14,571 | 15,634 | 18,237 |
| Crossarms | 462 | 351 | 373 | 352 | 437 | 93 | 78 | 41 | 41 |
| Piling | 14,363 | 12,809 | 13,562 | 12,376 | 12,768 | 8,529 | 7,473 | 9,495 | 9,993 |
| Lumber, timbers | 15,190 | 14,256 | 12,972 | 11,863 | 12,680 | 13,044 | 9,672 | 9,083 | 10,780 |
| Fence posts | 7,770 | 7,774 | 7,343 | 5,294 | 5,570 | 3,228 | 2,826 | 2,526 | 4,584 |
| Other | 2,612 | 2,417 | 2,144 | 1,940 | 2,445 | 3,078 | 3,501 | 7,782 | 7,815 |
| Total | 164,866 | 163,157 | 155,551 | 130,591 | 144,944 | 143,403 | 139,004 | 142,003 | 154,587 |

[a] Creosote, Creosote-Coal Tar, Creosote-Petroleum, and Creosote-Penta.

[b] Source: 1970-77--Maloney and Pagliai, 1978; and 1978--Micklewright, 1979.

Note: Columns may not add to totals due to rounding.

Table 84.--Products treated with penta,[a] 1970-1978[b]

| | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|
| | 1,000 cu. ft. | | | | | | | | |
| Crossties | 296 | 75 | 79 | 53 | 321 | 334 | 19 | 43 | 449 |
| Switch ties | 51 | 52 | 50 | 7 | -- | 24 | -- | 376 | |
| Poles | 37,259 | 40,162 | 45,230 | 47,193 | 42,031 | 32,155 | 36,525 | 33,193 | 41,905 |
| Crossarms | 2,968 | 2,688 | 2,093 | 2,234 | 1,947 | 1,301 | 4,541 | 1,299 | 1,615 |
| Piling | 674 | 710 | 239 | 288 | 135 | 384 | 368 | 1,042 | 1,154 |
| Lumber, timbers | 15,397 | 15,198 | 16,394 | 19,663 | 19,302 | 15,837 | 13,873 | 9,931 | 21,209 |
| Fence posts | 6,858 | 8,232 | 9,924 | 9,055 | 9,580 | 9,953 | 9,096 | 6,791 | 10,983 |
| Other | 2,183 | 2,380 | 1,786 | 1,528 | 2,450 | 783 | 1,208 | 2,117 | 2,681 |
| Total | 65,686 | 69,498 | 75,795 | 80,022 | 75,766 | 60,771 | 65,630 | 54,789 | 79,996 |

[a] Petroleum-penta only, creosote-penta included in Table 83.

[b] Source: 1970-77--Maloney and Pagliai, 1978; and 1978--Micklewright, 1979.

Note: Columns may not add to totals due to rounding.

Table 85.--Products treated with inorganic arsenicals,[a] 1970-1978[b]

| | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1,000 cu. ft. | | | | |
| Crossties | 116 | 141 | 121 | 116 | 29 | 86 | 133 | 2,195 | 2,498 |
| Switch ties | 11 | 12 | 4 | -- | -- | 9 | -- | 171 | |
| Poles | 1,813 | 1,619 | 1,747 | 1,854 | 1,833 | 1,277 | 1,423 | 3,704 | 4,038 |
| Crossarms | 24 | 36 | 21 | 6 | 29 | 30 | 8 | -- | 29 |
| Piling | 90 | 179 | 522 | 314 | 412 | 484 | 564 | 785 | 943 |
| Lumber, timbers | 19,635 | 24,161 | 27,503 | 30,146 | 38,704 | 27,331 | 37,354 | 39,108 | 73,317 |
| Fence posts | 479 | 660 | 904 | 786 | 2,120 | 2,023 | 1,837 | 1,341 | 4,461 |
| Other | 1,118 | 1,590 | 1,737 | 1,773 | 1,934 | 2,122 | 6,522 | 4,718 | 7,616 |
| Total | 23,286 | 28,398 | 32,559 | 34,995 | 45,061 | 33,362 | 47,841 | 52,022 | 92,903 |

[a] CCA, ACA, FCAP.

[b] Source: 1970-77--Maloney and Pagliai, 1978; and 1978--Micklewright, 1979.

Note: Columns may not add to totals due to rounding.

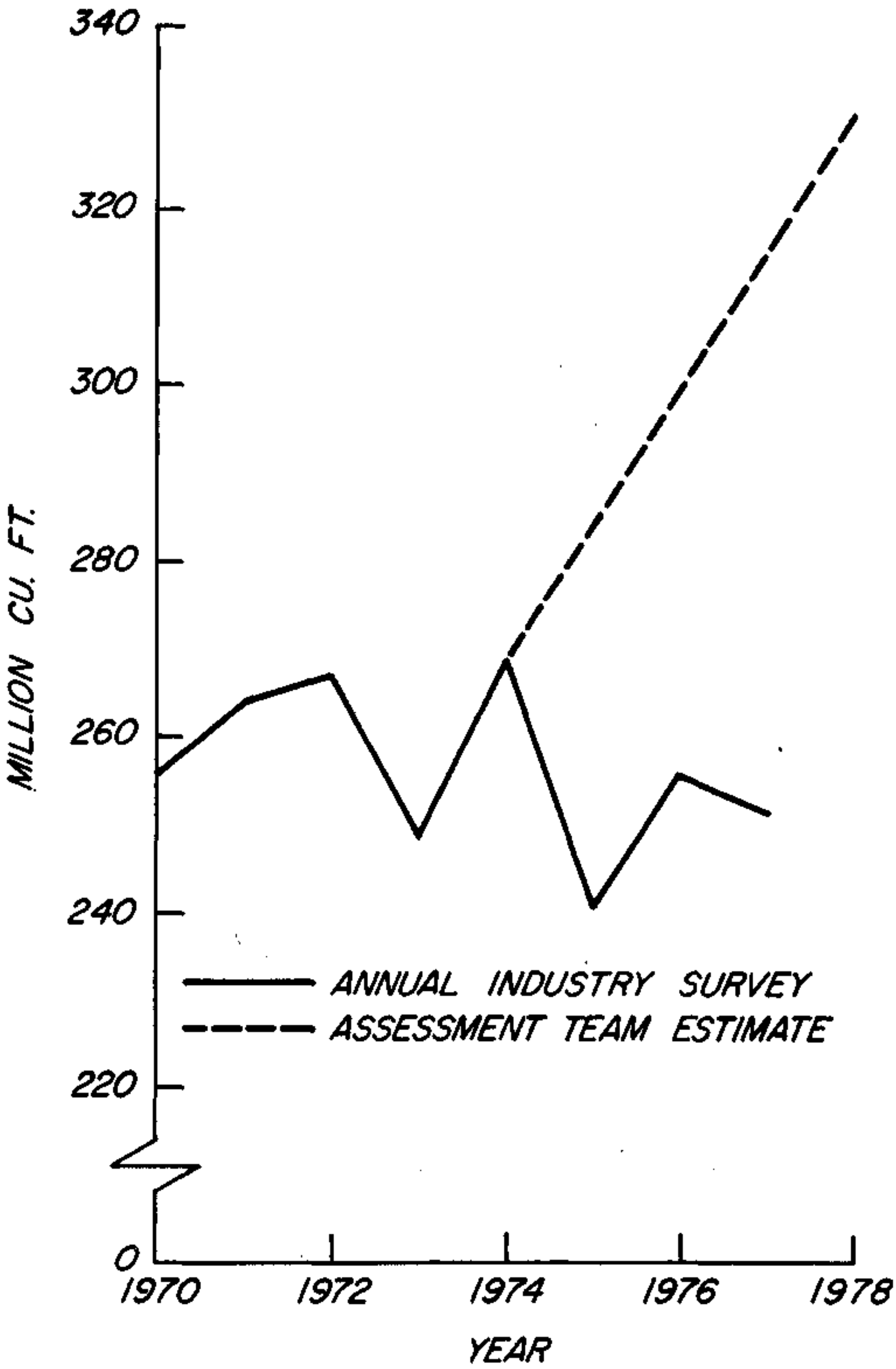

Figure 15. Production of treated wood for all preservatives, 1970-1978.

Figure 16 shows similar trends for all products treated with creosote solutions, penta, and arsenical salts.

Between 1970 and 1978, volume treated with creosote solutions declined slightly at an average annual rate of 0.8%. This was accompanied by a 2.5% average annual increase in volume treated with penta and a 18.9% average annual increase in production of arsenically treated wood. These trends combined to produce a 3.2% average increase in the total volume of wood treated annually.

Table 86 shows trends in use of the three major preservatives to treat the various wood products. For example, the volume of ties treated increased from 87.3 million cu. ft. in 1970 to 106 million cu. ft. in 1978, and creosote retained the bulk of this use. Practically all railroad ties are treated with creosote. The 2.4% of ties treated with arsenicals in 1978 were landscape ties. Creosote continues to be the dominant preservative for piling, but has lost some of this use to both penta and arsenicals.

The most dramatic change has occurred in treated lumber and timbers. Volume treated in 1978 was more than double the volume treated in 1970. The percentages of these products treated with creosote and penta both declined, while the percentage treated with arsenicals increased from 39 to 70. There has also been a substantial increase in production of treated fence posts, with creosote losing out to both penta and arsenicals for this use.

In terms of total treated wood, the percentage treated with creosote has declined from 65% in 1970 to 47% in 1978. Penta's share of the market remained fairly constant, while the percentage treated with arsenicals tripled from 9 to 28.

## Employment, Wages, Value Added, and Value of Shipments in the Wood-Preserving Industry

The quinquennial Census of Manufactures reports information such as the number of employees, payroll, hours worked, cost of materials consumed, value added by manufacture, and value of products shipped for all manufacturing establishments classified in the wood preserving industry. These statistics do not include treating plants operated as secondary activities by firms in other industries; however, census data provide indicators and factors that can be used to develop this information for all wood preserving establishments. Selected information about the wood-preserving industry, from recent censuses, is shown in Table 87. The table also includes estimates for 1978 based on data from the Assessment Team Survey (Micklewright, 1979) and factors developed from census data. These factors are shown in Tables 88 and 89.

Census data show that there has been relatively little change in the number of large treating plants (establishments with 20 employees or more) over the past 10 years. Furthermore, these large plants are primarily engaged in wood preserving and are, therefore, likely to be included in census statistics. We, therefore, assumed that the number of large treating plants is accurately reported by the Census, and that the difference between the 631 treating plants recorded by the Assessment Team Survey for 1978 and the 458 plants reported by Census for 1977 is in relatively small firms with fewer than 20 employees. Then, using the census average of 6 employees per establishment with less than 20 employees, and 55 employees per establishment with 20 employees or more, we estimate total employment in 631 wood-preserving plants in 1978 to be 13,333, of which 10,400 (78%) are production workers.

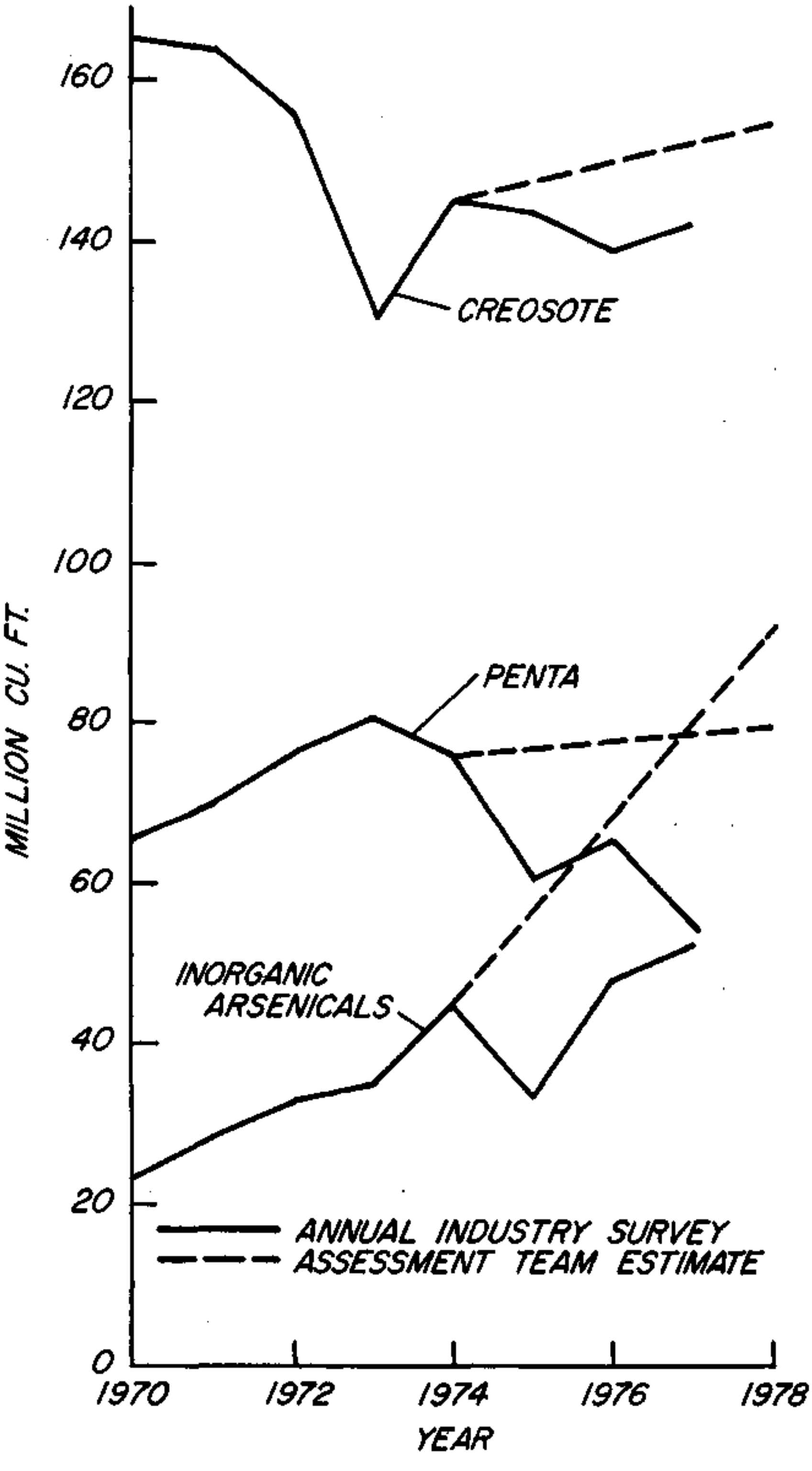

Figure 16. Production of treated wood by preservatives, 1970-1978.

Table 86.--Products treated and preservatives used 1970-1978[a]

| Product | Year | Volume Treated | Preservative Used | | |
|---|---|---|---|---|---|
| | | | Creosote Solutions | Penta | Inorganic Arsenicals |
| | | 1,000 cu. ft. | - - - - - - - - - Percent - - - - - - - | | |
| Ties (crossties switch ties and landscape ties) | 1970 | 87,256 | 99.5 | 0.4 | 0.1 |
| | 1971 | 93,237 | 99.7 | 0.1 | 0.2 |
| | 1972 | 91,851 | 99.7 | 0.1 | 0.1 |
| | 1973 | 72,608 | 99.8 | 0.1 | 0.2 |
| | 1974 | 82,323 | 99.6 | 0.4 | -- |
| | 1975 | 101,037 | 99.6 | 0.4 | 0.1 |
| | 1976 | 101,035 | 99.8 | -- | 0.1 |
| | 1977 | 100,225 | 97.2 | 0.4 | 2.4 |
| | 1978 | 106,085 | 97.2 | 0.4 | 2.4 |
| Poles | 1970 | 76,759 | 49.1 | 48.5 | 2.4 |
| | 1971 | 74,374 | 43.8 | 54.0 | 2.2 |
| | 1972 | 74,537 | 37.0 | 60.7 | 2.3 |
| | 1973 | 75,381 | 34.9 | 62.6 | 2.5 |
| | 1974 | 72,935 | 39.9 | 57.6 | 2.5 |
| | 1975 | 48,279 | 30.8 | 66.6 | 2.6 |
| | 1976 | 52,519 | 27.7 | 69.5 | 2.7 |
| | 1977 | 52,531 | 29.8 | 63.2 | 7.1 |
| | 1978 | 64,179 | 28.4 | 65.3 | 6.3 |
| Crossarms | 1970 | 3,454 | 13.4 | 85.9 | 0.7 |
| | 1971 | 3,075 | 11.4 | 87.4 | 1.2 |
| | 1972 | 2,487 | 15.0 | 84.2 | 0.8 |
| | 1973 | 2,592 | 13.6 | 86.2 | 0.2 |
| | 1974 | 2,413 | 18.1 | 80.7 | 1.2 |
| | 1975 | 1,424 | 6.5 | 91.4 | 2.1 |
| | 1976 | 4,627 | 1.7 | 98.1 | 0.2 |
| | 1977 | 1,340 | 3.1 | 96.9 | -- |
| | 1978 | 1,685 | 2.4 | 95.8 | 1.7 |
| Piling | 1970 | 15,127 | 94.9 | 4.5 | 0.6 |
| | 1971 | 13,698 | 93.5 | 5.2 | 1.3 |
| | 1972 | 14,323 | 94.7 | 1.7 | 3.6 |
| | 1973 | 12,978 | 95.4 | 2.2 | 2.4 |
| | 1974 | 13,315 | 95.9 | 1.0 | 3.1 |
| | 1975 | 9,397 | 90.8 | 4.1 | 5.2 |
| | 1976 | 8,405 | 88.9 | 4.4 | 6.7 |
| | 1977 | 11,322 | 83.9 | 9.2 | 6.9 |
| | 1978 | 12,090 | 82.7 | 9.5 | 7.8 |

Table 86.--Products treated and preservatives used 1970-1978[a]--continued

| Product | Year | Volume Treated | Preservative Used | | |
|---|---|---|---|---|---|
| | | | Creosote Solutions | Penta | Inorganic Arsenicals |
| | | 1,000 cu. ft. | Percent | | |
| Lumber & timbers | 1970 | 50,272 | 30.2 | 30.6 | 39.1 |
| | 1971 | 53,615 | 26.6 | 28.3 | 45.1 |
| | 1972 | 56,869 | 22.8 | 28.8 | 48.4 |
| | 1973 | 61,672 | 19.2 | 31.9 | 48.9 |
| | 1974 | 70,686 | 17.9 | 27.3 | 54.8 |
| | 1975 | 56,212 | 23.2 | 28.2 | 48.6 |
| | 1976 | 60,899 | 15.9 | 22.8 | 61.3 |
| | 1977 | 58,122 | 15.6 | 17.1 | 67.3 |
| | 1978 | 105,305 | 10.2 | 20.1 | 69.6 |
| Fence posts | 1970 | 15,107 | 51.4 | 45.4 | 3.2 |
| | 1971 | 16,666 | 46.6 | 49.4 | 4.0 |
| | 1972 | 18,171 | 40.4 | 54.6 | 5.0 |
| | 1973 | 15,135 | 35.0 | 59.8 | 5.2 |
| | 1974 | 17,270 | 32.3 | 55.5 | 12.3 |
| | 1975 | 15,204 | 21.2 | 65.5 | 13.3 |
| | 1976 | 13,759 | 20.5 | 66.1 | 13.4 |
| | 1977 | 10,658 | 23.7 | 63.7 | 12.6 |
| | 1978 | 20,028 | 22.9 | 54.8 | 22.3 |
| Other products | 1970 | 5,913 | 44.2 | 36.9 | 18.9 |
| | 1971 | 6,387 | 37.8 | 37.3 | 24.9 |
| | 1972 | 5,667 | 37.8 | 31.5 | 30.7 |
| | 1973 | 5,241 | 37.0 | 29.2 | 33.8 |
| | 1974 | 6,829 | 35.8 | 35.9 | 28.3 |
| | 1975 | 5,983 | 51.4 | 13.1 | 35.5 |
| | 1976 | 11,231 | 31.2 | 10.8 | 58.1 |
| | 1977 | 14,617 | 53.2 | 14.5 | 32.3 |
| | 1978 | 18,113 | 43.1 | 14.8 | 42.1 |
| All products | 1970 | 253,838 | 64.9 | 25.9 | 9.2 |
| | 1971 | 261,053 | 62.5 | 26.6 | 10.9 |
| | 1972 | 263,905 | 58.9 | 28.7 | 12.3 |
| | 1973 | 245,608 | 53.2 | 32.6 | 14.2 |
| | 1974 | 265,771 | 54.5 | 28.5 | 17.0 |
| | 1975 | 237,536 | 60.4 | 25.6 | 14.0 |
| | 1976 | 252,475 | 55.1 | 26.0 | 18.9 |
| | 1977 | 248,814 | 57.1 | 22.0 | 20.9 |
| | 1978 | 327,485 | 47.2 | 24.4 | 28.4 |

[a] Materials treated with creosote solutions, penta, and inorganic arsenicals only. ACC and CZC not included.

Source: 1970-77--Maloney and Pagliai, 1978; and 1978--Micklewright, 1979.

Table 87.--General statistics for the wood-preserving industry, 1958-1978[a]

| | 1958 | 1963 | 1967 | 1972 | 1977 | 1978 |
|---|---|---|---|---|---|---|
| Establishments | | | | | | |
| Total | 306 | 338 | 375 | 399 | 458 | 631 |
| With 20 employees or more | 148 | 157 | 177 | 168 | 193 | 193 |
| All Employees | | | | | | |
| Total (1,000) | 10.9 | 11.2 | 12.2 | 11.3 | 12.3 | 13.3 |
| In establishments with 20 employees or more (1,000) | 9.8 | 9.9 | 11.0 | 9.9 | 10.7 | 10.7 |
| Total payroll (million dollars) | 36.6 | 45.3 | 61.9 | 74.5 | 122.6 | 140.0 |
| Payroll per employee (dollars) | 3,358 | 4,045 | 5,074 | 6,593 | 9,697 | 10,500 |
| Production workers | | | | | | |
| Number (1,000) | 9.2 | 9.5 | 10.3 | 9.2 | 9.6 | 10.4 |
| Hours worked (million) | 17.9 | 19.4 | 21.7 | 18.8 | 18.7 | 20.3 |
| Wages paid (million dollars) | 28.1 | 34.7 | 47.1 | 54.4 | 80.5 | 94.8 |
| Hours per employee (number) | 1,946 | 2,042 | 2,107 | 2,043 | 1,948 | 1,952 |
| Wages per employee (dollars) | 3,054 | 3,653 | 4,573 | 5,913 | 8,385 | 9,115 |
| Wages per hour (dollars) | 1.57 | 1.79 | 2.17 | 2.89 | 4.30 | 4.67 |
| Value added by manufacture (million dollars) | 72.5 | 93.3 | 135.6 | 175.8 | 322.3 | 387.8 |
| Cost of Materials, etc. purchased (million dollars) | 127.9 | 155.4 | 214.5 | 303.6 | 650.5 | 796.1 |
| Value of shipments all products (million dollars) | 203.0 | 247.3 | 344.2 | 475.8 | 950.2 | 1,163.9 |
| Value of primary product shipments (million dollars) | 193.1 | 232.7 | 321.5 | 443.8 | 886.5 | 1,085.9 |
| Value added per employee (dollars) | 6,651 | 8,330 | 11,115 | 15,558 | 26,203 | 29,085 |
| Value of primary shipments per employee (dollars) | 17,716 | 20,777 | 26,352 | 39,274 | 72,073 | 81,442 |
| Cost of materials per dollar of shipments (dollars) | 0.63 | 0.63 | 0.62 | 0.64 | 0.68 | 0.68 |

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[a] Data for 1958-1977 from Censuses of Manufactures 1958, 1963, 1967, 1972, and 1977. (U.S. Dept. Comm., 1966; 1970; 1975; and 1979.) Estimates for 1978 based on Census data and Assessment Team Survey data (Micklewright, 1979).

Table 88.--Selected operating ratios in the wood-preserving industry, 1958-1978[a]

| | 1958 | 1963 | 1967 | 1972 | 1977 | 1978 |
|---|---|---|---|---|---|---|
| Percent of total establishments with | | | | | | |
| less than 20 employees | 51.6 | 53.6 | 52.8 | 57.9 | 57.9 | 69.4 |
| 20 employees or more | 48.4 | 46.4 | 47.2 | 42.1 | 42.1 | 30.6 |
| Percent of total employees in | | | | | | |
| establishments with less than 20 employees | 10.1 | 11.6 | 9.8 | 12.4 | 13.0 | 19.8 |
| establishments with 20 employees or more | 89.9 | 88.4 | 90.2 | 87.6 | 87.0 | 80.2 |
| Average number of employees per | | | | | | |
| establishment with less than 20 employees | 7.0 | 7.0 | 6.6 | 6.1 | 6.0 | 6.0 |
| establishment with 20 employees or more | 66.2 | 63.1 | 62.1 | 58.9 | 55.4 | 55.4 |
| Production workers as percent of total employees | 84.4 | 84.8 | 84.4 | 81.4 | 78.0 | 78.0 |
| Value of primary product shipments as percent of total value of shipments | 95.1 | 94.1 | 93.4 | 93.3 | 93.3 | 93.3 |

[a] Data for 1958-1977 from Censuses of Manufactures 1958, 1963, 1967, 1972, and 1977 (U.S. Dept. Comm. 1966; 1970; 1975; and 1979). Estimates for 1978 based on census data for prior years.

Using these employment estimates and the percentages underlined in Table 89, we computed for 1978:

| | |
|---|---|
| Value added per employee | $29,085 |
| Value of primary product shipments per employee | $81,442 |
| Payroll per employee | $10,500 |
| Wages per hour for production workers | $ 4.67 |

Using these relationships, we calculated the other values in Table 87, for 1978. Thus, we estimate that 631 treating plants employed 13,300 people and had a payroll of $140 million in 1978. These plants spent $796 million for materials, fuels, etc.; added $388 million in value; and shipped 328 million cu. ft. of treated wood products with a value of $1,086 million ($3.32 per cu. ft., f.o.b. plant).

## Importance of Wood Preservation to Producers and Processors of Forest Products

For every dollar's worth of treated wood it produces, the wood preserving industry spends 68 cents for materials, parts, supplies, fuels, and electrical energy (Table 87). Census data show that 90% of these expenditures are for materials, parts, and supplies (excluding fuels and electrical energy); and that more than 71% of materials purchased are wood products. Thus, we estimate that the industry spent $716 million for materials, parts, and supplies in 1978--$510 million for wood products and $206 million for preservative chemicals and other materials.

Based on Census data, expenditures for wood raw materials can be further divided into those for 1) poles, piling, and other round wood products, and 2) hardwood and softwood lumber and other sawn products. We estimate that, in 1978, the industry spent $176 million for round wood products, $153 million for hardwood sawn products (mostly crossties and switch ties), and $178 million for softwood sawn products.

Table 89.--Average annual rates of increase in selected operating factors in the wood-preserving industry, 1958-1978[a]

| Period | Value Added by Manufacture | Value of Total Shipments | Value of Primary Product Shipments | Value Added per Employee | Value of Primary Products per Employee | Payroll per Employee | Wages per Production Worker | Wages per Hour, Production Workers |
|---|---|---|---|---|---|---|---|---|
| | Percent | | | | | | | |
| 1958-63 | 5.2 | 4.0 | 3.8 | 4.6 | 3.2 | 3.8 | 3.7 | 2.7 |
| 1963-67 | 7.8 | 6.8 | 6.7 | 5.9 | 4.9 | 4.7 | 4.6 | 3.9 |
| 1967-72 | 5.3 | 6.7 | 6.7 | 7.0 | 8.3 | 5.4 | 5.3 | 5.9 |
| 1972-77 | 12.9 | 14.8 | 14.8 | 11.0 | 12.9 | 8.1 | 7.2 | 8.3 |
| 1977-78 | 20.3 | 22.5 | 22.5 | 11.0 | 13.0 | 8.3 | 8.7 | 8.5 |

[a] Data for 1958-77 from Censuses of Manufactures 1958, 1963, 1967, 1972, and 1977 (U.S. Dept. Comm. 1966; 1970; 1975; and 1979). Estimates for 1978 based on census data for prior years. Key factors used to compute other 1978 production data are underlined.

On a volume basis, 96 million cu. ft. (about 29%) of the wood treated in 1978 was in round products (poles, piling, fence posts), and 231 million cu. ft. (71%) was lumber, timbers, ties, crossarms, and other sawn wood (Table 86). Round products are produced with little waste. Production of sawn wood, however, involves waste or residues in the woods and at the sawmill. Yield of sawn products averages 50% to 60% of the volume of roundwood delivered to the sawmill. At 55% yield, the 231 million cu. ft. of treated sawn products represents 420 million cu. ft. of roundwood. Most sawmill residues are used for pulp and particleboard production, or fuel. Nevertheless, it is clear that production of treated wood provided markets for more than 500 million cu. ft. of stumpage in 1978.

Many treated products such as fence posts, crossties, mine timbers, and landscape timbers come from small, relatively low quality trees and logs for which markets are limited. Crossties, for example, are commonly produced from small, low-quality hardwood logs, or the low-quality portions of larger logs (Church, 1966; Ellefson, 1966; and Garrett, 1969). This material is not suitable for higher value uses such as furniture or millwork. It could be used for pallets, flooring, containers, or pulpwood; but these markets are already being served by low-quality logs and processing residues. Thus, without preservative treatment, markets for low-quality timber would be greatly reduced (Howe, 1979). Conversely, by providing much needed profitable outlets for these materials, the wood-preserving industry enhances forest management, helps improve the forest environment, and provides increased employment and income for timber producers and processors in many areas of the United States.

Our study shows that more than 80% of all treated wood is produced in the Eastern United States. About half of the total is southern pine. Another 30% is hardwood ties, 45% of which are produced in the South. The Southeast and South Central regions have 55% of the treating plants and produce about 57% of all treated products. It follows that about 57% of treating industry expenditures for wood raw materials ($289 million in 1978) goes to the 12 States in these regions. This represents payment to timber growers for stumpage, and employment in harvesting, transporting, and processing wood products enroute to treating plants.

About 28,900 people were employed in logging, and 64,600 worked in sawmills in the South in 1977 (U.S. Dept. Comm., 1979a and 1979b). Since about 5% of the wood harvested, and 13% of the sawmill products (lumber, timbers, ties, etc.) are destined to be treated, it would appear that some 1,450 loggers and 8,400 sawmill employees are dependent on the wood preserving industry in the Southeast and South Central regions. With 7,500 employed by treating plants in these States, we have 17,350 jobs directly dependent on the wood preserving industry--an average of about 1,450 in each of the 12 States. The benefits, in terms of logging, sawmilling, and treating plant wages, and payment for wood raw materials in 1978 were $368 million in these States alone. They accrue to many communities, mostly small, rural towns in which the wood preserving plant and the production and processing of wood raw materials are major sources of employment and income (Micklewright, 1979).

The industry, thus, contributes significantly to the Carter Administration's policy on small community and rural development (Carter, 1979) whose goals include:

- meeting the basic human needs of rural America;
- providing opportunities for rural people to be fully and productively employed and providing a favorable climate for business and economic development;
- addressing the rural problems of distance and size; and

- promoting the responsible use and stewardship of rural America's natural resources and environment while preserving the quality of rural life.

Assuming that employment, wages, and payments for raw materials, per unit production, in other regions are similar to the South, total estimated direct benefits from wood preservation, and benefits by region, based on volumes of wood treated, are as shown in Table 90. Benefits from distribution and sale of more than $206 million worth of preservative chemicals and other materials and supplies are not included, nor are secondary benefits to merchants, businesspersons, professional people, and others in the many communities dependent on the industry for their livelihood.

Table 90.--Estimated direct benefits from wood preservation by region, 1978

| Region | Wood Treated | Employment in Producing, Processing, and Treating Wood | Direct Wages and Payments for Wood Raw Materials |
|---|---|---|---|
| | Million cu. ft. | 1,000 | Million Dollars |
| South | 185.4 | 17.4 | 368 |
| Northeast | 24.9 | 2.3 | 49 |
| North Central | 55.0 | 5.2 | 109 |
| Rocky Mountain | 16.0 | 1.5 | 32 |
| Pacific | 46.2 | 4.3 | 92 |
| United States | 327.5 | 30.7 | 650 |

Finally, the importance of wood preservation is not fully indicated by the figures on employment and income generated by the industry. The Rocky Mountain region in general, and the States of Idaho and Montana in particular, are a case in point. Table 90 shows the importance of wood preservation in this region to be relatively minuscule from a national point of view. But, the region has some 10 million acres of lodgepole pine in need of management (Hutchison, 1964; Green and Setzer, 1974; Wellner, 1975; Brown, 1974; Tunnock and Dooling, 1978; and Host and Schlieter, 1978). Sound timber management requires profitable markets for materials that must be removed to combat stagnation of forest stands and stimulate growth of remaining trees. In Idaho and Montana, as elsewhere in the region, lodgepole pine is used primarily for treated fence posts and small poles (Benson, 1975; Wright and Hanley, 1979). In the past few years markets have also developed for treated house logs and corral rails (Benson and Strong, 1977; and Wright and Hanley, 1979). Thus, wood preservation is vital to management of this species. Without it, utilization of lodgepole pine would be sharply curtailed. In the absence of harvesting, stands would become stagnated and vulnerable to insects, disease, and fire. Sixty-one percent of the treating plants in the Rocky Mountain region are in Idaho and Montana, where lodgepole pine is prevalent. Almost 80% of the treating plants in these States are located in towns of less than 10,000 population; more than half are in towns of less than 2,000 population (Micklewright, 1979). The treating industry is important to these small communities. But the statistics on industry employment, wages, and expenditures for raw materials are hardly indicative of the true economic and environmental importance of wood preservation to the Rocky Mountain region.

## Production, Use, and Value of Treated Wood

The wood-preserving industry provides markets for more than 500 million cu. ft. of timber, and employment for some 30,700 people in treating plants and related timber production, harvesting, and processing operations. Wages paid to workers directly dependent on the industry, and payments for wood raw materials total $650 million, annually. An additional $286 million is spent for preservative chemicals and other materials and supplies, including fuels and electrical energy. In 1978, the industry shipped treated wood products valued at $1,086 million.

These benefits accrue to many thousands of citizens directly and indirectly dependent on the industry in more than 500 communities throughout the land, most of which are small, rural towns heavily dependent on the local treating plant for their livelihood.

Much of the industry's wood raw materials comes from relatively low quality trees and logs which are not suitable for higher value uses such as furniture or millwork, or from species such as lodgepole pine for which there would be few, if any, markets without preservative treatment. The industry, thus, provides markets for large volumes of materials that could not otherwise be sold at a profit and, thereby, contributes to sound forest management and improvement of the forest environment in many areas of the United States.

## Cost of Preservatives and Cost of Treating Wood

The preservatives considered in this report, and the recommended retentions and estimated service lives for specific products are shown in Table 91. Prices of preservative chemicals and costs of preservative per cu. ft. of wood treated to the recommended retentions are shown in Table 92. The Assessment Team obtained prices of preservative chemicals from various sources during October 1979. Prices of the preservative chemicals may vary from region to region, or from plant to plant, due to differences in shipping costs, volumes purchased, and other factors. For example, the price of creosote may be as much as 20 cents per gallon higher on the West Coast than in the Eastern United States. The price of penta is also believed to be slightly higher in the West than in the East and South. However, the prices in Table 92 are representative of October 1979 costs to treaters and are sufficiently accurate to determine differences in preservative costs for treating various products with different chemicals.

Wood to be treated with waterborne arsenicals must be dried to approximately 30% moisture content, prior to treating. This can be accomplished by air- or kiln-drying. For most uses, the saturated wood must be redried after treatment. The larger the members to be treated (e.g., poles, piling, large timbers vs. lumber or small posts), the more difficult and time consuming and costly it is to dry the wood without degrade. For treatment with creosote or penta, the moisture in wood can be reduced to the required level by steaming or Boultonizing in the cylinder prior to treatment. This conditioning lengthens the time that the material must be in the cylinder, and tends to offset the cost of predrying for treatment with arsenicals.

