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INDUSTRIAL HYGIENE ASSESSMENT OF COAL LIQUEFACTION PLANTS

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ABSTRACT

Comprehensive industrial hygiene surveys designed to characterize employee exposures to suspected hazardous chemicals were conducted at five coal liquefaction plants. Air sampling was carried out for polynuclear aromatics (PNAs), the simple aromatics benzene, toluene, and xylene, phenolics, aromatic amines, and the toxic gases, carbon monoxide and hydrogen sulfide. Sampling for PNAs was accomplished through the use of a silver-membrane filter followed by Chromosorb 102; analysis for 34 individual or groups of PNAs was performed by gas chromatography/mass spectrometry.

The results of both area and personal air sampling showed that workers are exposed to numerous PNAs usually at low microgram per cubic meter concentrations. The light molecular weight, 2- and 3-ring PNAs were found in the highest concentrations with very small or no quantities detected of the 4- through 7-ring compounds. Highest exposures to PNAs were found to be associated with maintenance activities being carried out in the process area during plant operation.

The results of air sampling for a aromatic amines, phenolic compounds and the simple aromatic compounds benzene, toluene, and xylene showed that these chemicals are present only occasionally and at very low levels. Therefore, airborne exposures to these compounds may not be a major health hazard during normal plant operation, although skin absorption would remain a major concern.

Nonquantitative wipe sampling for PNAs revealed the presence of up to 5-ring PNA compounds on most surfaces sampled indicating that dermal exposure to higher ring PNAs may present a potential health hazard.

Although no standard medical surveillance programs have been developed for coal liquefaction plants, the ongoing programs instituted by the plants reflect the awareness of the occupational hazards associated with these facilities. They have been developed through recommendations by NIOSH and corporate medical officers.

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1. INTRODUCTION

AUTHORITY

The Williams-Steiger "Occupational Safety and Health Act of 1970" was passed into law "to assure safe and healthful working conditions for working men and women...." This Act established the National Institute for Occupational Safety and Health (NIOSH) in the Department of Health, Education, and Welfare (presently the Department of Health and Human Services) and the Occupational Safety and Health Administration (OSHA) in the Department of Labor. The Act provides for research, informational programs, education, and training in the field of occupational safety and health and authorizes the enforcement of standards.

NIOSH has been given the authority and responsibility under the Act to conduct field research studies in industry, to evaluate findings, and to report on these findings. Section 20(a)(1) of the Act mandates NIOSH to "conduct (directly or by grants or contracts) research, experiments, and demonstrations relating to occupational safety and health...." Section 20(c) provides the authority to enter into contracts, agreements, or other arrangements with appropriate public agencies or private organizations for the purpose of conducting studies relating to responsibilities under the Act. For this purpose, NIOSH has established a contractual agreement with Dynamac Corporation/ Enviro Control Division (Enviro) to study worker exposures to potential health hazards in coal liquefaction plants.

BACKGROUND AND NEED FOR STUDY

It became apparent in the 1970s that the United States might be forced to obtain petroleum supplies from sources other than those then currently supplying the bulk of petroleum imports. Dramatically increased prices of

oil from all sources provided further impetus to identify and secure petroleum products from less expensive sources.

The availability of energy sources in the form of coal-derived petroleum substitutes had been long known but never exploited in the United States on a large scale. With the increased political and economic pressures to develop petroleum substitutes, the need for technologies for conversion of coal into gaseous and liquid fuels became apparent.

In its mandate to conduct studies to assess health effects in industry, NIOSH initiated a program in 1977 to study coal liquefaction workplace hazards. The strategy in this project was to characterize the various coal liquefaction technologies while the industry as a whole was in the developmental stage. Epidemiological evidence indicated that production of coal-derived liquids from a plant operating in Institute, West Virginia, led to excess cancers in workers exposed to the coal-derived materials (Sexton, 1960). Although relatively large, commercial-scale coal liquefaction plants had been in operation for several years during the 1930s and 1940s in Germany and at the present time in South Africa, no substantive data was available on long-term health effects of those particular technologies.

With this background, NIOSH, through this contract, began an industrial hygiene study assessment of coal liquefaction pilot plants which were either operating or under construction by the U.S. Department of Energy (DOE). At the beginning of the study, only three plants were in operation: the Plant A in Tacoma, Washington; Plant C in Wilsonville, Alabama; and Plant B in Wheeling, West Virginia. Two other plants, Plant D in Baytown, Texas, and Plant E in Catlettsburg, Kentucky, came on line later and were included in the study group.

The objectives of the study were:

- to identify hazardous chemical and physical agents in the work environment which are generated in the liquefaction process;
- to determine employee exposures to the agents which were identified;

- to identify work practices and controls which would reduce exposures to the agents; and
- to identify additional research activities required to eliminate or reduce risks to employees in future commercial-scale coal liquefaction plants.

SCOPE OF STUDY

The general approach for conducting the industrial hygiene study was first to conduct a review of existing literature to determine the state of knowledge on chemical hazards expected and methods for sampling and analysis. Following the literature search, walk-through surveys were planned to test sampling and analytical methods and to determine concentration ranges of the species of interest.

As a result of the literature review, it was apparent that no satisfactory method for sampling individual polynuclear aromatic hydrocarbons (PNAs) existed which was compatible with the requirements for personal sampling devices. Collection devices using large packed columns of solid sorbent had been used in environmental studies, but these devices required powerful vacuum pumps with nonportable electric motors. A sampling device was developed by Enviro for this study which could be adapted to standard, battery-operated personal sampling pumps.

Walk-through surveys were conducted during the first year of the contract at two coal liquefaction pilot plants. During the walk-through surveys, sampling was conducted for chemical and physical agents that had been identified in the literature review as potential health hazards. The initial sampling was also used to test the PNA sampling assembly and to determine concentration ranges of the various chemical species.

Results from the walk-through sampling were evaluated to determine if the sampling and analytical methods were adequate for the concentration ranges measured, and whether or not specific agents were present in significant amounts to warrant further monitoring during comprehensive industrial hygiene surveys at the five pilot plants.

The major difficulty which arose during the course of the project was scheduling of surveys to coincide with plant operations. The experimental nature of pilot plants results in frequent test run upsets, and there were also delays in startup of those plants that were not in operation at the beginning of the study. It was decided at the onset that sampling would be conducted when plant test run conditions were as near to test specifications as possible, rather than during major upset or downtime conditions. This factor caused some significant delays, particularly early in the project (1978-1979).

2. BACKGROUND

GENERAL COAL LIQUEFACTION PROCESS DESCRIPTION

Introduction

The liquefaction of coal is a method for producing energy-rich hydrocarbon materials of diverse utility; it currently involves the use of several different experimental technologies. The products of the liquefaction plants surveyed in this study vary from a solid to light liquids, such as naphtha.

The utility of these products is comparable to that of petroleum, and includes materials for use in commercial fuel-burning facilities and refinable materials which can substitute for gasoline and lighter oils. Some drawbacks of direct combustion of coal -- ash and sulfur content -- can be eliminated by liquefaction.

The technologies involved in achieving coal liquefaction have similarities to those utilized in petroleum processing, but generally require more rigorous procedures that tend to deteriorate process equipment more rapidly. Similar processes include thermal-cracking and hydrocracking of high molecular weight hydrocarbons and their subsequent distillation and fractionation. Several of the technologies required, however, are unique to coal liquefaction.

Process Details

A simplified process schematic of coal liquefaction is presented in Figure 2-1.

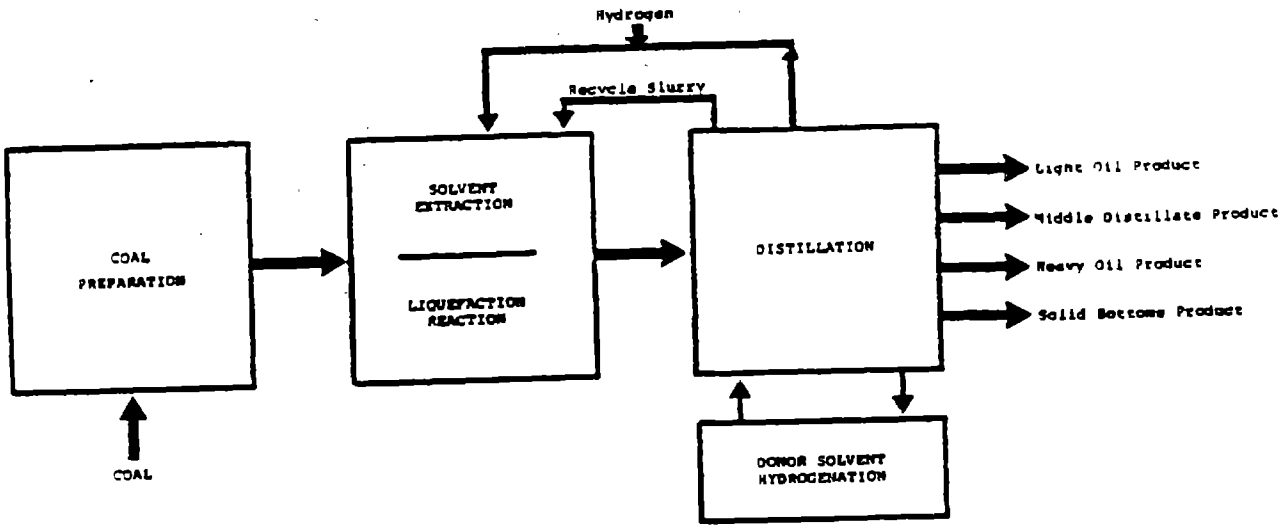

Figure 2-1. Simplified Coal Liquefaction Process Schematic

Coal liquefaction always requires the crushing and pulverization of coal to small mesh size to facilitate contact between the coal and the reaction process. Typically, coal is crushed and milled, and then mixed with a solvent medium. Liquefaction plants normally use bituminous and subbituminous coal. Coal preparation creates safety problems with dust, and liquefaction plants use techniques common to other coal preparation industries such as closed conveyance systems and baghouse filters.

Prepared coal is mixed with solvent which is a recycled product of the process. The solvent-coal slurry is the form in which the coal is reacted. Primary liquefaction is achieved by three processes: solvent extraction, thermal-cracking, and hydrocracking. Extraction causes some of the coal to simply dissolve in the solvent; however, the macromolecular form comprising the bulk of the coal requires more extensive chemical reaction. Thermal-cracking is the effect of heat (400 to 475°C; 750 to 875°F) fracturing the large organic molecules of coal into smaller molecular fragments.

Thermal-cracking is often accompanied by hydrocracking which is accomplished by introducing molecular hydrogen into the cracking process. These major chemical reactions are facilitated by high pressures (1,500 to 3,000 psig). Hydrocracking increases the hydrogen-to-carbon ratio by saturating some of the unsaturated bonds in the molecular structure. A catalyst is sometimes used to enhance the cracking reaction.

After the liquefaction reaction, the liquid coal stream is directed to unit processes which distill the liquid into different boiling ranges. The stream contains a heterogeneous mixture of light and heavy hydrocarbons, as well as ash, unreacted coal, and unconsumed hydrogen. The high-pressure stream is usually flashed to successively lower pressures, which permits recovery of the unconsumed hydrogen and very light, gaseous hydrocarbons. The hydrogen can be cleaned and recycled to the reaction process; and gases can be used for in-plant heating purposes.

Any water present in the process stream is also separated from the other compounds by flashing. This water contains a significant amount of the sulfur from the process and requires sour water treatment. Sulfur -- present as hydrogen sulfide -- also contaminates the hydrogen gas stream and is removed with water and diethanolamine (DEA) scrubbers. Treatment of sulfur-containing wastes yields elemental sulfur by use of systems such as a Stretford unit.

Continued flashing produces a naphtha or light distillate product which is taken as product. To further distill the main liquid coal stream containing concentrated ash and other solids, more extensive equipment including fractionators and vacuum strippers is used. In the instance of the (I) process, however, less severe reaction conditions result in a very heavy solid product that does not require the distillation necessary for lighter liquids. The more complicated liquefaction processes produce various boiling fractions. The distillation steps permit the products to be taken as homogeneous liquids for use as recycle solvent, for blending into petroleum substitutes, or for direct use as fuel oils.