Treating costs per cu. ft. of wood will vary with preservative, product, treatment specifications, species, the moisture content of the untreated wood, and the method of conditioning the wood prior to treatment. The amount and cost of energy, and the time required to heat wood and preservative to working temperatures, to maintain working temperatures, to condition the wood (in the cylinder or in a kiln), and

Table 91.--Products, recommended preservatives, retentions and service life (Table 78)

| Product | Preservative | Retention | Service Life | Remarks |
|---|---|---|---|---|
| | | Pcf | Years | |
| Poles, utility | Creosote | 9.0 | 35 | |
| | Penta | 0.45 | 35 | |
| | CCA/ACA | 0.60 | 50 | |
| | Cu-Naph | 0.68[a] | 35 | |
| Poles, residential | Penta | 0.80 | 50+ | Exterior only |
| | CCA/ACA | 0.80 | | |
| Poles, farm and industrial | Creosote | 9.0 | 35 | |
| | CCT[b] | 9.0 | 35 | |
| | Penta | 0.45 | 35 | |
| | CCA/ACA | 0.60 | 50 | |
| | Cu-Naph | 0.68[a] | 35 | |
| Poles, recreational and commercial | Penta | 0.60 | 35 | |
| | CCA/ACA | 0.60 | 50 | |
| Posts, fence-farm and highway | Creosote | 6.0 | 25 | |
| | CCT[b] | 6.0 | 25 | |
| | Penta | 0.30 | 25 | |
| | CCA/ACA | 0.40 | 35 | |
| | Cu-Naph | 0.45[a] | 35 | |
| | ACC | 0.50 | 35 | |
| Posts, fence-residential and commercial | Penta | 0.30 | 25 | |
| | CCA/ACA | 0.40 | 35 | |
| | ACC | 0.50 | 35 | |
| Posts, highway-guard rail and sign | Creosote | 12.0 | 30 | |
| | CCT[b] | 12.0 | 30 | |
| | Penta | 0.60 | 30 | |
| | CCA/ACA | 0.60 | 30 | |
| | Cu-Naph | 0.90[a] | 30 | |
| Piling, marine | Creosote | 20.0 | 20 | |
| | CCT[b] | 20.0 | 20 | |
| | CCA/ACA | 2.5 | 30 | |
| Piling, foundation, fresh water, land | Creosote | 12.0 | 50+ | |
| | CCT[b] | 12.0 | 50+ | |
| | Penta | 0.60 | 50+ | |
| | CCA/ACA | 0.80 | 50+ | |
| | Cu-Naph | 1.20[a] | 50+ | |

Table 91.--Products, recommended preservatives, retentions and service life (Table 78)--continued

| Product | Preservative | Retention | Service Life | Remarks |
|---|---|---|---|---|
| | | Pcf | Years | |
| Crossties and switch ties | Creosote | 8.0 | 35 | |
| | CCT[b] | 8.0 | 35 | |
| | Penta | 0.40 | 25 | |
| | Cu-Naph | 0.60[a] | 25 | |
| Crossarms | Creosote | 8.0 | 40 | |
| | Penta | 0.40 | 40 | |
| | CCA/ACA | 0.40 | 40 | |
| | Cu-Naph | 0.60 | 40 | |
| | ACC | 0.50 | 40 | |
| Industrial block flooring | Creosote | 8.0 | 50+ | |
| | CCT[b] | 8.0 | 50+ | |
| Cooling tower slats | CCA/ACA | 0.40 | 20 | |
| | ACC | 0.50 | 20 | |
| Agricultural uses and nurseries | CCA/ACA | 0.50 | 30 | |
| | Cu-Naph | 0.75[a] | 30 | |
| | ACC | 0.62 | 30 | |
| Landscape timbers and decking | Penta | 0.50 | 30 | |
| | CCA/ACA | 0.40 | 30 | |
| | ACC | 0.50 | 30 | |
| Containers (boxes, crates, etc.) | Penta | 0.30 | | |
| | CCA/ACA | 0.25 | | |
| | Cu-8 | 0.12 | | |
| | TBTO | 0.12 | | |
| | Cu-Naph | 0.45[a] | | |
| | ACC | 0.25 | | |
| | CZC | 0.45 | | |
| Boat hulls and decks | CCA/ACA | 0.60 | | |
| Sea walls, wharves, piers-salt water | Creosote | 25.0 | 20 | |
| | CCT[b] | 25.0 | 20 | |
| | CCA/ACA | 2.5 | 30 | |
| Bridges, crossing planks | Creosote | 12.0 | 35 | |
| | CCT[b] | 12.0 | 35 | |
| | Penta | 0.60 | 35 | |
| | CCA/ACA | 0.60 | 35 | |

Table 91.--Products, recommended preservatives, retentions and service life (Table 78)--continued

| Product | Preservative | Retention | Service Life | Remarks |
|---|---|---|---|---|
| | | Pcf | Years | |
| Mine ties and timbers | Creosote | 10.0 | 30 | |
| | CCT[b] | 10.0 | 30 | |
| | Penta | 0.50 | 30 | |
| | CCA/ACA | 0.40 | 30 | |
| | Cu-Naph | 0.75[a] | 30 | |
| | ACC | 0.50 | 30 | |
| House foundations, swimming pools | CCA/ACA | 0.60 | 50+ | |
| Playground equipment | CCA/ACA | 0.40 | 30 | |
| | ACC | 0.50 | 30 | |
| Highway sound barriers | Penta | 0.60 | 35 | |
| | CCA/ACA | 0.60 | 35 | |
| Residential, commercial-misc. construction lumber and plywood, nonstructural | Penta | 0.30 | 50+ | Above-ground |
| | CCA/ACA | 0.25 | 50+ | Above-ground |
| | Cu-8 | 0.12 | 50+ | Above-ground |
| | TBTO | 0.12 | 30 | Above-ground |
| | ACC | 0.25 | 50+ | Above-ground |
| | CZC | 0.45 | 50+ | Above-ground |
| Farm, industrial-misc. construction lumber and plywood, nonstructural | Creosote | 8.0 | 50 | Above-ground |
| | CCT[b] | 8.0 | 50 | Above-ground |
| | Penta | 0.40 | 50 | Above-ground |
| | CCA/ACA | 0.25 | 50 | Above-ground |
| | Cu-8 | 0.16 | 35 | Above-ground |
| | TBTO | 0.16 | 25 | Above-ground |
| | Cu-Naph | 0.60[a] | 50 | Above-ground |
| | ACC | 0.25 | 35 | Above-ground |
| | CZC | 0.45 | 35 | Above-ground |

[a] Based on copper metal.

[b] Creosote, coal-tar solution.

to treat it to specified retention have a significant effect on treating costs. Due to differences in these factors, it generally costs more to treat a given product with creosote than with either penta or arsenicals, and less to treat with arsenicals than with either creosote or penta. The cost of redrying after treatment would reduce or eliminate this cost advantage of arsenically treated wood.

Table 92.--Price of preservative chemicals[a] and cost of preservative per cu. ft. of wood treated

| Preservative | Unit | Weight per Unit | Price per Unit | Price per Pound of Preservative | Retention | Cost of Preservative per cu. ft. |
|---|---|---|---|---|---|---|
| | | Pounds | Dollars | Dollars | Pcf | Dollars |
| Creosote | Gallon | 9 | 0.83 | 0.092 | 8 | 0.738 |
| | | | | | 9 | 0.830 |
| | | | | | 12 | 1.106 |
| Coal tar | Gallon | 10 | 0.80 | 0.080 | -- | -- |
| Creosote coal tar[b] | Gallon | 9.5 | 0.815 | 0.086 | 8 | 0.687 |
| | | | | | 9 | 0.772 |
| | | | | | 12 | 1.029 |
| Petroleum | | | | | | |
| P9, Type A | Gallon | 7.5 | 0.70 | -- | -- | -- |
| P9, Type C | Gallon | 7.1 | 0.82 | -- | -- | -- |
| Penta | Pound | 1 | 0.53 | -- | -- | -- |
| Penta + P9 Type A[c] | Gallon | 7.9 | 0.99 | 1.77[d] | 0.3[d] | 0.530 |
| | | | | | 0.4[d] | 0.707 |
| | | | | | 0.5[d] | 0.884 |
| | | | | | 0.6[d] | 1.061 |
| Penta + co-solvent[e] | Gallon | 8.0 | 3.30 | -- | -- | -- |
| Penta + P9 Type C[f] | Gallon | 7.3 | 1.33 | 3.33[d] | 0.3[d] | 1.00 |
| | | | | | 0.4[d] | 1.33 |
| | | | | | 0.5[d] | 1.66 |
| CCA/ACA | Pound | 1 | 1.00 | 1.00 | 0.25 | 0.25 |
| | | | | | 0.32 | 0.32 |
| | | | | | 0.4 | 0.40 |
| | | | | | 0.6 | 0.60 |
| | | | | | 0.8 | 0.80 |
| | | | | | 2.5 | 2.50 |
| Cu-Naph[g] | Pound | 1 | 0.91 | -- | -- | -- |
| Cu-Naph + P9, Type A[h] | Gallon | 8.6 | 4.27 | 12.41[i] | 0.45[i] | 5.58 |
| | | | | | 0.60[i] | 7.45 |
| | | | | | 0.68[i] | 8.44 |
| | | | | | 0.75[i] | 9.31 |
| | | | | | 0.90[i] | 11.17 |
| | | | | | 1.20[i] | 14.89 |

Table 92.--Price of preservative chemicals[a] and cost of preservative per cu. ft. of wood treated--continued

| Preservative | Unit | Weight per Unit | Price per Unit | Price per Pound of Preservative | Retention | Cost of Preservative per cu. ft. |
|---|---|---|---|---|---|---|
| | | Pounds | Dollars | Dollars | Pcf | Dollars |
| Cu-Naph + P9, Type C[h] | Gallon | 8.2 | 4.19 | 12.77[i] | 0.45[i] | 5.75 |
| | | | | | 0.60[i] | 7.66 |
| | | | | | 0.68[i] | 8.69 |
| | | | | | 0.75[i] | 9.58 |
| Cu-8[j] | Pound | 1 | 18.00 | -- | -- | -- |
| Cu-8 + P9, Type C[k] | Gallon | 7.25 | 3.32 | 23.75[l] | 0.12[l] | 2.85 |
| | | | | | 0.16[l] | 3.79 |
| TBTO | Pound | 1 | 6.65 | -- | -- | -- |
| TBTO + P9, Type C[m] | Gallon | 7.25 | 1.73 | 12.33[n] | 0.12[n] | 1.48 |
| | | | | | 0.16[n] | 1.98 |
| ACC | Pound | 1 | 1.25 | | 0.25 | 0.313 |
| | | | | | 0.50 | 0.625 |
| | | | | | 0.62 | 0.775 |
| CZC | Pound | 1 | 0.50 | | 0.45 | 0.225 |

---

[a] Prices of chemicals developed by Assessment Team in consultation with industry representatives, October, 1979.

[b] 50% Creosote.

[c] 7% Penta.

[d] Pounds of penta.

[e] 22% Penta.

[f] 5% Penta.

[g] 8% Copper.

[h] 4% Copper.

[i] Pounds of copper.

[j] Solubilized Cu-8.

[k] 2% Cu-8.

[l] Pounds of Cu-8.

[m] 2% TBTO.

[n] Pounds of TBTO.

A shift from one preservative to another will affect the cost of the treated product due to differences in the cost of preservative and the cost of treating. For example, information on the price of treated southern pine poles shows that creosote-treated poles cost about $0.21 more per cu. ft. than penta-treated poles. The cost of creosote per cu. ft. at 9 pcf retention is $0.03 higher than the cost of penta at 0.45 pcf (Table 92). Thus, the cost of treating poles with creosote is apparently $0.18 per cu. ft. higher than the cost of treating with penta. A similar comparison of creosote- and CCA-treated poles shows that arsenically treated poles (0.6 pcf) cost about $0.54 less per cu. ft., including a $0.23 reduction in cost of preservative. The cost of treating poles with creosote is apparently $0.31 per cu. ft. higher than the cost of treating with CCA. The price (cost) of CCA-treated poles most likely does not include redrying, i.e., the poles would be shipped wet.

Both the cost of preservative and the cost of treatment will be considered in evaluating impacts of shifting from one preservative to another in the analyses that follow. For example, from Table 92 it can be seen that creosote for treating crossties to 8 pcf costs $0.03 more per cu. ft. than penta in P9 Type A solvent at 0.4 pcf. Assuming that treatment cost is $0.18 higher per cu. ft. for creosote, the cost of penta-treated ties is $0.21 less per cu. ft. than for creosote, or about $0.70 per tie.

## Future Availability and Price of Wood-Treating Chemicals

This section provides a brief survey of the availability of the three major wood preservatives and expected price trends. The availability of raw materials, trends in raw material prices, and manufacturing capacity are important variables influencing the future availability and price of the wood treatment chemicals.

### Future Availability and Price of Creosote

Coal tar is a by-product of the process of carbonizing coal to produce coke for use in blast furnaces. About 7.6 gallons of coal tar are produced when a ton of coal is carbonized (Energy Information Admin., 1979). Subsequently, creosote is obtained as a by-product when coal tar is distilled to produce pitch. About one-half gallon of pitch and one-quarter gallon of creosote are obtained from the distillation of a gallon of coal tar.

In 1978 about 71 million tons of coal were carbonized and yielded an estimated 541 million gallons of coal tar (Table 93). About 96 million gallons of this coal tar were burned as fuel. The steel industry refined approximately 131 million gallons of coal tar itself and sold another 319 million for refining into tar products (pitch and creosote). An estimated 357.6 million gallons of coal tar would have been required to produce the creosote used by the wood preserving industry as reported by AWPA in 1977. An estimated 23.9 million gallons of creosote produced in the process of making pitch was burned as fuel. Therefore, creosote available for wood treatment could be increased about 20% by using the creosote that is currently being burned. If one-half of the coal tar that is being burned by coke producers was refined, another 12 million gallons of creosote could be produced (an addition of 10%). Thus, current coal tar or creosote supplies appear adequate to permit creosote consumption to increase from 20 to 30% if required. Because of its value for fuel, the future price of creosote will be directly related to the price of No. 6 fuel oil.

Table 93.--Estimated coal tar and creosote production and utilization in the United States, 1977 and 1978

| | 1978 |
|---|---|
| | Million Gallons |
| Coke oven tar produced[a] | 541 |
| Coal tar used by producers of:[a] | |
| Refining or topping | 131 |
| Fuel | 95.8 |
| Other uses | 8.46 |
| Coal tar sold for refining into:[a] | |
| Tar products | 319 |
| Total coal tar refined[a] | 450 |
| Coal tar required to produce creosote reported by AWPI[b] | 462 |
| Excess coal tar refined but not required to fulfill current creosote needs[c] | 92.5 |

[a] Source: Energy Information Admin., 1979.

[b] Based on AWPI information (Dorman, 1979). Assumes that 4 gallons of tar are required to yield a gallon of creosote-coal tar.

[c] Assumes that 1 gallon of coal tar yields 1/4 gallon of creosote (Gore, 1980).

Creosote and No. 6 fuel oil both contain about 145,000 BTU's per gallon and coal tar contains about 160,000 Btu's per gallon. Hence, a gallon of No. 6 fuel oil has a fuel value equivalent to about 0.9 gallon of coal tar or 1 gallon of creosote. Since coal tar and creosote can be used as fuel substitutes for No. 6 fuel oil, an increase in the price of No. 6 fuel oil can be expected to cause the price of coal tar and creosote to rise by an equivalent amount. Given the expected future increases in fuel oil prices, it seems reasonable to expect similar increases in the price of creosote.

### Future Availability and Price of Penta

The penta-producing industry in the U.S. has the capacity to produce about 80 million pounds of penta per year (Johnson, 1980). Current production is between 40 and 50 million pounds per year. Benzene, a derivative of petroleum, and salt are the basic raw materials used in the production of penta. No supply problems with benzene or salt are expected.

The future price of penta is expected to increase in direct response to changes in petroleum prices. Penta contains about 40% phenol (derived from benzene) and 60% chlorine (derived from salt) (Johnson, 1980). The price of phenol will rise whenever the price of fuel oil increases. A 50% increase in the price of oil would lead to a 20% or more increase in the price of penta.

Between August 1979 and January 1980, the price of penta increased about 13% from 0.46 to $0.52 per pound as a result of oil price changes.

Oil price increases are especially critical for users of penta because large amounts of petroleum are also used as a carrier for penta. If the price of fuel oil increased $0.25 per gallon, the cost of penta and oil solvent used to treat a 20-cubic-foot utility distribution pole would increase about $4.10. This is based on a retention of 0.45 pcf penta in a 7% solution. Likewise, the cost of treating the same size pole with creosote would increase about $4.50 as a result of a $0.25 per gallon increase in the price of creosote (based on a retention of 9 pcf). In contrast, the direct cost of drying the pole before treatment with arsenicals (requires 6.22 gallons of fuel oil) and then treating with arsenicals would increase about $1.55. This is based on the need to remove 22.9 pounds of water per cu. ft. of southern pine (Simpson, 1979); 1,900 Btu's required to remove each pound of water; and 140,000 Btu's per gallon of No. 2 fuel oil. Clearly, fuel price increases are causing the cost of treating poles with creosote and penta to rise relative to treating with arsenicals.

### Future Availability and Price of Inorganic Arsenicals

The future availability and price of CCA and ACA will depend, in large part, upon the availability and price of raw materials. Arsenic, copper, and chromium are the major ingredients and account for about 75% of the final cost of arsenical preservatives.

An adequate supply of copper is anticipated by the industry; however, the price of copper will probably move upward from December 1979 levels if significant demand expansion occurs. The future availability of arsenic and chromium is less certain primarily because the United States imports most of its supply.

Arsenic.--Arsenic is a by-product of the refining of other metals such as copper, lead, and zinc. Therefore, the supply of arsenic would appear to be relatively price inelastic; however, large quantities of arsenic ore have accumulated around the world as mine wastes discarded in the past. At the current arsenic price, several countries are giving serious consideration to processing the arsenic available in their mine wastes.

The U.S. imported 10,306 short-tons of arsenic trioxide in 1978. The major foreign sources were: France, 5,077 tons; Mexico, 2,603 tons; and Sweden, 2,281 tons (Loebenstein, 1979). A Canadian supplier recently began to supply arsenic trioxide to American processors. Large quantities of arsenic crude ore that could be processed are available in South America (Peru) and Asia (China) (O'Brien, 1979). The purity of arsenic trioxide from Canada and South America may be below that of ore currently imported from Europe and Mexico. Additional processing could bring such ore up to the quality standards of arsenic acid processors in the United States, but the cost of arsenic trioxide would rise accordingly (Toth, 1979). The ASARCO plant in Tacoma, Washington is the only domestic producer of arsenic trioxide in the United States. Production at this plant has been limited by efforts to comply with worker safety and pollution regulations. The plant currently supplies about one-half of the arsenic trioxide consumed in the United States (Loebenstein, 1979), but future expansion in production is not expected.

The estimated consumption of arsenic is distributed among major uses (Loebenstein, 1979) as follows:

| | |
|---|---|
| Pesticides, herbicides, desiccants, and soil sterilizers | 70% |
| Wood preservatives and other chemical uses | 20% |
| Glass, non-ferrous alloys and other | 10% |

The wood preservative industry uses arsenic derived from arsenic acid to produce CCA and ACA. Arsenic acid in the liquid form is being used by most preservative formulators and wood treaters because there are no dust or fume problems during the production of CCA or ACA (Toth, 1979). A large proportion of the arsenic acid consumed in the United States is produced at the Pennwalt Corp. plant in Bryan, Texas. The Pennwalt plant has just been enlarged and modernized and currently is operating below capacity. If market demands increase, the plant's production could be doubled or tripled by the installation of additional reactors.

The price of arsenic trioxide increased from $250 per ton in 1977 to $700 per ton in 1979 (Toth, 1979). The December 1979 price of arsenic acid for use in preserving wood was $4.95 per gallon (1.57 pounds/gallon) f.o.b. Bryan, Texas in truckload lots. Three years ago, arsenic acid was about half this price. Clearly, the price of arsenic acid increased considerably during the period while arsenicals were becoming more competitive with creosote and penta.

An estimated 60% of all arsenic acid produced in the United States is now consumed by the wood preserving industry. Pennwalt expects the use of arsenic acid by the wood-preserving industry to be the major source of new demand for arsenic acid.

In general, there should be sufficient arsenic acid to meet the needs of the wood-treating industry provided adjustments to price and government regulations are permitted to occur in an orderly fashion (Toth, 1979).

Chromium.--Chromium acid is the source of chromium used to produce most of the arsenical preservatives. Approximately 20% of the estimated 50,000 tons of chromic acid produced in the United States is used by the wood preserving industry. The metal plating industry is the largest single user of chromic acid; however, this market is being reduced in size due to adjustments associated with pollution cleanup efforts in the automobile industry (Gilbert, 1979). Increased use of aluminum to reduce vehicle weight and improve gasoline mileage should cause a decline in the demand for chromium in automobiles (O'Brien, 1979).

Reduction in sales of chromic acid for metal plating is being off-set by the growth in sales to the wood-preserving industry. Diamond Shamrock Corporation views the wood-preserving industry as a growth market for chromic acid (Gilbert, 1979). In fact, Diamond Shamrock plans to increase its chromic acid production capacity about 25% by June 1980. This would represent a 10 to 12% increase in national production.

All the chromium ore currently processed in the United States is imported from South Africa or Rhodesia. Supplies from South Africa are sufficent to meet current needs. A solution of the political problems in Rhodesia would assure a larger and stable supply of chromium ore. Adequate supplies of chromium exist to meet the expected industrial needs of the United States during the next 20 years. Of course, political instability could lead to shortrun disruptions in imports of chromium from Africa. Chromium processors in the United States have stockpiled nearly a 2-year supply of chromium to ensure continued production of chromic acid in the event of temporary disruptions in supply (Gilbert, 1979).

The price of chromic acid purchased by the wood preservative industry was $0.95 per pound in truckload lots f.o.b. plant in North Carolina in December 1979 (Gilbert, 1979). This represents a price increase of about 39% above the chromic acid price reported in 1977 (Chemical Economic Handbook, 1979). In summary, the supply of chromium ore and processing capacity appear adequate to meet increased demand for arsenicals for wood treatment.

Supply and Price of CCA and ACA.--The production of CCA and ACA depends upon plant capacity, and the supply of raw materials. The industry has been expanding its production capacity in line with the increased use of arsenicals for wood treatment. Osmose, a major producer of CCA, could expand its production capacity by 20% within 6 or 7 months (O'Brien, 1979).

The sale price of CCA and ACA was about $1.00 per pound in October 1979. About 78% of this price represents the cost of raw materials and the other 22% reflects the cost of mixing, transportation, administration, etc.

The component costs of a pound of CCA are as follows:

| Chemical | Raw Material Source | Raw Material per Pound of Chemical | Price of Material per Pound | Nominal Composition CCA | Cost per Pound CCA |
|---|---|---|---|---|---|
| | | Pounds | Dollars | Percent | Dollars |
| $CrO_3$ | Chromic acid | 1.0 | 0.95 | 0.475 | 0.451 |
| CuO | Copper | 0.7987 | 1.01 | 0.185 | 0.149 |
| $As_2O_5$ | Arsenic acid | 1.6469 | 0.31 | 0.340 | 0.176 |
| Total | | | | | 0.776 |

Clearly, an increase in the price of chromic acid would have the largest impact on the price of CCA.

The component costs of a pound of ACA are as follows:

| Chemical | Raw Material Source | Raw Material per Pound of Chemical | Price of Material per Pound | Nominal Composition ACA | Cost per Pound ACA |
|---|---|---|---|---|---|
| | | Pounds | Dollars | Percent | Dollars |
| CuO | Copper | 0.79872 | 1.01 | 49.8 | 0.402 |
| $As_2O_5$ | Arsenic acid | 1.6469 | 0.315 | 50.2 | 0.260 |
| $NH_3$ | Ammonia | 1.0 | 0.125[a] | 1 | 0.125 |
| Total | | | | | 0.787 |

[a] Assumes ammonia costs $250 per ton.

Changes in copper prices would have the largest impact on the price of ACA. The price of ACA would increase about $0.12 per pound if the price of copper increased 30%; however, price changes for ACA and CCA will not necessarily cause large changes in the installed cost of treated wood because the cost of chemicals represents only a small proportion of the total installed cost of treated wood. Even if chromic acid or arsenic acid prices increased 50%, the impact on the installed cost of treated wood would be relatively small.

## Cost of Converting to Alternative Preservatives

Cancellation of any of the three classes of wood preservatives, and a switch to use of an alternative preservative for the various treated wood products, would require capital investment to convert treating facilities from one preservative to another. The most likely, and least costly, shifts would be from creosote to penta, from penta to creosote, or from either creosote or penta to arsenical salts. The most expensive, and least likely, conversion would be from arsenical salts to either creosote or penta. An extensive discussion of the factors involved in such shifts, and some information on costs, are contained in a report by the Mitre Corporation (Fuller, et. al., 1977). Josephson has prepared a detailed accounting of the capital requirements for converting a wood treating plant from use of waterborne preservatives to creosote or penta (Josephson, 1977 and 1979).

### Conversion from Creosote to Penta or from Penta to Creosote

Statistics on the wood-treating industry, presented earlier in this chapter, show that 64% of the plants that treat with creosote also treat with either penta or waterborne preservatives, or both. More than half (54%) of the plants that treat with penta--and nearly three-quarters of the pressure plants that treat with penta--also treat with either creosote or waterborne preservatives, or both. Thus, a high percentage of creosote and penta treaters is equipped to treat with either of these perservatives. There are a number of penta treaters that treat lumber, fence posts, and small timbers with little or no auxiliary heat. Conversion of these plants to creosote would require installation of a boiler, cylinder heating system, and insulation at considerable expense. Most conversions from penta to creosote, and conversions from creosote to penta, however, would require relatively small investment in plumbing and new or expanded chemical storage and mixing facilities. Estimated conversion costs would range between $20,000 and $30,000 for a 6 ft x 80 ft. cylinder whose capacity is estimated at 0.6 to 0.8 million cu. ft. per year (McGill, 1979).

### Conversion from Creosote or Penta to Arsenicals

Shifting from creosote or penta to arsenicals could be accomplished by either retrofitting existing cylinders or by constructing new arsenical cylinders. If new cylinders were constructed, the estimated minimum capital investment would range between $275,000 and $325,000 for a 6 ft. x 80 ft. cylinder (McGill, 1979). This estimate assumes that material handling equipment is already available at the plant.

Conversion of existing cylinders to treatment with other preservatives would be less expensive, require less time, and cause relatively small employment and community disruption. Conversion of a creosote or penta cylinder to arsenicals would involve cleaning of the cylinder, installation of some piping, and construction of mixing and storage facilities for salt. Costs would be the same as for converting from creosote to penta, or vice-versa (McGill, 1979).

Conversion from creosote or penta to arsenicals would require construction of dry kilns in addition to changes in plumbing, and construction of mixing and storage facilities for the salt preservative. The type, size, and cost of dry kiln required would depend on the the species of wood and the products to be treated

(Palmer, 1980). Poles and piling would require a kiln at least 50 ft. in length, equipped to dry at conventional temperatures, i.e. 110°-180° F (USDA, 1974). A charge of softwood poles or piling could be dried sufficiently for treatment in such a kiln in 5 days (Palmer, 1980). Lumber, timbers, posts, and other products could be dried in a shorter kiln. Some large softwood members and hardwood products would require conventional temperatures. Hardwoods would require as many as 25 to 30 days per charge to dry. Pine and other softwood lumber, small timbers, and posts can be dried at high temperatures (212° F or higher) in as little as 24 hours. A high-temperature kiln would be more costly to install, but its shorter drying cycle (higher capacity) would reduce drying costs in the long run. The cost of three selected dry kilns for drying various products for treatment with arsenicals is estimated as follows (Palmer, 1980):

| Item: | Cost in Dollars |
|---|---|
| Kiln A - 26' x 52' Conventional Temperature Kiln (poles, piling, etc.) | |
| 1. Equipment, building, and control room (equipment alone = $35,000) | 80,500 |
| 2. 100 horsepower boiler | 16,000 |
| 3. Erection of building and equipment installation | 19,000 |
| 4. Site preparation and building slab | 9,000 |
| Total | 124,500 |

Capacity per charge = 2,800 cu. ft. poles, piling, etc.
Drying time, green to fiber saturation = 5 days (softwoods)
Annual capacity = 204,400 cu. ft. (softwoods).

| | |
|---|---|
| Kiln B - 28' x 30' Conventional Temperature Kiln (lumber timbers, posts, etc.) | |
| 1. Equipment, building, and control room | 70,000 |
| 2. 60 horsepower boiler | 14,000 |
| 3. Erection of building and equipment installation | 15,000 |
| 4. Site preparation and building slab | 9,000 |
| Total | 108,000 |

Capacity per charge = 2,800 cu. ft.
Drying time, green to fiber saturation = 5 days (softwoods)
= 25-30 days (hardwoods)
Annual capacity = 204,000 cu. ft. (softwoods)
= 40,000 cu. ft. (hardwoods)

| | |
|---|---|
| Kiln C - 32' x 54' High Temperature Kiln (lumber and other small-size softwood items) | |
| 1. Equipment, building, and control room | 108,000 |
| 2. 500 horsepower boiler | 50,000 |
| 3. Erection of building and equipment installation | 31,000 |
| 4. Site preparation and building slab | 12,000 |
| Total | 200,000 |

Capacity per charge = 3,850 cu. ft.
Drying time, green to fiber saturation = 24 hr. (softwood)
Annual capacity = 1,405,000 cu. ft.

## Conversion from Arsenicals to Creosote or Penta

Unlike creosote and penta treaters, a majority of waterborne treaters uses only one preservative. Less than one-third of these plants also treats with creosote or penta. There is disagreement in available literature (Fuller, et. al., 1977; and Josephson, 1977 and 1979) as to the cost of converting a waterborne treating cylinder to use of creosote or penta. The disagreement centers around the need for a boiler, for additional cylinder heating equipment, for insulation of the cylinder, work tank, and oil and steam piping, and for diking and spill containment around preservative storage tanks. Most waterborne treating plants would not be equipped with sufficient steam generating capacity for conversion to creosote or penta. New or expanded boiler facilities and related equipment would very likely be required. Likewise, since much more energy would be needed to heat preservatives and maintain them at working temperatures, insulation of the cylinder, work tank, and plumbing would be an economic necessity (Meanor, 1980). Federal regulations require diking and spill containment wherever petroleum products are stored. There is no such requirement for waterborne salt treating plants and many waterborne treating plants have no such facilities. For these reasons, Josephson's costs (Josephson, 1979) will be used in estimating capital investment required to convert treating plants from use of waterborne salts to creosote or penta.

Actually, the question of cost of converting from waterborne salts to creosote or penta is probably academic. About 80% of the wood treated with arsenicals is lumber, timbers, and plywood; and 85% of the arsenically treated lumber and timbers is used in applications for which neither creosote nor penta is a suitable alternative (see Impacts of Canceling One or More Preservatives for Treatment of Lumber, Timbers, and Plywood, later in this chapter). A portion of the arsenically treated poles and posts that is used where clean, paintable, odorless, nonvolatile preservative is required, and marine piling for use in warm water where Limnoria tripunctata are present also could not be treated with creosote or penta. Thus, more than 70% of arsenically treated wood cannot be converted to creosote or penta. The volumes of arsenically treated ties, poles, piling, posts, and other products that could be converted are relatively low, and could probably be absorbed by existing creosote and/or penta treaters without any major conversion of waterborne salt treating facilities. For comparative purposes, however, a cost will be included where applicable for converting from arsenicals to creosote or penta.

## Conversion Costs Used in This Analysis

In the analyses that follow, costs of converting to alternative preservatives for the various commodities are based on a 6-ft. cylinder, 80 ft. long, whose capacity is estimated at 0.6 to 0.7 million cu. ft. per year. Estimated costs to convert are as follows:

1. Convert from creosote to penta, or from penta to creosote, all products: $25,000 per cylinder.
2. Convert from creosote or penta to arsenical salts for poles and piling: $25,000 per cylinder plus $125,000 per kiln (204,000 cu. ft./yr.).
3. Convert from creosote or penta to arsenical salts for crossarms and posts: $25,000 per cylinder plus $108,000 per kiln (204,000 cu. ft./yr.).

4. Convert from creosote or penta to arsenical salts for lumber: $25,000 per cylinder plus $200,000 per kiln (1,405,000 cu. ft./yr.).

5. Convert from arsenical salts to creosote or penta, all products: $500,000 per cylinder.

## Impacts of Canceling One or More Preservatives for Crossties and Switch Ties

### Current Production and Use of Treated Crossties and Switch Ties

Production of treated wood ties totaled 106 million cu. ft. in 1978 (Table 86). About 2.5 million cu. ft. were treated with arsenical salts and used primarily for landscape ties. These will not be considered here. The remaining 104 million cu. ft. of creosote- and penta-treated ties translates to more than 31 million ties used in construction and maintenance of U.S. railroads. The Association of American Railroads expects annual tie requirements to remain at approximately this level (Josephson, 1979). More than 99% of all crossties are treated with creosote.

We have compared the cost of creosote-treated, penta-treated, copper naphthenate-treated, and concrete tie systems for the 300,000 miles of U.S. railroad track (Table 94). Josephson (1979) analyzed the costs of using treated wood, untreated wood, and concrete crossties on U.S. railroads. The Assessment Team believes untreated wood is impractical for this use (Chapter 7), and that ties treated with penta or copper naphthenate in P9, Type A petroleum solvent are possible alternates, with reduced service life, in the event that creosote is canceled. For reasons stated in Chapter 7, we have assigned an average service life of 35 years to both creosote-treated wood ties and concrete ties. The estimated life of penta-treated and copper naphthenate-treated ties is 25 years.

U.S. railroads have traditionally used a system of spot replacements in their maintenance of tracks on treated wood ties. For many reasons, wood ties deteriorate at varying rates. Rail lines (ties, track, ballast, etc.) are inspected periodically. When inspection shows a need for replacement of 600 to 1,000 ties per mile of track, that section of track is scheduled for maintenance, i.e., replacement of defective ties (Collister, 1979). Of the approximately 30 million treated wood ties used annually by U.S. railroads, about 5% are used in new construction and 95% are used for spot replacements. Class I railroads used more than 25 million ties for this purpose in 1978 (Brotherton, 1979). At a replacement rate of 1,000 ties per mile, this would indicate that 28,500 miles of track are in need of maintenance, and are being upgraded annually by this traditional spot replacement system.

At 3,033 ties per mile and a service life of 35 years, an average of 26 million creosote-treated ties would be required annually to maintain the 300,000 mile rail system. Penta- or copper naphthenate-treated ties could be substituted directly for creosoted ties, and the number required would be the same for 25 years. Due to shorter service life, requirements would increase to 52 million ties annually in the 26th through 35th year, when all creosoted ties would be replaced. Requirements for years 36 through 70 would be the same as for years 1 through 35, and so on.

Since concrete ties cannot be intermixed in track with treated wood ties (Chapter 7), the indicated need for concrete ties to perform the upgrading currently being accomplished wth treated wood ties is 28,500 miles x 2,640 ties per mile, or 75.24 million concrete ties annually. Assuming that this number of concrete ties could be produced and installed annually, the system would be converted to concrete

Table 94.--Estimated costs of using treated wood ties and concrete ties on U.S. railroads

| Item | Creosote-Treated Wood Ties | Penta-Treated Wood Ties | Copper Naphthenate-Treated Wood Ties | Concrete Ties |
|---|---|---|---|---|
| Ties--each | $14.50[a] | $13.80[b] | $36.85[b] | $32.00[a] |
| Hardware--per tie[a] | $ 8.50 | $ 8.50 | $ 8.50 | $ 8.50 |
| Freight--per tie[a] | $ 1.50 | $ 1.50 | $ 1.50 | $ 4.00 |
| Installation--per tie[a] | $10.00 | $10.00 | $10.00 | $16.00 |
| Total installed cost | $34.50 | $33.80 | $56.85 | $60.50 |
| Number per mile[a] | 3,033 | 3,033 | 3,033 | 2,640 |
| Service life[c] | 35 yrs | 25 yrs | 25 yrs | 35 yrs |
| | - - - - - - - - - Million Dollars - - - - - - - - - - - - | | | |
| Present value of future costs[d] | 9,865[e] | 10,270[f] | 17,258[f] | 32,859[g] |
| Average annual cost[h] | 896.9 | 933.7 | 1,569 | 2,987.5 |

[a] From Josephson, 1979.

[b] Based on current preservative prices and recommended retention (Table 92).

[c] From Chapter 7.

[d] Of maintaining system with creosote or converting to penta, Cu Naph, or concrete, over 100 years at 10% interest.

[e] Based on 26 million ties per year for 100 years.

[f] Based on 26 million ties per year for 25 years, 52 million per year for 10 years, 26 million per year for 15 year, 52 million for 10 years, 26 million per year for 15 years, etc.

[g] Based on 75.24 million ties per year for 10 years, 39.6 million per year for 1 year, 0 ties for 24 years, 75.24 million per year for 10 years, etc.

[h] Average annual cost = Present Value x $\left[\frac{r(1+r)^n}{(1+r)^n-1}\right]$, where $r = 10\%$, $n = 100$

in about 10.5 years. There would be no need for additional concrete ties until the 36th year when replacement of those installed in years 1 through 11 would begin.

The present value of future costs, over a 100-year period, of maintaining the system with creosoted ties, and of converting to penta- or Cu-Naph-treated wood or to concrete ties (Table 94) was computed on the basis of the replacement and maintenance schedules outlined above. Costs for each year in the future were discounted to present value at 10% interest using the formula $Vo = Vn \times \frac{1}{(1 + r)^n}$, and summed to obtain the present value of future costs over a 100-year period. The present value is the initial investment that must be made, at 10% interest, so that the proceeds will equal the future costs over the 100-year period.

The initial investment was then amortized over the 100-year period at 10% interest to find the average annual cost of using the alternative materials.

## Impact of Canceling Creosote and Switching to Ties Treated with Penta

Due to differences in cost of preservatives and cost of treatment (1979 prices), the initial cost of penta-treated ties would be less ($0.70 per tie) than for creosoted ties. This advantage would be reduced at the outset by the cost of converting about 150 treating cylinders from creosote to penta. At $25,000 per cylinder, the capital investment would total $3.75 million. The first-year cost of such an investment, amortized over 10 years at 12% interest, would be $825,000 ($0.03 each for 26 million ties).

The average annual cost of using penta-treated ties would be $18.2 million less than for creosoted ties for the first 25 years. Due to shorter service life (greater number of ties required), however, the long-run cost of penta-treated ties would be higher than for creosote. Present value of future cost of converting to penta and maintaining the system, over 100 years at 10% interest, is $405 million higher than for creosote (Table 94). Average annual cost of using penta-treated ties over the longrun exceeds the cost of creosoted ties by $36.8 million. An additional 34.6 million pounds of penta and 61 million gallons of petroleum solvent would be required, annually, to replace creosote in 26 million ties. This would nearly double the current consumption of penta and oil for treatment of all wood products. It has been estimated that a lead time of 3 years and an investment of $14 million would be required to expand penta production sufficient to satisfy demand for treatment of crossties if creosote were canceled (Fuller, *et al*., 1977).

## Impact of Canceling Creosote and Switching to Ties Treated with Copper Naphthenate

The high cost of Cu-Naph preservative would increase the cost per tie by $22.35, compared to creosote (Table 92). In addition, long-run tie requirements would be increased by 40% due to shorter service life.

The present value of future costs of converting to Cu-Naph and maintianing the system, over 100 years at 10% interest, is $7.4 billion higher than for creosote. Average annual cost of using Cu-Naph-treated ties over the longrun would be $672 million higher than the cost of creosote ties.

About 52 million pounds of Cu-Naph (Cu metal) and 87 million gallons of petroleum solvent would be required, annually, to replace creosote for this use.

## Impact of Canceling Creosote and Switching to Concrete Ties

Though their true service life has yet to be proven (see Chapter 7), concrete ties are considered by some to be satisfactory substitutes for treated wood ties on U.S. railroads. Table 94 compares the cost of concrete ties to that of treated wood.

An estimated 24.4 million tons of concrete and steel would be required annually to produce 75 million ties required to convert the system to concrete without increasing the backlog of deteriorated, unsafe track in need of maintenance. This is equivalent to a 91% increase in the amount of cement, sand, gravel, crushed stone, and steel used in the manufacture of all precast and prestressed concrete products in 1977 (U.S. Dept. Comm., 1979c).

The present value of future costs of converting to concrete and maintaining the system in accordance with the schedule outlined above is $32.9 billion. Average annual cost of using concrete ties over the long run, at 10% interest on investments, would be $2.09 billion higher than for creosote-treated wood ties.

## Limitations of the Analysis

The projected impacts are based on 1977 tie installation costs (Josephson, 1979) and the assumption that the supply of alternative materials is adequate for substitution at these prices. In reality, shortages are likely to develop if creosote is canceled regardless of which alternative (penta-treated wood, copper naphthenate-treated wood or concrete) is chosen by the railroads.

Other impacts of canceling creosote and switching to concrete for ties have not been assessed. These include:

--Capital investment needed to build facilities to produce the required numbers of concrete ties, and to purchase new installation and maintenance equipment to handle heavier ties (Howe, 1979).

--Lost investment in railroad installation and maintenance equipment made obsolete by conversion to concrete.

--A probable increase in railroad transportation rates to cover increased costs to railroads, and its effect on all users of railroads.

--Lost markets for 31% of all treated wood, and its effect on the treating industry, its suppliers, and communities in which it is located.

--Effects of cross-sectoral and regional shifts in employment and income between the wood industry and the concrete industry.

--Increased demand for nonrenewable, energy-intensive raw materials and products.

--Increased environmental pollution from production of these materials, and costs of control.

These and other indirect impacts could add to the direct costs of cancellation and substitution outlined above.

# Impacts of Canceling One or More Preservatives for Poles

## Current Production and Use of Poles

Treated wood poles are the principal structural supports for 4.52 million miles of electric distribution lines in the United States. An estimated additional 0.64 million miles of electric transmission lines are supported by wood poles. Treated poles are also used to support telephone lines, for light standards, and for construction of farm and other buildings. Data collected by the Assessment Team indicate that the volume of treated wood poles produced in 1978 totaled an estimated 64.2 million cu. ft. This represented about 19% of all wood treated with preservatives (Table 82).