Fractionation is a distillation process occurring at low or atmospheric pressures that produces a clean, light hydrocarbon stream and a bottoms stream containing the heavier hydrocarbons, ash, and unreacted coal. The bottoms stream may be further processed by vacuum stripping at below atmospheric pressure. This enhances the distillation of heavier hydrocarbons and uses steam to increase the production of clean liquid fractions.

The bottoms stream from the vacuum stripper units is a solid hydrocarbon containing the ash and unreacted coal. This solid product is still a potentially valuable energy source, although it has less utility.

A variation of the liquefaction technology incorporates the use of a hydrogenated donor solvent. Processes utilizing this scheme include a reaction and fractionation step in addition to the initial solvent extraction and liquefaction reaction step. Hydrogen is reacted with coal liquids that have already been separated from ash and unreacted coal. This results in improved product liquids and in a recycle solvent capable of aiding in the hydrogenation of the initial coal slurry. Hydrogen recovery and distillation are similar to those previously described.

A checklist of process units used in the five liquefaction plants surveyed in this study is presented in Table 2-1. The major operating parameters specific to each plant are presented in Table 2-2. Complete process schematics and descriptions are presented in Appendix A.

Table 2-1. Major Process Units at Coal Liquefaction Plants

PROCESS UNIT	PLANT A	PLANT B	PLANT C	PLANT D	PLANT E
Coal Preparation	✓	-	✓	✓	✓
Noncatalytic Coal Hydrogenation	✓	-	✓	✓	-
Catalytic Coal Hydrogenation	-	✓	-	-	✓
Catalytic Solvent Hydrotreatment	-	-	-	✓	-
Fractionation	✓	✓	✓	✓	✓
Carbonization	-	✓	-	-	-
Residue Separation	Vacuum stripper/ Flaker belt	Precipitation	Filtration/ Deashing	Vacuum stripper/ Flaker belt	Vacuum stripper/ Flaker belt

Table 2-2. Operating Parameters of Coal Liquefaction Plants

PARAMETER	PLANT A	PLANT B	PLANT C	PLANT D	PLANT E
PLANT SIZE	50 ton/day	20 ton/day (revamped)	6 ton/day	250 ton/day	200 ton/day (syncrude mode)
PROCESS	Solvent extraction/ Noncatalytic coal hydrogenation	Solvent extraction/ Catalytic coal hydrogenation	Solvent extraction/ Noncatalytic coal hydrogenation	Solvent extraction/ Catalytic solvent hydrogenation/ Noncatalytic coal hydrogenation	Solvent extraction/ Catalytic coal hydrogenation
FEED COALS USED	Subbituminous/ Bituminous	Lignite/ Subbituminous	Subbituminous/ Bituminous	Subbituminous/ Bituminous	Lignite/ Subbituminous/ Bituminous
REACTOR					
Type	Vertical tubular plug flow	Stirred-tank extractor/ Ebullated-bed catalytic hydrogenator	Vertical tubular plug flow	Tubular plug flow	Ebullated-bed
Temp., °C (°F)	425-450 (800-850)	400-450 (750-850)	425-475 (800-875)	450 (850)	450 (850)
Pressure, psig	1500-2050	450 - extractor 1000-3500 - hydrogenator	2500	2000-	up to 3000
Residence time	60 minutes	30 minutes - extractor	10 to 60 minutes	80 minutes	no information

Process Specifics of Plant A--

Plant A uses two variations of a commercial process. In the first variation (I), the product is a solid material with a melting point of from 177 to 205°C (350 to 400°F). In the second variation (II), the major product is a liquid of approximate crude oil consistency.

In the (I) mode, coal is pulverized and mixed with recycled coal-derived solvent. The coal slurry is fed through a reciprocating pump for pressurization to approximately 1,500 to 2,000 psig. High-pressure hydrogen gas is added to the slurry. The three-phase stream is heated in the preheater, and then pumped to the dissolver where extraction and liquefaction occur. The gas, solvent, dissolved coal, and undissolved residue pass from the dissolver through a series of flash drums which separate the gas from the slurry. The high-pressure gas recovered from the flash steps is passed to the high-pressure gas purification system (diethanolamine unit). The sour gas which is removed is sent to the Stretford unit for treatment.

The liquid is further flashed and subsequently filtered to remove ash and unreacted coal. The filtrate is pumped to a vacuum-flash preheater and then flashed to below atmospheric pressure. The (I) product is pumped onto a Sandvik belt (a continuous, water-cooled, stainless steel belt) for solidification and then delivered either to a waiting truck or to a storage facility.

In general, the (I) and (II) processes are the same through the dissolver. However, in the (II) process, the slurry exiting the dissolver is split: one portion is recycled to provide solvent for the coal slurry mixing operation, and the other portion is fractionated. The fractionation products are naphtha, low-sulfur fuel oil, and bottoms residue. Bottoms residue, containing very heavy hydrocarbons, unreacted coal, and ash, is solidified on a Sandvik belt in an operation similar to (I) production. The increased severity of operating conditions in the dissolver (i.e., the increased residence time, operating pressure, and hydrogen concentration) results in the majority of the coal being converted to a liquid fuel resembling No. 2 fuel oil with a 175-455°C (350-850°F) boiling range.

Process Specifics of Plant B--

Plant B employs a commercial synthetic fuel process to produce low-sulfur, liquid fuels. In the process, coal is first crushed and mixed with aromatic solvent to form a coal/solvent slurry. The slurry -- pressurized and preheated -- passes through an extractor where coal dissolution occurs. The extractor is a vertical, compartmentalized, stirred vessel of sufficient volume for approximately one-half hour of residence time. The slurry is then depressurized and flashed to remove hydrocarbon vapors and noncondensable gases which are formed as a result of thermal-cracking and hydrogenation of the dissolved coal/solvent mixture in the extractor.

The remaining slurry is pumped to a solids separation unit which produces a clean liquid stream and a thickened slurry. The clean liquid stream -- composed of solvent and coal extract -- is sent through a second flash step which yields light and heavy distillate streams. The thickened slurry is pumped to a carbonization unit which removes solvent from the slurry and produces waste char.

Heavy distillate produced from the last flash step is directed to a second reaction and hydrogenation process. The light distillate is fractionated and withdrawn as part of the recyle solvent stream and as a product. Treatment of the heavy stream yields further reacted liquids which can be removed as products or used as a hydrogen donor solvent for a portion of the solvent recycle.

Process Specifics of Plant C--

Plant C uses the (I) process; it is very similar to that described for Plant A. In this process, pulverized coal is mixed with process-derived solvent in a slurry blend tank. The slurry is combined with hydrogen-rich (85%) feed gas and is pumped thrugh a preheater into a dissolver at 427-468°C (800-875°F) and 2500 psig. Residence time in the dissolver ranges from 10 to 60 minutes.

From the dissolver, the slurry is split into a vapor and a slurry phase. The vapor overhead-- consisting of unreacted hydrogen and hydrocarbon gases -- is sent to the hydrogen recovery and desulfurization units. Unreclaimed gases are cleaned and discharged by venting or flare. The slurry phase undergoes additional treatment to remove organic vapors; and the liquid product is then fed onto two water-cooled trays to solidify and fragment the final product. The organic vapors are condensed and processed to reclaim the low-boiling (below 177°C) organics, recycle process solvent, and filter wash solvent.

Plant C has a maximum coal feed rate of 6 tons per day. The plant does not have a coal preparation plant onsite. Coal of desired size and moisture content is purchased and transported to the facility.

Process Specifics of Plant D--

Plant D uses a noncatalytic coal liquefaction process utilizing prehydrogenated "donor" solvent to facilitate hydrocracking of coal. The donor solvent is a recycled distillate of the liquefaction stream, and is catalytically hydrogenated in a separate process. Several liquid fractions, as well as an internally consumed fuel gas, are produced by this process.

Coal can be prepared by either of two milling processes. In one, an impact mill crushes the coal to minus 8 mesh and relies on later heating of the slurry for drying. In the other, a gas-swept roller mill crushes the coal to either minus 8 or minus 30 mesh and dries it to a moisture content of less than 4 percent.

The crushed coal is mixed with hot donor solvent and the resultant slurry along with hydrogen is pumped to four vertical upflow reactors with additional hydrogen. Liquefaction is noncatalytic and depends on hydrocracking and on the dissolving properties of the solvent.

Reactor product consists of gas, vapor, liquefied coal, recycle solvent, unreacted coal, and mineral matter. This stream is fed to the reactor separator drum where it is split into a vapor stream and a slurry stream.

The vapor phase passes through hot and cold separator drums where condensable hydrocarbons, sour water, and unused hydrogen gas are separated. The main slurry stream passes directly from the reactor separator to distillation.

Distillation is achieved through atmospheric fractionation and vacuum stripping. Fractionation produces naphtha, a light gas/oil, a heavy gas/oil, and bottoms. Both gas/oils are pumped to the donor solvent hydrogenation unit. Naphtha may be blended with the gas/oil stream or taken as product. Bottoms are sent to the vacuum stripper.

Preheated bottoms are pumped to the vacuum stripper where an overhead stream, two side streams, and a solids-containing bottoms residue are produced. The overhead stream is condensed and separated into liquid hydrocarbons, sour water, and fuel gas. Hydrocarbons are sent to the solvent hydrogenation section. The vacuum stripper side streams include a light vacuum gas/oil (LVGO) and a heavy vacuum gas/oil (HVGO). The HVGO can be withdrawn as product, or can be combined with the LVGO stream and pumped to the solvent hydrogenation section. Vacuum bottoms are pumped to a stainless steel belt where they are cooled and solidified.

The solvent hydrogenation section replenishes the donor hydrogen in the recycle solvent. In effect, solvent hydrogenation is a middle distillate hydrotreating plant. The replenished solvent flows through separator drums where unconsumed hydrogen is recovered, and sour water and organic vapors are condensed and removed. Hydrocarbons from the separator drums and the solvent stream are combined and sent to a second fractionation system. The fractionation process separates the hydrogenation products into three streams: fuel gas, naphtha, and recycle donor solvent. Donor solvent possessing the proper characteristics is cycled back to the liquefaction section and mixed with coal in the slurry drier.

Process Specifics of Plant E--

Plant E uses a catalytic coal liquefaction process capable of producing either synthetic crude oil suitable for refining or heavy fuel oil. Coal is hydrogenated and liquefied in a catalytic ebullated-bed reactor. The hydroliquefaction product is then separated by distillation into liquid fractions of different boiling temperatures. The process also products a fuel gas that is consumed onsite for heating purposes.

Coal is pulverized, dried, and delivered to a slurry preparation drum where it is mixed with recycled slurry oil. Slurry oil comes from the hydroclone (liquid-phase cyclones) overflow stream and from additional product oil from fractionation. The slurry is pumped at approximately 3,000 psig to a gas-fired preheater where it is heated to about 400°C (750°F). Hydrogen (H_2) is introduced as the stream enters the preheater. The hot slurry is fed to the reactor along with additional preheated hydrogen. Plant E's reactor utilizes a cobalt-molybdenum catalyst in an ebullated bed. The ebullating pump recirculates the catalyst-free slurry from the top of the reactor to the bottom and returns it up through the catalyst bed.

The reaction product is withdrawn from the top of the ebullating bed and depressurized in a series of flash vessels. Reactor effluent -- consisting of gaseous and liquid products, unconverted coal, and mineral matter -- is separated into a vapor phase and a solid/liquid phase in the reactor effluent separator. The vapor phase, containing unreacted hydrogen and gaseous hydrocarbons, is cooled and the heavier hydrocarbons are condensed. The solid/liquid phase is flashed in two steps from 3,000 psig to 50 psig. Flashed vapor is condensed and sent to the fractionator. Some hydrogen is recovered from the flash vessels and is recycled. Bottoms material from the flash steps is directed to a set of hydroclones.

Hydroclones are used to separate solids from the slurry stream and produce a solids-free oil for recycling to slurry preparation. Solids-free hydroclone overflow not used for recycling is sent to fractionation. Hydroclone bottoms containing all the solids are pumped to the atmospheric and vacuum strippers.

Process streams enter the fractionation unit at two points. The solid/liquid slurry stream is pumped through a preheat furnace to the atmospheric stripper and the vacuum stripper. Condensed liquids from the flash steps and hydroclone overhead move directly to the fractionator.

Bottoms from the atmospheric stripper are directed to the vacuum stripper and are flashed and steam-stripped again. Bottoms from the vacuum stripper consisting of a residuum of unreacted coal and mineral material are delivered to a flaker solidification process.