The ownership of the 126.5 million treated wood utility poles currently used in the United States is shown in Table 95. Electric utilities have an estimated 95.1 million treated wood poles in service. Telephone companies, railroads, industry, and others account for another 31.4 million utility poles. The annual purchase of utility poles in 1978 was estimated to be 2.65 million poles or 59.6 million cu. ft. of treated wood. Electric utility poles accounted for about 87% of total pole volume (cu. ft.) purchased in 1978.

The volume of treated wood poles by type of use and preservative is presented in Table 96. Penta was the most frequently used preservative, accounting for 65.3% of total poles. Creosote accounted for another 28.4%, while arsenical treatment accounted for the other 6.3% of wood pole volume.

In addition to pole requirements for utilities, an estimated 1.8 million poles are used annually in farm, commercial, and residential construction. As shown in Table 96, the total annual volume of construction poles is about 4.6 million cu. ft., or roughly 7.2% of total treated wood pole production.

Eighty-four percent of the total electric distribution system in the United States is owned by rural electric cooperatives and investor-owned electric companies, each of which maintains 1.9 million miles of distribution line (REA, 1979; and Edison Electric Institute, 1979). The remaining 16% is owned by municipalities and other agencies. Projected average annual distribution pole purchases by investor-owned electric companies for the 1977-1986 period are estimated as 1.1 million, 45% of which are projected for new construction and 55% for replacements or rebuilding of existing lines (Edison Electric Institute, 1979). Comparable data for the rural electric cooperatives are 0.78 million poles purchased, with 44% and 56% being used for new construction and maintenance of existing lines, respectively.

Virtually all of the utility poles are produced in two regions of the United States that are contiguous with the natural ranges of the southern pines and Douglas-fir--the species which account for more than 85% of total pole production. Seventy-five percent of annual pole production is produced in the southern pine region, which extends from Maryland to east Texas. The Douglas-fir region, which is centered in California, Oregon, and Washington, produces about 10% and is responsible for most of the poles used in the United States that are longer than 70 feet. Average length and volume of distribution, transmission, and construction poles used are shown below.

| Type | Length (ft.) | Volume (cu. ft.) |
|---|---|---|
| Distribution | 35 to 40 | 19 |
| Transmission | 65 | 61 |
| Construction | 14 | 3 |

Expected service life of poles in line varies with the quality of preservative treatment and the severity of the biological hazard at the point of end use. A recent survey of investor-owned electric companies revealed that all companies recorded an average service life of greater than 20 years for the poles in their

Table 95.--Estimated utility poles in use and annual purchases, by ownership, 1978

| Owner | Poles in Service | Annual Purchases | Average Size Class | Cu. ft. per Pole | Annual Volume |
|---|---|---|---|---|---|
| | - - - - 1,000 | - - - - | | | 1,000 cu. ft. |
| Investor-owned | | | | | |
| Electric Co[a] | 51,500 | | | | |
| Trans. | 6,500 | 151 | 65/2 | 61 | 9,211 |
| Distr. | 45,000 | 1,098 | 40/3-4 | 23 | 25,254 |
| Rural Electric Co-ops[b] | 38,000 | | | | |
| Trans. | 1,000 | 72.6 | 65/2 | 61 | 4,429 |
| Distr. | 37,000 | 780.5 | 35/5-6 | 14 | 10,927 |
| Other Elect. Util. | 5,639 | | | | |
| DOD[c] | | 12.0 | 35/5-6 | 14 | 168 |
| Bu. Rec.[d] | | 7.4 | 65/2 | 61 | 451 |
| Bonneville[d] | | 3.3 | 65/2 | 61 | 201 |
| TVA[d] | | 1.6 | 65/2 | 61 | 98 |
| BIA[d] | | 3.0 | 35/5-6 | 14 | 42 |
| Other[d,e] | | 40.0 | 40/5 | 18 | 720 |
| Bell Telephone System[f] | 30,000[g] | 300 | 40/5 | 18 | 5,400 |
| Other telephone[f] | 7,500[g] | 100 | 40/5 | 18 | 1,800 |
| Railroads[d] | 6,000 | 80 | 35/6 | 10 | 800 |
| Industry[d] | 100 | 1 | 35/5-6 | 14 | 14 |
| Other misc.[d] | 300 | 4 | 35/5-6 | 14 | 56 |
| Total Utility | 139,039<br>-12,500[g] | 2,654 | | | 59,571 |
| Net | 126,539 | | | | |

[a] Edison Electric Institute, 1979.

[b] REA, 1979.

[c] Bielarski, 1979.

[d] Cravens, 1979.

[e] Municipal power, etc.

[f] Ochrymowych and Kressbach, 1979.

[g] One-third (1/3) jointly owned = 12,500 poles.

Table 96.--Estimated consumption of treated wood poles by type of use and preservative, 1978

| Type of use | Preservative | Volume | Percent of Total |
|---|---|---|---|
| | | 1,000 cu. ft. | |
| Utilities | Creosote | 17,367 | 29.2 |
| | Penta | 38,259 | 64.2 |
| | CCA/ACA | 3,945 | 6.6 |
| | Subtotal | 59,571 | 100.0 |
| Construction | Creosote | 870 | 18.9 |
| | Penta | 3,646 | 79.1 |
| | CCA/ACA | 93 | 2.0 |
| | Subtotal | 4,609 | 100.0 |
| All uses | Creosote | 18,237 | 28.4 |
| | Penta | 41,905 | 65.3 |
| | CCA/ACA | 4,038 | 6.3 |
| | Total | 64,179 | 100.0 |

systems. Eighty-five percent of the companies indicated an average service life of more than 35 years. A service life of 40 years or longer was reported by 29% of the companies. Line maintenance programs that include supplementary preservative treatments at the groundline can effectively extend service life. (See Analysis of Groundline Treatment later in this chapter.)

## Economic Effect of Preservative Cancellation

Although the efficacy of the three major wood preservatives is generally considered to be comparable, the economic impact of cancellation would depend upon which ones are retained. With the possible exception of copper naphthenate, there are no other registered preservatives for which substitution for creosote, penta, and the arsenicals is feasible. The availability, high cost, and certain physical characteristics of copper naphthenate raise serious questions regarding its suitability for large-scale use in pole production. The cost of copper naphthenate required to treat one cu. ft. of utility pole is about $8.45. This is more than 10 times the cost of creosote required to treat a cubic foot of utility pole. Given its high cost and physical limitations, copper naphthenate was not included in the analysis as a viable alternative.

Although concrete, steel, aluminum, and fiberglass poles have been suggested as alternatives for wood poles, price and technical considerations indicate that concrete and steel offer the only real alternatives to treated wood poles in the near future. The use of untreated poles is not feasible since effective pole life would be only 2 to 4 years.

Realistic alternatives include wood poles treated with one of the three major wood preservatives, or structures constructed from concrete or steel. Underground installation provides an additional alternative for distribution lines and transmission lines in special situations.

The utility industry would probably continue to use wood poles if any one of the three preservatives were retained. If all preservatives were canceled the utility industry would probably shift to some combination of steel and concrete poles and underground installation. The construction industry would probably switch from pole buildings to foundation supported buildings.

In this analysis we will examine the impacts on the utility industry and then look at the overall impact on both utilities and construction industries.

## Cost Impact on Distribution Poles

An estimated 2.4 million utility distribution poles were consumed in 1978. Table 97 presents estimates of distribution pole use, and costs for alternative distribution systems. A class 4-40 distribution pole costs about $110 f.o.b. the treating plant in the Southeast. Transportation costs depend upon the distance transported from the plant. On the average, transportation will cost between $10 and $25 per pole. Installation costs are estimated to average about $225, ranging from less than $100 to more than $1,000.

Assuming that the average cost of an installed distribution pole is $350.80, the present value of future cost of maintaining the current distribution system of 118 million poles for the next 100 years with the current pole mix is $10,335.45 million (assumes 10% discount rate).

The annualized cost of this present value is $1,033.54 million. The annualized cost indicates the equal-cost series for the next 100 years which has a present value of $10,335.45 million, given a 10% discount rate. The annualized cost per pole would be $8.76.

A shift to the use of only creosote would cause the annualized cost of maintaining the distribution system to increase to $1,066.34 million. In contrast, a shift to all arsenically treated poles would cause the annualized cost of maintaining the system to decline to $989.10 million. The corresponding annualized costs per pole would be $9.04 and $8.38. These estimates assume that sufficient preservatives would be available to permit shifts to the alternative preservatives.

A shift from the current mix of wood distribution poles to concrete poles would mean that the present value of future costs of maintaining the system would increase to $23,129.17 million (224% increase). Likewise, the annualized cost of maintaining the system would increase to $2,312.92 million and annualized pole cost would rise to $19.60.

A shift from treated wood poles to steel poles or towers would cause the installed cost of poles to increase about $700 per pole. Consequently, the present value of the future cost of maintaining the distribution system would rise to about $30,573 million. This represents an increase of 296% above present value of current wood pole system. The annualized cost of maintaining the system would rise to $3,057.35 million and the annualized cost per pole would increase to $25.90.

This analysis shows that wood distribution poles have an annualized cost of less than 1/2 that of concrete poles and nearly 1/3 that of steel poles or towers.

Table 97.--Estimated costs of treated wood, concrete, and steel poles or towers in utility distribution systems, 1978

| Item | Current Mix of Treated Poles[a] | Creosote-Treated Poles | Penta-Treated Poles | Arsenically Treated Poles | Concrete Poles | Steel Poles or Towers |
|---|---|---|---|---|---|---|
| Installed cost per pole (dollars)[b] | 350.80 | 355.00 | 350.00 | 340.00 | 770.00 | 1,050 |
| Service life (years) | 36.00 | 35.00 | 35.00 | 50.00 | 35.00 | 50 |
| Poles in system (million) | 118 | 118 | 118 | 118 | 118 | 118 |
| Average number of poles installed per year to maintain the system | 3,227,777 | 3,371,428 | 3,371,428 | 2,360,000 | 3,371,428 | 2,360,000 |
| Present value of future cost of maintaining the system (million dollars)[c] | 10,335.45 | 10,663.45 | 10,513.26 | 9,899.99[e] | 23,129.17 | 30,573.50[e] |
| Annualized cost of maintaining the system (million dollars)[d] | 1,033.54 | 1,066.34 | 1,051.33 | 989.10 | 2,312.92 | 3,057.35 |
| Annualized cost per pole (dollars) | 8.76 | 9.04 | 8.91 | 8.38 | 19.60 | 25.90 |

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[a] Assumes: creosote = 29.2%, penta = 64.2% and CCA/ACA = 6.6%.

[b] Weighted average of data supplied by Edison Electric Institute and Rural Electrification Adminstration.

[c] Assumes number of poles used per year will expand in equal increments during next 10 years from current 2,418,500 poles to average number required to maintain the system. Discount rate = 10 percent, system life = 100 years.

[d] Annualized cost = Present Value x $\left[\frac{r(1+r)^n}{(1+r)^n-1}\right]$, where r = interest rate = .1 and n = system life = 100.

[e] Annual 3,371,428 poles per year for 35 years, 0 poles for 15 years, 3,371,428 poles for 35 years, and 0 poles for 15 years.

These estimates assume that the number of poles in the system will not increase as the system expands. This assumption is based on trends in the utility industry. A significant proportion of future distribution lines in urban areas will probably be underground due to local regulations. The number of distribution poles required for replacements could also decline as the result of the increased use of groundline treatment to extend the life of existing poles.

Over 40% of new distribution line was installed underground in 1978 (Electric World, 1979). Most of this line was installed in new subdivisions as required by municipal ordinances. Recent innovations in wire cable and installation techniques have reduced the relative cost of underground installation in subdivisions. Actual underground installation costs may be similar to above-ground installation costs in new subdivisions, but underground installation may be several times more expensive than above-ground installation in existing housing areas. Cancellation of wood poles would probably encourage more underground installation in areas where it could compete with concrete or steel poles.

### Cost Impact on Transmission Poles

Table 98 presents similar findings for transmission poles. Although concrete transmission poles may be less expensive than steel towers, the use of concrete is limited by length and weight problems encountered in transportation and installation. For example, the TVA cannot use long concrete transmission poles in the mountains because road curves are too sharp to accommodate long concrete transmission poles. Steel transmission towers that can be assembled at the site enable TVA to avoid transportation and installation problems (Wilhoite, 1979).

The relative costs shown in Table 98 are relevant for steel or concrete structures used to replace poles in existing transmission lines; however, the relative cost of steel is much lower in large new transmission lines. In fact, between 70 and 90% of new transmission lines now being constructed are supported by steel towers or individual steel poles. Although individual steel towers are more expensive than wood poles, fewer towers are required per mile due to the greater height and strength of steel transmission towers. Wood poles are normally used only for transmission lines under 230 KV's. Since the trend is to larger KV transmission lines, the proportion of new transmission lines supported by wood poles is decreasing. It cost TVA about $100,000 to construct a mile of 161 KV line using wood (H-frame construction) and about $135,000 using 6.5 steel towers per mile (actual TVA construction costs per mile in 1979). In this case, the cost of a steel-supported line was about 1.35 times the cost of a wood-supported line.

The total line cost per wood pole structure averaged $6,250 compared to about $20,769 per steel tower, or about 3.32 times higher for steel. The annualized cost of maintaining the transmission system (Table 98) varies from $342.05 million with the current wood pole mix to $1,093.31 million when steel structures are used to replace poles in existing lines on a one-for-one basis. This represents an increase in the annualized cost per pole from 41.06 to $131.25.

### Cost Impact on All Utility Poles

The relative costs of alternative support structures for utility lines are summarized in Table 99. A shift to creosote for all utility poles would increase the installed cost of utility poles about 1%. A shift of all utility poles to arsenical salts would lower installed costs of distribution and transmission poles by 3 and 2%, respectively. Likewise, annualized system costs for utility poles would be reduced about 5%.

Table 98.--Estimated costs of treated wood, concrete, and steel poles or towers in utility transmission systems, 1978

| Item | Current Mix of Treated Poles[a] | Creosote-Treated Poles | Penta-Treated Poles | Arsenically Treated Poles | Concrete Poles | Steel Poles or Towers[b] |
|---|---|---|---|---|---|---|
| Installed cost per pole (dollars)[c] | 1,478 | 1,491 | 1,476 | 1,446 | 3,838 | 4,723 |
| Service life (years) | 36 | 35 | 35 | 50 | 35 | 50 |
| Poles in system (million) | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 | 8.33 |
| Average number of poles installed per year to maintain the system | 231,388 | 238,000 | 238,000 | 166,600 | 238,000 | 166,600 |
| Present value of future cost of maintaining the system (million dollars)[d] | 3,420.49 | 3,549.17 | 3,513.47 | 3,347.29[e] | 9,135.96 | 10,933.10[e] |
| Annualized cost of maintaining the system (million dollars)[f] | 342.05 | 354.92 | 351.35 | 334.73 | 913.60 | 1,093.31 |
| Annualized cost per pole (dollars) | 41.06 | 42.60 | 42.18 | 40.18 | 109.68 | 131.25 |

---

[a] Assumes: creosote = 29.2%, penta = 64.2% and CCA/ACA = 6.6%.

[b] Replacement structures in existing transmission lines.

[c] Weighted average of data supplied by Edison Electric Institute and Rural Electrification Adminstration.

[d] Present value equals the total cost stream for 100 years discounted at 10 percent.

[e] Assumes 238,000 poles per year for 35 years, 0 poles for 15 years, 238,000 poles for 35 years, and 0 poles for 15 years.

[f] Annualized cost = Present Value x $\left[\frac{r(1+r)^n}{(1+r)^n-1}\right]$, where r = interest rate = .1 and n = system life = 100.

Table 99.--Comparison of cost of alternatives for installed distribution and transmission utility structures, 1978

| Support Structure | Ratio of Cost of Alternative Installed Structures to Current Cost Mix of Installed Wood Poles[a] | | | |
|---|---|---|---|---|
| | Distribution | | Transmission | |
| | Current Installation Cost | Annualized System Costs | Current Installation Cost | Annualized System Cost |
| | - - - - - - - - - - - - Ratio - - - - - - - - - - - - | | | |
| All creosote-treated poles | 1.01 | 1.03 | 1.01 | 1.04 |
| All penta-treated poles | 1.00 | 1.02 | 1.00 | 1.03 |
| All arsenically treated poles | 0.97 | 0.96 | 0.98 | 0.98 |
| Concrete poles | 2.20 | 2.24 | 2.60 | 2.67 |
| Steel poles or towers | 2.99 | 2.96 | 3.20 | 3.12 |

[a] From Tables 97 and 98.

In contrast, if all wood pole treatment were canceled and utility companies switched to concrete poles, the cost of installed poles would increase 120% for distribution systems and 160% for transmission systems.

Substituting steel poles or towers for wood poles would increase installed costs by nearly 200% for distribution systems and about 220% for transmission systems. Other technological alternatives such as aluminum or fiberglass have physical limitations and cost more than concrete or steel.

## Economic Impacts of Restricting One or Two Major Wood Preservatives

Ten scenarios which show the impact of restricting one or two of the three major wood preservatives are presented in Table 100. The quantity of wood treated, the quantity of preservative used, cost of preservative, and total value of the treated poles is given for each scenario. Scenario I presents the actual 1978 situation for the pole treatment industry in the United States. The industry treated 64.2 million cu. ft. of wood poles and used about $51.2 million worth of preservative and solvent. These treated poles had an estimated value of $274.8 million f.o.b. factory. The cost of preservatives ranged from $38.5 million with Scenario IV (all poles treated with arsenicals) to $52.2 million with Scenario X (cancel penta and shift to creosote). The cost of the treated poles ranged from $247.1 million with Scenario IV to $285.6 million with Scenario VIII (all poles treated with creosote).

The ratios of preservative costs and costs of treated poles for alternative scenarios compared to the 1978 actual situation (Scenario I) are presented in Table 101. Costs of preservatives fall to only about 75% of current preservative costs when only arsenicals are used, assuming preservative prices do not rise when

Table 100.--Alternative scenarios for estimated consumption of preservatives, cost of preservatives, and cost of treated poles by type of preservative, 1978

| | Volume | Quantity of Preservative | Cost of Preservative[a] | Cost of Treated Poles[b] |
|---|---|---|---|---|
| | 1,000 cu. ft. | 1,000 Pounds | 1,000 Dollars | |
| Scenario I: 1978 Actual situation | | | | |
| Creosote | 18,237 | 164,133 | 15,100 | 81,155 |
| Penta | 41,905 | 18,857 | 33,734 | 178,096 |
| CCA/ACA | 4,038 | 2,423 | 2,423 | 15,546 |
| Total | 64,180 | 185,413 | 51,257 | 274,797 |
| Scenario II: Cancel creosote and shift to penta | | | | |
| Creosote | 0 | 0 | 0 | 0 |
| Penta | 60,142 | 27,064 | 48,414 | 255,603 |
| CCA/ACA | 4,038 | 2,423 | 2,423 | 15,546 |
| Total | 64,180 | 29,487 | 50,837 | 271,150 |
| Scenario III: Cancel creosote and shift to arsenicals | | | | |
| Creosote | 0 | 0 | 0 | 0 |
| Penta | 41,905 | 18,857 | 33,734 | 178,096 |
| CCA/ACA | 22,275 | 13,365 | 13,365 | 85,759 |
| Total | 64,180 | 32,222 | 47,098 | 263,855 |
| Scenario IV: Cancel creosote and penta and shift to arsenicals | | | | |
| Creosote | 0 | 0 | 0 | 0 |
| Penta | 0 | 0 | 0 | 0 |
| CCA/ACA | 64,180 | 38,507 | 38,507 | 247,089 |
| Total | 64,180 | 38,507 | 38,507 | 247,089 |
| Scenario V: Cancel penta and shift to arsenicals | | | | |
| Creosote | 18,237 | 164,133 | 15,100 | 81,154 |
| Penta | 0 | 0 | 0 | 0 |
| CCA/ACA | 45,943 | 27,566 | 27,566 | 176,881 |
| Total | 64,180 | 191,699 | 42,666 | 258,035 |
| Scenario VI: Cancel arsenicals and shift to penta | | | | |
| Creosote | 18,237 | 164,133 | 15,100 | 81,155 |
| Penta | 45,943 | 20,674 | 36,984 | 195,258 |
| CCA/ACA | 0 | 0 | 0 | 0 |
| Total | 64,180 | 184,807 | 52,084 | 276,412 |
| Scenario VII: Cancel arsenicals and shift to creosote | | | | |
| Creosote | 22,275 | 200,475 | 18,444 | 99,124 |
| Penta | 41,905 | 18,857 | 33,734 | 178,096 |
| CCA/ACA | 0 | 0 | 0 | 0 |
| Total | 64,180 | 219,332 | 52,178 | 277,220 |
| Scenario VIII: Cancel arsenicals and penta and shift to creosote | | | | |
| Creosote | 64,180 | 557,611 | 51,300 | 285,596 |
| Penta | 0 | 0 | 0 | 0 |
| CCA/ACA | 0 | 0 | 0 | 0 |
| Total | 64,180 | 557,611 | 51,300 | 285,596 |
| Scenario IX: Cancel arsenicals and creosote and shift to penta | | | | |
| Creosote | 0 | 0 | 0 | 0 |
| Penta | 64,180 | 28,881 | 51,664 | 272,760 |
| CCA/ACA | 0 | 0 | 0 | 0 |
| Total | 64,180 | 28,881 | 51,664 | 272,760 |
| Scenario X: Cancel penta and shift to creosote | | | | |
| Creosote | 60,142 | 541,278 | 49,797 | 267,632 |
| Penta | 0 | 0 | 0 | 0 |
| CCA/ACA | 4,038 | 2,423 | 2,423 | 15,546 |
| Total | 64,180 | 543,701 | 52,220 | 283,176 |

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[a] Based on preservative prices shown in Table 92. Includes cost of carrier for penta.

[b] Cost per cu. ft. f.o.b. plant: creosote = $4.45; penta = $4.25; CCA = $3.85 (Compton, 1979).

Table 101.--Comparison of alternative treatment scenarios for wood poles, 1978

| Treatment Scenario[a] | Ratio of cost for Alternative Scenarios to Cost Under Current Situation | |
|---|---|---|
| | Cost of Preservative Used | Cost of Treated Poles at Factory |
| I | 1.000 | 1.000 |
| II | 0.992 | 0.988 |
| III | 0.919 | 0.960 |
| IV | 0.751 | 0.899 |
| V | 0.832 | 0.939 |
| VI | 1.016 | 1.006 |
| VII | 1.018 | 1.009 |
| VIII | 1.001 | 1.039 |
| IX | 1.008 | 0.992 |
| X | 1.019 | 1.030 |

[a] From Table 100.

consumption rises. Expenditures for preservatives would increase about 2% if all poles were treated with creosote. If all poles were treated with arsenicals (Scenario IV), the total cost of poles (f.o.b. factory) would decrease about 10% below the actual 1978 level. Conversely, if all poles were treated with creosote (Scenario VIII), the value of poles would increase about 4%. These data suggest that changing the current mix of preservative used to treat poles would not cause a significant increase in the cost of treated wood poles.

## Financial Impact of Possible Capital Investment and Price Changes

The preceding analysis assumed that the per-unit cost of treating poles with specific preservative would not increase when shifts were made among alternatives; however, some concern has been expressed that restrictions on preservatives could cause large capital investment or price impacts for individual firms. The financial impact of a 50% increase in preservative prices and the capital expenditures required for plant modifications are now examined. An examination of preservative production indicates that market supplies will probably be adequate to meet industry demand for alternative regulation options. Thus a 50% relative price increase should be considered as an extreme price increase that will probably not occur. But even if it did, the analysis shows that treated wood could remain price competitive with alternative products.

### Additional Capital Investment For Alternatives

Shifts to alternative wood preservatives would require cleaning and changing pipes in existing cylinders, installation of new storage and mixing facilities for chemicals, and the construction of dry kilns in the case where the shift is to arsenicals. The equipment changes and capital investment required for each scenario are shown in Table 102. The capital investment required to shift to alternative preservatives ranges from $0.75 million with Scenario II, which would require the conversion of 30 cylinders from creosote to penta, to $39.3 million with Scenario IV,

Table 102.--Additional capital investment required for alternative pole treatment scenarios

| Scenario[a] | Equipment Changes Required | Capital Investment Required |
|---|---|---|
| | | 1,000 Dollars |
| II | Convert 30 cylinders from creosote to penta at $25,000 each. | 750 |
| III | Convert 30 cylinders from creosote to arsenicals at $25,000 each + 89 dry kilns at $125,000 each.[b] | 11,875 |
| IV | Convert 97 cylinders from creosote and penta to arsenicals at $25,000 each + 295 dry kilns at $125,000 each.[b] | 39,300 |
| V | Convert 68 cylinders from penta to arsenicals at $25,000 each + 205 dry kilns at $125,000 each.[b] | 27,325 |
| VI | Convert 7 cylinders from arsenicals to penta at $500,000 each. | 3,500 |
| VII | Convert 7 cylinders from arsenicals to creosote at $500,000 each. | 3,500 |
| VIII | Convert 7 cylinders from arsenicals to creosote at $500,000 each + convert 68 cylinders from penta to creosote at $25,000 each. | 5,200 |
| IX | Convert 7 cylinders from arsenicals to penta at $500,000 each + convert 30 cylinders from creosote to penta at $25,000 each. | 4,250 |
| X | Convert 68 cylinders from penta to creosote $25,000 each. | 1,700 |

[a] From Table 100.

[b] Assumes 2,800 cu. ft. per kiln charge and 73 charges per year (5 days per charge), or 204,000 cu. ft. per kiln, per year.

which would require the conversion of 97 cylinders to arsenicals and the construction of 295 dry kilns. The largest capital investments are required in those situations where the use of arsenicals would be increased.

The annual financial effect of the additional capital investment is presented in Table 103. This effect was calculated by amortizing the required capital investment (Table 102) over 10 years and assuming the interest rate at which capital is borrowed would be 12%. The annual financial cost effect varies from $0.17 million under Scenario II (shift from creosote to penta) to $8.6 million under Scenario IV

Table 103.--Cost effects of required capital investment and a 50% increase of preservative prices for wood poles, 1978

| Scenario[a] | Cost Effect of Additional Investment[b] | Cost Effect of 50% Increase in Preservative Cost | Combined Cost Effect | Adjusted Cost of Treated Poles after Capital Price Increase[c] | Ratio of Cost of Treated Pole Under Alternative Scenario to Actual 1978 Value |
|---|---|---|---|---|---|
| | - - - - - - - - - - - - 1,000 Dollars | - - - - - - - - - - - - | | | |
| I | 0 | 0 | 0 | 274,797 | 1.000 |
| II | 165 | 24,207 | 24,372 | 295,522 | 1.075 |
| III | 3,613 | 6,683 | 10,296 | 274,151 | 0.998 |
| IV | 8,646 | 19,254 | 27,900 | 274,989 | 1.001 |
| V | 6,012 | 13,783 | 19,795 | 277,830 | 1.011 |
| VI | 770 | 0[d] | 770 | 277,182 | 1.009 |
| VII | 770 | 0[d] | 770 | 277,990 | 1.012 |
| VIII | 1,144 | 25,650 | 26,794 | 312,390 | 1.137 |
| IX | 935 | 25,832 | 26,767 | 299,527 | 1.090 |
| X | 374 | 24,898 | 25,272 | 308,448 | 1.122 |

[a] From Table 100.

[b] First year effect: Based on amortizing investment over 10 years and 12% annual interest.

[c] Derived by adding combined cost effect to total value of treated poles for each scenario given in Table 100.

[d] Small volume of additional preservative required is assumed to have no price effect.

(shift from creosote and penta to arsenicals). The largest financial cost effect would increase the value of treated poles by about 3.5%.

## Effect of 50% Preservative Price Increase

A restriction placed on one preservative will stimulate the demand for the other preservatives. If the supply of the preservative is relatively inelastic, a shift in preservative demand could cause the preservative price to increase. Thus, the impact of canceling a preservative is dependent, in part, upon the future supply response of the alternative preservatives. Each additional cu. ft. of wood treated with penta requires 0.80 gallons of petroleum solvent (7% penta). An increase in the demand for penta solvent will be too small relative to total petroleum consumption to cause petroleum prices to rise. But future petroleum price increases may cause the penta solvent price to increase significantly. Declines in steel production, with a resulting decrease in coke, may lead to a decline in creosote production. In this case, expansion in the demand for creosote could lead to a large increase in creosote prices.

Concern exists regarding future supply of arsenic and chromium for use in manufacturing the CCA and ACA preservatives. While supplies of arsenic and chromium are now tight, it remains unclear how much they would increase if metal prices were increased. Although domestic production of arsenic has declined recently, the supply of raw ore overseas appears sufficient to fulfill future needs. The Osmose Corp. could double its production of arsenical salts within a reasonable period of time. Industry officials do not expect any serious supply problems in 1980.

The supply of chromium available to the salt industry is less certain. In the long run, the supply of chromium available to the wood treatment industry will depend upon competition of other industries. Since the wood industry uses only a small proportion of all chrome consumed, the wood industry might be able to bid chromium away from other industries by raising the price paid for the metal. Information regarding the price elasticity of chromium is unavailable, thus it is difficult to say how much price would have to increase to attract chromium to the wood treatment industry.

The cost effect of a possible 50% increase in the price of preservatives is shown for the alternative scenarios in Table 103. It is assumed that the price of penta and creosote would not increase if arsenicals were canceled for use on poles because of the relatively small volume of wood that would be shifted. The cost effect of the relatively large 50% price increase varies from no change with Scenarios VI and VII (cancel arsenicals) to $25.8 million with Scenario IX (cancel creosote and arsenicals and shift to penta).

### Combined Capital Investment and Price Effect

The combined capital cost and price effect ranges from $0.77 million with Scenarios VI and VII (cancel arsenicals and shift to creosote or penta) to $27.9 million with Scenario IV (shift all pole treatment to arsenicals). When the combined cost effect is added to the total cost of treated poles given in Table 100, the adjusted cost of the treated poles shown in Table 103 is derived. This adjusted cost ranges from $273.2 million with Scenario III (cancel creosote and shift to arsenicals) to $312.4 million with Scenario VIII (all creosote). These figures represent 99.4% and 113.7% of the 1978 estimated actual costs of treated wood poles. Even if the required investments were undertaken and preservative prices increased 50%, the impact on the cost of treated wood is relatively small because the preservative cost represents a small proportion of total treated wood cost. If the effect of a preservative price increase were calculated for installed poles, the preservatives represent an even smaller proportion of installed pole cost.

## Limitations of the Analysis

Indirect impacts of canceling wood preservatives and switching to use of concrete or steel poles have not been assessed. These include:

--A need for some 3.5 million tons of concrete and steel, annually (based on the assumption that concrete poles weigh 2 times as much as treated wood poles at 54 pounds per cu. ft.), to convert to use of concrete poles. This is equivalent to a 14% increase in 1977 consumption of these materials in all precast and prestressed concrete products (U.S. Dep. Comm., 1979c).

--A need for 1.3 million tons of steel, annually (based on the assumption that steel poles weigh 0.7 times as much as treated wood), to convert to use of steel poles or towers.

--Capital investment needed to build facilities to produce required nonwood poles, and to purchase new installation and maintenance equipment to handle these materials.

--Lost investment in present installation and maintenance equipment rendered obsolete by conversion to nonwood poles.

--A probable increase in electric and telephone rates to cover increased costs to utilities, and its effect on all users of these services.

--Lost markets for 20% of all treated wood, and its effect on the treating industry, its suppliers, and communities in which it is located.

--Effect of cross-sectoral and regional shifts in employment and income between the wood industry and the concrete or steel industries.

--Increased demand for nonrenewable, energy-intensive raw materials and products.

--Increased environmental pollution from production of these materials, and costs of control.

These and other indirect impacts could add to the direct costs of cancellation and substitution outlined above.

## Impact of Canceling Wood Preservatives for Crossarms

An estimated 1.68 million cu. ft. of crossarms (0.5% of total treated wood) was treated with wood preservatives in 1978. The distribution of crossarms by treatment in 1978 was as follows:

| Treatment | Volume (1,000 cu. ft.) | Percent |
|---|---|---|
| Creosote | 41 | 2.5 |
| Penta | 1,615 | 95.8 |
| Arsenicals | 29 | 1.7 |
| Total | 1,685 | 100.0 |

The consumption of preservatives for treating crossarms in 1978 is given in Table 104. Consumption included: creosote, 389,000 pounds; penta, 646,000 pounds + 1,144,066 gallons of petroleum solvent; arsenicals, 11,600 pounds. The estimated

Table 104.--Alternative scenarios for estimated consumption of preservatives, and cost of preservatives and treated crossarms by type of preservative, 1978

| Scenario | Volume cu. ft. | Quantity of Preservatives[a] | Cost of Preservatives[b] | Cost of Crossarms[c] |
|---|---|---|---|---|
| | 1,000 cu. ft. | 1,000 Pounds | - - - 1,000 Dollars | - - - |
| I 1978 Actual situation | | | | |
| Creosote | 41 | 328 | 30 | 377 |
| Penta | 1,615 | 646 | 1,142 | 14,244 |
| Arsenicals | 29 | 11.6 | 12 | 242 |
| Total | 1,685 | 985.6 | 1,184 | 14,863 |
| II Cancel penta-shift to creosote | | | | |
| Creosote | 1,656 | 13,248 | 1,222 | 15,235 |
| Penta | 0 | 0 | 0 | 0 |
| Arsenicals | 29 | 11.6 | 12 | 242 |
| Total | 1,685 | 13,259.6 | 1,234 | 15,477 |
| III Cancel penta-shift to arsenicals | | | | |
| Creosote | 41 | 328 | 30 | 377 |
| Penta | 0 | 0 | 0 | 0 |
| Arsenicals | 1,644 | 657.6 | 658 | 13,695 |
| Total | 1,685 | 985.6 | 688 | 14,072 |

[a] Retentions per cu. ft.: creosote, 8 pounds.; penta 0.4 pound; arsenicals, 0.4 pound.

[b] Includes value of carrier for penta.

[c] Price of crossarms per cu. ft. was estimated as: creosote, $9.20; penta, $8.82; arsenicals, $8.33. Based on truckload lots f.o.b. plant (Coleman, 1979).

cost of these preservatives was $1.18 million. The value of the treated crossarms was estimated as $14.9 million.

## Impact of Canceling Penta for Crossarms

Since penta accounts for nearly 96% of treated crossarms, its restriction would have major implications for the crossarm treatment industry.

The impacts of canceling penta and shifting to creosote and arsenicals are presented in Table 104. A shift from penta to creosote would result in a $47,000 increase in the cost of preservatives (Scenario II); however, the cost of treated crossarms would increase about $614,000, assuming the price of creosote remained unchanged. In recent years the utility industry has been requesting penta instead of creosote. Thus, substitution of creosote for penta would probably encounter some opposition from utility companies.

Although less than 2% of crossarms were treated with arsenicals in 1978, arsenical-treated crossarms are gaining acceptance among some utility companies, such as VEPCO in Virginia, which is now using arsenical-treated crossarms exclusively (Farmer, 1979).

If penta were canceled and arsenicals were substituted for use on crossarms (Scenario III), the expenditures on preservatives would decline about $496,000 compared to the 1978 actual situation. Likewise, the value of crossarms would decline about 5.3% from $14.9 million to $14.1 million.

## Impact of Capital Investment and Preservative Price Increase

The first year cost effect of additional capital investment required for plant conversion is given in Table 105. It ranges between $16,500 and $206,600. If preservative prices were to increase 50% as a result of increased demand for the chemical, the price effect would range from $329,000 (Scenario III) to $610,000 (Scenario II).

Table 105.--Cost effects of required capital investment and a 50% increase in preservative prices for crossarms, 1978

| Scenario | Cost Effect of Additional Investment | Cost Effect of 50% Increase in Preservative Prices | Combined Cost Effect | Adjusted Cost of Treated Crossarms after Increase | Ratio of Cost of Crossarms Under Alternative Scenario to Actual 1978 Cost |
|---|---|---|---|---|---|
| | - - - - - - - - - | 1,000 Dollars | - - - - - - - - - | | |
| I 1978 actual | 0 | 0 | 0 | 14,863 | 1.000 |
| II Shift from penta to creosote | 16.5[a] | 609.5 | 626.0 | 16,103 | 1.083 |
| III Shift from penta to arsenicals | 206.6[b] | 328.8 | 535.4 | 14,607 | .983 |

[a] Convert 3 cylinders to creosote at $25,000 each. First-year cost of $75,000 principal amortized over 10 years at 12% interest.

[b] Convert 3 cylinders to arsenicals and construct 8 dry kilns. First-year cost of $939,000 principal amortized over 10 years at 12% interest.

Given the combined cost effect of capital investment and a 50% preservative price increase, the total value of treated crossarms would increase about 8.3% with Scenario II; however, the total value would be reduced about 1.7% with Scenario III (shift from penta to arsenicals). This analysis suggests that a cancellation of penta would not have a significant cost impact on the crossarm industry provided arsenical-treated crossarms were accepted by the industry. Steel crossarms are used by some utility companies. A steel distribution crossarm that is competitive with wood has been used by VEPCO.

## Limitation of the Analysis

The analysis does not look at the distributional effects of cross-sectoral and regional shifts caused by possible regulation changes.

# Impact of Canceling One or More Preservatives for Piling

## Current Production and Use of Piling

An estimated 12.1 million cu. ft. of piling (3.7% of all treated wood) were treated with preservatives in 1978 (Tables 83, 84, and 85). The distribution of this piling by type of preservative was as follows:

| Preservative | 1,000 cu. ft. | Percent |
|---|---|---|
| Creosote | 9,993 | 82.7 |
| Penta | 1,154 | 9.5 |
| CCA/ACA | 943 | 7.8 |
| Total | 12,090 | 100.0 |

Piling can be used for foundations (this includes land and fresh water piling) and marine uses. During the 1977-1978 period about 36% of the piling was used for marine purposes. It is assumed that only creosote- or arsenical-treated piling were used for marine purposes since penta is not suitable for marine applications. The estimated 1978 distribution of piling among marine and foundation uses was:

| Piling[a] | Creosote | Penta | CCA/ACA | Total | Percent |
|---|---|---|---|---|---|
| Marine (1,000 cu. ft.) | 3,977 | 0 | 375 | 4,352 | 36 |
| Foundation (1,000 cu. ft.) | 6,015 | 1,154 | 568 | 7,737 | 64 |

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[a] Source: Maloney and Pagliai, 1978; and Micklewright, 1979.

The estimated pounds and value of preservatives used to treat piling in 1978 are shown in Table 106. While marine piling accounted for an estimated 36% of treated piling in 1978, it consumed more than 49% of the total value of preservative used to treat piling. Creosote represented about 84.2% of the total preservative expenditure for piling. This reflects the large proportion of marine piling treated with creosote. The total expenditure for preservatives to treat piling in 1978 was estimated as $16.6 million.

Table 106.--Quantity and cost of preservatives used for piling in 1978

| Use | Treatment | Quantity of Preservative[a] | Cost of Preservative[b] |
|---|---|---|---|
| | | 1,000 Pounds | 1,000 Dollars |
| Foundation: | | | |
| | Creosote | 72,189 | 6,641 |
| | Penta | 692 | 1,224 |
| | CCA | 454 | 454 |
| | Total | 73,335 | 8,319 |
| Marine: | | | |
| | Creosote | 79,544 | 7,318 |
| | Penta | 0 | 0 |
| | CCA | 938 | 938 |
| | Total | 80,482 | 8,256 |
| Total | Creosote | 151,734 | 13,959 |
| | Penta | 692 | 1,224 |
| | CCA | 1,392 | 1,392 |
| | Total | 153,818 | 16,575 |

[a] Based on retentions given in Table 91.

[b] Based on prices given in Table 92. Includes value of carrier for penta.

## Value of Treated Piling

The total value of treated piling in 1978 was estimated as \$79.28 million. This value was distributed between marine and foundation piling as follows:

Foundation: 7,169,777 x \$6.14[a] = \$44,022,431
567,823 x \$5.84[b] = \$3,316,086
Marine: 4,352,400 x \$7.34[c] = \$31,946,615
Total \$79,285,132

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[a] Price estimate derived from price of \$3.45 per linear foot for a 50-ft. foundation piling with 12-in. diameter 3 ft. from the butt and 7-in. diameter at the point, f.o.b. New York (Engineering News Record, 1979). Assumes 0.562 cu. ft. per linear foot of piling.

[b] CCA-treated foundation piling priced at \$0.30 per cu. ft. less than creosote-treated piling (Compton, 1979).

[c] Price of marine piling is estimated as \$1.20 higher per cu. ft. than foundation piling due to use of more pounds of creosote per cu. ft. Source: (Compton, 1979.)

## Impact of Switching to Alternative Preservatives

Arsenicals could serve as an alternative for creosote in some marine uses. But the brittleness imparted to piling by arsenicals results in some breakage of piling during shipping and mechanical driving. Brittleness and breakage become a more serious problem at the higher salt retentions necessary for marine use. Foundation piling with a 0.8 pcf retention should not experience serious breakage problems (Armstrong, 1979). The Koppers Co. originally experienced 15 to 20% breakage of some arsenical marine piling during shipping. They now place a warning on all arsenically treated piling stating that the piles must be handled with care and unloaded with a crane (Davies, 1979). Marine piling installed in sandy soils in Florida by the injection method experience little breakage. Although the cost of breakage must be considered in the analyses of marine piling treated with CCA, breakage is not expected to exceed 5%. Arsenically treated marine piling should not be used for dolphins or bumpers in docks or marinas (Davies, 1979).

Since penta is not recommended for marine piling, cancellation of creosote would cause a shift to arsenical-treated marine piling. If all marine piling currently treated with creosote was treated with arsenicals, an additional 9.94 million pounds of arsenicals would be required.

The price of arsenical-treated marine piling is the same as creosote-treated marine piling, thus switching to arsenicals would not increase the price of treated piling provided arsenical treating capacity were available. The price, however, of arsenical-treated foundation piling is about $0.30 less per cu. ft. than creosote-treated piling. Such a price differential would result in a treatment savings of about $1.8 million if foundation piling were treated with arsenicals instead of creosote (Compton, 1979).

Assuming that foundation piling were shifted to penta, canceling creosote would create a need for an additional 3.61 million pounds of penta and 6.4 million gallons of No. 2 oil for solvent. Conversely, if these foundation piling were treated with arsenicals, an additional 4.81 million pounds of arsenical salts would be required.

Alternative scenarios showing the quantity and cost of preservatives, and cost of treated piling, are presented in Table 107. If creosote were canceled and foundation piling shifted to penta and marine piling shifted to arsenicals (Scenario II), the expenditure for preservatives would increase to $18.9 million (14.3%). On the other hand, if penta were canceled and arsenicals were substituted, the cost of preservatives would decline to $16.3 million (1.8% decline).

The feasibility of shifting from one preservative to another depends upon:

1) treating cylinder capacity;
2) kiln drying capacity if shift is to arsenicals; and
3) available supply and preservative price changes that may be induced by the shift.

## Capital Investment for Changes in Treatment

The estimated capital investments for plant conversions required to implement the alternative scenarios are given in Table 108. The required investment would range from a low of $50,000 with Scenario V (convert from penta to creosote) to a high of $7.3 million with Scenario IV. The first year cost (amortized principal and interest) would range from $11,000 (Scenario V) to $1.6 million (Scenario IV).

Table 107.--Alternative scenarios for estimated consumption of preservatives, and cost of preservatives and treated piling by type of preservative, 1978

|  | Volume | Quantity of Preservative | Cost of Preservative[a] | Cost of Piling[b] |
|---|---|---|---|---|
|  | 1,000 cu. ft. | 1,000 Pounds | - - - 1,000 Dollars | - - - |
| Scenario I: 1978 Actual situation |  |  |  |  |
| Creosote | 9,993 | 151,733 | 13,959 | 66,130 |
| Penta | 1,154 | 692 | 1,224 | 7,085 |
| CCA/ACA | 943 | 1,392 | 1,392 | 6,070 |
| Total | 12,090 | 153,818 | 16,575 | 79,285 |
| Scenario II: Cancel creosote and shift foundation to penta and marine to arsenicals |  |  |  |  |
| Creosote | 0 | 0 | 0 | 0 |
| Penta | 7,170 | 4,302 | 7,607 | 44,022 |
| CCA/ACA | 4,920 | 11,335 | 11,335 | 35,263 |
| Total | 12,090 | 15,637 | 18,942 | 79,285 |
| Scenario III: Cancel creosote and shift to arsenicals |  |  |  |  |
| Creosote | 0 | 0 | 0 | 0 |
| Penta | 1,154 | 692 | 1,224 | 7,086 |
| CCA/ACA | 10,936 | 17,465 | 17,465 | 70,395 |
| Total | 12,090 | 18,157 | 18,690 | 77,480 |
| Scenario IV: Cancel creosote and penta and shift to arsenicals |  |  |  |  |
| Creosote | 0 | 0 | 0 | 0 |
| Penta | 0 | 0 | 0 | 0 |
| CCA/ACA | 12,090 | 17,071 | 17,071 | 77,134 |
| Total | 12,090 | 17,071 | 17,071 | 77,134 |
| Scenario V: Cancel penta and shift to creosote |  |  |  |  |
| Creosote | 11,147 | 165,582 | 15,233 | 73,215 |
| Penta | 0 | 0 | 0 | 0 |
| CCA/ACA | 943 | 1,392 | 1,392 | 6,070 |
| Total | 12,090 | 166,974 | 16,625 | 79,285 |
| Scenario VI: Cancel penta and shift to arsenicals |  |  |  |  |
| Creosote | 9,993 | 151,734 | 13,959 | 66,130 |
| Penta | 0 | 0 | 0 | 0 |
| CCA/ACA | 2,097 | 2,315 | 2,315 | 12,809 |
| Total | 12,090 | 154,049 | 16,274 | 78,939 |

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[a] Includes value of carrier for penta.

[b] Marine piling = $7.34 per cu. ft. (Compton, 1979) and foundation piling = $6.14 per cu. ft. (Engineering News Record, 1979).

Table 108.--Additional capital investment required for alternative piling treatment scenarios, 1978

| Scenario[a] | Equipment Changes Required | Capital Investment Required |
|---|---|---|
| | | 1,000 Dollars |
| II | Convert 10 cylinders from creosote to penta at $25,000 each and convert 6 cylinders to arsenicals at $25,000 + 20 dry kilns at $125,000.[b] | 2,900 |
| III | Convert 16 cylinders from creosote to arsenicals at $25,000 each + 49 dry kilns at $125,000 each.[b] | 6,525 |
| IV | Convert 18 cylinders from creosote and penta to arsenicals at $25,000 each + 55 dry kilns at $125,000.[b] | 7,325 |
| V | Convert 2 cylinders from penta to creosote at $25,000 each. | 50 |
| VI | Convert 2 cylinders from penta to arsenicals at $25,000 each + 6 dry kilns at $125,000 each.[b] | 300 |

[a] From Table 107.

[b] Assumes 204,000 cu. ft. per kiln, per year.

## Effect of Possible Induced Preservative Price Changes

The data given in Table 107 assume capital changeover costs are not passed on to the consumer and that preservative prices would not increase if shifts were made among preservatives. Possible price changes induced by shifts among preservatives are of concern to people in the wood preserving industry. The magnitude of such changes would depend upon the future availability of preservatives.

The total cost effect (Table 109) of a 50% increase in preservative prices would range from $8.14 million with Scenario VI (convert from penta to creosote) to $9.47 million with Scenario II (convert from creosote to penta and arsenicals).

The adjusted cost of treated piling, after including the additional capital investment and price increase effects, would range from $87.28 million with Scenario IV to $89.39 million with Scenario II. These adjusted costs represent increases above the actual 1978 value of 11.3% and 12.8%, respectively. As in the case of poles, the 50% increase in preservative prices had a relatively small impact on the final value of piling because preservative costs represent less than 25% of the value of treated piling (Table 107).

Table 109.--Cost effects of required capital investment and a 50% increase in preservative prices for piling, 1978

| Scenario[a] | Cost Effect of Additional Investment[b] | Cost Effect of 50% Increase in Preservative Prices | Combined Cost Effect | Adjusted Cost of Treated Piling after Capital and Price Increase[c] | Ratio of Cost of Treated Piling Under Alternative Scenario to Actual 1978 Value |
|---|---|---|---|---|---|
| | - - - - - - - - - - - | - - 1,000 Dollars | - - - - - - - - - - | | |
| I | 0 | 0 | 0 | 79,285 | 1.000 |
| II | 638 | 9,471 | 10,109 | 89,394 | 1.128 |
| III | 1,436 | 9,345 | 10,781 | 88,261 | 1.113 |
| IV | 1,612 | 8,536 | 10,148 | 87,282 | 1.101 |
| V | 11 | 8,312 | 8,323 | 87,608 | 1.105 |
| VI | 176 | 8,137 | 8,313 | 88,252 | 1.113 |

[a] From Table 107.

[b] First year cost: Investment over 10 years at 12% interest.

[c] Derived by adding combined cost effect to total cost of treated piling for each scenario given in Table 107.

## Effect of Arsenical-Treated Marine Piling Breakage

If the breakage of arsenical-treated marine piling during shipping and mechanical driving were about 4%, the adjusted value of treated piling would have been about $91.8 million for Scenario VI or about 15.8% more than the actual 1978 estimated value. This would be significantly lower than the cost of concrete or steel piling.

## Impact of Switching to Alternative Materials

Both concrete and steel are technically acceptable alternative materials for piling in foundation uses; however, steel would be subject to corrosion in highly acidic soils or in marine environments (Fuller, et al., 1977). The cost of concrete and steel piles is higher than wood piles per linear ft. (except for long lengths). Likewise, the cost of mechanical driving is higher for both concrete and steel piling (Smith, 1980a; and Andrews, 1980).

The installed costs of piling will usually increase when steel or concrete piles are substituted for wood piles on a one-for-one basis. If heavy loads are involved, however, it may be possible to reduce the number of piles used at a given site by shifting from wood to concrete or steel. A concrete or steel pile can carry a load two to five times heavier than that carried by a wood pile. Consequently, the total cost of piling at a given site may not increase significantly when concrete or steel piling is substituted for wood if opportunities exist for assigning heavier loads to individual piles. In the case of residential and small commercial buildings where loads are relatively low, the cost of wood piles will usually be much lower than the cost of concrete or steel.

The actual installed cost of piles depends on several site-specific variables such as required pile length, type of soil, number of piles required, and load distribution. Since the initial site setup cost for the pile driver ranges between $12,000 to $15,000, the average cost per linear foot of pile driving declines substantially as the volume driven increases. The average installed cost per linear foot of treated wood pile has been estimated to decline from an average of about $19.00 for a 30 pile site to $9.00 for a 400 pile site (Smith, 1980a).

Table 110 provides a comparison of the installed costs of wood, concrete, and steel piling. This comparison is based on the use of 400, 50-ft. piling per site--a common size job as reported by pile drivers (Smith, 1980a). Assuming wood pile costs of $4.00 per linear ft. and driving costs of $5.00 per linear ft., a 50-ft. wood pile will cost about $450 installed. Such a pile would contain about 28.1 cu. ft. of wood. The 12 million cu. ft. of wood treated in 1978 would be equivalent to about 430,249 wood piles 50 ft. long (Table 110). The total installed cost of these wood piles is estimated as $193.6 million. The installed cost of a substitute concrete pile would be about $600 (Smith, 1980a). The total installed cost of 430,249 concrete piles would be $258.1 million (33.3% more than the cost of wood piles). The installed cost of substitute steel piles would be about $750 each (Smith, 1980a). In this case, total installed costs for 430,249 steel piles would be $322.7 million (67% more than cost of wood piles).

If concrete or steel piles can be assigned heavier loads than that previously assigned to wood piles, the number of substitute piles can be reduced. Assuming that a concrete or steel pile will replace 1.5 wood piles, the required number of piles could be reduced from 430,249 to 286,822 as shown in the concrete "B" and steel "B" columns in Table 110. In such a case, the total installed cost of concrete piles would decline to $172.1 million (11% less than cost of wood piling). Likewise, the installed cost of steel piling would decline to $215.1 million (only 11% more than wood piling).

An estimated 6 to 7 million linear ft. of precast and prestressed piling, bearing piles, and sheet piles were produced in 1977 (U.S. Dept. Comm., 1979c). This is equivalent to 120,000 to 140,000 50-ft. piling. These concrete piles were no doubt used where site or loading conditions, or economics, favored the use of concrete. It is likely that a sizable portion of the treated wood piling is used where site or economics favor treated wood, e.g., small number of piling per site, lower loads, etc. It is also likely that many treated wood marine, land, and fresh water piling are used where substitution of concrete or steel would be on a one-for-one basis. For these reasons, it is felt that the cost advantages of wood piling are closer to those indicated by the concrete "A" and steel "A" columns in Table 110 than to those indicated by the concrete "B" and steel "B" columns.

Assuming continued average annual consumption of 12 million cu. ft. of treated wood piling (430,000 piles), interest on investments at 10%, and an average service life of 50 years for both wood and non-wood piling, average annual cost of treated wood piling would be $193.6 million compared to 172.1 to $258.1 million for concrete, and 215.1 to $322.7 million for steel.

Table 110.--Estimated cost of using treated wood piles, concrete piles or steel piles in the United States, 1979

| | Treated Wood | Concrete | | Steel | |
|---|---|---|---|---|---|
| | | A | B | A | B |
| Installed cost per pile (50 ft. pile) (dollars) | 450[a] | 600[a] | 600[a] | 750[a] | 750[a] |
| Service life (years) | 50 | 50 | 50 | 50 | 50 |
| Number of 50 ft. pile equivalents installed per year | 430,249[b] | 430,249[b] | 286,832[c] | 430,249[b] | 286,832[c] |
| Current total cost per year (million dollars) | 193.6 | 258.1 | 172.1 | 322.7 | 215.1 |
| Present value of future cost stream (million dollars)[d] | 1,935.98 | 2,581.31 | 1,720.87 | 3,226.63 | 2,150.85 |
| Annualized cost (million dollars)[e] | 193.6 | 258.1 | 172.1 | 322.7 | 215.1 |

[a] Based on estimated installed costs for 50 ft. piling installed on a site with 400 piles required (Smith, 1980a).

[b] Assumes 28 cu. ft. per average 50-ft. pile and 12,090,000 cu. ft. of treated wood piles in the United States.

[c] Assumes 1 concrete or steel pile will replace 1.5 wood piles.

[d] Present value = total cost stream for 100 years discounted at 10%.

[e] Annualized costs = Present Value x $\left[\frac{r(1 + r)^n}{(1 + r)^n - 1}\right]$ where $r = .10$ and $n = 100$.

## Limitations of the Analysis

Indirect impacts of canceling wood preservatives and switching to use of concrete or steel piling have not been assessed. These include:

- A need for about 1 million tons of concrete and steel annually (based on the assumption that reinforced, prestressed concrete piles weigh three times as much as treated wood piles at 60 pounds per cu. ft.), to convert to concrete piles.

- A need for about 0.4 million tons of steel annually (based on the assumption that steel piling weigh the same as treated wood), to convert to steel piling.

- Capital investment needed to build facilities to produce required non-wood piling.

- Lost markets for 4% of all treated wood and its effect on the treating industry, its suppliers, and communities in which it is located.

- Effects of cross-sectoral and regional shifts in employment and income.

- Increased demand for nonrenewable, energy intensive raw materials and products.

- Increased environmental pollution from production of these materials, and costs of control.

These and other indirect impacts could add to the direct costs of cancellation and substitution outlined above.

## Impact of Canceling One or More Preservatives for Fence Posts

### Current Production and Use of Treated Fence Posts

The Assessment Team estimates show that 20.0 million cu. ft. of fence posts were treated with preservatives in 1978. Treated wood posts are used for farm fencing, yard and patio fencing, highway fencing, highway guardrails, and highway sign posts. Farm fence posts account for a large proportion of treated fence posts.

Studies conducted by the Forest Service in Mississippi showed that untreated southern pine posts had an average life of only 3.3 years compared with 38 years for posts treated with creosote or ACA, and 33 years for posts treated with penta (Gjovik and Davidson, 1979).

The distribution of fence posts by type of treatment in 1978 was as follows:

| Treatment | Volume (1,000 cu. ft.) | Percent |
|---|---|---|
| Creosote | 4,584 | 22.9 |
| Penta | 10,983 | 54.8 |
| Arsenicals | 4,461 | 22.3 |
| Total | 20,028 | 100.0 |

The estimated quantity of preservatives used to treat this wood is shown in Table 111. An estimated 27.5 million pounds of creosote were used to treat posts. Penta treatment required 3.3 million pounds of penta and 5.8 million gallons of petroleum. Arsenical treatment required 1.78 million pounds of arsenical salts. The total estimated cost of preservatives used to treat fence posts in 1978 was $10.13 million. The estimated f.o.b. plant value of treated wood posts was $66.1 million.

Table 111.--Alternative scenarios for quantity of preservative, and cost of preservative and treated posts by type of preservative, 1978

| | Volume | Quantity of Preservative | Cost of Preservative[a] | Cost of Posts[b] |
|---|---|---|---|---|
| | 1,000 cu. ft. | 1,000 Pounds | - - - - 1,000 Dollars | - - - - |
| Scenario I: 1978 Actual situation | | | | |
| Creosote | 4,584 | 27,504 | 2,530 | 15,815 |
| Penta | 10,983 | 3,295 | 5,821 | 36,354 |
| Arsenicals | 4,461 | 1,784 | 1,784 | 13,918 |
| Total | 20,028 | 32,583 | 10,135 | 66,087 |
| Scenario II: Cancel creosote and shift to penta | | | | |
| Creosote | 0 | 0 | 0 | 0 |
| Penta | 15,567 | 4,670 | 8,251 | 51,527 |
| Arsenicals | 4,461 | 1,784 | 1,784 | 13,918 |
| Total | 20,028 | 6,454 | 10,035 | 65,445 |
| Scenario III: Cancel creosote and shift to arsenicals | | | | |
| Creosote | 0 | 0 | 0 | 0 |
| Penta | 10,983 | 3,295 | 5,821 | 36,354 |
| Arsenicals | 9,045 | 3,618 | 3,618 | 28,220 |
| Total | 20,028 | 6,913 | 9,443 | 64,574 |
| Scenario IV: Cancel penta and shift to creosote | | | | |
| Creosote | 15,567 | 93,402 | 8,593 | 53,706 |
| Penta | 0 | 0 | 0 | 0 |
| Arsenicals | 4,461 | 1,784 | 1,784 | 13,918 |
| Total | 20,028 | 95,186 | 10,377 | 67,624 |
| Scenario V: Cancel penta and shift to arsenicals | | | | |
| Creosote | 4,584 | 27,504 | 2,530 | 15,815 |
| Penta | 0 | 0 | 0 | 0 |
| Arsenicals | 15,444 | 6,178 | 6,178 | 48,185 |
| Total | 20,028 | 33,682 | 8,708 | 64,000 |
| Scenario VI: Cancel arsenicals and shift to creosote | | | | |
| Creosote | 9,045 | 54,270 | 4,993 | 31,205 |
| Penta | 10,983 | 3,295 | 5,821 | 36,354 |
| Arsenicals | 0 | 0 | 0 | 0 |
| Total | 20,028 | 57,565 | 10,814 | 67,559 |
| Scenario VII: Cancel arsenicals and shift to penta | | | | |
| Creosote | 4,584 | 27,504 | 2,530 | 15,815 |
| Penta | 15,444 | 4,633 | 8,185 | 51,120 |
| Arsenicals | 0 | 0 | 0 | 0 |
| Total | 20,028 | 32,137 | 10,715 | 66,935 |
| Scenario VIII: Cancel creosote and penta and shift to arsenicals | | | | |
| Creosote | 0 | 0 | 0 | 0 |
| Penta | 0 | 0 | 0 | 0 |
| Arsenicals | 20,028 | 8,011 | 8,011 | 62,487 |
| Total | 20,028 | 8,011 | 8,011 | 62,487 |

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[a] Based on prices given in Table 92. Includes cost of carrier for penta.

[b] Prices per cu. ft. of treated wood are: CCA, \$3.12; penta, \$3.31; creosote, \$3.45 (Stevens, 1979).

## Impacts of Canceling Wood Preservatives

The impacts associated with alternative scenarios for treating wood posts are shown in Table 111. The cost of preservatives ranges from $8.01 million with Scenario VIII (cancel creosote and penta and shift to arsenicals) to $10.8 million with Scenario VI (cancel arsenicals and shift to creosote). The estimated value of treated posts varies from $62.5 million with Scenario VIII to $67.6 million with Scenario IV (cancel penta and shift to creosote).

## Financial Impact of Capital Investment and Preservative Price Increase Effects

The additional capital investment required to make the changes specified in each scenario is shown in Table 112. Additional capital requirements would vary from $0.2 million with Scenario II (switch from creosote to penta) to $8.86 million with Scenario VIII (treat all posts with arsenicals).

Table 112.--Additional capital investment required for alternative post treatment scenarios, 1978

| Scenario[a] | Equipment Changes Required | Capital Investment Required |
|---|---|---|
| | | 1,000 Dollars |
| II | Convert 8 cylinders from creosote to penta at $25,000 each. | 200 |
| III | Convert 8 cylinders from creosote to arsenicals at $25,000 + 22 kilns at $108,000 each. | 2,576 |
| IV | Convert 18 cylinders from penta to creosote at $25,000 each. | 450 |
| V | Convert 18 cylinders from penta to arseni-icals at $25,000 each + 54 kilns at $108,000 each. | 6,282 |
| VI | Convert 8 cylinders from arsenicals to creosote at $500,000 each. | 4,000 |
| VII | Convert 8 cylinders from arsenicals to penta at $500,000 each. | 4,000 |
| VIII | Convert 26 cylinders from penta and creosote to arsenicals at $25,000 each + 76 kilns at $108,000 each. | 8,858 |

[a] From Table 111.

The potential impacts of additional capital investment and a 50% increase in preservative prices are shown in Table 113. The combined cost of these two effects would range from $2.4 million with Scenario III to $6.0 million with Scenario VIII. After adding this combined effect to the total post cost shown in Table 111, the adjusted cost ranges from $67.0 million for Scenario III to $72.0 million for Scenario VII. Comparing the estimated adjusted total fence post cost for each scenario with the 1978 actual fence post cost (Scenario I) shows that total post cost would not change with Scenario III. The largest increase in total post cost would be 7.6% with Scenario IV (shifting from penta to creosote). These results suggest that canceling one or two of the preservatives should not lead to large increases in post prices.

Table 113.--Cost effects of required capital investment and a 50% increase in preservative prices for fence posts, 1978

| Scenario[a] | Cost Effect of Additional Investment[b] | Cost Effect of 50% Increase in Preservative Prices | Combined Cost Effect | Adjusted Cost of Treated Posts After Capital and Price Increase | Ratio of Cost of Treated Posts Under Alternative Scenario to Actual 1978 Cost |
|---|---|---|---|---|---|
| | - - - - - - - - - - - | 1,000 Dollars | - - - - - - - - - - - | | |
| I | 0 | 0 | 0 | 66,935 | 1.000 |
| II | 44 | 4,125 | 4,169 | 69,614 | 1.040 |
| III | 567 | 1,809 | 2,376 | 66,950 | 1.000 |
| IV | 99 | 4,296 | 4,395 | 72,019 | 1.076 |
| V | 1,382 | 3,089 | 4,471 | 68,471 | 1.023 |
| VI | 880 | 2,496 | 3,376 | 70,935 | 1.060 |
| VII | 880 | 4,093 | 4,973 | 71,908 | 1.074 |
| VIII | 1,949 | 4,006 | 5,955 | 68,442 | 1.023 |

[a] From Table 111.

[b] First year costs: Investment amortized over 10 years at 12% interest.

## Alternative Fence Post Material

If all preservatives were canceled, steel or concrete posts seem to be the most likely alternative materials that would be used for fence posts. T-type steel posts, which serve as substitutes for wood posts in farm fences, are priced competitively with treated wood posts. Thus, substitution of steel posts in many farm applications would not necessarily lead to much higher fencing costs. Concrete posts would be more expensive than steel and probably not be substituted in most farm situations.

Available statistics on treated wood post production and use indicate that treated post production has been underreported for some time, and that treated wood posts are preferred by farmers by at least 3 to 1 over metal posts (Baumgartner, 1969; and Reid and McKeever, 1978).

Baumgartner (1969) found that, though the amount of farm fencing constructed declined between 1956 and 1966, use of treated wood posts increased. During the period January 1963 to July 1966, farmers in 17 central and Appalachian States (from Iowa to Delaware and New Jersey, and south to Georgia and Alabama) used 38.5 million fence posts annually, 29.3 million (76%) of which were wood, and the remainder were metal.

Reid and McKeever (1978) found that about 2 million wood right-of-way fence posts and 3.8 million wood guardrail posts were used annually in highway construction from 1969 through 1971. The numbers declined to 1.4 million right-of-way fence posts and 2.8 million guardrail posts annually from 1973 through 1975. The decline was associated with a proportionate decline in total expenditures for highway construction between the two periods.

Wood preservation statistics for 1969-1975 show an average of 25.8 million fence posts and only 262 thousand "highway posts" produced annually during this period. If farm use of wood fence posts in only 17 States approximated the 1963-66 annual rate of 29 million reported by Baumgartner, and highway use during the period was 4 to 6 million, the production of treated wood posts was obviously underreported.

Farmers' preference for treated wood posts, as reported by Baumgartner (1969), would indicate that treated wood posts are superior to metal posts from the standpoint of cost or performance.

## Impacts of Canceling One or More Preservatives for Treatment of Lumber, Timbers, and Plywood

### Current Production of Treated Lumber, Timbers, and Plywood

An estimated 105.3 million cu. ft. of lumber and timbers were treated with the three major wood preservatives in 1978 (Table 86). In addition, more than 2 million cu. ft. of plywood were treated, and a substantial volume of sawn material reported as "Other" products (millwork, crossing plank, mine timbers, highway posts, and agricultural products such as grape and tomato stakes) falls, logically, into the category of "Lumber and Timbers." It is clear that this category of products is a rapidly growing, increasingly important segment of the market for treated wood, and is largely responsible for the substantial growth of the wood preserving industry in recent years. More than 70% of the total lumber, timbers, and plywood is treated with inorganic arsenicals; about 20% is treated with penta; and 10% with creosote.

Figure 17 shows the trends in production of lumber and timbers treated with creosote solutions, penta, and inorganic arsenicals. The solid lines depict trends indicated by annual industry surveys (Maloney and Pagliai, 1978). Again, for reasons discussed in Chapter 1 (Data Base), we believe the trends are more accurately represented by the broken lines on the chart.

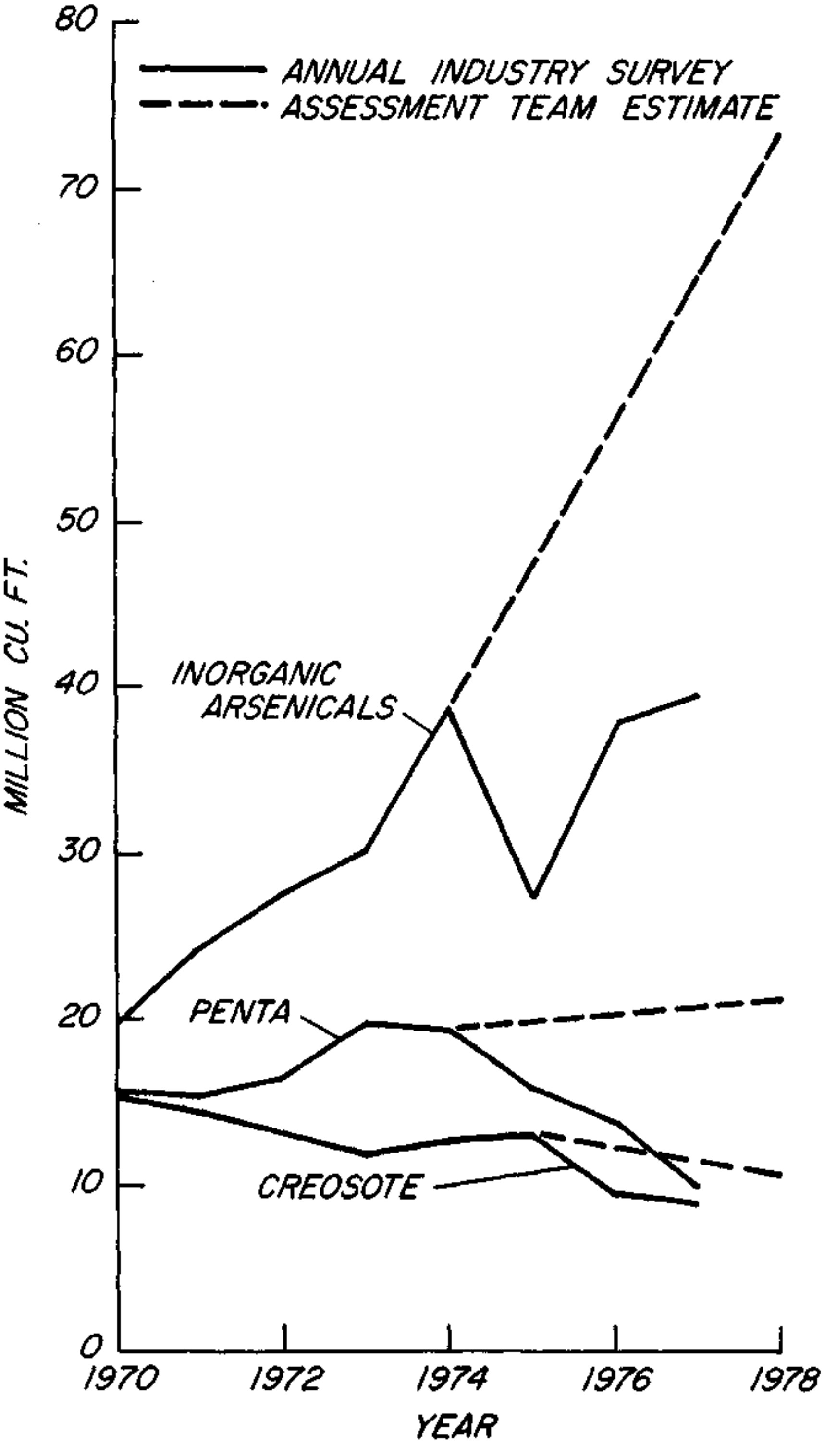

Figure 17. Production of treated lumber and timber, 1970-1978.

A recent market study (Random Lengths, 1979) revealed that rapidly expanding markets for treated wood products contributed to tight supplies and strong prices of some lumber and plywood items during the past few years. Growth in lumber sales to treating plants has been greatest in the southern pine region, but expanding markets have resulted in increased production and use of treated lumber and plywood in all regions.

Treated lumber is now used in many applications once served almost exclusively by cedar and redwood. Short supplies and high prices of these species have resulted in greater demand for treated material of other species. In addition, promotional efforts by the wood products and treating industries have boosted demand for treated material in a variety of other applications. These efforts have focused on lumber and plywood pressure treated with arsenical salts. The easy-to-treat characteristics of southern pine have contributed to rapid expansion of wood treating capacity in the South, and in markets served by southern pine. While treating plants are being built and expanded most rapidly in the South and Midwest, many have opened in other parts of the United States and Canada, and are treating other species. One California treater reported 25% annual growth in his sales of treated ponderosa pine and hemlock-fir in recent years (Random Lengths, 1979).

Estimates (by lumber producers) of the amount of southern pine lumber purchased by treating plants in 1979 range from 15 to 33% of production. Southern lumber producers estimated 1979 sales to treaters are about 50% ahead of the 1978 pace (Random Lengths, 1979).

The American Wood Preservers Bureau (AWPB), which certifies the quality of treated products, extended its services to more than 968.4 million bd. ft. in 1978, up from 424.4 million bd. ft. in 1972. AWPB estimates that its quality control program covers only about one-half of the treated lumber produced. The Bureau served 207 treating plants in 1978, up from 113 in 1972.

## Uses of Treated Lumber, Timbers, and Plywood

Lumber, timbers, and plywood account for about one-third of all treated wood produced. These commodities are used in a wide variety of applications, and the benefits from (and alternatives to) use of treated wood vary with the specific end use. Data on the volumes of treated lumber, timbers, and plywood used for different applications are lacking, and are difficult to obtain due to the large number of uses and users involved.

To remedy this situation, members of the Assessment Team met with knowledgeable treating industry officials in August 1979 to develop reliable estimates of the end uses of treated lumber, timbers, and plywood. The total market was divided into five general areas or categories of end use, and the major applications of treated lumber, timbers, and plywood within each of those end-use areas were listed as follows:

Residential and Commercial Construction

- Buildings
- Decks, patios, fences, etc.
- Landscape, garden timbers

Farm and Industrial Construction

Buildings
Fences
Agricultural (fruits and vegetables)
Nurseries, greenhouses
Mine ties and timbers
Cooling towers

Recreation

Swimming pools
Playgrounds, stadiums
Boardwalks, marinas
Boats

Marine (saltwater)

Seawalls, wharves, piers, etc.

Transportation

Highway and railroad bridges
Crossing planks, culverts
Guardrails, signs
Sound barriers
Loading docks
Car decking

These uses were discussed in terms of creosote-, penta-, and arsenically treated lumber, timbers, and plywood, and estimates of the percentages of treated material that are consumed in each application or end-use area were developed. The consensus of the group is summarized in Table 114. These use data were further qualified as follows:

<u>Creosote-treated material</u> used in:

--Residential and commercial construction is primarily landscape and garden timbers.

--Farm and industrial construction is mostly block flooring, sawn posts for barns, and mine timbers.

--Recreation is primarily for marinas.

--Marine applications is for seawalls, wharves, and piers.

--Transportation is for loading docks, car decking, highway posts, and bridge timbers.

<u>Penta-treated material</u> used in:

--Residential and commercial construction is primarily for light standards and bumper strips.

- --Recreation is used primarily in parks for signs, trail markers, and open shelters.

- --Marine uses is for decks of docks and piers above salt water.

- --Transportation is mostly guardrail posts.

<u>CCA-treated material</u> used in:

- --Farm and industrial construction is mostly for farm structures.

- --Transportation is primarily for sound barriers.

<u>ACA-treated material</u> used in:

- --Farm and industrial construction is mostly for industrial construction.

- --Transportation is for sound barriers and bridge lumber.

Table 114.--Use of treated lumber, timbers, and plywood[a]

| End-use Area | Lumber, Timbers, and Plywood Treated with | | | |
|---|---|---|---|---|
| | Creosote | Penta | CCA | ACA |
| | Percent | | | |
| Residential and commercial construction | 3 | 2 | 65 | 75 |
| Farm and industrial construction | 12 | 40 | 5 | 10 |
| Recreation | 1 | 15 | 15 | 5 |
| Marine | 45 | 3 | 10 | 5 |
| Transportation | 40 | 40 | 5 | 5 |

[a] Estimates developed by the Assessment Team in consultation with treating industry representatives, Boston, Mass., August 17, 1979.

NOTE: Columns may not add to 100 due to rounding.

By using the factors shown in Table 114 and estimates of volumes of treated lumber and timbers produced in 1978 (Table 86), the volumes of treated lumber and timbers used in each of the major areas of end-use were estimated (Table 115). Plywood volumes are not included in this table; however, about 80% of the plywood is treated with arsenicals (excluding fire retardant treatment) and most of the rest is treated with penta. Treated plywood is used in conjunction with treated lumber, and its use patterns are assumed to be the same as for lumber.

Table 115.--Estimated volume of treated lumber and timbers, by end-use, 1978[a]

| End-use Area | Lumber and Timbers Treated With | | | | |
|---|---|---|---|---|---|
| | All Preservatives | Creosote | Penta | CCA | ACA |
| | 1,000 cu. ft. | | | | |
| All uses | 105,305 | 10,780 | 21,209 | 63,317 | 10,000 |
| Residential and commercial construction | 49,403 | 323 | 424 | 41,156 | 7,500 |
| Farm and industrial construction | 13,994 | 1,294 | 8,484 | 3,166 | 1,000 |
| Recreation | 13,287 | 108 | 3,181 | 9,498 | 500 |
| Marine | 12,265 | 4,797 | 636 | 6,332 | 500 |
| Transportation | 16,408 | 4,258 | 8,484 | 3,166 | 500 |

[a] Based on Tables 86 and 114.

From Table 115, it can be seen that:

--Forty-seven percent of all treated lumber and timbers is used in residential and commercial construction.

--Sixteen percent is used in transportation.

--The remainder is evenly divided between marine uses (12%), recreation uses (13%), and farm and industrial construction (13%).

Also, it can be seen that:

--More than 98% of the treated wood used in residential and commercial construction is treated with inorganic arsenicals.

--Sixty-one percent of treated farm and industrial construction materials is treated with penta, 30% is treated with arsenicals, and 9% is treated with creosote.

--Seventy-five percent of the treated wood used for recreation structures is treated with arsenical salts. Most of the rest is penta-treated material used primarily in park structures.

--More than 55% of the treated material used in marine structures is treated with arsenicals. About 40% is treated with creosote, and 5% is penta-treated material used for parts of marine structures above the water line.

--Fifty-two percent of the treated lumber and timbers used in transportation is penta-treated, 26% is treated with creosote, and 22% with arsenicals.

The market study cited above (Random Lengths, 1979) tends to corroborate this picture of the use of treated lumber, timbers, and plywood. The study found that sales of these treated products have expanded primarily because of increased use in "backyard" applications such as decks, fences, and walkways; and in the All Weather Wood Foundation (AWWF) for houses and other light-frame buildings. Treated products are also being used more frequently for sill and plate stock on slab foundations, and in other foundation and floor applications where decay and/or termite hazards exist. Development of the Plen-Wood System (wood-frame foundation for crawl space construction, in which the crawl space is used as a plenum for heating and air conditioning) has also boosted demand for treated wood in residential construction.