The combined liquids from the stripper and the flash steps are fed to the fractionator through a preheat furnace. The process stream is partially vaporized in the preheat furnace before being introduced to the flash zone of the fractionator. The overhead product from the fractionator is sent to a stabilizer tower where the gases (C_4 and lighter) are removed. The bottoms product from this tower is stabilized naphtha. The fractionator produces two other streams -- light oil and heavy oil.

Both streams are steam-stripped to remove light ends which are returned to the fractionator. The heavy oil stream is recycled with hydroclone overhead to slurry preparation. A portion of this stream may be blended with the other streams to produce a synthetic crude oil.

Health Implications of Coal Liquefaction Processes

Coal liquefaction processes present several health concerns. The exact extent of these hazards may be expected to change with the scale of a commercial size operation. A list of occupational health hazards associated with each process unit is presented in Table 2-3.

Table 2-3. Potential Occupational Health Hazards in Coal Liquefaction

Unit Process	Potential Hazard
Coal Preparation	Carbon monoxide; coal dust; noise; trace metals; fire
Extraction/Reaction	Polynuclear aromatic hydrocarbons (PNAs); aromatic amines; benzene, toluene, xylene; phenolics
Distillation	PNAs; aromatic amines; benzene, toluene, xylene; phenolics
Solvent Recovery	PNAs; aromatic amines; benzene, toluene, xylene; phenolics
Bottoms Solidification	PNAs; aromatic amines; particulates; noise
Hydrogen Recovery	Hydrogen sulfide; mercaptans; ammonia; noise
Wastewater Treatment	Hydrogen sulfide; phenolics; aromatic amines; ammonia

WORK FORCE ACTIVITIES

A total of about 800 workers were employed in the five coal liquefaction plants surveyed during this industrial hygiene study. At present, due to the shutdown of two of these plants, this number is closer to 450. In the future, a single commercial plant producing 50,000 barrels of oil per day is expected to require about 1,000 to 2,000 workers. Based on data concerning job assignments and work descriptions obtained from the pilot plants, it is projected that between 50 and 80 percent of these workers will have the potential for significant exposure to coal-derived materials.

Pilot plant workers were found to fit into one of three job categories: operators or process technicians, maintenance personnel, and laboratory technicians. Job assignments within these categories are not standardized, and some variations of the general descriptions that follow occur.

Operators/Process Technicians

Operators or process technicians work on 8- or 12-hour shifts and have the responsibility for the operation of one or more unit processes of the pilot

plant. In a commercial facility, several operators are projected for each process unit. In most cases, operators/process technicians duties are clearly defined and include a significant amount of time spent in relatively routine activities such as reading gauges, checking valve positions, and monitoring process operating parameters. During normal plant operations, up to 80 percent of their time may be spent in the control room where exposure can be expected to be less than in the process area. Depending upon the particular operation involved, extended periods up to a full shift may be required in the process area where exposure potentials are greater. These operations involve the performance of routine activities such as blowing down vessels, taking process stream samples, handling chemicals (e.g., in the Stretford unit), loading waste materials for disposal, and general housekeeping chores such as cleaning the baghouse filters. Upset conditions require the operator to assist the maintenance crew in such high-exposure situations as cleaning plugged valves and lines, and repairing steam leaks and pump strainers.

Maintenance Personnel

Shift and nonshift maintenance personnel, belonging to one of several crafts, are responsible for maintaining, repairing, and remodeling all equipment in the facility. The majority of this work occurs during plant turnarounds or upset conditions. These workers may be regular plant employees or outside contractors. At the pilot plant, both the job performed by the maintenance personnel and the areas of the plant frequented vary unpredictably on a day-to-day basis. In a commercial facility, exposure situations are expected to be normalized by the instigation of detailed maintenance instructions which outline the frequency of maintenance work and detail procedures for decontamination of equipment. Jobs with a high potential for exposure include removing pumps or equipment containing process material, breaking into process lines, and entering tanks or vessels. In general, field exposure is minimized whenever possible by performing maintenance work in offsite shops.

Laboratory Technicians

Laboratory technicians analyze process stream samples; however, job responsibilities vary widely. In one plant, these technicians are also responsible for securing process stream samples (a high-exposure assignment) and therefore spend time in the process area of the plant. In another plant, laboratory technicians are responsible only for determining the physical properties of the samples, and consequently do not experience any significant exposure. In most plants, exposure to process materials and to solvents used in the analytical procedures occurs during sample preparation and analysis. In these cases, vacuum distillation of sample materials presents the greatest potential for exposure.

Ultimately, analysis of work force activities and correlation with sampling data can be used to develop industrywide, uniform job classifications which may include semiquantitative or rank-order exposure estimates both to coal conversion mixtures and to specific chemicals known to represent health hazards. At the pilot plant level, however, changing work practices, cross-contamination of the small plant units, and the unsteady state of most plants preclude such analyses.

HEALTH EFFECTS OF EXPOSURE TO COAL LIQUEFACTION MATERIALS

Workers in coal liquefaction pilot plants are chronically exposed by skin contact, inhalation, and inadvertent ingestion to unknown levels of potentially toxic but as yet incompletely characterized liquid, gaseous, and particulate emissions and/or solid products and wastes. Acute exposure to high levels of these same materials can also occur during maintenance and repair operations, as well as during accidents.

Concern over health hazards associated with exposure to these materials is based on two types of information. Epidemiological studies have long shown an increased risk of mortality and morbidity in workers exposed to coal-derived materials in related industries. In addition, experimental laboratory findings in animals, cells, and bacteria have demonstrated the

potential toxicity and carcinogenicity of certain coal conversion materials, as well as of individual components of these materials.

Chemical analysis of materials produced from bench-scale or pilot-scale conversion plants is incomplete. However, coal liquids have been found to have a higher degree of aromaticity and a more condensed ring structure than petroleum crudes. In addition, the heteroatomic content of coal liquids is increased primarily due to increased amounts of nitrogen and oxygen. The result is a considerable amount of material boiling at 370°C (700°F). Correlation of these high-boiling materials with positive results from mutagenicity and/or carcinogenicity testing suggests a high potential for carcinogenicity and perhaps teratogenicity following exposure (Mobile, 1976; Pelroy and Wilson, 1981). In addition, lighter, lower boiling oil fractions (315-425°C; 600-800°F) from coal exhibiting minimal direct carcinogenic activity have been shown to possess promoting and/or cocarcinogenic activity. Comparison with the petroleum industry has demonstrated that coal liquid fractions are generally more mutagenic than are petroleum fractions of comparable boiling ranges (Kimball and Munro, 1981). Further, synthetic coal liquids, in contrast to petroleum, possess higher levels of acidic components such as phenols and cresols which appear in the lower boiling distillates. Thus, these fractions, too, represent a potential for adverse health effects.