The AWWF for houses with basements and the Plen-Wood system for basementless houses were developed during the late 1960's and early 1970's through cooperative research by the U.S. Forest Service, the University of Florida, the National Forest Products Association (NFPA), the American Wood Preservers Institute (AWPI), and the National Association of Home Builders (NAHB). The systems use treated lumber and plywood in panelized sections or fastened together on site to form the building foundation. The systems were developed as alternates to masonry block or cast-in-place concrete foundations for houses with or without basements, and to slab-on-ground construction. Among their many advantages are (AWPI, 1970; and APA, 1977 and 1978):

1. Significant cost savings, especially in remote (rural) areas where cost and availability of skilled labor and materials are detrimental to use of concrete or masonry foundations. Elimination of air distribution ducts in the Plen-Wood system also lowers costs.

2. All-weather capability which extends the building season and eliminates costly construction delays in cold or very wet climates.

3. Capability for prefabrication which permits housing manufacturers to supply the complete house package and increases control over the total building process.

4. Warm, dry, easily insulated, and easy-to-finish foundation walls provide comfortable, habitable space below grade (AWWF).

5. Improved insulation, lower heating and cooling costs, conservation of energy, and a greater degree of comfort to occupants.

Since the early to mid 1970's, these systems have been actively promoted by NFPA and AWPI, joined by the American Plywood Association (APA), Southern Forest Products Association (SFPA), and Western Wood Products Association (WWPA).

Research on the AWWF (3 experimental houses) was completed in 1969 and acceptance of the system by national and local building code groups followed shortly. Commercial use of the AWWF grew from practically nothing in 1970, to 200 units in 1973 and 10,000 units in 1978 (Dixon, 1979). The APA estimates that there were 27,000 AWWF homes in the United States by the end of 1978. In addition, there are between 7,000 and 8,000 AWWF homes in Canada, and the system has been tried in Japan and Saudi Arabia.

Annual production of treated lumber for wood foundations grew from 0.51 million bd. ft. in 1973 to 19.4 million bd. ft. in 1978. Production of treated plywood for this use grew from 0.24 million sq. ft. (3/8-inch) to 10.6 million sq. ft. during the same period. These statistics indicate that approximately 2,000 bd. ft. of treated lumber and 1,000 sq. ft. of treated plywood are used per foundation. Use of treated products in crawl space foundations or in the Plen-Wood system would approximate 25% of that used per AWWF of the same length and width. While "foundation" lumber and plywood represent a very small proportion of the current market for all treated lumber and plywood, their use grew forty-fold in 5 years, and the potential for further growth is tremendous.

## Suitability of Preservatives for End Use

Table 116 shows the relative suitability of various wood preservatives for treatment of lumber, timbers, and plywood for specific end uses. Based on efficacy and other performance characteristics, arsenically treated materials are suitable for practically all uses without restriction. Furthermore, arsenicals are the only preservatives suitable for materials to be used in critical, structural applications in enclosed, habitable space in residential and other buildings. Also, of the three major classes of RPAR'd preservatives, only arsenicals are suitable for use in patios and decks, playground equipment, cooling towers, greenhouses, nurseries, and agricultural products such as grape and tomato stakes. Together, the above uses comprise the bulk of the market for treated lumber, timbers, and plywood. Arsenically treated wood is clean, odorless, paintable, easy to handle, harmless to plants, and durable. This is why more than 70% of all lumber, timbers, and plywood is treated with arsenicals.

Due to odor, objectionable vapors, and oily, unpaintable surfaces, penta- and creosote-treated lumber, timbers, and plywood have limited uses. Penta treatment is not effective for marine applications where attack by marine borers is likely. Penta and creosote are not usable in enclosed, unvented, habitable space. Penta in heavy oil and creosote are not generally suitable for treatment of materials to be used in decks, patios, playground equipment, stadium seats, agricultural uses, greenhouses, nurseries, cooling towers, and boat hulls and decks.

Wood treated with penta in light oil or volatile solvents--liquefied petroleum gas (Cellon process) or dimethylene chloride (Dow Process)--retains its natural color, and is durable, clean, and paintable. Such material is suitable for exterior, structural applications where clean treatment is required.

There are some uses for treated lumber and timbers for which arsenically treated material is not best suited, or is totally unsuitable. Industrial block flooring, for example, is treated only with creosote. The lubricating effect of the creosote protects the wood from mechanical, as well as physical, deterioration. Creosote also improves dimensional stability and reacts with the mastic to help bond the wood block to the concrete subfloor. Neither penta nor arsenical treatment is satisfactory for this use.

In other applications where treated material is subjected to a high volume of heavy traffic--e.g., crossing plank and decking for bridges, loading docks, wharves and piers--creosote-treated material is preferred because of the protection from weathering and abrasion that creosote imparts to the wood. Penta in P9, Type A oil provides some protection, but arsenical treatment provides little or no protection from the elements or mechanical wear.

Creosote-treated wood is preferred for industrial applications in high-acid environments because of creosote's high resistance to acids. Penta in heavy oil ranks second to creosote in this regard. Arsenical salts have no acid resistance.

Table 116.--Preservatives for lumber, timbers, and plywood[a]

| Uses | Creosote | Penta | CCA/ ACA | Cu-8 | TBTO | Cu-Naph | ACC | CZC |
|---|---|---|---|---|---|---|---|---|
| Residential, recreation, and commercial construction | | | | | | | | |
| Foundations, swimming pools | | | 1 | | | | | |
| Footings, sills, joists, etc within 12 inches of ground | | | 1 | | | | | |
| House logs, decks, patios, fences | | 2,4 | 1 | | | | 1 | |
| Landscape, garden timbers | 1 | 1 | 1 | | | | 1 | |
| Playground equipment, stadium seats | | | 1 | | | | 1 | |
| Boardwalks, marina piers | | | 1 | | | | | |
| Misc. nonstructural | | 2,4 | 1 | 3 | 3 | | 3 | 3 |
| Farm and industrial construction | | | | | | | | |
| Buildings, fences | 4 | 4 | 1 | | | 1 | | |
| Agricultural uses, greenhouses, nurseries | | | 1 | | | 1 | 1 | |
| Cooling towers | | | 1 | | | | 1 | |
| Mine ties and timbers | 1 | 1 | 1 | | | 1 | 1 | |
| Industrial block flooring | 1 | | | | | | | |
| Containers | | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| Misc. nonstructural | 4 | 4 | 1 | 3 | 3 | 3 | 3 | 3 |
| Marine uses | | | | | | | | |
| Seawalls, wharves, piers | 1 | | 1 | | | | | |
| Boat hulls and decks | | | 1 | | | | | |
| Transportation | | | | | | | | |
| Highway, railroad, pedestrian bridges | 1 | 1 | 1 | | | | | |
| Crossing planks, culverts | 1 | 1 | 1 | | | | | |
| Guardrails, signs | 1 | 1 | 1 | | | | | |
| Sound barriers | | 2 | 1 | | | | | |

[a] Based on Chapter 6, Table 78.

Legend:

1. Satisfactory-use without restriction.
2. Clean treatment only-light oil (mineral spirits) or other volatile solvent.
3. Above-ground only
4. Open, vented, nonhabitable space only-exterior.

Table 91 lists a number of preservatives, other than creosote, penta, and inorganic arsenicals, for use in treating various wood products. These are:

Copper Naphthenate (Cu-Naph)
Acid Copper Chromate (ACC)
Copper-8-quinolinolate (Cu-8)
Tributyltin Oxide (TBTO)
Chromated Zinc Chloride (CZC)

The characteristics and limitations of these preservatives are described in Chapter 6. For the most part they are recommended only for treatment of wood for noncritical, nonstructural uses above ground. Cost is a significant factor in use of most of these chemicals for general applications (Tables 91 and 92) as illustrated by the following comparative costs of chemicals for treating lumber or plywood for miscellaneous, nonstructural, above-ground uses in farm or industrial construction:

| Preservative | Retention | Cost of Preservative Per cu. ft. of Wood | Service Life |
|---|---|---|---|
| | Pcf | Dollars | Years |
| Creosote | 8.0 | 0.738 | 50 |
| Penta | 0.40 | 0.707 | 50 |
| CCA/ACA | 0.25 | 0.25 | 50 |
| Cu-8 | 0.16 | 3.79 | 35 |
| TBTO | 0.16 | 1.98 | 25 |
| Cu-Naph | 0.60 | 7.45 | 50 |
| ACC | 0.25 | 0.313 | 35 |
| CZC | 0.45 | 0.225 | 35 |

Due to their limitations and/or cost, Cu-8, TBTO, Cu-Naph, ACC, and CZC are not considered to be acceptable alternates for the large-volume, structural uses of creosote-, penta- and arsenically treated wood. CZC, however, can and is being used to treat sill plates, studs, and other parts of buildings used above ground and protected from the weather.

## Cost of Treated Lumber and Timbers

As noted previously, both the cost of preservative and the cost of treating are higher for creosote and penta than for CCA/ACA. The magnitude of the cost differences depends on the specific product, required retention of preservative, and whether or not CCA/ACA-treated material is redried after treatment. The price of CCA/ACA-treated lumber and timbers, f.o.b. treating plant, is estimated to be $5.58 per cu. ft., for material shipped wet and $6.03 per cu. ft. for redried material (see "Cost of Arsenically Treated Wood versus Untreated Wood" under "Impact of Canceling Inorganic Arsenicals for Treatment of Lumber, Timbers, and Plywood"). For comparative purposes, in the analyses that follow, the price of creosote- and penta-treated lumber and timbers is estimated to be $6.13 and $5.99 per cu. ft., respectively.

## Impact of Canceling Creosote for Treatment of Lumber, Timbers, and Plywood

Creosote is now used for about 10% of all treated lumber, timbers, and plywood, and 85% of the creosote-treated material is used in marine and transportation applications for which creosote is best suited (Table 115). About 10 million bd. ft. of creosote-treated material (6% of total) is industrial block flooring for which there is no substitute preservative. The remaining 9%, used primarily for landscape timbers and farm, mine, and marina construction, could be replaced with either penta- or arsenically treated material with no significant impact. (Arsenical treatment would be required in salt water marinas.)

Cancellation of creosote for treatment of industrial block flooring would result in loss of this market for some 700,000 cu. ft. of treated wood. There is no known substitute material with the resilience, strength, abrasion resistance, sound deadening, cushioning, and protective properties of wood block for this use. The alternative would likely be unprotected concrete floors and loss of the advantages that wood block affords to industrial plant owners and workers.

Penta in P9, Type A oil is the most likely substitute for creosote in bridge timbers, crossing planks, highway posts, car decking, loading docks, and wharf or pier decking above salt water, where protection from weather and mechanical wear are important considerations. Arsenicals are the only effective substitutes for creosote in seawalls and other marine applications subject to attack by marine borers. From the standpoint of protection from insects and decay organisms, arsenicals could be used in place of creosote for all uses, except industrial block flooring (about 94% of the lumber, timbers, and plywood now treated with creosote). For the heavy-duty uses in heavy traffic, however, arsenically treated material might require additional protection from weathering and/or mechanical wear at substantial additional cost. "Wear resistance" of arsenically treated boardwalk decking, and ways to improve it, were recently reported to be problems of concern to engineers of the city of Atlantic City, New Jersey (SAWP, 1979).

Also, treatment with arsenicals requires thorough seasoning before and, for some uses, after, treatment. For the relatively large wood members ordinarily treated with creosote, seasoning would be difficult and time consuming. Large wood members require months to air dry and would be difficult to kiln dry without serious loss in grade. Steaming or Boultonizing, followed by treatment with creosote or penta, would probably be cheaper in the long run.

A high percentage of the creosote-treated lumber and timbers used in transportation and marine applications is used for replacements in maintenance and repair of structures by railroads, utility companies, shipping companies, state highway departments and others--much the same as treated crossties are used by railroads (Pulakos, 1979; Cramer, 1978; King, 1978; Hagerty, 1978; and Wagner, 1979). The impracticability of using concrete or steel members to replace parts of existing wood structures, such as bridges, precludes the use of non-wood substitutes for this purpose. The Pennsylvania Department of Transportation currently maintains 246 wood bridges (Pulakos, 1979). The number of wood bridges in the North Carolina State highway system is so large ("literally thousands") that an accurate count does not exist (Wagner, 1979). The alternative to use of treated wood timbers for replacements in these structures (i.e. if all preservatives were canceled) would be complete rebuilding of all timber bridges whenever parts of them deteriorate to the point where repairs are required. This would upset existing bridge maintenance and replacement programs and cost incalculable billions of dollars.

Three scenarios for canceling creosote and shifting to CCA/ACA or penta for treatment of lumber and timbers are shown in Table 117. The difference in value (price) of treated products, the number of cylinders to be converted, the number of dry kilns required, and the conversion cost are also shown for each scenario.

Table 117.--Alternatives to creosote-treated lumber and timbers

| Scenario | Difference in Cost of Treated Products[a] | Cost of Conversion | | | |
|---|---|---|---|---|---|
| | | Number of Cylinders[b] | Number of Kilns[c] | Capital Investment[d] | First Year Cost[e] |
| | Million Dollars | | | - 1,000 Dollars - | |
| I Shift marine applications to CCA/ACA; shift remainder to penta[f] | (3.8) | 15 | 4 | 1,175 | 259 |
| II Shift marine, farm, residential and recreational applications to CCA/ACA; shift remainder to penta[f] | (4.2) | 15 | 4 | 1,175 | 259 |
| III Shift all except block flooring to CCA/ACA[f] | (6.0) | 14 | 7 | 1,750 | 385 |

[a] Assuming the price per cu. ft. f.o.b. treating plant equals $6.17 for creosote, $5.99 for penta, and $5.58 for CCA/ACA shipped wet. Cost reductions in parentheses.

[b] At 700,000 cu. ft. per cylinder.

[c] At 1,405,000 cu. ft. per kiln.

[d] At $25,000 per cylinder and $200,000 per kiln.

[e] Investment amortized over 10 years at 12% interest.

[f] 700,000 cu. ft. of industrial block flooring not included.

A switch from creosote to CCA/ACA and/or penta would reduce both the cost of preservative and the cost of treatment per cu. ft. of wood. These cost reductions would total $3.8 million for Scenario I, $4.2 million for Scenario II, and $6.0 million for Scenario III. These reductions would be partially offset by the cost of converting treating plants to the alternative preservatives. The combined effect of these cost differences, for the 10 million cu. ft. of lumber and timbers now treated with creosote would be as follows:

| | Reduction in Preservative and Treatment Cost | First-year Cost of Conversion | Net Reduction in Cost of Treated Wood |
|---|---|---|---|
| | - - - - - - - - - - - | Million Dollars | - - - - - - - - - - - |
| Scenario I | 3.8 | 0.259 | 3.54 |
| Scenario II | 4.2 | 0.259 | 3.94 |
| Scenario III | 6.0 | 0.385 | 5.62 |

The lowest cost alternative would be Scenario III, shift all creosote-treated material to CCA/ACA shipped wet, which would reduce the cost of treated wood by $0.56 per cu. ft. This savings would be reduced by the cost of redrying any of the CCA/ACA-treated material, or by a need for supplemental protection of any CCA/ACA-treated products from weathering or mechanical wear in use.

The amounts of penta, petroleum solvent, and CCA/ACA required annually to replace 99.8 million pounds of creosote used to treat lumber and timbers (1978) are:

| | |
|---|---|
| Scenario I | 3.1 million pounds penta, 5.4 million gallons petroleum solvent, and 2.9 million pounds CCA/ACA |
| Scenario II | 2.6 million pounds penta, 4.5 million gallons petroleum solvent, and 3.3 million pounds CCA/ACA. |
| Scenario III | 5.0 million pounds CCA/ACA |

## Impact of Canceling Penta for Treatment of Lumber, Timbers, and Plywood

The 20% of lumber, timbers, and plywood treated with penta is used primarily in farm and industrial construction, transportation (guardrail posts), and for signs, trail markers, and open shelters in parks. About 0.5 million cu. ft. is used in residential and commercial construction, mostly in light standards and bumper strips. Light standards are usually of laminated construction, in which case the material would be treated with penta in volatile solvent (Cellon or Dow Process). Salt-treated lumber can be glued but requires special adhesive formulations and more exacting gluing procedures which increase costs and the potential for failures. Penta is commonly used for treatment of laminated products.

Except for material to be laminated, all of these uses for penta-treated lumber and timber could be served with equal efficacy by either creosote- or arsenically treated material. Because of its cleanliness, freedom from odor, ease of handling, and lower cost, arsenically treated material would probably be preferred for most, if not all, of these uses.

Thus, if penta were canceled for treatment of lumber, timbers, and plywood, all but the small percentage of these materials that is used in laminated products would probably be treated with arsenicals. The shift from penta to CCA/ACA would require conversion of 30 cylinders and construction of 20 dry kilns at a cost of $4.75 million. The first-year cost of this investment, amortized over 10 years at 12% interest, would be $1.045 million.

Cost of preservative and cost of treatment would be reduced by $8.7 million, assuming that arsenically treated material would be shipped wet. The net reduction in the value (cost) of treated wood, after deducting the first-year cost of conversion, would be $7.7 million, or about $0.36 per cu. ft. If the arsenically treated material was redried, its value (cost) would increase to $0.9 million more than the cost of penta-treated material (about $0.04 per cu. ft.). The increased demand for arsenical salts (10.3 million pounds) would add about 28% to estimated 1978 consumption. This would replace about 11.8 million pounds of penta and 20.0 million gallons of petroleum solvent.

## Impact of Canceling Inorganic Arsenicals for Treatment of Lumber, Timbers, and Plywood

More than 70% of all lumber, timbers, and plywood is treated with arsenicals. About 86% of this material is treated with CCA, and nearly 14% is treated with ACA (Table 115). Use of FCAP has dwindled to less than 1% of the volume treated, and this preservative appears to be decreasing in use each year.

ACA was developed for treating refractory western species such as Douglas-fir, hemlock, spruce, true firs, and larch, which are not treatable with CCA. ACA is, therefore, used almost exclusively in the West where these species dominate. Without it there would be no clean, paintable, odorless treatment of these species for critical structural uses where penta and creosote are precluded.

Arsenically treated lumber, timbers, and plywood comprise 80% of total wood treated with arsenicals and more than 22% of all treated wood products (Tables 82 and 85). Two-thirds of these materials are used in residential and commercial construction and account for 98% of treated lumber, timbers, and plywood consumed in this segment of the market. About 14% is used in recreation structures, 9% in marine applications, 6% in farm and industrial construction, and 5% in transportation (Table 115).

As indicated earlier in this chapter, arsenicals are the only preservatives suitable for use in house and other habitable building construction, patios and decks, greenhouses, nurseries, fruit and vegetable production, playground equipment, stadium seats, and cooling towers. These uses account for practically all of the arsenically treated lumber, timbers, and plywood used in residential and commercial construction, farm and industrial uses, and recreation structures. It, therefore, seems reasonable to assume that at least 80% of these materials go into applications for which neither creosote nor penta is a usable alternative.

As noted previously, these applications represent a rapidly growing, increasingly important segment of the market for treated wood, and are largely responsible for substantial growth of the wood preserving industry in recent years. In Florida alone, an estimated 7.0 million cu. ft. of arsenically treated lumber and plywood are used annually, about 75% of it in residential construction for sill plates on concrete slabs, studs in contact with slabs, and for patios and decks (Petot, 1979; and Walker, 1979). Similar use patterns were described by treaters in Alabama (Jamison, 1979; and Hallman, 1979) and Georgia (Zimmerman, 1979).

In Hawaii, arsenically treated lumber, timbers, and plywood are particularly important for protection of buildings and other structures against the destructive Formosan termite (Coptotermes formosanus), aggressive drywood termites, and the year-round climate which is favorable to both wood decay and termite activity. More than one billion bd. ft. of treated products--enough material to build 70,000 homes--have been used in Hawaii since 1936 (Hallsted, 1979). Practically all housing is of wood frame construction and treated wood is commonly used for all parts of the building. Treated wood has been used increasingly in recent years to replace previously used all-heart redwood which is in short supply, high-priced, and variable or inconsistent in its resistance to attack by insects and decay (Dost, 1979a). Soil poisoning, alone, will not provide the necessary protection from Formosan and drywood termites which are peculiar to Hawaii. There is no known, economically feasible alternative to arsenically treated wood for combating these pests in houses and other habitable structures (Hallsted, 1979).

In the Chicago market, sales of CCA-treated lumber by the area's largest building materials distributor are reported to have increased from one million bd. ft. (66,000 cu. ft.) in 1976-77 to 10 million bd. ft. (660,000 cu. ft.) in 1979 (Larsen, 1979). Treated wood is being used increasingly for sill plates, for wood decks which are rapidly replacing concrete, and for yard and garden fencing. A Minneapolis wholesaler also sold 10 million bd. ft. of CCA-treated material in 1979 for the same uses (Larsen, 1979).

Other estimates (Petot, 1979; Walker, 1979; Waters, 1979; Conover, 1979; and Dost, 1979) indicate that practically all of the arsenically treated farm and industrial construction materials are used for grape and tomato stakes, nursery shade structures, greenhouses, and cooling towers.

Southern lumber producers have estimated that 1979 sales to treating plants are as much as 50% ahead of the 1978 pace (Random Lengths, 1979). The bulk of this increased production was probably treated with arsenicals for the uses described above. For all practical purposes then, creosote and penta are not suitable substitutes for arsenicals in lumber, timbers, and plywood. If arsenicals were canceled for treatment of these materials, the alternatives would be to use untreated wood--preferably cedar, redwood, or cypress which are scarce, high-priced, and less durable than treated wood--or switch to non-wood substitutes where applicable.

At least one important and rapidly growing use of treated wood--foundations for houses and other light-frame buildings--would be eliminated by cancellation of arsenicals. This market would revert to concrete or masonry substitutes, and the advantages of treated wood construction would be lost to builders and home buyers.

### Durability of Arsenically Treated Wood Versus Untreated Wood

Lumber, timbers, and plywood properly treated to recommended retentions of arsenical salts for specific uses will resist attack by insects and decay organisms for 30 or more years (Table 91).

The service life of untreated cedar or redwood depends on exposure conditions and whether or not any sapwood is included in the material. A cedar fence in Gulfport, Mississippi, recently failed due to decay in posts and rails, after 9 years of service (Smith, 1979a). This fence was protected from termite damage by application of chlordane to the soil around the posts. A similar cedar fence in the same location failed due to termite damage after 7 years. Exposure conditions in Gulfport are typical of the Southern and Southeastern Gulf and Coastal States where decay and termite hazards are severe (USDA, 1974). For cedar and redwood in ground contact, an average life of 10 years is assumed. For less severe exposure in above-ground structures, an average life of 15 years is assumed for these species.

Untreated wood of nondurable species normally used in construction cannot be expected to last more than 2-5 years under conditions of exposure in which treated lumber, timbers, and plywood are normally used. A 2-year life is assumed in the analyses that follow.

### Cost of Arsenically Treated Wood Versus Untreated Wood

Random Lengths (1979a) weekly lumber price guide of September 14, showed the f.o.b. mill price per 1,000 bd. ft. of various species and grades of construction lumber to be as follows:

|  | Green | Kiln Dried |
|---|---|---|
| Southern pine, No. 2 & Btr., 2 x 6 | $216 | $308 |
| Ponderosa pine, No. 2 & Btr., 2 x 6 | - | 295 |
| Douglas-fir, No. 2 & Btr., 2 x 6 | 187 | 308 |
| Hem-Fir, No. 2 & Btr., 2 x 6 | 183 | 296 |
| Western redcedar, No. 2 & Btr., 2 x 6 | 375 | NA |
| Inland redcedar, No. 3 & Btr., 1 x 6 | - | 585 |
| Douglas-fir, select decking, 2 x 6, 2 x 8 | - | 355 |
| Ponderosa pine, select decking, 2 x 6, 2 x 8 | - | 295 |
| Cedar, select decking, 2 x 6, 2 x 8 | - | 525 |

Discussion with knowledgeable treating industry officials and with individual treaters and distributors of treated wood (Petot, 1979; Walker, 1979; and Zimmerman, 1979) indicates that treatment with inorganic arsenicals adds $60.00 per 1,000 bd. ft. to the cost of southern pine lumber, f.o.b. treating plant, and $75.00 per 1,000 bd. ft. to the cost of Douglas-fir and other western species. Drying of the material after treatment adds an additional $30.00 to southern pine and $45.00 to western species. The cost (price) of arsenically treated lumber and timber f.o.b. treating plant is, therefore, estimated to be:

|  |  |
|---|---|
| Southern pine, No. 2 & Btr., 2 x 6, shipped wet | $368 |
| Southern pine, No. 2 & Btr., 2 x 6, shipped dry | 398 |
| Douglas-fir, No. 2 & Btr., 2 x 6, shipped wet | 383 |
| Douglas-fir, No. 2 & Btr., 2 x 6, shipped dry | 428 |

The cost of CCA/ACA preservative chemicals per 1,000 bd. ft. of treated wood at 0.4 pcf retention would be $23 to $33, depending on whether the material was rough sawn or surfaced to American Lumber Standard thickness and width. At the average volume of 66 cu. ft. per 1,000 bd. ft. used in this report, the cost of preservative would be $26 (Table 92).

Recent newspaper advertisements show the retail prices per 1,000 bd. ft. of various materials in the Washington Metropolitan area to be:[4]

|  |  |
|---|---|
| Southern pine dimension lumber, untreated | $359 |
| Southern pine dimension lumber, treated, 0.4 pcf CCA | 520 |
| Western redcedar fencing lumber | 897 |
| All-heart redwood lumber, construction grade | 983 |

Based on the foregoing, we conclude that the cost ratios of various construction materials in the Eastern United States where most treated wood is produced and consumed, is as follows:

|  |  |
|---|---|
| Untreated southern pine | 1.00 |
| Treated southern pine | 1.45 |
| Western redcedar | 2.50 |
| Redwood | 2.75 |

Compared to treated southern pine, western cedar costs 73% more, and redwood costs 90% more.

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[4] Lowest regular prices shown for these materials in advertisements by Suburban Lumberteria, Bladensburg, Md.; Dale Lumber Co., Falls Church, Va.; and Hechinger Co., October, 1979.

These ratios will vary from region to region. In Florida, cedar is said to cost 2.4 times, and redwood 3 or more times, as much as treated southern pine (Petot, 1979; and Walker, 1979). In the Western United States, the cost of treated lumber is higher, and cedar and redwood should be lower priced, therefore narrowing the cost differences. The ratios developed for the Eastern United States, above, will be considered average, and used in this analysis.

### Impact of Substituting Untreated Wood for Treated Wood

About half of the arsenically treated lumber and timbers used in residential construction goes into decks, patios, and fences (some 23 million cu. ft. or nearly 350 million bd. ft.). The cost of this material is about $140 million at the treating plant, and $182 million at retail prices in the Washington Metropolitan area. For comparative purposes, the cost and durability of alternative materials for this use are as follows:

|  | Retail Value Million Dollars | Service Life Years |
|---|---|---|
| Untreated southern pine | 125.7 | 2 |
| Treated southern pine | 182.0 | 30+ |
| Western redcedar | 314.0 | 12 |
| Redwood | 344.0 | 12 |

Note: Cedar and redwood are given a 12-year average life on the assumption that part would be used in ground contact and part would be used above ground.

It is apparent that the cost of untreated pine, cedar, or redwood, over a 30-year period, would be considerably greater than the cost of treated pine. Compared to treated pine, 15 times as much untreated pine, and 3 times as much cedar or redwood would be required for a given application over the life of treated pine. These cost comparisons are for materials only and do not include the cost of labor for installing, repairing, or rebuilding structures constructed of either treated or untreated wood.

The National Association of Home Builders (NAHB) conducts periodic surveys of the component costs of typical single family houses produced throughout the United States. A recent report of construction component costs, 1973-77 (NAHB, 1978) shows that the cost of carpentry labor averaged about two-thirds the cost of lumber and one-third the cost of all wood materials (including flooring and millwork) in the typical single family house during this 5-year period. It, thus, seems reasonable to assume that installation labor costs would average at least half of the material costs for structures in which pressure-treated lumber is commonly used. Based on material cost of untreated southern pine (installation cost would most likely not be affected by treatment) installation labor cost, regardless of treatment or species, is estimated to be $179.50 per 1,000 bd. ft., or $2.72 per cu. ft. The cost ratios of alternative construction materials, installed, in the Eastern United States then become:

|  |  |
|---|---|
| Untreated southern pine | 1.00 |
| Treated southern pine | 1.30 |
| Western redcedar | 2.00 |
| Redwood | 2.16 |

The initial installed cost and durability of alternative materials used for decks, patios, and fences is estimated to be:

| | Installed Cost<br>Million Dollars | Service Life<br>Years |
|---|---|---|
| Untreated southern pine | 188.5 | 2 |
| Treated southern pine | 244.8 | 30+ |
| Western redcedar | 376.8 | 12 |
| Redwood | 406.9 | 12 |

Assuming continued consumption of treated pine for patios, decks, and fencing at the estimated 1978 rate of 23 million cu. ft. annually, and average service lives of 30 years for treated pine, 2 years for untreated pine, and 12 years for cedar and redwood, the annual expenditure (cost) for treated pine and alternative materials can be calculated for any number of years in the future. For example, assuming that structures are replaced in kind at the end of their service lives, the expenditure (installed cost) for treated pine would be $244.8 million each year for 30 years, and would double in the 31st year. The investment in untreated pine would double in the 3rd year, triple in the 5th year, and so on. Investments in cedar and redwood would double in the 13th year and triple in the 25th year. Costs for each year in the future can be discounted to present value at a selected rate of interest, using the formula $Vo = Vn \times \frac{1}{(1 + r)^n}$, and summed to find the present value of the series of future costs over any number of years.

The present value is the initial investment that must be made at the specified rate of interest so that the proceeds will equal the anticipated future costs over the period of n years. The initial investment can then be amortized over the number of years, n, to find the average annual cost of using the alternative materials. The estimated cost of using alternative materials in patios, decks, and fencing over the 30-year life of treated pine is shown in Table 118.

Table 118.--Estimated cost of using alternative materials in patios, decks, and fencing[a]

| Item | Treated Pine | Untreated Pine | Western Redcedar | Redwood |
|---|---|---|---|---|
| Installed cost (million dollars) | 244.8 | 188.5 | 376.8 | 406.9 |
| Service life (years) | 30 | 2 | 12 | 12 |
| Present value[b] (million dollars) | 2,538.5 | 9,480.2 | 5,173.5 | 5,586.8 |
| Average annual cost[c] (million dollars) | 244.8 | 914.3 | 498.9 | 538.8 |

[a] Assuming continued consumption of 23 million cu. ft. annually, and replacement of structures in kind at the end of their service lives.

[b] Of future costs of alternative materials over 30 years at 10% interest on investment.

[c] For 30 years at 10% interest on investment.

The initial investments required to cover the costs of using untreated pine, redcedar, and redwood for these applications over 30 years at 10% interest exceed that required for treated pine by 6.9, 2.6, and $3.0 billion, respectively. Assuming sufficient supplies of alternative materials to replace treated pine at current prices, the average annual cost of using untreated pine, redcedar, and redwood would be 254 to $670 million higher than the cost of treated pine.

A typical wood deck, with 2-inch-thick deckboards, elevated 4 feet off the ground, is estimated to require about 4 bd. ft. of lumber per sq. ft. of deck area. A recent advertisement in Washington, D.C. newspapers quoted prices of materials for decks ranging in size from 8 x 12 ft. (96 sq. ft.) to 12 x 16 ft. (192 sq. ft.). The average area of the decks described was 142 sq. ft.

If two-thirds of the 350 million bd. ft. of arsenically treated lumber and timber ascribed to patios, decks, and fencing is used for patios and decks, and if the average area is 142 sq. ft. per patio or deck, then some 540 bd. ft. of material is used per deck and 433,000 decks were built from arsenically treated lumber and timbers in 1978. This number is equivalent to 30% of the 1,433,000 privately-owned, single-family housing starts reported by the Bureau of the Census in 1978.

All decks are not built on new houses and this estimate of the number being built may not be exact. But wood preservation statistics clearly show that the number of houses with wood decks is fast increasing. An estimated 85% of the treated lumber sold in the Chicago market area is currently going into wood decks (Larsen, 1979). Cancellation of arsenically treated materials for this use would leave home builders and home buyers with 3 alternatives:

--Use untreated pine, or similar nondurable species, for decks at 3.7 times the cost of using treated wood. At the 1978 estimated rate of consumption, average annual cost of untreated wood over 30 years would exceed that of treated wood by $446.4 million. Annual requirements for untreated lumber in 30 years would be 15 times current use of treated wood, or 3.5 billion bd. ft.

--Use western redcedar or redwood at 2 to 2.2 times the cost of using treated wood, assuming that sufficient materials would be available at current prices. Annual costs over 30 years would average 169 to $196 million more than the cost of treated wood.

--Forego the wood deck and use a concrete slab. This alternative would require design changes in large numbers of new homes and thwart the obvious desires and preferences of increasing numbers of homebuyers for designs that include wood decks. A concrete deck at ground level is not equivalent to a wood deck which is often elevated 4 to 8 feet above the ground. The cost of forming for, and supporting a concrete deck above ground, would very likely be prohibitive.

Agricultural, industrial, and recreational uses of arsenically treated lumber and timbers totaled an estimated 14.2 million cu. ft. in 1978 (Table 115). An indication of the importance of treated wood in these applications can be had from analysis of the use of treated wood in Florida agriculture.

Florida has 35,000 acres of tomatoes. Tomato production is a $150 million industry in the State. About two-thirds of the acreage in south Florida is grown on stakes. Staking increases the cost per acre, but also increases yield and quality of tomatoes, and reduces the acreage required to produce a given volume of product. The trend is toward increased use of stakes. Tomato stakes are rough sawn wood, 1-inch square and 4 to 6 feet long (average 5 feet). Metal stakes are too expensive, and trellising requires too much labor to take down wire, roll it, and restring it between crops (Waters, 1979).

There are an estimated 100 million stakes in use in Florida and approximately 20 million are required annually for replacements (Waters, 1979). Average life is, therefore, 5 years. In south Florida it is not uncommon to grow two crops of tomatoes each year. Stakes are, therefore, driven and pulled twice annually. Failures of treated stakes are by breakage. Due to high termite and decay hazard, untreated stakes would last 2 years at best (Petot, 1979). Cypress stakes resist attack by insects and decay (Waters, 1979), but cypress is in high demand for fencing at $420.00 per 1,000 bd. ft., and too expensive and scarce for production of tomato stakes (Petot, 1979). Treated stakes sell for 10 to 12 cents each. Thus, 20 million new treated stakes represent a 2.0 to $2.4 million annual cost to Florida tomato growers. About 5 million bd. ft. (net volume in stakes) or 416,000 cu. ft. of treated wood is used for this purpose in Florida. Treaters report markets for treated stakes throughout the South, west to the Rio Grande, and as far north as Michigan.

Use of untreated wood stakes (with 2-year life) in Florida would boost requirements to 50 million stakes annually--12.5 million net board feet of stakes. Dry, 1-inch, No. 2 & Btr. southern pine lumber currently sells for $300 per 1,000 bd. ft., f.o.b. mill (Random Lengths, 1979). Assuming a 70% yield of tomato stakes from this material, 17.9 million bd. ft. of lumber would be required to produce 50 million stakes at a cost of $5.4 million for materials. Labor, equipment, and overhead would add an estimated $50 per 1,000 bd. ft. of raw material for processing lumber into tomato stakes. This would bring the initial cost of 50 million untreated stakes to $6.3 million--an increase of 4 to $4.3 million over the annual expenditure for treated wood stakes. Due to its shorter service life, the annual cost of using untreated pine stakes at 10% interest on investment would be about 6 times the cost of using treated wood.

Similarly, using cypress at $420 per 1,000 bd. ft. at 70% yield of stakes and $50 per 1,000 bd. ft. for processing would require 7.1 million bd. ft. of lumber to produce 20 million stakes annually. Assuming that cypress would last an average of 5 years (the same as treated wood), the initial cost of cypress stakes would be $3.4 million, an increase of 1 to $1.4 million over the cost of treated wood. Annual cost of using cypress would be 1.4 to 1.7 times that of using treated wood.

The tropical foliage plant and cut foliage industry in Florida is another user of treated wood. The material is used for framing (posts, stringers, and roof supports) in open structures to provide shade for foliage plants, and in fiberglass greenhouses. Most of the wood that is used is rough sawn and treated with CCA. Proper treatment can add 10 or more years to the life of wood structures. Termites and decay will destroy untreated wood in 1.5 years (Conover, 1979).

There are an estimated 1,500 acres of open wood structures for shading foliage plants, and 1,000 acres of similar structures for cut fern and foliage. In addition, there are an estimated 300-400 acres of fiberglass greenhouses consisting of treated wood trusses mounted on treated wood posts, with treated wood stringers attached to sides and roof. Fiberglass panels are mounted on the wall and roof stringers. These wood structures are low-cost and easy to construct with unskilled labor. They are used primarily by small producers who cannot afford high-cost masonry or metal construction. These producers would be severely impacted by cancellation of arsenically treated wood (Conover, 1979).

The uses of arsenically treated lumber, timbers, and plywood are widespread and varied. It is not possible to examine every use and analyze the benefits or costs of every alternative. The examples cited above (i.e., patios, decks, and yard and garden fences; and agricultural and horticultural uses) clearly show that untreated wood, of either "durable" or "nondurable" species, would be an expensive and impractical substitute for arsenically treated lumber for most, if not all, of its uses. Cedar or redwood would cost 2 to 3 times as much as treated wood, depending on the end use and geographic location. Use of untreated pine or similar nondurable species would increase costs by 300% to 500%.

A recent study (Bolsinger, 1979) found that demand for western redcedar products has increased rapidly over the past 10 years (coincidentally with growth in demand for arsenically treated lumber). Consumption and prices of cedar products have risen more rapidly than for most other West Coast woods. Cedar is currently being used more rapidly than it is being replaced in the forests. Supply is declining, especially in western Oregon and western Washington. Old-growth is becoming scarce outside the National Forests. National Forests will continue to supply old-growth cedar for many decades, but in smaller quantities than are now being produced from all public and private forests. Total future supply of western redcedar, including young (second) growth, will be considerably less than is now being consumed. The supply, demand, and price situation for redwood is much the same as for cedar (Oswald, 1978). Therefore, these species are not regarded as practicable substitutes for the large volumes of arsenically treated materials currently being consumed.

### Use of Nonwood Substitutes for Arsenically Treated Lumber, Timbers, and Plywood

There are some uses for arsenically treated lumber and timbers for which concrete or metal could be used at lower cost. For example:

- The installed cost of chain link fence might be considerably less than the cost of materials for a treated wood fence of the same height and length (Smith, 1979a). Welded, galvanized wire mesh on steel posts would cost less than chain link.

- At current prices[5] of ready-mix concrete ($45 per cu. yd.), reinforcing wire mesh ($.082 per sq. ft.), and CCA-treated pine lumber ($520 per 1,000 bd. ft.), the materials for a 4-inch concrete patio slab would cost about one-half as much as lumber and fasteners for a wood deck on grade.