A more detailed discussion of the known health effects of coal-derived materials is presented in Appendix C.

OTHER RELEVANT STUDIES

Industrial Hygiene Monitoring

A comprehensive health program comprising an industrial hygiene monitoring program, a clinical medical examination program, a personal hygiene and educational program, and a toxicological program was conducted by the DOE contractor at the Fort Lewis pilot Plant (DOE, 1980).

Individual quantitative PNA analysis of air samples has been carried out using high-pressure liquid chromatography (HPLC) with both a UV detector and spectrophotofluorometer. The determination of total concentrations of 15 selected PNAs in random samples has shown a wide variability ranging from nondetectable to 1,200 ug/m^3. The product solidification area showed the highest PNA concentrations.

Other conclusions of the program to date include:

- n-Hexane, benzene, toluene, and xylene concentrations are extremely low, resulting in virtually negligible exposures.
- Rainy days have been associated with decreased total suspended particulate levels, but with increased concentrations of benzene solubles.
- Temporary helpers showed the highest exposures to total particulates.
- Geometric mean exposures to benzene-soluble particulates were significantly lower in the (II) mode than in the (I) mode.
- H_2S concentrations reached a few thousand parts per million during loading of raw naphtha and light distillates.
- Virtually no airborne phenolics were found despite their presence in high concentrations in many liquid streams.
- High CO levels were associated with the use of plant inert gas at the coal pulverizer.
- Welders working on material contaminated with coal liquids experienced exposure to benzene solubles of up to 44 percent of the total welding fumes.

An industrial hygiene monitoring survey of PNA concentrations in petroleum refineries was conducted by Enviro Control, Inc. (Futagaki, 1981). Sampling and analytical methods for PNAs were identical to those used in this coal liquefaction study.

Results showed that worker exposure, as measured in three different types of process units at nine petroleum refineries, was similar to that of the coal liquefaction workers monitored in this study. In both studies, the lighter molecular weight 2- and 3-ring PNAs were found in the highest concentrations, with only minimal amounts of the heavier 4-, 5-, 6-, and 7-ring

compounds detected. In the petroleum refinery study, the levels of PNAs showed a positive correlation with the age of the facility and with the crude petroleum utilized; no correlation was found for production capacity of the plant, duration since last major turnaround, or environmental conditions during sampling.

In a closely related study conducted by Enviro in three coal gasification plants, personal and area sampling was conducted for the same species of chemical hazards (Cubit and Tanita, 1982). Additional discussion and comparisons of the results of this study with the petroleum refinery and coal liquefaction studies are presented in the Analysis and Discussion of Results chapter of this document.

A third industrial hygiene monitoring survey quantifying PNA concentrations in air samples was found in the literature (Smith, 1971). PNA compounds in coke oven emissions were measured at 20 different coke plants using a gas chromatographic/ultraviolet procedure (Smith, 1971). Since air volumes and sampling times were not included in the report, direct comparison with other studies is not possible. However, in this study of eight PNAs, the mean concentrations of the measured PNAs decreased in the following order: fluoranthene benz(a)pyrene = benz(a)anthracene pyrene chrysene benz(e)pyrene. Benz(a)acridine and benz(a)anthrone were not found.

Safety and Health Standards and Guidelines

The National Institute for Occupational Safety and Health (NIOSH) has published a criteria document for a recommended standard for coal gasification plants (NIOSH, 1978). This document recommends standards for each of three types of processes distinguished by both operating process and technology and the potential exposures. Included are high-Btu product coal gasification; low- or medium-Btu product gasification utilizing bituminous coal or lower ranked feedstocks, and low- or medium-Btu product gasification utilizing anthracite feedstock or very high temperatures. No attempt has been made to develop permissible levels of exposure to toxic chemicals.

A similar document for a recommended standard for coal liquefaction plants is not available. Instead, an occupational hazard assessment of the industry has been developed (NIOSH, 1981). This report is a lengthy review of the scientific and technical information available; it discusses the occupational safety and health issues of pilot plant operations.

3. METHODS OF STUDY

At the beginning of this project in late 1977, three coal liquefaction pilot plants were in operation: Plants A, B, and C, located in Tacoma, Washington, Cresap, West Virginia, and Wilsonville, Alabama. Walk-through surveys were conducted at Plants A and B during the first year of the project. Sampling was conducted for the purposes of: (1) testing the PNA sampling assembly; (2) evaluating PNA analytical protocols: (3) identifying chemical hazards by species; and (4) determining concentration ranges of species to be studied in the comprehensive surveys.

In 1979, two additional coal liquefaction pilot plants, one in Baytown, Texas, and one in Catlettsburg, Kentucky, were brought on line. All pilot processes are variations of the same technology for producing either a liquid or solid fuel product. The project scope included comprehensive surveys at all five pilot plant facilities. Figure 3-1 shows the locations of the five pilot plants in which sampling was conducted. Table 3-1 lists the dates of the walk-through and comprehensive surveys.

Table 3-1. Dates of Industrial Hygiene Surveys at Coal Liquefaction Pilot Plants

Plant	Walk-through Surveys	Comprehensive Surveys
A	June 1978	February 1979
B	October 1978	April 1979
C	none	November 1979
D	none	May 1981
E	none	August 1981

Figure 3-1. Location of Coal Liquefaction Pilot Plants Studied in This Project

WALK-THROUGH SURVEYS

The sampling program during the walk-through surveys consisted primarily of "high-volume" area sampling to collect the largest practicable amounts of PNAs, aromatic amines, and simple aromatic species for qualitative analysis. The samples were analyzed by gas chromatography/mass spectroscopy and the mass spectra compared with a library of 25,000 mass spectra.

Tables 3-2 and 3-3 show the results of the screening for PNAs and other organic compounds conducted on area samples taken during the walk-through surveys at Plants A and B.