- Some users of treated wood for structures such as bikeway and pedestrian bridges, and highway sound barriers, indicate that steel or concrete structures can be built at lower cost (Kinstlinger, 1978).

As discussed in Chapter 7, aesthetics and the purpose or function of the fence are probably the most important determinants in the selection of fence materials, particularly for yard, garden, and patio fences. Chain link or galvanized wire fencing are effective for confining pets or small children at relatively low cost, but they are seldom used for decorative purposes. Few, if any, homeowners who pay 6 to $8 per lineal foot for treated wood, yard or patio, privacy fences would regard galvanized wire or chain link fence as a suitable substitute. Wood is most often used for decorative or rustic appearance to blend in with or complement its surroundings.

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[5] Washington Metropolitan area, October 1979.

Aesthetics and function are also important in selection of materials for patios and decks. A concrete slab on ground may be lower in cost, but it is no substitute for a wood deck, which is most often elevated above the ground. A concrete deck above ground would be considerably more costly to construct than a slab on ground, and probably would not be aesthetically satisfactory to the builders and buyers of the majority of new homes with wood decks.

Finally, aesthetics may outweigh initial cost in the selection of materials for many structures by park and recreation managers, state highway departments, port authorities, and others (Kinstlinger, 1978; Wagner, 1979; Hagerty, 1978; King, 1978; and Langley, 1979).

For most applications where treated lumber, timbers, and plywood are used, concrete and steel are commonly considered to be more costly substitutes, both initially and over the long run. The installed cost of a concrete crosstie is 75% higher than for a treated wood crosstie (Table 94). Concrete and steel poles are estimated to cost 2.2 and 3 times as much as treated wood, respectively (Table 97). Estimates of comparative costs of treated lumber and timbers, concrete, and steel for other structures are similar to those for crossties and poles. For example:

- Bulkheads, retaining walls, fishing piers in salt or fresh water. Concrete or steel are estimated to cost 5 to 7 times as much as treated wood (Weisinger, 1978).

- Piling for bridges, docks, wharves, and similar structures. Concrete is estimated to cost 1.4 to 2.4 times as much, and steel 1.5 times as much, as treated wood (Gehler, 1978; Jenkins, 1979; and Cramer, 1978).

- Bridges, fender systems, docks, landings, and other light-duty transportation facilities in or near the water. Concrete or steel would cost 3 to 4 times as much as treated wood (Cramer, 1978).

- Lumber and planking for bridges and other structures. Concrete or steel would cost 2 times as much as treated wood (Gehler, 1978).

- Posts for highway signs and guardrails. Steel posts would cost 1.5 to 3 times as much as treated wood (Gehler, 1978; Jenkins, 1979; and Wagner, 1979).

Thus, designers, specifiers, and users of treated wood for a variety of applications agree that concrete or steel are high-cost substitutes in these applications. Depending on the locality and end-use, concrete and steel are estimated to cost 40% to 600% more than treated wood.

Josephson (1979) estimated, conservatively, that use of concrete, steel, or other non-wood materials would cost 10% to 15% more in applications where treated lumber, timbers, and plywood are commonly used. Josephson's estimate was, indeed, conservative. The examples cited above indicate that the increased cost of using concrete or steel could well exceed 50%.

According to Josephson's estimate of 15% cost increase from substitution of non-wood materials for all arsenically treated lumber and timbers, continued use of some 73.3 million cu. ft. (Table 115) of these products, annually, (valued at $10.60 per cu. ft., installed) would result in savings of some $116 million annually in current expenditures. The present value of future payments for non-wood substitutes over

30 years at 10% interest would exceed that for arsenically treated wood by $1,208.6 million.

If concrete or steel substitutes cost 50% more than treated wood, the savings cited above would be more than 3 times as high, i.e., $388.5 million annually in current expenditures, and $4.028 million in present value at 10% interest over 30 years.

### Costs of Canceling Arsenicals

Based on estimated 1978 production, cancellation of arsenicals for treatment of lumber, timbers, and plywood would eliminate 80% of the total wood treated with arsenicals, 70% of all treated lumber, timbers, and plywood, and more than 22% of all treated wood products. Since creosote and penta are not suitable for use in most applications of arsenically treated material, very little of this production (less than 20%) could be shifted to either of these preservatives. For all practical purposes, the markets now served by arsenically treated materials would be lost to untreated wood or non-wood substitutes. Alternatives to arsenically treated lumber and timbers for its various uses are shown in Table 119. The present value of future investments in these alternatives over 30 years at 10% interest, and the average annual cost of each alternative, are shown in Table 120.

Table 119.--Alternatives to arsenically treated lumber and timbers

| Use | Estimated Volume 1978 | Alternative | Percent of Total Treated Material |
|---|---|---|---|
| | 1,000 cu. ft. | | |
| All uses | 73,317 | -- | 100.0 |
| AWWF | 1,600 | None | 2.2 |
| Patios, decks | 15,300 | Untreated wood | 20.9 |
| Residential fences | 7,700 | Untreated wood or steel | 10.5 |
| Other residential[a] | 24,000 | CZC | 32.7 |
| Farm, industrial, recreation | 14,200 | Untreated wood or concrete or steel | 19.4 |
| Marine | 6,832 | Creosote[b] or concrete or steel | 9.3 |
| Transportation | 3,666 | Creosote or penta or concrete or steel | 5.0 |

[a] Sills, plates, studs, joists, and other structural uses.

[b] For use only where *Limnoria tripunctata* are not present.

Table 120.--Cost of alternatives to arsenically treated lumber and timbers

| Use and Volume Treated[a] | Alternative | Installed Cost | | Service Life | Present Value[b] | Average Annual Cost[c] |
|---|---|---|---|---|---|---|
| | | Per cu. ft. | Total | | | |
| 1,000 cu. ft. | | Dollars | Million Dollars | Years | Million Dollars | |
| Patios, decks | Treated pine | 10.60 | 163.2 | 30 | 1,692.3 | 163.2 |
| 15,300 | Untreated pine | 8.16 | 124.8 | 2 | 6,276.6 | 605.3 |
| | Redcedar | 16.31 | 249.5 | 12 | 3,425.7 | 330.4 |
| | Redwood | 17.61 | 269.4 | 12 | 3,698.9 | 356.7 |
| Residential | Treated pine | 10.60 | 81.6 | 30 | 846.2 | 81.6 |
| fences | Untreated pine | 8.16 | 62.8 | 2 | 3,158.4 | 304.6 |
| 7,700 | Redcedar | 16.31 | 125.6 | 12 | 1,724.5 | 166.3 |
| | Redwood | 17.61 | 135.6 | 12 | 1,861.8 | 179.5 |
| | Steel[d] | 15.90 | 122.4 | 30 | 1,269.3 | 122.4 |
| Other residential | Treated pine | 10.60 | 254.4 | 30 | 2,638.1 | 254.4 |
| 24,000 | CZC[e] | 10.57 | 253.7 | 30 | 2,630.8 | 253.7 |
| Farm, industrial, | Treated pine | 10.60 | 150.5 | 30 | 1,560.6 | 150.5 |
| recreation | Untreated pine | 8.16 | 115.9 | 2 | 5,829.0 | 562.1 |
| 14,200 | Redcedar | 16.31 | 231.6 | 12 | 3,179.9 | 306.7 |
| | Redwood | 17.61 | 250.1 | 12 | 3,433.9 | 331.2 |
| | Concrete/Steel[d] | 15.90 | 225.8 | 30 | 2,341.5 | 225.8 |
| Marine | Treated pine | 10.60 | 72.4 | 30 | 750.8 | 72.4 |
| 6,832 | Creosote | 11.35 | 77.5 | 30 | 803.7 | 77.5 |
| | Concrete/Steel[d] | 15.90 | 108.6 | 30 | 1,126.1 | 108.6 |
| Transportation | Treated pine | 10.60 | 38.9 | 30 | 403.4 | 38.9 |
| 3,666 | Creosote | 11.32 | 41.5 | 30 | 430.3 | 41.5 |
| | Penta | 11.16 | 40.9 | 30 | 424.1 | 40.9 |
| | Concrete/Steel[d] | 15.90 | 58.3 | 30 | 604.6 | 58.3 |

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[a] From Table 119.

[b] Of future costs over 30 years at 10% interest on investment.

[c] For 30 years at 10% interest on investment.

[d] At 1.5 times the installed cost of treated pine.

[e] Chromated zinc chloride treatment.

Costs to Consumers of Treated Wood.--Losses or costs to consumers of these treated products are difficult to aggregate, but would undoubtedly be substantial. The AWWF system, for example, would no longer be available as an option to home buyers. At 1977 prices, the system saves an estimated $600 per housing unit (Josephson, 1979). At the 1978 rate of use, this represents an annual loss of

$6 million to builders or home buyers. The rapidly increasing acceptance and use of the system in recent years indicates that potential losses are far greater than $6 million, annually. In addition, the advantages of easy-to-apply, more effective insulation; easy-to-finish interior foundation walls; lower heating and cooling costs; conservation of energy; and more confortable space below grade would be lost to increasing numbers of home buyers. It is impossible to put a dollar value on such losses, but they could well exceed those attributed to increased foundation construction costs.

As indicated in Table 119, arsenically treated materials used in marine and transportation applications (about 14% of total) could be shifted to creosote, provided that the marine materials were not subject to attack by Limnoria tripunctata. The 3.7 million cu. ft. used in transportation could also be shifted to penta. The shift to creosote, or to creosote and penta, would require conversion of 15 cylinders at a cost of $7.5 million. First-year cost, if amortized over 10 years at 12% interest, would be $1.6 million.

If all of this material were converted to creosote, increased costs of preservative and treatment would increase the value (cost) of the treated products by $6.1 million. Adding the $1.6 million first-year cost of conversion would bring the total increase to $7.7 million--about $0.74 per cu. ft. of treated wood. About 132 million pounds of creosote would be needed to replace 9.5 million pounds of arsenical salts for these uses.

If materials used in transportation were converted to penta, 2.1 million pounds of penta and 3.7 million gallons of petroleum solvent would replace 2.0 million pounds of arsenicals. The combination of creosote for marine uses and penta for transportation uses would increase preservative and treatment costs by $5.5 million. This, plus the first-year cost of conversion, would raise the value (cost) of treated wood by $7.1 million, or $0.68 per cu. ft.

Cancellation of arsenically treated lumber for sill plates, studs, and other structural members of houses and other buildings (above-ground uses where material is protected from the weather) would probably result in a switch to chromated zinc chloride (CZC). At current (1979) prices, CZC at 0.45 pcf retention could replace CCA/ACA at 0.25 pcf for about $0.025 less cost per cu. ft. of treated wood (Tables 91 and 92). The impact of such a switch on cost and durability of treated wood for these uses would be negligible.

As described above, cancellation of treated wood for patios, decks, and fences would increase average annual expenditures for these structures by 254 to $670 million (Table 118), depending on whether builders would switch to "durable" cedar or redwood, or to untreated lumber of non-durable species. Rather than pay such costs, architects, builders, and home buyers would probably change their perferences and select house designs that exclude decks.

The costs of substituting untreated wood or non-wood materials for arsenically treated lumber and timbers are shown in Table 121. The three scenarios described in the table cover a range of possibilities from:

I. Converting patios and decks to untreated wood, "other residential" uses to treatments with CZC and all other uses to concrete or steel.

II. Converting residential fences, along with patios and decks, to untreated wood; "other residential" uses to CZC and converting all other uses to concrete or steel.

III. Using untreated wood wherever it might reasonably be substituted, and converting marine and transportation uses to concrete or steel.

Total costs, to all users, of the loss of arsenically treated lumber, timbers, and plywood obviously depend on which of the alternatives to treated wood are selected by various users. Depending on which combination of alternatives is selected, the present value of future investments in alternatives over 30 years at 10% interest would exceed those for arsenically treated wood by 3.5 to $11.7 billion. Annual savings (difference in average annual cost) from use of treated wood, at 10% interest over 30 years, would be 338 to $613 million for Scenario I (maximum use of concrete or steel); 382 to $795 million for Scenario II; and 463 to $1,132 million for Scenario III (maximum use of untreated wood).

The lowest cost in each of these comparisons is based on use of western redcedar with a service life of 12 years. There is a serious question as to the availability of sufficient cedar (or redwood) to replace the large volumes of arsenically treated lumber and timbers. Thus, the costs of canceling arsenicals would likely be close to the high end of the range for each of the comparisons, above. Average annual costs of switching to untreated wood and non-wood substitutes are estimated to be at least $400 million. The present value of these increased costs over 30 years at 10% interest is $4.1 billion. If users were to switch to untreated non-durable species of wood wherever they might reasonably be used, average annual costs over 30 years would be $1.1 billion higher than the cost of using treated wood. The present value of these increased costs at 10% interest is $11.7 billion.

The scenarios in Table 121 do not include costs of canceling treated lumber and plywood for wood foundations. The cost to users of the loss of these treated materials would be in addition to those shown for each scenario in the table.

Impacts on Producers, Processors, and Treaters of Forest Products.--Cancellation of arsenicals for treatment of lumber, timbers, and plywood would have a severe impact on the wood preserving industry, and on producers and processors of forest products. The recent growth trends in the treating industry would be halted. More than 22% of estimated 1978 production of all treated products would be eliminated, and very little of it would be replaced by penta- or creosote-treated material. Eighty percent of all arsenically treated material would be canceled, and few of the 221 treating plants that treat only with arsenicals could survive without the markets for treated lumber, timbers, and plywood. Another 104 plants, that treat with arsenicals, along with other preservatives, would also be affected.

Losses are estimated to include more than 2,600 jobs in the treating industry and $28 million in wages, mostly in small plants in small, rural communities. In terms of value of products shipped, losses would approximate $400 million. This total includes the wages cited above, along with payments to producers and processors of wood raw materials. There would be additional losses in the production, distribution, and sale of preservative chemicals ($37 million worth of arsenicals in 1978) and other materials and supplies to the treating industry. There would also be lost investments in treating facilities and equipment that would be put out of business by cancellation of arsenicals for lumber and timbers. Finally, there would be substantial losses of secondary benefits to merchants, businessmen, and others in the communities where impacted treating plants are located. Since 80% of the arsenically treated lumber, timbers, and plywood is southern pine, these losses would be felt most heavily in the South Central and Southeastern Regions. These impacts would be immediate and would continue until such time as affected individuals and resources could be put to other gainful uses.

Table 121.--Estimated cost of alternatives to arsenically treated lumber and timbers[a]

| Use | Alternative | Cost of Using Alternative[b] | | |
|---|---|---|---|---|
| | | Installed Cost[c] | Present Value[d] | Average Annual Cost[e] |
| | | Million Dollars | | |
| Scenario I | | | | |
| Patios and decks | Western redcedar | 86 | 1,733 | 167 |
| | Redwood | 106 | 2,007 | 194 |
| | Untreated pine[f] | (38) | 4,584 | 442 |
| Other residential | CZC | (1) | (7) | (1) |
| All other[g] | Concrete or steel[h] | 172 | 1,781 | 172 |
| | | 133-277 | 3,507-6,358 | 338-613 |
| Scenario II | | | | |
| Patios, decks, fences | Western redcedar | 130 | 2,612 | 252 |
| | Redwood | 160 | 3,022 | 291 |
| | Untreated pine[f] | (57) | 6,897 | 665 |
| Other residential | CZC | (1) | (7) | (1) |
| All other[i] | Concrete or steel[h] | 131 | 1,357 | 131 |
| | | 73-290 | 3,962-7,539 | 382-795 |
| Scenario III | | | | |
| Patios, decks, fences, farm, industrial, recreational | Western redcedar | 211 | 4,231 | 408 |
| | Redwood | 260 | 4,896 | 472 |
| | Untreated pine[f] | (92) | 11,165 | 1,077 |
| Other residential | CZC | (1) | (7) | (1) |
| All other[j] | Concrete or steel[h] | 56 | 577 | 56 |
| | | 37-315 | 4,801-11,735 | 463-1,132 |

[a] Alternatives to arsenical salts for patios, decks, fences, other residential, farm, industrial, recreational, marine, and transportation uses only. AWWF (Table 119) not included.

[b] Difference in cost due to use of alternative. Cost reductions in parentheses.

[c] Installed cost at estimated 1978 rate of use (Table 120).

[d] Of future costs of using alternatives over 30 years at 10% interest (Table 120).

[e] For 30 years at 10% interest on investment (Table 120).

[f] Or similar non-durable species.

[g] Residential fences, farm, industrial, recreational, marine, and transportation uses.

[h] At 1.5 times the installed cost of treated pine.

[i] Farm, industrial, recreational, marine, and transportation uses.

[j] Marine and transportation uses.

To the extent that users of treated products would switch to use of untreated wood, cancellation of arsenicals would result in increased employment in logging and sawmilling to produce the increased volumes of untreated products that would be required. The extent of such a switch and its effect on the impacts cited above have not been evaluated.

Losses of employment and income in the production, processing, and treatment of forest products would probably be offset, to some degree, by increased activity in the production and processing of substitute materials. This activity is not likely to occur, however, in the same localities where the impacted treating industry is located. The extent and effect of such cross-sectoral and regional shifts in employment and income have not been evaluated.

## Summary—Impacts of Canceling One or More Preservatives for Treatment of Lumber, Timbers, and Plywood

### Cancellation of Creosote

About 10% of the total production of treated lumber, timbers, and plywood would be affected. Depending on end-use, either penta or inorganic arsenic could be used in place of creosote for all but a small portion of these products. The market for some 0.7 million cu. ft. of industrial block flooring would be lost for lack of a suitable substitute for creosote.

Penta in heavy oil solvent would be the preferred substitute for creosote for 4.3 million cu. ft. used in transportation applications. Arsenicals would be the only effective substitute for creosote in marine uses (4.8 million cu. ft.). The remainder of the creosote-treated lumber and timbers could be treated with either penta or CCA/ACA, but arsenicals would probably be preferred. Depending on which alternatives were selected for creosote, the cost of preservative plus the cost of treatment, preservative costs would be reduced by from 3.8 to $6.0 million. Capital investment required to convert treating plants to alternative chemicals would vary from 1.2 to $1.8 million (260 to $385 million the first year). The net result would be a reduction in cost of treated wood of 3.54 to $5.62 million. The lowest cost alternative would be to switch all creosote-treated material to CCA/ACA. This would reduce the cost of treated wood by about $0.56 per cu. ft. About 5 million pounds of arsenical salts would be required to replace some 100 million pounds of creosote for these uses.

Since much of the creosote-treated lumber and timbers is used for replacements in maintenance and repair of existing structures, concrete and steel are not practical substitutes for this treated wood. Cancellation of penta and arsenicals, along with creosote, for treatment of lumber and timbers would create havoc in industrial and governmental maintenance programs, and necessitate rebuilding--or closing down--of treated timber structures in need of repairs. Costs to the U.S. economy would be astronomical.

### Cancellation of Penta

Twenty percent of the total production of treated lumber, timbers, and plywood--more than 21 million cu. ft. of treated wood--would be affected. Arsenically treated material would probably be preferred as a substitute for most, if not all, of the uses of penta-treated wood. Cancellation of penta in volatile solvents would cause problems to producers of laminated products from treated lumber. New adhesives and laminating procedures would have to be developed for gluing arsenically treated wood.

This would be time consuming and costly, at best, and could eliminate treated wood for laminated products, at worst.

Substitution of arsenicals for penta in lumber, timbers, and plywood would add about 10.5 million pounds of arsenical salts (28%) to estimated 1978 consumption. About 11.8 million pounds of penta and 10.9 million gallons of petroleum solvent would be replaced at a savings of $10.6 million in the cost of preservative chemicals. Conversion of plants from penta to CCA/ACA would require capital investment of $4.75 million. The first-year cost of this investment, amortized over 10 years at 12% interest, would be $1.045 million. A reduction of $8.7 million in cost of preservative and cost of treatment would result in a net reduction in the value (cost) of treated wood of about $7.7 million or $0.36 per cu. ft.

### Cancellation of Arsenicals

Seventy percent of the total production of treated lumber, timbers, and plywood; 80% of the total wood treated with arsenicals; and more than 22% of all treated wood products would be affected. Very little of this production (about 14%) could be shifted to either penta or creosote. Markets now served by arsenically treated materials would be lost to untreated wood or non-wood substitutes. The most practicable substitute for penta- and/or creosote-treated lumber, timbers, and plywood would also be lost.

Total costs to users of arsenically treated material would depend on which alternatives (untreated wood or non-wood substitutes) were selected by the many, varied users. It is estimated that canceling arsenicals would increase average annual costs of all users by at least $400 million. If users were to switch to untreated, non-durable species of wood wherever they might reasonably be used, average annual cost over 30 years would be $1.1 billion higher than the cost of using treated wood.

Some 325 plants that treat with arsenicals would be affected. Many of them would not survive. Based on estimated 1978 production, losses in terms of value of products shipped would be approximately $400 million. This total includes employment and wages in the treating industry, and payments to producers and processors of wood raw materials. There would be additional losses in production, distribution, and sale of preservative chemicals and other materials and supplies to the treating industry, as well as lost investment in treating plants put out of business by cancellation of arsenicals. Finally, there would be substantial losses of secondary benefits to merchants, businesspersons, and others in communities where impacted treating plants are located. These losses would be most heavily felt in many small, rural communities in the South Central and Southeastern Regions where production, processing, and treatment of forest products are major sources of employment and income.

These impacts on the wood treating and related industries would probably be offset, at least in part, by increased activities in the production and processing of untreated wood and/or non-wood substitutes.

### Cancellation of Creosote, Penta, and Arsenicals

Cancellation of creosote, penta, and arsenicals for treatment of lumber, timbers, and plywood would eliminate 32% of all treated wood products. The 32 million cu. ft. of lumber and timbers now treated with creosote and penta would be replaced by non-wood substitutes. The costs of this conversion would be added to those cited above as resulting from cancellation of arsenicals (Table 121). Alternatives to treated wood for all lumber and timbers are shown in Table 122. Costs of using alternatives to treated lumber and timbers are summarized for three scenarios in Table 123.

Table 122.--Alternatives to treated wood for lumber and timbers[a]

| Treatment | Use | Estimated Volume 1978 | Alternative | Percent of Total Treated Material |
|---|---|---|---|---|
| | | 1,000 cu. ft. | | |
| All treatments | All Uses | 105,305 | -- | 100.0 |
| CCA/ACA | AWWF | 1,600 | None | 1.5 |
| CCA/ACA | Patios, decks | 15,300 | Untreated wood | 14.5 |
| CCA/ACA | Residential fences | 7,700 | Untreated wood or steel | 7.3 |
| CCA/ACA | Other residential[b] | 24,000 | CZC | 22.8 |
| CCA/ACA | Farm, industrial, recreational | 14,200 | Untreated wood or concrete or steel | 13.5 |
| CCA/ACA | Marine, transportation | 10,500 | Concrete or steel | 10.0 |
| Penta | All uses | 21,200 | Concrete or steel | 20.1 |
| Creosote | Ind. block flooring | 700 | None | 0.7 |
| Creosote | All other uses | 10,100 | Concrete or steel | 9.6 |

[a] Assuming cancellation of all preservatives.

[b] Sills, plates, studs, joists, and other structural members.

Total costs, to all users, of the loss of treated lumber, timbers, and plywood depend on which combination of alternatives to treated wood are selected by various users. Depending on which combination is selected, the present value of future investments in alternative materials over 30 years at 10% interest would exceed that for treated wood by 5.0 to $13.3 billion. Annual savings (difference in average annual cost) from use of treated wood, at 10% interest over 30 years, would be 485 to $1,279 million. For reasons stated previously under "Costs of Canceling Arsenicals," costs of substitution would be expected to be near the high end of the range for each of the scenarios described (Table 123).

The costs to users of the loss of creosote-treated industrial block flooring and CCA/ACA-treated foundation materials are not included in Table 123. These costs should be added to costs shown for each scenario in the table.

Table 123.--Estimated cost of using alternatives to treated lumber and timbers[a]

| Scenario | Cost of Using Alternative[b] | | |
|---|---|---|---|
| | Installed Cost[c] | Present Value[d] | Average Annual Cost[e] |
| | - - - - - | Million Dollars | - - - - - |
| I Shift CCA/ACA-treated material for patios and decks to untreated wood (cedar, redwood, or pine); shift "other residential" to CZC; shift other uses of CCA/ACA to concrete or steel. | 133-277[f] | 3,507-6,358 | 336-613 |
| Shift all uses of penta to concrete or steel. | 101[g] | 1,042 | 101 |
| Shift all uses of creosote to concrete or steel. | 46[g] | 476 | 46 |
| | 280-424 | 5,025-7,876 | 485-760 |
| II Shift CCA/ACA-treated material for patios, decks, and fences to untreated wood; shift "other residential" to CZC; shift other uses of CCA/ACA to concrete or steel. | 73-290[f] | 3,962-7,539 | 382-795 |
| Shift all uses of penta to concrete or steel. | 101[g] | 1,042 | 101 |
| Shift all uses of creosote to concrete or steel. | 46[g] | 476 | 46 |
| | 220-437 | 5,480-9,057 | 529-942 |
| III Shift CCA/ACA-treated material for patios, decks, fences, farm, industrial, and recreational uses to untreated wood; shift "other residential" to CZC; shift other uses of CCA/ACA to concrete or steel. | (37)-315[f] | 4,801-11,735 | 463-1,132 |
| Shift all uses of penta to concrete or steel. | 101[g] | 1,042 | 101 |
| Shift all uses of creosote to concrete or steel. | 46[g] | 476 | 46 |
| | 110-462 | 6,319-13,253 | 610-1,279 |

[a] Alternatives to all creosote-treated products except industrial block flooring, all penta-treated products, and all arsenically treated products except foundation materials (Table 122).

[b] Difference in cost due to use of alternative. Cost reductions in parentheses.

[c] Installed cost at estimated 1978 rate of use (Table 122).

[d] Of future costs of using alternatives over 30 years at 10% interest on investment.

[e] For 30 years at 10% interest on investment.

[f] From Table 121.

[g] At 1.5 times the installed cost of treated wood (Table 120).

Losses to producers, processors, and treaters of these products would exceed $550 million, in terms of value of treated wood shipments. In addition, there would be losses in production, distribution, and sale of preservative chemicals and other materials and supplies; lost investment in treating facilities and equipment; and losses of secondary benefits to merchants, businesspersons, and others.

## Summary—Economic Impact of the Loss of Wood Preservatives for Pressure Treatment

An estimated 327.5 million cu. ft. of wood products were treated with creosote, penta, and inorganic arsenical preservatives by 631 wood preserving plants in 1978. Total production of treated wood between 1970 and 1978 increased at an average annual rate of 3.2%. Volume treated with creosote during the period declined slightly at a rate of 0.8% annually, while volumes treated with penta and arsenicals increased at average annual rates of 2.5% and 18.9%, respectively.

The most dramatic change during the 8-year period was in treatment of lumber and timbers. Volume treated in 1978 was more than double the volume treated in 1970. The percentages of these products treated with creosote and penta both declined, while the percentage treated with arsenicals increased from 39 to 70. In terms of total treated wood, the percentage treated with creosote declined from 65 to 47; penta's share remained fairly constant at about 25%; and the percentage treated with arsenicals tripled from 9 to 28.

The South led the Nation with 55% of the treating plants which produced 57% of the treated wood. The balance of the production was divided among the Northeast Region, 8%; North Central Region, 17%; Rocky Mountain Region, 5%; and the Pacific Region, 14%.

Based on information developed from the 1977 Census of Manufactures, we estimate that the wood-preserving industry employed 13,300 people; paid $140 million in wages; spent $796 million for wood raw materials, preservative chemicals, fuels, and other materials and supplies; added $388 million in value; and shipped 327.5 million cu. ft. of treated wood products with a value of $1,086 million in 1978. We estimate that an additional 17,400 jobs in producing, harvesting, and processing wood raw materials were dependent on the wood preserving industry. This does not include employment generated by the production, distribution, and sale of some $206 million worth of preservative chemicals and other materials and supplies.

The wood-preserving industry provides markets for more than 500 million cu. ft. of timber. Much of the industry's raw material comes from relatively low quality trees and logs which are not suitable for higher value uses, or from species for which there would be few, if any, markets without preservative treatment. The industry, thus, provides markets for large volumes of materials that could not otherwise be sold at a profit and, thereby, contributes to sound forest management and improvement of the forest environment in many areas of the United States.

The benefits of wood preservation in the form of employment, wages, and payments for wood raw materials, chemicals, and other materials and supplies accrue to many thousands of citizens directly and indirectly dependent on the industry in more than 500 communities throughout the land. Most of these are small, rural towns in which the wood-preserving plant and the production and processing of wood raw materials are major sources of employment and income.

Estimates of the volume of wood treated, amounts of preservatives used, and value of treated wood products produced in 1978 are summarized in Table 124. The value of all treated wood products, at prices quoted in November and December 1979, is estimated to be about $1.46 billion f.o.b. treating plant.

Except for a sizable volume of arsenically treated materials, suitable alternative preservatives exist for all treated wood products. Cancellation of any of the three RPAR'd preservatives for any or all of its uses would, in most cases, lead to use of an alternate preservative rather than to use of a non-wood substitute. In many cases, if two of the three preservatives were canceled, the remaining preservative could be used as an alternate. For most arsenically treated lumber, timbers, and plywood, and for some arsenically treated poles and posts used in applications where cleanliness, paintability, and freedom from odor or volatile components are required, neither creosote nor penta is a suitable substitute. In these cases, cancellation of arsenicals would result in a shift to untreated wood or to a non-wood substitute.

## Cancellation of Creosote

The costs, advantages, and disadvantages of chemical alternatives to creosote are summarized in Table 125. Crossties and switch ties (67%) and poles (12%) account for the bulk of creosote-treated wood, followed by lumber and timbers (7%), piling (6%), and fence posts (3%). The remaining 5% is "other" miscellaneous products which are not included in the cost analysis.

Crossties and switch ties could be shifted to penta or to Cu-Naph, but service life would be reduced from 35 to 25 years, and the number of ties required to maintain the system would increase by 40%. Due to this increase in tie requirements, the average annual cost of using penta-treated ties would be $36.8 million higher than for creosote. The very high cost of Cu-Naph preservative would increase the average annual cost to railroads by $672 million compared to creosote.

All other creosote-treated products, with the exception of piling, lumber, and timbers used in marine applications, could be shifted to either penta or CCA/ACA. Material for marine use would require treatment with arsenicals.

Cancellation of creosote and a shift to penta where applicable would require an estimated $5.2 million investment to convert treaters from creosote to penta. First-year cost, if amortized over 10 years at 12% interest, would be $1.1 million. Assuming continued production of these treated products at the estimated 1978 rate, 57 million pounds of penta and 101 million gallons of petroleum solvent would be required, annually, to replace 127.4 million gallons of creosote. This would be a 142% increase in the estimated 1978 industry consumption of penta and oil. Penta supply problems and production delays would probably result. Substantial capital investment would be needed to increase production of penta. The price of penta would probably be affected.

Based on late 1979 prices of preservative chemicals and treated wood products, the value (cost) of treated products would decrease by more than $26 million due to the lower cost of treating with penta. About $18 million of this apparent saving is in the lower initial cost of penta-treated crossties and switch ties. Due to their shorter service life, the average annual cost of using penta-treated ties would be $36.8 million higher than for creosote. Thus, the net result of switching to penta for all products now treated with creosote would be an increase in the annual cost of these treated products amounting to 28.4 to $28.8 million.

Table 124.--Estimated volume of wood treated, amount of preservative used, and value of treated wood, by product and preservative, 1978[a]

| Product | Preservative | Volume Treated | Percent of Total | | Preservative Used[b] | Value of Treated Product[c] |
|---|---|---|---|---|---|---|
| | | | Product | Treated Wood | | |
| | | 1,000 cu. ft. | | | 1,000 Pounds | Million Dollars |
| Crossties, switch ties, and landscape ties | Creosote | 103,138 | 97.2 | 31.5 | 825,104 | 412.6 |
| | Penta | 449 | 0.4 | 0.1 | 180[d] | 1.8 |
| | CCA/ACA | 2,498 | 2.4 | 0.8 | 999 | 10.0 |
| | Total | 106,085 | 100.0 | 32.4 | | 424.4 |
| Poles | Creosote | 18,237 | 28.4 | 5.6 | 164,133 | 81.2 |
| | Penta | 41,905 | 65.3 | 12.8 | 18,857[d] | 178.1 |
| | CCA/ACA | 4,038 | 6.3 | 1.2 | 2,423 | 15.5 |
| | Total | 64,179 | 100.0 | 19.6 | | 274.8 |
| Crossarms | Creosote | 41 | 2.4 | -- | 328 | 0.4 |
| | Penta | 1,615 | 95.8 | 0.5 | 646[d] | 14.2 |
| | CCA/ACA | 29 | 1.7 | -- | 12 | 0.2 |
| | Total | 1,685 | 100.0 | 0.5 | | 14.8 |
| Piling | Creosote | 9,993 | 82.7 | 3.1 | 151,734 | 66.1 |
| | Penta | 1,154 | 9.5 | 0.4 | 692[d] | 7.1 |
| | CCA/ACA | 943 | 7.8 | 0.3 | 1,392 | 6.1 |
| | Total | 12,090 | 100.0 | 3.7 | | 79.3 |
| Lumber and timbers | Creosote | 10,780 | 10.2 | 3.3 | 105,428 | 66.7 |
| | Penta | 21,209 | 20.1 | 6.5 | 11,813[d] | 127.0 |
| | CCA/ACA | 73,317 | 69.6 | 22.4 | 29,887 | 409.1 |
| | Totl | 105,305 | 100.0 | 32.2 | | 602.7 |
| Fence posts | Creosote | 4,584 | 22.9 | 1.4 | 27,504 | 15.8 |
| | Penta | 10,983 | 54.8 | 3.4 | 3,295[d] | 36.4 |
| | CCA/ACA | 4,461 | 22.3 | 1.4 | 1,784 | 13.9 |
| | Total | 20,028 | 100.0 | 6.1 | | 66.1 |
| Other products[e] | Creosote | 7,815 | 43.1 | 2.4 | NA | NA |
| | Penta | 2,681 | 14.8 | 0.8 | NA | NA |
| | CCA/ACA | 7,616 | 42.1 | 2.3 | NA | NA |
| | Total | 18,113 | 100.0 | 5.5 | | |
| All products | Creosote | 154,587 | 47.2 | 47.2 | 1,274,231 | 642.8 |
| | Penta | 79,996 | 24.4 | 24.4 | 35,483[d] | 364.6 |
| | CCA/ACA | 92,903 | 28.4 | 28.4 | 36,497 | 454.8 |
| | Total | 327,485 | 100.0 | 100.0 | | 1,462.1 |

[a] Based on estimated 1978 production (Micklewright, 1979) and prices quoted Nov.-Dec. 1979.

[b] Estimates based on retentions shown in Table 91.

[c] F.o.b. treating plant. Assume the CCA/ACA-treated material is shipped wet.

[d] Pounds of penta. 1.771 gallons petroleum solvent required per pound of penta (7% penta).

[e] Plywood, crossing planks, mine ties and timbers, agricultural products, pole stubs, tie plugs, and other miscellaneous products.

Note: Columns may not add to totals due to rounding.

Table 125.--Costs,[a] advantages, and disadvantages of chemical alternatives to creosote

| Product and Volume Treated With Creosote | Alternative | Difference in Annual Cost Due to Use of Alternative[b] | Advantages/Disadvantages |
|---|---|---|---|
| 1,000 cu. ft. | | Million Dollars | |
| Crossties and switch ties<br>103,138 | Treat with penta in P9, Type A petroleum solvent. | 36.8 | Shorter service life; 40% increase in volume of ties required; $3.75 million investment ($825,000 first year at 12% interest for 10 years) required to convert treaters from creosote to penta; increased dependence on petroleum--41.3 million pounds penta and 73 million gallons petroleum required to replace 82.5 million gallons creosote used in 1978; 103% increase in consumption of penta and oil; 3 years and $14 million investment required to increase penta production; 67% of creosote-treated wood eliminated. |
| | Treat with copper naphthenate in P9, Type A petroleum solvent. | 672.1 | Shorter service life; 40% increase in volume of ties required; increased dependence on petroleum--62 million pounds CuNaph (copper) and 104 million gallons petroleum required to replace 82.5 million gallons creosote used in 1978; 67% of creosote-treated wood eliminated. |
| Poles<br>18,237 | Treat with penta in P9, Type A petroleum solvent. | (3.6)[c] | $750,000 investment ($80,000 first year at 12% interest for 10 years) to convert treaters from creosote to penta; 8.2 million pounds penta and 18.9 million gallons petroleum required annually; 12% of creosote-treated wood eliminated; 16.4 million gallons creosote replaced. |
| | Treat with CCA/ACA. | (10.9)[c] | $11.9 million investment ($2.6 million first year at 12% interest for 10 years) to convert treaters from creosote to CCA/ACA; 11 million pounds arsenicals required annually; 12% of creosote-treated wood eliminated; 16.4 million gallons creosote replaced. |
| Piling<br>9,993 | Treat with CCA/ACA. | (1.8)[c] | $6.5 million investment ($638,000 first year at 12% interest for 10 years) to convert treaters from creosote to CCA/ACA; 16.1 million pounds arsenicals required annually; 6% of creosote-treated wood eliminated; 15.2 million gal- |

Table 125.--Costs,[a] advantages, and disadvantages of chemical alternatives to creosote--continued

| Product and Volume Treated With Creosote | Alternative | Difference in Annual Cost Due to Use of Alternative[b] | Advantages/Disadvantages |
|---|---|---|---|
| 1,000 cu. ft. | | Million Dollars | |
| | Treat foundation piling with penta, marine piling with CCA/ACA. | 0.0[c] | $2.9 million investment ($638,000 first year at 12% interest for 10 years) to convert treaters from creosote to penta and CCA/ACA; 3.6 million pounds penta, 6.4 million gallons petroleum, and 9.9 million pounds arsenicals required annually; 6% of creosote-treated wood eliminated; 15.2 million gallons creosote replaced. |
| Fence posts<br>4,584 | Treat with CCA/ACA. | (1.5)[c] | $2.6 million investment ($567,000 first year at 12% interest for 10 years) to convert treaters from creosote to CCA/ACA; 1.8 million pounds arsenicals required annually; 3% of creosote-treated wood eliminated; 2.8 million gallons creosote replaced. |
| | Treat with penta in P9, Type A petroleum solvent. | (0.6)[c] | $200,000 investment ($44,000 first year at 12% interest for 10 years) to convert treaters from creosote to penta; 1.4 million pounds penta and 2.4 million gallons petroleum required annually; 3% of creosote-treated wood eliminated; 2.8 million gallons creosote replaced. |
| Lumber and timbers<br>10,780 | Treat marine applications with CCA/ACA; treat remainder with penta.[e] | (3.8)[d] | $1.2 million investment ($259,000 first year at 12% interest for 10 years) to convert treaters from creosote to penta and CCA/ACA; 3.1 million pounds penta, 5.4 million gallons petroleum, and 2.9 million pounds arsenicals required annually; 7% of creosote-treated wood eliminated; 10.5 million gallons creosote replaced. |
| | Treat marine, farm, residential, and recreational uses with CCA/ACA; treat remainder with penta.[e] | (4.2)[d] | $1.2 million investment ($259,000 first year at 12% interest for 10 years) to convert treaters from creosote to penta and CCA/ACA; 2.6 million pounds penta, 4.5 million gallons petroleum, and 3.3 million pounds arsenicals required annually; 7% of creosote-treated wood eliminated; 10.5 million gallons creosote replaced. |
| | Treat with CCA/ACA.[e] | (6.0)[d] | $1.75 million investment ($385,000 first year at 12% interest for 10 years) to convert treaters from creosote to CCA/ACA; 5 million pounds arsenicals required annually; might require additional treatment (costs) to protect some CCA/ACA-treated products from weather and mechanical wear; 7% of creosote-treated wood eliminated; 10.5 million gallons creosote replaced. |

Table 125.--Costs,[a] advantages, and disadvantages of chemical alternatives to creosote--continued

| Product and Volume Treated With Creosote | Alternative | Difference in Annual Cost Due to Use of Alternative[b] | Advantages/Disadvantages |
|---|---|---|---|
| 1,000 cu. ft. | | Million Dollars | |
| All products 146,732[f] | Treat with penta where applicable. | 28.4 to 28.8 | Cost depends on which alternative is chosen for lumber and timbers; $5.2 million investment ($1.1 million first year at 12% interest for 10 years) to convert treaters from creosote to penta; 57 million pounds penta and 101 million gallons petroleum required annually; all creosote-treated wood eliminated; 127.4 million gallons creosote replaced. |
| All products except crossties and switch ties 43,594 | Treat with CCA/ACA where applicable. | (16.2) to (20.2) | Applies to one-third of creosote-treated wood, only; cost depends on which alternatives are chosen for piling, lumber, and timbers; 18.2 to $22 million investment (4.0 to $4.8 million first year at 12% interest for 10 years) to convert treaters from creosote to CCA/ACA; 25.6 to 33.9 million pounds arsenicals required annually; all creosote-treated wood except crossties and switch ties eliminated; 45 million gallons creosote replaced. |

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[a] Assuming sufficient supply of alternative chemical at current (1979) prices.

[b] Difference due to cost of treated products, based on estimated 1978 production, 1979 prices. Cost reductions in parentheses.

[c] Difference in value (cost) of treated products between current mix and alternative at 1979 prices.

[d] Difference in value (cost) of treated products assuming cost per cu. ft. of treated wood = $6.17 for creosote, $5.99 for penta, and $5.58 for CCA/ACA shipped wet.

[e] 0.7 million cu. ft. of industrial block flooring not included.

[f] 0.7 million cu. ft. of industrial block flooring and 7.8 million cu. ft. of crossarms and "Other" miscellaneous products (5.5% of creosote-treated wood) not included in the analysis.

Inorganic arsenicals could be used in place of creosote for about one-third of the creosote-treated wood (all products except crossties and switch ties). Depending on which alternatives were chosen for piling, lumber, and timbers, an estimated 18 to $22 million investment would be required to convert treaters from creosote to arsenicals. First-year cost, amortized over 10 years at 12% interest, would be 4.0 to $4.8 million. Assuming continued production of treated products at the 1978 rate, 26 to 34 million pounds of arsenicals would be required annually, to replace 45 million gallons of creosote--a 70% to 90% increase in estimated 1978 industry consumption of arsenicals. This increase in demand would probably necessitate investment in facilities for expanded production of arsenicals and would most likely affect the price of these chemicals.

Based on late 1979 prices of preservative chemicals and treated wood products, the value (cost) of treated products would be reduced by 16.2 to $20.2 million, assuming that arsenically treated material would be shipped wet. These indicated savings would be reduced by the high cost of converting treating facilities from creosote to arsenicals, by any increase in price of arsenicals that might result from the increased demand, by the cost of redrying any of the products treated with arsenicals, and by the probable need for additional treatment to protect some arsenically treated products from weather and mechanical wear in use.

## Cancellation of Penta

The costs, advantages, and disadvantages of chemical alternatives to penta are summarized in Table 126. Poles (52%), lumber and timbers (27%), and fence posts (14%) account for the bulk of penta-treated wood, followed by crossarms (2%) and piling (1.5%). About 3% is "other" miscellaneous products which are not included in the cost analysis. All of these products could be treated with either creosote or inorganic arsenicals. Due to cleanliness, freedom from odor, ease of handling, and lower cost, lumber and timbers would most likely be converted to arsenicals.

Cancellation of penta and a shift to creosote for all products except lumber and timbers (73% of penta-treated wood) would require an estimated $2.3 million investment to convert treaters from penta to creosote. If amortized over 10 years at 12% interest, first-year cost would be $500,000. Assuming continued production of these treated products at the estimated 1978 rate, 47 million gallons of creosote would be required, annually, to replace 23.5 million pounds of penta and 41.6 million gallons of petroleum solvent. This would be a 38% increase in estimated 1978 industry consumption of creosote. Supplies of creosote appear adequate for such an increase. Due to its high fuel value and resultant relationship to the price of petroleum, creosote can be expected to increase in price at about the same rate as the price of penta in oil. At late 1979 prices of preservative chemicals and treated wood products, the value (cost) of treated products would increase by $10.5 million due to the higher cost of treating with creosote.

Cancellation of penta and a shift to arsenicals for all products, including lumber and timbers, would require an estimated $40 million investment to convert treaters from penta to arsenicals. First-year cost, if amortized over 10 years at 12% interest, would be $8.8 million. Assuming continued production at the estimated 1978 rate, 41.3 million pounds of arsenicals would be required, annually, to replace 35.3 million pounds of penta and 62.5 million gallons of petroleum solvent. This 111% increase in estimated 1978 industry consumption of arsenicals would probably necessitate investment in expanded production of arsenicals, and would most likely affect the price of these chemicals.

Table 126.--Costs,[a] advantages and disadvantages of chemical alternatives to penta

| Product and Volume Treated with Penta | Alternative | Difference in Annual Cost Due to Use of Alternative[b] | Advantages/Disadvantages |
|---|---|---|---|
| 1,000 cu. ft. | | Million Dollars | |
| Poles<br>41,905 | Treat with creosote | 8.4[c] | $1.7 million investment ($374,000 first year at 12% interest for 10 years) required to convert treaters from penta to creosote; 37.7 million gallons creosote required annually; 52% of penta-treated wood eliminated; 18.9 million pounds penta and 33.5 million gallons petroleum replaced. |
| | Treat with CCA/ACA. | (16.8)[c] | $27.3 million investment ($6.0 million first year at 12% interest for 10 years) required to convert treaters from penta to CCA/ACA; 25.1 million pounds arsenicals required annually; 52% of penta-treated wood eliminated; 18.9 million pounds penta and 33.5 million gallons petroleum replaced. |
| Lumber and timbers<br>21,209 | Treat with CCA/ACA. | (8.7)[d] | $4.75 million investment ($1.05 million first year at 12% interest for 10 years) required to convert treaters from penta to CCA/ACA; 10.3 million pounds arsenicals required annually; 27% of penta-treated wood eliminated; 11.8 million pounds penta and 20.9 million gallons petroleum replaced. |
| Fence posts<br>10,983 | Treat with creosote. | 1.5[c] | $450,000 investment ($99,000 first year at 12% interest for 10 years) required to convert treaters from penta to creosote; 6.6 million gallons creosote required annually; 14% of penta-treated wood eliminated; 3.3 million pounds penta and 5.8 million gallons petroleum replaced. |
| | Treat with CCA/ACA. | (2.1)[c] | $6.3 million investment ($1.4 million first year at 12% interest for 10 years) required to convert treaters from penta to CCA/ACA; 4.4 million pounds arsenicals required annually; 14% of penta-treated wood eliminated; 3.3 million pounds penta and 5.8 million gallons petroleum replaced. |
| Crossarms<br>1,615 | Treat with creosote. | 0.6[c] | $75,000 investment ($16,500 first year at 12% interest for 10 years) required to convert treaters from penta to creosote; 1.3 million gallons creosote required annually; 2% of penta-treated wood eliminated; 0.6 million pounds penta and 1.1 million gallons petroleum replaced. |

Table 126.--Costs,[a] advantages and disadvantages of chemical alternatives to penta--continued

| Product and Volume Treated with Penta | Alternative | Difference in Annual Cost Due to Use of Alternative[b] | Advantages/Disadvantages |
|---|---|---|---|
| 1,000 cu. ft. | | Million Dollars | |
| | Treat with CCA/ACA. | (0.8)[c] | $939,000 investment ($207,000 first year at 12% interest for 10 years) required to convert treaters from penta to CCA/ACA; 0.6 million pounds arsenicals required annually; 2% of penta-treated wood eliminated; 0.6 million pounds penta and 1.1 million gallons petroleum replaced. |
| Piling<br>1,154 | Treat with creosote. | 0.0[c] | $50,000 investment ($11,000 first year at 12% interest for creosote; 10 years) required to convert treaters from penta to 1.4 million gallons creosote required annually; 1.4% of penta-treated wood eliminated; 0.7 million pounds penta and 1.2 million gallons petroleum replaced. |
| | Treat with CCA/ACA. | (0.3)[c] | $800,000 investment ($176,000 first year at 12% interest for 10 years) required to convert treaters from penta to CCA/ACA; 0.9 million pounds arsenicals required annually; 1.4% of penta-treated wood eliminated; 0.7 million pounds penta and 1.2 million gallons petroleum replaced. |
| All Products[e]<br>76,866 | Treat with creosote. | 10.5 | Applies to 73% of penta-treated wood, only--lumber and timbers not included in this option; $2.3 million investment ($500,000 first year at 12% interest for 10 years) required to convert treaters from penta to creosote; 47 million gallons creosote required annually; 73% of penta-treated wood eliminated; 23.5 million pounds penta and 41.6 million gallons petroleum replaced. |
| | Treat with CCA/ACA. | (28.7) | $40.1 million investment ($8.8 million first year at 12% interest for 10 years) required to convert treaters from penta to CCA/ACA; 41.3 million pounds arsenicals required annually; all penta-treated wood eliminated; 35.3 million pounds penta and 62.5 million gallons petroleum replaced. |

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[a] Assuming sufficient supply of alternative chemical at current (1979) prices.

[b] Difference due to installed cost of treated products, only, based on 1978 production and 1979 prices. Cost reductions in parentheses.

[c] Difference in value (cost) of treated products between current mix and alternative at 1979 prices.

[d] Difference in value (cost) of treated products assuming cost per cu. ft. of treated wood = $5.99 for penta and $5.58 for CCA/ACA shipped wet.

[e] 449,000 cu. ft. of crossties and landscape ties, and 2.7 million cu. ft. of "Other" miscellaneous products (4% of penta-treated wood) not included in the analysis.

Based on late 1979 prices of preservative chemicals and treated wood products, the switch from penta to arsenicals would reduce the value (cost) of treated wood products by $28.7 million, assuming that arsenically treated material would be shipped wet. This apparent saving would be reduced by the high cost of converting treating facilities from penta to arsenicals, by any increase in price of arsenicals that might result from the increased demand, and by the cost of redrying any of the products treated with arsenicals.

## Cancellation of Arsenicals

The costs, advantages, and disadvantages of chemical alternatives to CCA/ACA are summarized in Table 127. Lumber and timbers (79%), fence posts (5%), and poles (4%) make up the bulk of arsenically treated wood, followed by landscape ties (3%) and piling (1%). About 8% is "other" miscellaneous products which are not included in the cost analysis.

Most arsenically treated lumber and timbers (about 86%) and some posts and poles are used in construction of buildings or other applications where clean, paintable, odorless treatment is required. Material for these uses cannot be shifted to either creosote or penta in heavy oil. In addition, arsenically treated products for marine use cannot be converted to penta. Thus, we estimate that about 30% of CCA/ACA-treated wood could be shifted to creosote, and only 25% could be shifted to penta. Except for some limited above-ground or interior applications where CZC might be substituted, cancellation of arsenicals would eliminate the availability of treated wood for use in confined, unvented, habitable space and for many residential, industrial, commercial, agricultural, and recreational uses where neither creosote nor penta could be substituted. About 70% of the market for arsenically treated materials would be lost to untreated wood or to non-wood substitutes. In addition, an effective, low-cost alternative to creosote and/or penta would be lost.

Conversion of about 30% of the CCA/ACA-treated wood to creosote would require an estimated $16 million investment to convert treaters from arsenicals to creosote. First-year cost, amortized over 10 years at 12% interest, would be $3.5 million. About 21 million gallons of creosote would be required, annually, to replace 15 million pounds of arsenicals. At late 1979 prices for preservative chemicals and treated wood products, the value (cost) of treated products would be $9.7 million higher than CCA/ACA-treated material shipped wet.

If about 25% of the CCA/ACA-treated wood were converted to penta, an estimated $12.5 million investment ($2.75 million the first year at 12% interest over 10 years) would be required to convert treaters from arsenicals to penta. About 6.7 million pounds of penta and 12 million gallons of petroleum would be required, annually, to replace 7.7 million pounds of arsenicals. The value (cost) of treated products would be $5.2 million higher than CCA/ACA-treated products shipped wet.

In addition to the increased costs associated with conversion of 25% to 30% of the arsenically treated wood to penta or creosote (Table 127), there would be large costs associated with the use of untreated wood or non-wood substitutes for the 70% of CCA/ACA-treated wood that could not be converted (Table 121). Average annual costs to users of this material would be increased by an estimated 283 to $1,077 million, depending on which substitutes were used for CCA/ACA-treated wood in its various applications. Thus, if arsenicals were canceled for all uses, the least-cost combination of substitutes would add about $293 million to annual costs of users. If untreated, non-durable species of wood were substituted wherever they might be used, annual costs would be increased by $1,087 million.

Table 127.--Costs,[a] advantages, and disadvantages of chemical alternatives to CCA/ACA

| Product and Volume Treated With CCA/ACA | Alternative | Difference in Annual Cost Due to Use Alternative[b] | Advantages/Disadvantages |
|---|---|---|---|
| 1,000 cu. ft. | | Million Dollars | |
| Lumber and timbers 73,317 | Treat marine uses with creosote (6.8 million cu. ft.). | 5.1[c] | Not effective against *Limnoria tripunctata*; $5 million investment ($1.1 million first year at 12% interest for 10 years) required to convert treaters from CCA/ACA to creosote; 9.3 million gallons creosote required annually; 9% of CCA/ACA-treated wood eliminated; 7.5 million pounds arsenicals replaced. |
| | Treat transportation uses with creosote (3.7 million cu. ft.). | 2.6[c] | $2.5 million investment ($55,000 first year at 12% interest for 10 years) required to convert treaters from CCA/ACA to creosote; 3.9 million gallons creosote required annually; 5% of CCA/ACA-treated wood eliminated; 2 million pounds arsenicals replaced. |
| | Treat transportation uses with penta (3.7 million cu. ft.) | 2.0[c] | $2.5 million investment ($55,000 first year at 12% interest for 10 years) required to convert treaters from CCA/ACA to penta; 2.1 million pounds penta and 3.7 million gallons petroleum required annually; 5% of CCA/ACA treated wood eliminated; 2 million pounds arsenicals replaced. |
| | Treat "other residential" uses with CZC (24 million cu. ft.). | (0.7)[c] | Not usable in ground contact or in applications exposed to weather or high moisture; 10.8 million pounds CZC required to replace CCA/ACA for this use--a twenty fold increase in in current industry consumption of CZC. |
| Fence posts 4,461 | Treat with creosote. | 1.5[d] | Not usable where clean, paintable, odorless treatment required; $4 million investment ($880,000 first year at 12% interest for 10 years) required to convert treaters from CCA/ACA to creosote; 2.7 million gallons creosote required annually; 5% of CCA/ACA-treated wood eliminated; 1.8 million pounds arsenicals replaced. |
| | Treat with penta. | 0.8[d] | Penta in volatile solvents, only, where clean, paintable surface required; not usable in confined, unvented, habitable space; $4 million investment ($880,000 first year at 12% interest for 10 years) required to convert treaters from CCA/ACA to penta; 1.3 million pounds penta and 2.4 million gallons petroleum required annually; 5% of CCA/ACA-treated wood eliminated; 1.8 million pounds arsenicals replaced. |

Table 127.--Costs,[a] advantages, and disadvantages of chemical alternatives to CCA/ACA--continued

| Product and Volume Treated With CCA/ACA | Alternative | Difference in Annual Cost Due to Use Alternative[b] | Advantages/Disadvantages |
|---|---|---|---|
| 1,000 cu. ft. | | Million Dollars | |
| Poles<br>4,038 | Treat with creosote. | 2.4[d] | Not usable where clean, paintable, odorless treatment required; $3.5 million investment ($770,000 first year at 12% interest for 10 years) required to convert treaters from CCA/ACA to creosote; 3.6 million gallons creosote required annually; 4% of CCA/ACA-treated wood eliminated; 2.4 million pounds arsenicals replaced. |
| | Treat with penta. | 1.6[d] | Penta in volatile solvents, only, where clean, paintable surface required; not usable in confined, unvented, habitable space; $3.5 million investment ($770,000 first year at 12% interest for 10 years) required to convert treaters from CCA/ACA to penta; 1.8 million pounds penta and 3.2 million gallons petroleum required annually; 4% of CCA/ACA-treated wood eliminated; 2.4 million pounds arsenicals replaced. |
| Landscape ties<br>2,498 | Treat with penta. | 1.1[d] | $2 million investment ($440,000 first year at 12% interest for 10 years) to convert treaters from CCA/ACA to penta; 1.2 million pounds penta and 2.2 million gallons petroleum required annually; 3% of CCA/ACA-treated wood eliminated; 1 million pounds arsenicals replaced. |
| Piling<br>943 | Treat with creosote | 0.0[d] | Not effective against Limnoria tripunctata; $1 million investment ($220,000 first year at 12% interest for 10 years) required to convert treaters from CCA/ACA to creosote; 1.4 million gallons creosote required annually; 1% of CCA/ACA-treated wood eliminated; 1.4 million pounds arsenicals replaced. |
| | Treat with penta--foundation only (568,000 cu. ft.). | 0.2[d] | $500,000 investment ($110,000 first year at 12% interest for 10 years) required to convert treaters from CCA/ACA to penta; 0.3 million pounds penta and 0.6 million gallons petroleum required annually; 1% of CCA/ACA-treated wood eliminated; 0.5 million pounds arsenicals replaced. |

Table 127.--Costs,[a] advantages, and disadvantages of chemical alternatives to CCA/ACA--continued

| Product and Volume Treated With CCA/ACA | Alternative | Difference in Annual Cost Due to Use Alternative[b] | Advantages/Disadvantages |
|---|---|---|---|
| 1,000 cu. ft. | | Million Dollars | |
| All products[e]<br>85,257 | Treat with creosote where applicable. | 9.7 | Applies to about 30% of CCA/ACA-treated wood, only; 70% cannot be converted to creosote; $16 million investment ($3.5 million first year at 12% interest for 10 years) required to convert treaters from CCA/ACA to creosote; 20.9 million gallons creosote required annually; 30% of CCA/ACA-treated wood converted to creosote; 15.1 million pounds arsenicals replaced. |
| | Treat with penta where applicable. | 5.2 | Applies to about 25% of CCA/ACA-treated wood, only; 75% cannot be converted to penta; $12.5 million investment ($2.75 million first year at 12% interest for 10 years) required to convert treaters from CCA/ACA to penta; 6.7 million pounds penta and 11.9 million gallons petroleum required annually; 25% of CCA/ACA-treated wood converted to penta; 7.7 million pounds arsenicals replaced. |

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[a] Assuming sufficient supply of alternative chemical at current (1979) prices.

[b] Difference due to installed cost of treated products, only, based on 1978 production and 1979 prices. Cost reductions in parentheses.

[c] Assuming installed cost per cu. ft. of treated wood = $11.35 for creosote, $11.16 for penta, $10.60 for CCA/ACA, and $10.57 for CZC.

[d] Difference in value (cost) of treated products between current mix and alternative at 1979 prices.

[e] 7.6 million cu. ft. of crossarms and "Other" miscellaneous products (8% of CCA/ACA-treated wood) not included in the analysis.

Finally, the loss of markets for 70% of the CCA/ACA-treated wood, due to cancellation of arsenicals, would have a severe impact on the wood-preserving industry and on its suppliers of wood and other raw materials and supplies. Recent growth trends in the wood-preserving industry would be halted. Few of the 221 treating plants that treat only with arsenicals would survive. Another 104 plants that treat with arsenicals, along with other preservatives, would also be affected. Losses or costs to the economy are estimated to include 2,600 jobs in the treating industry and $28 million in wages, mostly in small plants in small, rural communities. In terms of value of products shipped, losses would approximate $400 million, consisting of the wages cited above, and payments to producers and processors of wood raw materials. There would be additional losses in production, distribution, and sale of preservative chemicals ($37 million worth of arsenicals in 1978) and other materials and supplies to the treating industry, and lost investments in treating facilities and equipment put out of business by such action. Substantial losses of secondary benefits to merchants, businessmen, and others in communities where impacted treating plants are located would also result. Since 80% of arsenically treated materials is southern pine, these losses would be concentrated in the South Central and Southeastern Regions. These impacts would be immediate and would continue until such time as affected individuals and resources could be put to other gainful uses. The extent and effect of offsetting cross-sectoral and regional shifts in employment and income have not been evaluated.

To the extent that users of treated products would switch to use of untreated wood, cancellation of arsenicals would result in increased employment in logging and sawmilling to produce the increased volumes of untreated products that would be required. The extent of such a switch, and its effect on the impacts described above, have not been evaluated.

## Cancellation of Creosote, Penta, and Arsenicals

The costs, advantages, and disadvantages of alternatives to treated wood are summarized in Table 128. Costs associated with the loss of 700,000 cu. ft. of creosote-treated block flooring, 1.6 million cu. ft. of CCA/ACA-treated foundation materials, 2.9 million cu. ft. of penta- and CCA/ACA-treated ties, 1.7 million cu. ft. of treated crossarms, and 18 million cu. ft. of "other" miscellaneous products are not included. Also, due to the wide variation in types and cost of substitutes for treated fence posts, no estimates were made of the costs of substituting untreated wood or metal for treated posts. Together, these products comprise about 14% of all treated wood. Therefore, the costs shown for "All Products" in Table 128 represent the estimated benefits to the U.S. economy from 86% of the treated wood produced and used in 1978.

If all preservatives were canceled, users would probably switch to untreated wood for some applications of treated lumber and timbers, to concrete for crossties and switch ties, and to concrete or steel for poles, piling, and the remainder of the lumber and timbers. If concrete was used for crossties, poles, and piling, and untreated wood or concrete was used where applicable for lumber and timbers, the present value of future costs of using these substitutes would be 47.2 to $55.4 billion higher than for treated wood, depending on which combination of untreated wood and concrete substitutes was used.

If steel poles and piling were used instead of concrete in the above analysis, the present value of future costs of substitutes would exceed that for treated wood by 57.1 to $65.3 billion.

Table 128.--Costs,[a] advantages, and disadvantages of alternatives to treated wood[b]

| Product and Volume Treated | Alternative | Increase in Cost Due to Use of Alternative[c] |  | Advantages/Disadvantages |
|---|---|---|---|---|
|  |  | Present Value[d] | Average Annual Cost[e] |  |
| 1,000 cu. ft. |  | - - - Million Dollars - - - |  |  |
| Crossties and switch ties<br>103,138 | Use concrete ties. | 22,994 | 2,091 | At current rate of track maintenance (28,500 miles per year) 75.2 million concrete ties (24.4 million tons concrete and steel) required annually for 10.5 years to convert system to concrete; $4.6 billion annual investment in installed ties required for conversion; 67% of creosote-treated wood and 31% of total treated wood eliminated; 82.5 million gallons creosote replaced. |
| Poles<br>64,179 | Use concrete poles. | 18,509 | 1,851 | 3.5 million tons concrete and steel required annually; 20% of all treated wood eliminated; 16.4 million gallons creosote, 18.9 million pounds penta, 33.5 million gallons petroleum, and 2.4 million pounds arsenicals replaced. |
|  | Use steel poles. | 27,751 | 2,775 | 1.3 million tons steel required annually; 20% of all treated wood eliminated; 16.4 million gallons creosote, 18.9 million pounds penta, 33.5 million gallons petroleum, and 2.4 million pounds arsenicals replaced. |
| Piling<br>12,090 | Use concrete piling. | 645 | 64 | 1 million tons concrete and steel required annually; problems with corrosion of reinforcing steel in acidic soils and marine environments; 4% of all treated wood eliminated; 15.2 million gallons creosote, 692,000 pounds penta, 1.2 million gallons petroleum, and 1.4 million pounds arsenicals replaced. |
|  | Use steel piling. | 1,291 | 129 | 0.4 million tons steel required annually; problems with corrosion in acidic soils and marine environments; 4% of all treated wood eliminated; 15.2 million gallons creosote, 692,000 pounds penta, 1.2 million gallons petroleum, and 1.4 million pounds arsenicals replaced. |
| Fence posts<br>20,028 | Use concrete posts. | NA | NA | Not likely--costs too high and materials too scarce compared to metal. |
|  | Use steel posts. | NA | NA | Competitive with or lower in cost than treated wood for some uses; 1.5 to 3 times as costly as treated wood for other uses; treated wood preferred at least 3 to 1 over metal for farm fences; aesthetics and function of fence favor treated wood for many other uses; 6% of all treated wood eliminated; 2.8 million gallons creosote, 3.3 million pounds penta, 5.8 million gallons petroleum, and 1.8 million pounds arsenicals replaced. |

Table 128.--Costs,[a] advantages, and disadvantages of alternatives to treated wood[b]--continued

| Product and Volume Treated | Alternative | Increase in Cost Due to Use of Alternative[c] | | Advantages/Disadvantages |
|---|---|---|---|---|
| | | Present Value[d] | Average Annual Cost[e] | |
| 1,000 cu. ft. | | - - - Million Dollars - - - - | | |
| Lumber and timbers 105,305 | Shift CCA/ACA-treated material for patios and decks to untreated wood; shift "other residential" uses to CZC; shift other uses of CCA/ACA and all uses of creosote- and penta-treated material to concrete or steel[f] (Scenario I, Table 123). | 5,025-7,876 | 485-760 | 2.2% of treated lumber and timbers not included[f]; costs depend on whether shift is to untreated cedar, redwood, or pine; due to scarcity of cedar and redwood, costs likely to be near high end of ranges shown; compared to treated pine, 15 times as much untreated pine or 3 times as much cedar or redwood required over the life of treated pine; 32% of all treated wood eliminated; 10.5 million gallons creosote, 11.8 million pounds penta, 20.9 million gallons petroleum, and 29.9 million pounds arsenicals replaced. |
| | Shift CCA/ACA-treated material for patios, decks, and fences to untreated wood; shift "other residential" uses to CZC; shift other uses of CCA/ACA and all uses of creosote- and penta-treated material to concrete or steel[f] (Scenario II, Table 123). | 5,480-9,057 | 529-942 | 2.2% of treated lumber and timbers not included[f]; costs depend on whether shift is to untreated cedar, redwood, or pine; due to scarcity of cedar and redwood, costs likely to be near high end of ranges shown; compared to treated pine, 15 times as much untreated pine or 3 times as much cedar or redwood required over life of treated pine; 32% of all treated wood eliminated; 10.5 million gallons creosote, 11.8 million pounds penta, 20.9 million gallons petroleum, and 29.9 million pounds arsenicals replaced. |
| | Shift CCA/ACA-treated material for patios, decks, fences, farm, industrial, and recreational uses to untreated wood; shift "other residential" uses to CZC; shift other uses of CCA/ACA and all uses of creosote- and penta-treated materials to concrete or steel[f] (Scenario III, Table 123). | 6,319-13,253 | 610-1,279 | 2.2% of treated lumber and timbers not included[f]; costs depend on whether shift is to untreated cedar, redwood, or pine; due to scarcity of cedar and redwood, costs likely to be near high end of ranges shown; compared to treated pine, 15 times as much untreated pine or 3 times as much cedar or redwood required over the life of treated pine; 32% of all treated wood eliminated; 10.5 million gallons creosote, 11.8 million pounds penta, 20.9 million gallons petroleum, and 29.9 million pounds arsenicals replaced. |

Table 128.--Costs,[a] advantages, and disadvantages of alternatives to treated wood[b]--continued

| Product and Volume Treated | Alternative | Increase in Cost Due to Use of Alternative[c] | | Advantages/Disadvantages |
|---|---|---|---|---|
| | | Present Value[d] | Average Annual Cost[e] | |
| 1,000 cu. ft. | | - - - Million Dollars - - - - | | |
| All products[g] 304,440 | Shift crossties, poles, and piling to concrete; shift lumber and timbers as described above. | 47,173-55,401 | 4,491-5,285 | Costs depend on which scenario is selected for lumber and timbers; 14% of treated wood not included in cost analysis;[h] more than 29 million tons of concrete and steel required annually; large volumes of untreated wood required annually; all treated wood eliminated; 127.4 million gallons creosote, 35.5 million pounds penta, 62.8 million gallons petroleum, and 36.5 million pounds arsenicals replaced. |
| | Shift crossties, to concrete; shift poles and piling to steel; shift lumber and timbers as described above. | 57,061-65,289 | 5,480-6,274 | Costs depend on which scenario is selected for lumber and timbers; 14% of treated wood not included in cost analysis;[h] more than 24.4 million tons concrete, 1.7 million tons of steel, and large volumes of untreated wood required annually; all treated wood eliminated; 127.4 million gallons creosote, 35.5 million pounds penta, 62.8 million gallons petroleum, and 36.5 million pounds arsenicals replaced. |

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[a] Assuming sufficient supply of alternative materials at current (1979) prices.

[b] Suitable chemical alternatives exist for all products except most CCA/ACA-treated lumber and timbers. Costs and effects in this table would result only from cancellation of all three major wood preservatives. Total costs (all products) represent direct savings from use of all treated wood. See footnote h.

[c] Increase due to cost of alternative materials only.

[d] Present value of future costs over n years at 10% interest. n = 100 years for crossties, poles, and piling.
= 30 years for lumber and timbers.

[e] Average annual cost = initial investment x $\left[\frac{r(1 + r)^n}{(1 + r)^n - 1}\right]$ where r = 10%, n = 100 years for crossties, poles, and piling.
= 30 years for lumber and timbers.

[f] 2.3 million cu. ft. creosote-treated block flooring and CCA/ACA-treated foundation materials (Table 122) not included (2.2% of treated lumber and timbers).

[g] 22.7 million cu. ft. (2.9 million cu. ft. penta- and CCA/ACA-treated ties, 1.7 million cu. ft. crossarms, and 18.1 million cu. ft. "Other" miscellaneous products), 7% of treated wood, not included (Table 124).

[h] 2.3 million cu. ft. lumber and timbers; 22.7 million cu. ft. ties, crossarms, and miscellaneous products; and 20 million cu. ft. fence posts (14% of treated wood) not included in cost analysis.

Based on this analysis, direct savings to consumers of treated wood railroad ties, poles, piling, lumber, timbers, and other products average an estimated 4.5 to 7.3 billion, annually, compared to various combinations of untreated wood and concrete substitutes. If steel is used instead of concrete for poles and piling, the annual savings from use of treated wood increase to an estimated 5.5 to $6.3 billion. Additional savings from use of the 14% of treated wood not included in the analysis would increase the totals given above.

In addition to the direct economic losses to consumers of treated wood indicated above, cancellation of wood preservatives would have serious impacts on the wood preserving industry and its suppliers in terms of losses of employment, capital investment, and community facilities. Substantial investments in plant and equipment used in timber harvesting, wood processing, and wood treatment would be lost.

An estimated 30,700 people were employed in treating plants and related timber production, harvesting, and processing operations in 1978. Wages paid to these workers, and payments for wood raw materials, totaled $650 million. An additional $286 million was spent for preservative chemicals and other materials and supplies, including fuels and electrical energy. In 1978, the industry shipped treated wood products valued at $1.46 billion at 1979 prices.

These benefits accrue to many thousands of citizens directly and indirectly dependent on the industry in more than 500 communities, most of which are small, rural towns in which the production, processing, and preservation of wood products are major sources of employment and income. Finding new jobs for workers displaced by cessation of wood treating operations could entail substantial transfer costs to many families. Many workers might not find new jobs because of a lack of opportunities in some areas, or a lack of skills required in other industries. Many would be at least temporarily dependent on unemployment insurance and welfare.

Many small forest landowners who supply raw materials to the treating industry also would suffer economic losses if markets for treated wood were no longer available. Although some consumers might turn to untreated wood, thereby increasing demand for timber products, the ultimate result of the high cost of using untreated material would be a general loss in wood markets, and loss of cash income for many small woodlot owners, through extensive substitution of other structural materials.

Poles, posts, piles, ties, mine timbers and most other products generally treated today can be made from relatively small trees or from grades of material or species for which markets would otherwise be very limited. Loss of markets for this material would have a detrimental effect on timber management and the forest environment in many areas of the United States.

## Limitations of the Analysis

The projected savings to consumers from use of treated wood (costs of cancellation) are based on the assumption that supplies of alternative chemicals or alternative materials are sufficient to meet increased demands at current (1979) prices. In reality, shortages are likely to develop if any or all of the wood preservatives are canceled. Any increase in prices of alternative chemicals or materials that might result would add to the listed costs of cancellation and substitution.

Other impacts of canceling wood preservatives and switching to use of untreated wood, concrete, or steel have not been assessed. These include:

1. A need for more than 29 million tons of cement, sand, gravel, crushed stone, and reinforcing steel, annually, to produce concrete ties, poles, piling, and other concrete substitutes for treated wood. This would more than double the amount of these materials used in the manufacture of all precast and prestressed concrete products in 1977. Such an increase could be expected to cause shortages, delays, and price changes that would affect all users of concrete products.

2. A need for more than 1.7 million tons of steel, annually, to produce poles, piling, and other steel substitutes for treated wood.

3. Effects of cross-sectoral and regional shifts in employment and income between the wood industry and the concrete or steel industries.

4. Capital investments needed to build facilities to produce required non-wood substitutes, and to purchase new installation and maintenance equipment to handle these materials.

5. Lost investment in present installation and maintenance equipment (especially by railroads and utilities) rendered obsolete by conversion to non-wood materials.

6. Problems and costs of intermixing concrete or steel substitutes with treated wood in maintenance programs during the period required to convert various systems to non-wood substitutes.

7. A probable increase in rail transportation and utility rates to cover increased costs of using substitute materials, and its effect on all users of these services.

8. A substantial increase in the amount of energy required to mine, process, and manufacture substitute materials, all of which are more energy intensive than treated wood.

9. Increased air and water pollution and degradation of the landscape (or increased costs of pollution control) associated with production of substitute materials.

10. Increased dependence on imports of non-wood raw materials and energy, with attendant effects on the United States' balance of payments.

These and other indirect impacts could add to the direct costs of cancellation and substitution described in this report.

## Non-Pressure Treatments

The economic impact analysis for wood treated by pressure methods is presented on a commodity-by-commodity basis. Where wood is treated by non-pressure processes, the treatment may be applied to a new product made of wood (i.e., window sash) or it may be applied to a wooden structure in service (i.e., utility poles). In both cases, the function of the treatment is either to protect the utility or extend the service life of the item. The treatment gives a supplemental attribute to new products but does not lend itself to commodity-by-commodity breakdown because of the wide range of products that may be involved. Field treatments of wood in use are best classified as maintenance services. They add useful life to improvements on real property and are unrelated to commodities.

Non-pressure applications generally require relatively simple equipment which results in a low capital investment. The users of non-pressure type treatments are widely dispersed and as a general rule can be categorized as small volume users, since treatment is a minor step in the total operation. Because of the large number of applicators and the fact that the treatment provides an incremental rather than a primary product characteristic, economic analysis of these treatments is less precise. A similar situation exists in the case of field treatments, and the analysis is complicated by the wide geographic dispersal of application locations, large number of applicators, and the often non-commercial nature of the use. For these reasons, it is felt that these analyses of non-pressure treatments are substantially less precise than those for the pressure treatments.

A small amount of each of the RPAR'd preservatives is used for brush or other non-pressure field application to the cuts made during the fabrication and installation of pressure-treated lumber. This field treatment is critical to the effective performance of the treated wood. Since this field application is actually a part of the preservative treatment system, no separate economic impact analysis is presented.

## Economic Impact Analysis of Canceling Penta and Creosote for In-Place Groundline Treatment of Utility Poles

### Introduction

The in-place groundline treatment of utility poles is a small, but increasingly important, segment of the wood treatment industry. Groundline treatment involves the application of additional wood treatment chemicals (mainly creosote, penta, and sodium fluoride) to the critical groundline area of the pole. This segment of the pole (6 in. above ground to approximately 16 in. below ground) is critical because optimum decay conditions usually cause more rapid deterioration and failure in this area. Decay and subsequent pole failure at the groundline can be delayed for 20 or more years if this area is given supplementary preservative treatments. The normal groundline treatment cycle involves giving a pole the first treatment 15 or 20 years after installation, followed by subsequent treatments at 30 and 40 years.

There are two major types of commercial groundline treatments marketed in the United States. One type has a high creosote content and the other has a high penta content. Continuation of the present groundline treatment system is dependent upon the availability of either penta or creosote.

### Methodology

The expected life of a pole without groundline treatment is assumed to be 30 years in this analysis instead of the 35 years used in the treated pole analysis because different pole populations are involved. The analysis of treated poles deals with the national population of poles that receive pressure treatment as applied in 1978, whereas the groundline-treated poles are drawn from the population of poles that was treated 20 to 40 years ago when the average quality of treatment was lower. Thus, average service life tended to be less than that of poles currently treated.

In the South where decay occurs more rapidly, utility companies are expected to have more incentive to use groundline treatment than utility companies in the North. Since the average life of poles is expected to be lower in the South, the anticipated life of those selected for groundline treatment is hypothesized to be less than the national average life of poles currently receiving treatment.

The benefits associated with groundline treatment can be estimated by determining the savings in pole replacement costs resulting from an extension of service life. In this analysis it is assumed that the pole life can be extended 20 years beyond the present estimated 30-year life by groundline treatment. The savings will be discounted to a common time period for comparison purposes and expressed as equivalent uniform annual savings per pole. The annual amount that must be set aside drawing compound interest in order to cover cost of poles over their life cycle is often referred to as the sinking fund. A utility line manager is interested in how much the annual amount set aside for pole replacement (sinking fund) can be reduced as a result of switching to in-place groundline treatment. This reduction is equal to the present value of the cost differences multiplied by the annualization factor. The annualized cost savings can be calculated as:

$$\text{Annual Cost Savings} = \begin{pmatrix}\text{present value of} \\ \text{cost savings}\end{pmatrix} \times \left[\frac{r(1+r)^n}{(1+r)^n-1}\right]$$

where: $r$ = annual interest rate
$n$ = life cycle

The following assumptions were used in the annualized savings analysis:

| | | |
|---|---|---|
| 1. | Average life of pole without groundline treatment | 30 years |
| 2. | Average life of pole with groundline treatment | 50 years |
| 3. | Current average installed replacement cost | |
| | a. distribution pole | \$ 350.00 |
| | b. transmission pole | \$1,478.00 |
| 4. | Cost of single groundline treatment | \$ 10.00 |
| 5. | Average number of groundline treatments each pole receives | 3 |
| 6. | Current interest rate | 10% |
| 7. | Treating cycle | 10 years |
| 8. | Minimum age when pole was first treated | 20 years |
| 9. | Pole is subject to straight line depreciation | |

## Current Use and Savings in Pole Replacement Costs

The number of utility poles receiving groundline treatment in the United States was estimated to range from 0.9 to 1.1 million poles in 1978. The groundline treatment industry used an estimated 172,000 pounds of penta and 655,000 pounds of creosote to treat poles in 1978 (Jansen, 1979). Industry sources estimated that the average cost of treating distribution poles varies between 10 and \$12 per pole (Cravens, 1979 and Nagel, 1979a). The unit cost for transmission poles averages about \$4 higher. If one assumes that about 93% of the treated poles were distribution poles, the total cost of groundline application for one million poles ranged between 10.3 and \$12.3 million in 1978.