In addition to air samples collected for GC/MS analysis, bulk samples of process stream and by-product streams were collected for qualitative analysis of PNAs and aromatic amines, and wipe samples were taken from surfaces of equipment, work areas, tools, and protective clothing for PNA analysis. No attempt was made for these analyses to be quantitative. Rather, the data was to be used as a guideline for the selection of species to be quantitated during the comprehensive surveys.

REFINEMENT OF PROJECT SCOPE

Based on results of data from walk-through surveys, it was decided to delete some agents from the sampling protocols in the comprehensive surveys. These were eliminated primarily because the concentrations measured at each of the first two pilot plants were below detection limits of the sampling and analytical protocols, or because the concentrations were far below levels considered to have health implications.

The qualitative work done with the GC/MS showed the presence of many PNA compounds and homologs. The selection of individual PNAs that would be quantitated routinely in subsequent sampling was based on three requirements:

Table 3-2. PNA Compounds Screened in Walk-Through Surveys at Two Coal Liquefaction Plants

Compound	Plant: A							Plant: B					
	Sample Type: AIR					WIPE	BULK	AIR				WIPE	BULK
	Location: Coal Preparation	Mineral Separation	Solvent Recovery	Product Solidification	Water Treatment	Solvent Recovery	Process Solvent	Extraction	Solid Separation	Solvent Recovery	Carbonization	Fuel Oil Pump	Process Solvent
Naphthalene	●[a]	●	--[b]	●	●	--	●	●	●	--	--	--	●
Methanonaphthalenes	●	●	●	●	--	--	--	●	●	●	--	--	●
Naphthalene, 2-methyl	●	●	●	●	●	--	●	●	●	--	--	--	●
Naphthalene, 1-methyl	●	●	●	●	--	--	●	●	●	--	--	--	●
Naphthalene, dimethyls	--	--	--	--	--	--	●	●	●	●	--	--	●
Naphthalene, ethyl	--	--	--	--	--	--	●	--	--	--	--	--	●
Naphthalene, butyl	●	--	--	--	--	--	--	--	--	--	--	--	●
Naphthalene, trimethyls	--	--	--	--	--	--	●	--	--	--	--	--	●
Naphthalene, trimethyl propenyls	●	--	--	--	--	--	--	--	--	--	--	--	--
Naphthalene, phenyl	--	--	--	--	--	●	--	--	--	--	--	●	--
Quinoline	--	--	--	--	--	--	--	--	--	--	--	--	--
Quinoline, carbonitrile	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(h)quinoline	--	--	--	--	--	●	--	--	--	--	--	--	--
Acenaphthalene	--	--	--	--	--	●	●	--	--	--	--	--	●
Acenaphthylene, dihydros	●	--	--	--	--	--	--	--	--	--	--	●	--
Acenaphthene	--	--	--	--	--	●	--	--	--	--	--	--	●
Benzofuran, dihydros	--	--	--	--	--	--	--	--	--	--	--	--	●
Dibenzofuran	●	--	●	--	--	●	--	--	--	--	--	●	--
Dibenzothiophene	●	--	--	--	--	●	--	--	--	--	--	--	--
Fluorene	●	●	●	●	--	●	●	●	--	--	--	●	●
Fluorene, monomethyls	--	--	--	--	--	●	●	--	--	--	--	●	●
Phenanthrene/Anthracene	●	●	●	●	--	●	●	●	--	--	--	●	●
Phenanthrene, monomethyls	●	--	●	●	--	●	●	--	--	--	--	●	●
Phenanthrene, dimethyls	--	--	--	--	--	●	●	--	--	--	--	●	●
Phenanthrene, dihydros	--	--	--	--	--	--	--	--	--	--	--	--	--
Acridine	●	--	--	--	--	●	--	--	--	--	--	--	--
Carbazole	●	●	--	--	--	--	--	--	--	--	--	●	--
Carbazole, monomethyls	--	--	--	--	--	--	--	--	--	--	--	●	--
Fluoranthene	●	●	●	●	--	●	●	●	--	--	--	●	●
Pyrene	●	●	●	●	--	●	●	●	--	--	--	--	●
Pyrene, monomethyls	--	--	--	●	--	●	●	--	--	--	--	●	--
Pyrene, dihydros	●	--	--	--	--	--	--	--	--	--	--	--	●
Indole, phenyl	●	--	--	--	--	--	--	--	--	--	--	--	--
Phenylene	--	--	--	--	--	--	--	--	--	--	--	--	●
Phenylene, biphenyls	--	--	--	--	--	--	--	--	--	--	--	--	●
Benzo(a)fluorene	●	--	●	●	--	●	●	--	--	--	--	●	●
Benzo(b)fluorene	●	●	--	●	--	●	●	--	--	--	--	--	●
Benz(a)anthracene/Triphenylene/Chrysene	●	●	●	●	--	●	●	●	--	--	--	●	●
Benzanthracene, monomethyls	--	--	--	--	--	●	●	--	--	--	--	--	--
Benzfluoranthenes	--	--	--	--	--	●	●	--	--	--	--	--	--
Naphthacene	--	--	--	--	--	●	--	--	--	--	--	--	--
Benzo(e)pyrene	●	●	●	●	--	●	●	--	--	--	--	--	●
Benzo(a)pyrene	●	●	●	●	--	●	●	--	--	--	--	--	●
Perylene	●	●	●	●	--	●	●	--	--	--	--	--	●
Dibenzanthracenes	--	--	--	--	--	--	--	--	--	--	--	--	●
Indeno(1,2,3-cd)pyrene	●	●	●	●	--	--	●	●	--	--	--	--	●
Benzo(g,h,i)perylene	●	--	●	●	--	--	●	●	--	--	--	--	●
Anthanthrene	--	●	●	●	--	--	●	●	--	--	--	--	●
Dibenzpyrene	--	--	--	--	--	--	--	--	--	--	--	--	--
Coronene	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,j)acridine	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)carbazole	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzophenanthrene, monomethyls	--	--	--	--	--	--	●	--	--	--	--	--	--

[a] "●" indicates compound detected. "--" indicates compound not detected.

ible 3-3. Other Organic Compounds and Gases Screened in Walk-Through Surveys at Two Coal Liquefaction Plants