### Calculation of Equivalent Uniform Annual Savings Per Pole

The flow of costs associated with the in-place groundline treatment of distribution poles compared to those not given groundline treatment is shown in Table 129.

Table 129.--Calculation of present value of savings per pole due to in-place groundline treatment of distribution poles

| No. of Years | Current Cost per Pole | | | | |
|---|---|---|---|---|---|
| | Without Groundline Treatment | With Groundline Treatment | Difference in Cost | Discount Factors | Present Value of Cost Difference |
| | - - - - - - - - - | Dollars | - - - - - - - - - | | Dollars |
| 0 | 350 | 350 | 0 | 1.0 | 0 |
| 20 | 0 | 10 | -10 | 0.1487 | -1.487 |
| 30 | 350 | 10 | 340 | 0.0573 | 19.482 |
| 40 | 0 | 10 | -10 | 0.0221 | -0.221 |
| 50 | -116.67<br>(salvage value) | 0 | -116.67 | 0.0085 | -0.992 |
| Total | 583.33 | 380 | 203.33 | | 16.78 |

The total savings in current dollars is \$203.33 or \$4.07 per year. Of course, these figures do not take into consideration the time value of money. The current value of cost differences is converted to present value at the beginning of the project by multiplying the cost differences by the appropriate discount factors. After discounting for the time factor, we observe that the present value of expected \$203.33 savings is \$16.78. The annualized savings associated with the \$16.78 present value of pole cost savings is calculated as:

$$\text{Annual Pole Cost Savings} = (16.78)\left[\frac{.10(1 + .10)^{50}}{(1 + .10)^{50} - 1}\right]$$

$$= (16.78)\ (0.1008592) = \$1.69$$

Given the assumptions used in this analysis, the calculations indicate that the annual amount to be set aside drawing compound interest for use in pole replacement can be reduced by \$1.69 per pole if groundline treatment is used. Performing the same calculations for a transmission pole with an installed cost of \$1,478 indicates that the annualized savings from groundline treatment would be \$7.80 per transmission pole. If we assume that 7% of the treated poles are transmission poles and 93% are distribution or telephone poles, the weighted annualized savings per pole equals \$2.12.

There are an estimated 126 million utility poles installed in the United States, but only a portion of the system is now subject to groundline treatment. If we assume that a pole receives three groundline treatments during its 50-year life, the annual treatment of one million poles is sufficient to maintain a system of 16.67 million poles. The average annualized savings per pole multiplied by the number of poles in the system subject to groundline treatment will indicate the total benefits of the groundline treatment program. The annualized savings for the system would be:

$$\$2.12 \text{ per pole} \times 16.67 \text{ million poles} = \$35,340,400.$$

In this case, an annual estimated expenditure of $10.2 million for the treatment of one million poles yields a significant savings.

If all groundline treatments were canceled, the demand for new replacement poles would not change above current levels during the next 10 years. Shorter pole life would cause an increase in replacement pole demand beginning 10 years after cancellation. In the long run, annual consumption of replacement poles would increase about 222,300 per year above that expected with current levels of groundline treatment.

It has been estimated that groundline treatment will double within the next 5 years. Potential benefits from groundline treatment would exceed $70 million per year if 2 million poles received groundline treatment. About 7.5 million poles would require treatment each year in order to include the entire 126 million poles in the United States in a groundline treatment program.

Currently, creosote is included in the formula of most groundline treatments and is a major component in about 2/3 of all treatments. If creosote were canceled, heavy oil or coal tar could probably be used as a substitute for creosote. Penta is a major component in the formula for about 1/3 of the groundline treatments. If only penta were canceled, creosote or heavy oil would probably be used as a substitute.

## Limitations of the Analysis

The actual industry benefits are difficult to estimate due to lack of information concerning which poles were treated. The benefits of groundline treatment are greatest for poles that have the largest installation costs. If a large proportion of the poles that have received groundline treatment are located in urban areas, the average installation cost used is this analysis would underestimate actual savings.

## Summary of Economic Impact Analysis of Canceling Penta and Creosote for In-Place Groundline Utility Pole Treatments

| | |
|---|---|
| A. USE: | Penta and creosote used commercially in various combinations to retard groundline decay of in-place utility poles. |
| B. MAJOR PEST CONTROLLED: | Wood decay fungi. |
| C. ALTERNATIVES: | Penta or creosote groundline treatment. |
| <u>Comparative efficacy</u>: | Penta and creosote groundline treatments appear equally effective. |
| <u>Comparative cost</u>: | Penta and creosote treatments cost approximately the same. |
| D. EXTENT OF USE: | One million poles treated per year. |
| E. ECONOMIC IMPACTS: | |
| <u>User</u>: | Annualized pole replacement impact of $35,340,400 for a system of 16.67 million poles. |

| | |
|---|---|
| Market: | |
| Shortrun | No change in demand for poles during the next 10 years. |
| Longrun | The average consumption of new poles would increase by 222,266 per year above that required with current groundline treatment levels. |
| Consumer: | Not investigated. |
| Macroeconomics: | Not investigated. |
| F. SOCIAL/COMMUNITY IMPACTS: | Minimal. |
| G. LIMITATIONS OF THE ANALYSIS: | Specific location of groundline-treated poles and actual installed costs of poles given groundline treatment not available. |
| H. ANALYST AND DATE: | Edmund F. Jansen, Jr., Nov. 1979. |

## Economic Impact Analysis of Canceling Na-Penta for Sapstain Control

### Introduction

Penta was first introduced in the 1930's as a wood preservative. Na-penta is the sodium salt of pentachlorophenol and is used in aqueous formulations which are applied to green lumber and poles for control of sapstain fungi. These applications provide short-term protection against unsightly and aesthetically objectionable staining of freshly cut lumber during storage and transportation.

The control of sapstain fungi is a minor use of penta. Approximately 1.15 million pounds of Na-penta are used annually for this purpose (NFPA, 1979). This figure represents about 1.02 million pounds of penta, or 2.3% of the estimated 43.6 million pounds of penta used commercially in the United States in 1978.

### Methodology

Estimated economic impacts associated with the cancellation of Na-penta for sapstain control are given in Table 130. They are calculated by using the following assumptions:

1. The Na-penta cost is $7.00 per gallon of concentrated solution.
2. Copper-8-quinolinolate (Cu-8) costs $12.15 per gallon of concentrated solution.
3. The application rate of both chemicals is 8 gallons of diluted solution per 1,000 bd. ft. of lumber (NFPA, 1979).
4. The solution of Cu-8 is diluted over a range of 1:50 to 1:250 with water for all treatments.
5. The penta solution is diluted with water as follows: Exported lumber 1:50, one half domestic lumber 1:60, one half domestic lumber 1:100.
6. The technology is assumed to be identical for alternative chemical treatment.

Table 130.--Comparative costs of Na-penta and Cu-8 for sapstain control in lumber

| Item | Na-Penta | | | Cu-8 |
|---|---|---|---|---|
| | Export Treatment | Domestic Treatment | | |
| | All Treatments | 50 Percent | 50 Percent | All Treatments |
| Cost per gallon[a] of concentrate (dollars/gallon) | 7.00 | 7.00 | 7.00 | 12.15 |
| Percent of chemical[a] in concentrate (% by weight) | 28 | 28 | 28 | 5.4 |
| Gallons of concentrate[a] per gallon of solution | 0.02 | 0.017 | 0.01 | 0.01 |
| (gallon concentrate/ gallon water) | (1:50) | (1:60) | (1:100) | (1:100) |
| Cost of treating solution[b] (dollars/gallon) | 0.14 | 0.117 | 0.07 | 0.12 |
| Application rate of[a] solution (gallon/1,000 bd. ft.) | 8 | 8 | 8 | 8 |
| Chemical cost[c] (dollars/1,000 bd. ft.) | 1.12 | 0.93 | .56 | 0.97 |

[a] Nagel, 1979.

[b] Cost of concentrate x gallon of concentrate per gallon of solution.

[c] Application rate x cost of solution.

## Cost of Treatment

Treatment solutions containing Na-penta are the primary materials used by the forest products industry to control sapstain fungi on freshly sawn lumber. Currently, an estimated 4.2 billion bd. ft. of lumber is treated annually with Na-penta or formulations containing Na-penta (NFPA, 1979). The application rate is 8 gallons of solution per 1,000 bd. ft. of lumber. The lumber is treated by dipping or spraying. Exported lumber is treated with a 1:50 solution of penta at a cost of $1.12 per 1,000 bd. ft. (Table 130). Approximately half the domestic lumber is treated with a 1:60 solution at a cost of $0.93 per 1,000 bd. ft., and the remainder is treated with a 1:100 solution at a cost of $0.56 per 1,000 bd. ft. (Arsenault, 1979).

Total U.S. production of lumber in 1978 was approximately 38 billion bd. ft. (Phelps, 1979). Thus, 11% of the lumber produced in the United States in 1978 was treated for sapstain control with chlorinated phenates. The material cost for treatment is $2.69 million (Table 131).

Table 131.--Volume and cost of U.S. lumber products treated with Na-penta formulations, 1978

| Product | Volume[a] | Percent | Chemical Cost[a] | Alternative Chemical Cost[b] |
|---|---|---|---|---|
| | Billion bd. ft. | Percent | Million Dollars | Million Dollars |
| Hardwood (total) | 1.23 | 100 | 1.00 | 1.19 |
| Domestic use | 1.01 | 82 | 0.75 | 0.98 |
| Export | 0.22 | 18 | 0.25 | 0.21 |
| Softwood (total) | 1.83 | 100 | 1.69 | 1.77 |
| Domestic use | 0.95 | 52 | 0.71 | 0.92 |
| Export | 0.88 | 48 | 0.99 | 0.85 |
| Total wood treated | 3.06[c] | -- | 2.69 | 2.97 |

[a] NFPA, 1979.

[b] Volume treated x cost of solution (Table 124).

[c] An additional 1.14 billion bd. ft. are treated with other chlorinated phenates.

## Alternative Treatment Methods and Costs

The only non-chemical alternative for sapstain control is kiln drying. This alternative is feasible only if accomplished within 48 hours of sawing, which greatly limits its potential. The Assessment Team identified Cu-8 as the primary chemical substitute for Na-penta, but also pointed out that Cu-8 could cause corrosion of steel-treating equipment (Chapter 6).

The cost of Cu-8 is $12.15 per gallon of concentrate, which is diluted with water to produce treating solution concentrations ranging from 1:50 to 1:250 (Gjovik, 1979; and Nicholas, 1979). If the dilution is 1:100, the cost of the formulation is $0.12 per gallon. If 8 gallons per 1,000 bd. ft. of lumber were used, the total cost would be $2.97 million.

This figure for Cu-8 represents a net cost increase of $0.28 million to the lumber industry. An additional cost would be incurred to protect steel-treating equipment, but no estimates of this cost are available. Since 3.06 billion bd. ft. of lumber were treated in 1978, the increased chemical cost if Cu-8 were used in place of Na-penta would be $0.085 per 1,000 bd. ft.

## Summary of Economic Impact Analysis of Canceling Na-Penta for Sapstain Control

| | |
|---|---|
| A. USE: | Used commercially to control sapstain in green lumber and freshly peeled poles. |

| | |
|---|---|
| B. MAJOR PESTS CONTROLLED: | Sapstain and mold fungi. |
| C. ALTERNATIVES: | |
| Chemical: | Copper-8-quinolinolate (Cu-8). |
| Non-Chemical: | Kiln drying. |
| Efficacy of alternatives: | The chemical alternatives at specific concentrations have been shown to control sapstain and mold fungi effectively. |
| Comparative costs: | Penta formulations: approximately $2.69 million. Cu-8 formulations: approximately $2.97 million. |
| D. EXTENT OF USE: | 1.02 million pounds of penta are used in the treatment of 3.06 billion bd. ft. of lumber per year. |
| E. ECONOMIC IMPACTS: | |
| User: | Increase of $0.28 million in chemical costs to the mills. |
| Market: | Small. |
| F. SOCIAL/COMMUNITY IMPACTS: | Small. |
| G. LIMITATIONS OF THE ANALYSIS: | Insufficient information on volume of poles treated, and additional costs of treatment caused by required equipment modification. |
| H. ANALYSTS AND DATE: | Gail Willette, Jan. 14, 1980. |

## Economic Impact Analysis of Canceling Penta for Millwork and Plywood Uses

### Introduction

Penta in a 5% solution of light petroleum solvent is the most widely used wood preserving chemical in the millwork industry. Millwork includes wood window frames, sash, screens, blinds, shutters, doors, door frames, mouldings, and similar products. These items are manufactured primarily from ponderosa pine and other softwoods and are used in exterior applications. Few, if any, interior millwork products are treated with wood preservatives.

Softwood plywood is sometimes treated with penta by dipping or spraying. This treatment is considered important for plywood in exterior uses or when the plywood will be subjected to excessive moisture.

### Current Use

Penta is applied to millwork and plywood by non-pressure treating methods which include dipping, spraying, and a vacuum process. An estimated 1 billion bd. ft.

(approximately 60 million cu. ft.) of millwork products are treated with penta annually by the millwork industry, consuming 600,000 pounds of penta in 1.7 million gallons of solution (NFPA, 1979).

A small volume of plywood and particleboard is treated with mixtures containing 5% penta. Approximately 15 million square feet (3/8 in. basis) of plywood are treated annually. The volume of solution used is estimated to be 150,000 gallons. More than 19 billion square feet of plywood are produced annually in the United States. Thus, less than 0.1% of the U.S. plywood produced is treated with penta.

The largest single application involving plywood is for textured siding where it serves as a water repellent and mildewcide. Use of a mildewcide is considered particularly important for redwood siding (NFPA, 1979).

## Alternative Treatments

Many millwork products are later stained, painted, or finished with clear coatings. As a result, wood preservatives and their solvents must not color the treated wood or affect the compatibility with stains, paints, sealers, glazing compounds, caulkings, or metal fasteners and other hardware.

Two percent tributyltin-oxide (TBTO) and 2% Cu-8 solutions were identified by the Assessment Team as alternatives to penta for millwork and plywood treatments. It should be noted that these preservatives are not currently registered at the above concentrations. Nevertheless, the Assessment Team concluded on the basis of published test results that higher concentrations were necessary in order for these preservatives to be satisfactory alternatives (Chapter 3).

## Comparative Treatment Costs

Penta formulations used in millwork and plywood treatments are sold to treatment mills by formulators for $1.73 per gallon ($1.33 + 30% profit markup) as a premixed ready to use solution (Arsenault, 1979). The treatment of 60 million cu. ft. of millwork products and 15 million square feet of plywood requires 1.85 million gallons of solution (Table 132). This results in a total chemical cost of $3.20 million (1.85 million x $1.73).

Because the Assessment Team listed alternative chemicals which are not registered by EPA at the specified concentrations, it was not possible to obtain current market prices for the alternatives. The methodology adopted by the Assessment Team to provide these data was to calculate manufacturers' costs of producing Cu-8 and TBTO at the specified concentrations and then add a 30% profit markup to these costs. The total chemical costs obtained by using these prices are $7.99 million and $5.42 million for Cu-8 and TBTO, respectively (Table 132).

## Economic Impacts

The economic impacts to treaters' facilities if Cu-8 or TBTO were substituted for penta include the increased chemical costs. For Cu-8, an increase of $4.8 million in chemical costs was calculated. Substituting TBTO for penta would increase chemical costs by $2.22 million. It should be noted, however, that the profit markups and manufacturing costs of these two alternatives are hypothetical as discussed above.

Table 132.--Comparative costs of penta and alternatives for millwork and plywood treatment

| Item | Penta | Cu-8 | TBTO |
|---|---|---|---|
| 1. Manufacturers' cost[a] (dollars/galllon) | 1.33 | 3.32 | 2.25 |
| 2. Cost of ready to use solution[b] (dollars/gallon) | 1.73 | 4.32 | 2.93 |
| 3. Active ingredient in solution (%) | 5.0 | 2.0 | 2.0 |
| 4. Total solution used[c] (million gallon) | 1.85 | 1.85 | 1.85 |
| 5. Cost of chemicals[d] (million dollars) | 3.20 | 7.99 | 5.42 |

[a] Manufacturers' costs calculated by Lee Gjovik from costs of ingredients obtained from Roberts Consolidated, Kalamazoo, Mich. (Winebrenner, 1980).

[b] Profit markup of 30% added to item 1.

[c] 1.7 million gallons used for millwork treatments and 0.15 million gallons used for plywood treatments.

[d] Item 2 x item 4.

In addition, it is impossible to determine the impacts of these cost increases on the prices of final products. Information on the volumes and values of final products is not available. Demand elasticity estimates for wood products have traditionally had wide variations caused by variations in species and grades of lumber used. As a result, it was not possible to determine what portion of the cost increases would be passed on to consumers in the form of higher retail prices.

## Summary of Economic Impact Analysis of Canceling Penta for Millwork and Plywood Uses

| | |
|---|---|
| A. USE: | Used commercially to treat millwork and plywood. |
| B. MAJOR PESTS CONTROLLED: | Decay and mildew fungi. |
| C. ALTERNATIVES: | Tributyltin-oxide (TBTO) and Copper-8-quinolinolate (Cu-8). |
| <u>Comparative efficacy</u>: | TBTO (2.0%) and Cu-8 (2.0%) are considered equally effective for this use. |
| <u>Comparative costs</u>: | \$3.20 million for penta formulations.<br>\$7.99 million for Cu-8 formulations.<br>\$5.42 million for TBTO formulations. |
| D. EXTENT OF USE: | 1.85 million gallons of 5% penta solution are used annually to treat 60 million cu. ft. of millwork and 15 million square feet of plywood. |

E. ECONOMIC IMPACTS:

<u>User</u>: Increase of 2.2 to $4.8 million in chemical costs to the treatment mills.

<u>Market</u>: About 1% of the annual penta production is used for millwork and plywood treatments.

F. SOCIAL/COMMUNITY IMPACTS: Not investigated.

G. LIMITATIONS OF THE ANALYSIS: Lack of exact prices for alternative chemicals and information on volumes and values of final products.

H. ANALYST AND DATE: Gail Willette, Jan. 9, 1980.

# Economic Impact Analysis of Canceling Penta for Use in Particleboard Manufacturing

## Introduction

In some areas of the United States (Hawaii) it is necessary to treat particleboard to prevent attack by termites and other wood-destroying insects. Penta is presently the only preservative that can be applied to the particleboard in the manufacturing process. The Willamette Industries Duraflake Plant in Albany, Oregon, is currently the only known plant producing penta-treated board. Less than 10,000 pounds of penta are used to treat approximately 180,000 square feet (3/4-in. basis) of particleboard annually (NFPA, 1979). This treated board makes up less than 1% of the average annual particleboard production of the Albany plant and represents a very small part of the 3.9 billion square feet of particleboard produced in the United States in 1978 (National Particleboard Assoc., 1979).

The penta-treated board can be made in thicknesses ranging from 3/8 inch to 1-3/4 inches and any size up to 5- by 16-feet. The finished board is sold to distributors and eventually used in cabinets and similar applications.

## Methodology

The individual particles in particleboard are bonded together by the polymerization of urea-formaldehyde resin. When treated board is manufactured, the penta solution, resin, and wax emulsion are applied to the wood particles at the same time. After blending, the wood particles are conveyed to a forming station where the material is formed into a mat and then moved to the press where the mats are consolidated into boards (NFPA, 1979).

Premixed penta solution (40 to 42% by weight) is obtained from the penta manufacturer in 55-gallon drums. This penta concentrate is pumped directly into the resin blender. Here the penta solution is applied to the wood particles at a rate of 0.65% (penta solids based on oven-dry weight of the wood) along with the resin and wax (NFPA, 1979).

## Alternatives

No alternative chemical has been used in the manufacture of treated board (Cheo, 1979), nor has any substitute been found that will give the degree of protection provided by the levels of penta currently used (NFPA, 1979). This is partially due to the requirement that any alternate be compatible with the urea-formaldehyde resin so that it does not interfere with the effectiveness of this bonding agent.

A possible alternative is the pressure treatment of the particleboard after manufacture. This has been successfully accomplished by using the Cellon process, so the validity of this alternative has been demonstrated.

### Comparative Costs

The price of the premixed penta solution purchased for the manufacture of treated board is approximately $5.65 per gallon (McVey, 1980). Since there is no known alternative chemical available for this use, no comparative prices were derived.

## Economic Impacts

Approximately 180,000 square feet (3/4-in. basis) of penta-treated particleboard are manufactured annually, with the exception of 1979 (Table 133). In 1979, only 29,500 square feet of treated board was produced compared to 186,600 square feet in 1978. The average annual value of treated board sold to distributors in recent years is about $35,000 (NFPA, 1979).

Table 133.--Quantity of treated particleboard and total particleboard produced by the Duraflake plant of Willamette Industries, 1973-79[a]

| Year | Total Treated Particleboard Produced[b] | Percent of Total | Total Particleboard Produced |
|---|---|---|---|
| | 1,000 sq. ft. | | Million sq. ft. |
| 1973 | 166.9 | 0.10 | 161 |
| 1974 | 294.6 | 0.19 | 156 |
| 1975 | 147.3 | 0.09 | 166 |
| 1976 | 275.0 | 0.16 | 167 |
| 1977 | 147.3 | 0.08 | 174 |
| 1978 | 186.6 | 0.11 | 171 |
| 1979 | 29.5 | 0.02 | 166[c] |

[a] Source: McVey, 1980.

[b] Volumes based on the amount of penta solution purchased in these years.

[c] Estimated.

In 1978, approximately 3.9 billion square feet (3/4-in. basis) of particleboard were produced in the United States (National Particleboard Assoc., 1979). This is an increase of about 8% above the 1977 total production of 3.6 billion square feet. The National Particleboard Association reports a value of shipments of $818 million for 1978, almost a 70% increase over 1977. Total production, total shipments and value of shipments of particleboard for 1969-1978 are presented in Table 134.

Table 134.--Total production and shipments of particleboard, and value of shipments, 1969-1978[a]

| Year | Total Production of Particleboard | Total Shipments of Particleboard | Value of Shipments |
|---|---|---|---|
| | Million sq. ft. | Million sq. ft. | Million dollars |
| 1969 | 1,716 | 1,615 | 200.8 |
| 1970 | 1,764 | 1,662 | 159.4 |
| 1971 | 2,394 | 2,300 | 206.3 |
| 1972 | 3,117 | 3,015 | 284.9 |
| 1973 | 3,494 | 3,428 | 389.4 |
| 1974 | 3,104 | 2,988 | 347.4 |
| 1975 | 2,539 | 2,526 | 272.6 |
| 1976 | 3,202 | 3,178. | 364.9 |
| 1977 | 3,593 | 3,554 | 484.9 |
| 1978 | 3,866 | 3,720 | 818.4 |

[a] Source: National Particleboard Assoc., 1979.

### User Impacts

Willamette Industries in Albany, Oregon is currently the only known producer of penta-treated particleboard. The user impacts of canceling penta for this application would be limited to this plant. In this event the plant would no longer incur the costs and inconvenience of treating the board. At the same time they would not be able to supply a unique product to their customers.

In recent years an average of 180,000 square feet (3/4-in. basis) of treated particleboard was produced. This accounts for less than 1% of the average total production of the plant during the last 7 years (Table 133). The value of the treated board is approximately $35,000 annually. Subtracting cost of treatment (unknown) from this revenue value would make the economic loss to the plant minor.

### Market Impacts

The data needed for a detailed analysis of market impacts were insufficient, and therefore only broad statements can be made. The demand for untreated board may rise slightly to replace unavailable treated board. It is not known what kind of effect, if any, this may have on prices. A price change will affect input costs of industries, such as cabinet and furniture makers, which use treated board to manufacture their products.

### Consumer Impacts

The price of treated-board is somewhat higher than untreated board. The price of certain final particleboard products will be lower where treated board is replaced by untreated board; however, these products will be more susceptible to termite attack.

## Limitations of the Analysis

Production costs of treated board are not known. Separate dollar values of treated and untreated board were not available. Lack of efficacy data makes it difficult to evaluate the non-monetary importance of treated board.

## Summary of Economic Impact Analysis of Canceling Penta for Use in Particleboard Manufacturing

| | |
|---|---|
| A. USE: | Used to control insects in particleboard. |
| B. MAJOR PESTS CONTROLLED: | Termites and other wood destroying insects. |
| C. ALTERNATIVES: | |
| <u>Chemicals</u>: | There are currently no registered alternative chemicals that have been shown to be satisfactory for this application; however, pressure treatment of the finished product by using the Cellon process is a viable alternative. |
| <u>Non-chemical controls</u>: | Use untreated particleboard in place of treated board. |
| <u>Efficacy of alternatives</u>: | Untreated board would be more susceptible to attack, but to what extent is not known. |
| <u>Comparative performance</u>: | No performance data are available for treated or untreated particleboard. |
| <u>Comparative costs</u>: | Cost of penta solution used in manufacturing treated particleboard is approximately $5.65 per gallon. Untreated board would be slightly cheaper than treated board. |
| D. EXTENT OF USE: | Less than 10,000 pounds of penta are used to treat approximately 178,000 sq. ft. (3/4 in. basis) of particleboard annually. |
| E. ECONOMIC IMPACTS: | |
| <u>User</u>: | Currently, only one plant is producing treated particleboard. The average annual value of treated board sold to distributors was about $35,000 in recent years. |
| <u>Market</u>: | If no treated board is available, there will most likely be a slight increase in the demand for untreated particleboard. |

Consumer: Final products made with treated board will probably decrease in price if untreated board is used.

Macroeconomics: Not investigated.

F. SOCIAL/COMMUNITY IMPACTS: Not investigated.

G. LIMITATIONS OF THE ANALYSIS: Efficacy data for treated board, untreated board, and registered chemicals were not available. Exact prices of treated versus untreated board were not available. Cost comparison of chemicals was not investigated.

H. PRINCIPAL ANALYST AND DATE: Robert F. Esworthy, Economic Analysis Branch/BFSD/OPP, U.S. Environ. Prot. Agency, Wash., D.C., Jan. 1980.

# Economic Impact Analysis of Canceling Penta for Home and Farm Uses

## Introduction

Approximately 1.5 million pounds of penta are used at the home and farm level for protection of various wood structures and products subjected to exterior exposure. Penta solutions are applied by homeowners, farmers, and to some extent on-the-job carpenters, to protect wood from decay-causing organisms. The application can be by brushing, roll on, dipping, soaking, or spraying. Typical items sometimes treated include decks, siding, millwork lumber, fences, shingles, outdoor furniture, and other miscellaneous wood products. Penta solutions are widely available in concentrate and ready-to-use solutions.

The treated wood is colorless and paintable. The treatment is most effective when applied to wood for above-ground use but does provide some control when wood is used in ground contact.

## Current Use

An estimated 3.75 million gallons of 5% penta solution are used annually in home and farm applications to approximately 150 million cu. ft. of wood. The ready-to-use water-repellent penta formulation is the most widely used. Treatment can be applied to structures already standing (e.g., fences, sheds, etc.) or to items prior to installation. Even though the majority of treated items are finished with paint, varnish, or stain, some users prefer the natural finish of the preservative itself. Several water-repellent penta products are also available as stains in various colors for home and farm applications.

Penta is effective against numerous decay and stain fungi, insects, molds, and mildew. The water repellent reduces warping, checking, swelling, and shrinking caused by the changes in moisture content of the wood. Homeowners and farmers rely heavily on penta formulations to extend the useful life of wood in above-ground applications.

## Alternative Treatments

Alternative preservative chemicals registered for use at the home and farm level include: copper naphthenate, zinc naphthenate, TBTO, Cu-8, and creosote (currently under RPAR). None of the chemicals mentioned has the broad range effectiveness of penta, but they have known merit and are partial substitutes for certain uses.

Copper naphthenate ready-to-use solutions may also contain water repellents to control warping, swelling, and checking. Most are for above-ground use, but some highly concentrated formulations have manufacturers' directions for treating wood to be used in ground contact. The various copper naphthenate stains are for above-ground use only. Copper naphthenate imparts color to the wood, makes a poor base for paint, and is difficult to finish naturally. Zinc naphthenate is colorless, but also is considered to be less effective than copper naphthenate.

TBTO treating solutions are colorless, which leaves the wood clear and paintable. This chemical has some known merit for protecting wood above-ground, but is ineffective for ground contact use. The TBTO preservative can be degraded by sunlight, causing it to be less effective against decay. TBTO is only partially effective in controlling insects.

Brush, dip, and spray creosote treatments will reduce the rate of attack of wood-destroying fungi and insects in above-ground applications, but are generally ineffective when the wood is used in ground contact situations. When properly applied, however, hot and cold soak treatments will provide protection for wood used in ground contact (Chapter 5). Creosote formulations discolor wood and interfere with paintability.

Copper naphthenate, zinc naphthenate, and creosote products are all persistently malodorous. The Assessment Team notes that the registered concentration levels of Cu-8 (0.25%) and TBTO (0.3%) will not be effective against fungi and insect attack. Therefore, chemical concentrations of 2% for both Cu-8 and for TBTO are recommended.

An estimated 2 million pounds (0.2% of total production) of creosote are sold to individuals for home and farm treatment of wood annually (Chapter 5). The amount of the other alternate chemicals used for home and farm application is unknown.

Possible non-chemical alternatives include not treating the wood, using non-wood materials (aluminum, concrete) or purchasing lumber already pressure-treated. The production of lumber pressure-treated with arsenicals is growing rapidly, which makes it more readily available for use by homeowners.

### Comparative Costs

The average prices of several wood preservative products are presented in Table 135. The price of penta varies depending on the type of product. The most commonly used formulation, 5% penta ready-to-use in mineral spirits, costs about $9.50 per gallon. The zinc naphthenate, copper naphthenate, and TBTO products are somewhat more expensive (no price was obtained for Cu-8 products). The prices in Table 135 are for products using the chemicals at the registered concentration levels. If the TBTO and Cu-8 products were formulated at the concentration of 2.0% recommended by the Assessment Team, the costs to the consumer would be substantially higher. Present technology is such that a 2% solution of TBTO would be difficult if not impossible to achieve (Winebrenner, 1980).

Table 135.--Average retail price of various wood preservative products[a]

| Type of Solution | Active Ingredient | Retail Price |
|---|---|---|
| | | Dollars/ Gallon |
| Ready-to-use in fuel oil | 5% penta | 7.40 |
| 10-1 concentrate to be diluted with mineral spirits or diesel oil | 40% penta | 13.60 |
| Ready-to-use in mineral spirits with water repellents (clear, pigmented and paintable) | 5% penta | 9.50 |
| Ready-to-use in mineral spirits with water repellents (green) | 20% copper naphthenate (2% metallic copper) | 13.45 |
| Ready-to-use with water repellents (clear) | 13.5% zinc naphthenate (2% metallic zinc) | 12.40 |
| Ready-to-use in mineral spirits with water repellents (clear, pigmented, and paintable) | 0.3% TBTO | 14.50 |

[a] Based on a spot check of several lumber and hardware stores in metropolitan Washington, D.C. as well as communications with Roberts Consolidated, Darworth Inc., Chapman Chemical and Koppers Chemical Co.

The cost of the non-wood substitutes would be roughly comparable to wood material. Exact costs were not derived since they would depend on the specific end use.

Table 136 presents average prices for lumber of various dimensions both untreated and pressure-treated with CCA. If one assumes that 5% ready-to-use penta in mineral spirits would be applied to untreated lumber, the cost of penta solution for treatment can be calculated. Dip treatment at an estimated 8 gallons per 1,000 bd. ft.and $9.50 per gallon would cost $76 per 1,000 bd. ft. for treating chemical; brush applications at 4 gallons per 1,000 bd. ft. would cost $38 per 1,000 bd. ft. This cost of 38 to $76 (plus application) may be compared with the range of average costs for pressure treatment of 90 to $170. However, pressure-treated wood sizes, grades, and species required for farm and home use are often not available in retail lumber yards.

## Economic Impacts

### User Impacts

Since penta is used for so many different applications by homeowners and farmers, it is difficult to assess the impact of cancellation. Untreated wood has a substantially shorter service life than penta-treated wood when subjected to exterior exposure; consequently it is not a viable alternative. There is no single substitute for all uses of penta, but a number of products have limited potential. These are:

1. There are several preservative products currently available to homeowners and farmers. The most readily available appear to be solutions containing copper naphthenate, zinc naphthenate, Cu-8, creosote, or TBTO. None of these chemicals has the overall performance of penta, but all have limited application potential. The prices of the alternative products are notably higher than the price of the penta products.

2. Non-wood materials can replace wood in certain circumstances and are comparable in price. This does not account for an individual's aesthetic value of wood. Substituting material such as aluminum or steel for wood raises the controversial question of non-renewable resource versus renewable resources, as well as the much higher energy consumption required for extraction and processing of the non-renewable resource products.

3. Rather than dip or brush-treat untreated lumber, an individual could use lumber that has been pressure-treated. The price of pressure-treated lumber is slightly higher than lumber treated by brush or dip, but the pressure treatment would provide better protection; however, substituting pressure-treated lumber does not satisfy the need for supplemental treatment of standing structures or treating cut ends during the installation of treated material.

Table 136.--Retail prices of pressure treated and untreated dimension lumber

| Lumber Size | Price of Untreated Lumber[a] | | | Price of Treated Lumber[b] | | | Average Price Increase for Treatment |
|---|---|---|---|---|---|---|---|
| | Low | High | Average[c] | Low | High | Average[c] | |
| | - Dollars/bd. ft. - | | | - Dollars/bd. ft. - | | | Percent |
| 2 in. x 4 in. x 8 ft. | 0.26 | 0.35 | 0.32 | 0.42 | 0.63 | 0.49 | 53 |
| 2 in. x 6 in. x 12 ft. | 0.37 | 0.57 | 0.47 | 0.50 | 0.66 | 0.56 | 19 |
| 2 in. x 8 in. x 12 ft. | 0.33 | 0.56 | 0.46 | 0.50 | 0.66 | 0.56 | 22 |
| 2 in. x 10 in. x 12 ft. | 0.35 | 0.66 | 0.52 | 0.56 | 0.71 | 0.61 | 17 |

Source: Based on a spot check of several lumber and hardware stores in metropolitan Washington, D.C., Jan. 1980.

[a] Untreated lumber is usually No. 2 southern pine. Other prices included are for No. 1 southern pine, spruce, and Douglas-fir. The No. 2 southern pine is the least costly of the four. Untreated lumber is almost always kiln-dried in this market area.

[b] Treated lumber is normally No. 1 or No. 2 southern pine, pressure-treated with CCA to 0.25 or 0.40 pcf retention. Some prices include kiln drying. These factors are partly responsible for the varying prices.

[c] The average price was calculated by using all the prices gathered.

### Market Impacts

The available data are insufficient for a detailed analysis of market impacts. The consumption of alternative chemical products, non-wood material, and pressure-treated lumber would increase if penta were canceled for home and farm use. The impact that the increased consumption of these alternatives will have on their prices and production is difficult to estimate.

#### Consumer Impacts

See "User Impacts."

### Social/Community Impacts

Penta has proven its effectiveness during its 40 years of use. Users may not readily accept the alternatives which have limited field experience or less desirable characteristics.

### Macroeconomic Impacts

Macroeconomic impacts cannot be measured with the data available. Cancellation would cause an impact based on the assumption that the homeowner and farmer would substitute one or a combination of the alternatives. This impact would be minor at the macro level.

### Limitations of the Analysis

The penta is applied to numerous products for many different reasons. It is difficult to assess the impact of no treatment without knowing the specific application. The effectiveness of a particular alternative also depends on the specific application.

The chemical alternatives, with the exception of creosote and copper naphthenate, do not have the field use experience of penta. Thus, the degree of effectiveness of these chemicals in actual use is questioned.

### Summary of Economic Impact Analysis of Canceling Penta for Home and Farm Use

| | |
|---|---|
| A. USE: | Used on home and farm sites to protect wood from decay-causing organisms and insects. |
| B. MAJOR PESTS CONTROLLED: | Decay fungi, stain fungi, and wood destroying insects. |
| C. ALTERNATIVES: | |
| <u>Major registered chemicals</u>: | Tributyltin-oxide (TBTO), copper naphthenate, copper-8-quinolinolate (Cu-8), zinc naphthenate and creosote. |
| <u>Non-chemical alternatives</u>: | Untreated wood, commercially pressure-treated wood, non-wood structural materials (e.g., concrete, aluminum, and steel). |
| <u>Efficacy of alternatives</u>: | All of the chemical alternatives have some known merit; however, their overall efficacy is suspect. Non-wood materials are not subject to attack by wood-destroying insects and fungi. Pressure treatment effectively controls attack by wood-destroying organisms. Untreated wood |

has a shorter service life, requiring frequent replacement if attacked.

Comparative costs: The consumer cost of non-wood structural materials parallels wood costs. Untreated wood is slightly cheaper, but is more susceptible to attack, leading to possible replacement costs. Pressure-treated lumber costs are 20% higher than untreated lumber. Prices of various preservative products are:

| Chemical | Dollars/ Gallon |
|---|---|
| Penta (concentrate, 10-1) | 13.60 |
| Penta (ready-to-use) | 9.50 |
| Copper naphthenate (ready-to-use) | 13.45 |
| Zinc naphthenate (ready-to-use) | 12.40 |
| TBTO (ready-to-use) | 14.50 |

Conclusion There is no perfect substitute for penta, and what can be substituted depends on the specific applications.

D. EXTENT OF USE: Home and farm use of penta accounts for the largest portion of total non-pressure use (44%), but a small portion of total use (less than 5%). Approximately 1.5 million pounds of penta were used in 1978.

E. ECONOMIC IMPACTS:

User: Homeowners and farmers will switch to the alternate chemicals, pressure-treated lumber or non-wood material. This would incur some higher costs.

Market: Increased use of other preservative products, pressure-treated lumber and non-wood material.

Macroeconomic: Not investigated.

F. SOCIAL/COMMUNITY IMPACTS: Not investigated.

G. LIMITATIONS OF THE ANALYSIS: Lack of information on: (1) Specific uses of the perservative; (2) impact if no treatment is used; (3) dollar savings resulting from treatment.

H. PRINCIPAL ANALYST AND DATE: Robert F. Esworthy, Economic Analysis Branch/BFSD/OPP, U.S. Environ. Prot. Agency, Wash., D.C., Feb. 1980.

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