Compound	Plant:	A							B									
	Sample Type:	AIR					WIPE	BULK	AIR								WIPE	BULK
	Location:	Coal Prep	Mineral Separation	Solvent Recovery	Product Solidification	Water Treatment	Solvent Recovery	Process Solvent	Coal Drying	Solvent Extraction	Solid Separation	Solvent Recovery	Carbonization	Stretford	Waste Treatment	Tank Farm	Fuel Oil Pump	Process Solvent
Benzene		●[a]	●	●	--[b]	--	--	--	--	--	--	--	--	--	--	--	--	--
Substituted benzenes:																		
1,1-oxybis		●	●	●	●	●	--	--	--	--	--	--	--	--	--	--	--	●
one group		●	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
two groups		●	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	●
three groups		●	●	●	--	--	--	--	--	--	--	--	--	--	--	--	--	●
four groups		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	●
nitriles		●	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
carboxylic acids		●	--	●	●	--	--	--	--	--	--	--	--	--	--	--	--	--
Toluene		●	●	●	--	●	--	--	--	--	--	--	--	--	--	--	--	--
Xylene		●	●	●	--	●	--	--	●	●	--	--	--	--	--	--	--	--
Hexanes		●	●	●	--	●	--	--	--	--	--	--	--	--	--	--	--	--
Higher straight chain hydrocarbons		--	--	●	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Indene		●	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	●
Substituted indenes		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
dihydrodimethyls		--	--	--	--	--	--	--	--	--	●	●	--	--	--	--	--	●
dihydrotrimethyls		--	--	--	--	--	--	--	--	●	--	--	--	--	--	--	--	--
Tetrahydronaphthalene		●	●	●	●	●	--	--	--	●	●	--	--	--	--	--	--	●
Substituted tetrahydronaphthalenes		--	--	--	●	--	--	●	--	●	●	--	--	--	--	--	--	--
monomethyls		--	--	--	--	--	--	--	--	●	●	--	--	--	--	--	--	●
dimethyls		--	--	--	--	--	--	--	--	●	●	--	--	--	--	--	--	●
Substituted tetrahydroquinones		●	--	--	--	--	--	--	--	--	●	--	--	--	--	--	--	--
Phenylenes		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	●	●
Biphenylene		--	--	--	--	--	●	--	--	--	--	--	--	--	--	--	--	--
Biphenyl		●	●	●	●	●	--	--	--	--	--	--	--	--	--	--	--	--
Substituted biphenyls		●	●	●	●	--	●	--	--	--	--	--	--	--	--	--	●	●
Terphenyl		--	--	--	--	--	●	--	--	--	--	--	--	--	--	--	--	--
Xanthine		--	--	--	--	--	●	--	--	--	--	--	--	--	--	--	●	--
Phthalate ester		●	--	--	--	●	--	--	--	--	--	--	--	--	--	--	--	--
Bipyrazole		--	--	●	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Substituted thiazoles		●	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Thiophene		●	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Pentyloxirane		●	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Octacosane		●	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Triphenyl ester		--	--	--	●	--	--	--	--	--	--	--	--	--	--	--	--	--
Azulene		●	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Phenol		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Substituted phenols		--	--	●	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cresol		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
p-Ethylphenol		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
o-Ethylphenol		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2,3-Xylenol		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3,5-Xylenol		●	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Aniline		●	●	--	--	●	--	--	--	--	--	--	--	--	--	--	--	--
N,N-Dimethylaniline		●	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
o-Anisidine		●	●	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
p-Anisidine		●	●	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Carbon monoxide[c]		●	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Hydrogen sulfide[c]		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sulfur dioxide[c]		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ammonia[c]		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

[a] "●" indicates compound detected. [b] "--" indicates compound not detected. [c] Gases identified by detector tube.

- availability of analytical standards to permit quantitation of PNA exposures.
- inclusion of an adequate number of PNAs to represent 2-, 3-, 4-, 5-, 6-, and 7-ring species.
- inclusion of as many of the known or suspected PNA carcinogens as possible.

Originally, 29 compounds with available reference standards were identified and quantitatively determined in air and bulk sampling. Five more were added during the course of this study as standards became available, making a total of 34 compounds. They are: seven 2-ring, seven 3-ring, ten 4-ring, eight 5-ring, one 6-ring, and one 7-ring compound. Eighteen of these are listed in the Registry of Toxic Effects of Chemical Substances (NIOSH, 1980) as suspected neoplastic or carcinogenic agents; others are considered equivocal neoplastic or carcinogenic agents.

Five nitrogen-containing heterocyclic compounds were included because of toxicological evidence showing carcinogenic potential for many of these related compounds. On the other hand, no such body of evidence associates cancer with the sulfur- or oxygen-containing heterocyclic polynuclear aromatics; thus none were included. Table 3-4 shows the PNAs which were routinely quantified on all samples in the comprehensive surveys.

Table 3-5 lists all classes of samples collected at the five liquefaction pilot plants and the analyses conducted.

Table 3-4. PNAs Routinely Quantitated by CG/MS in Comprehensive Surveys

Order of Elution	Compound
1	Naphthalene
2	1-Methylnaphthalene
3	2-Methylnaphthalene
4	Quinoline
5	Acenaphthalene
6	Acenaphthene
7	Fluorene
*8	Phenanthrene/Anthracene
9	Acridine
10	Carbazole
11	Fluoranthene
12	Pyrene
*13	Benzo(a)fluorene/Benzo(b)fluorene
*14	Benz(a)anthracene/Chrysene/Triphenylene
*15	Benzo(j)fluoranthene/Benzo(b)fluoranthene/Benzo(k)fluoranthene
*16	Benzo(e)pyrene/Benzo(a)pyrene
17	Perylene
18	Dibenz(a,j)acridine
19	Dibenz(a,i)carbazole
20	Indeno(1,2,3-cd)pyrene
21	Dibenz(a,h)anthracene
22	Benzo(g,h,i)perylene
23	Coronene
24	Dibenz(a,i)pyrene
25	Dimethylbenz(a)anthracene
26	3-Methylcholanthrene
27	6,13-Dimethyldibenz(a,h)anthracene

*Compounds not separated with 6' 3% OV-17 column.

Table 3-5. Classes of Samples Collected at Coal Liquefaction Plants

SAMPLES	PLANT A		PLANT B		PLANT C	PLANT D	PLANT E
	WT[a]	CS[b]	WT	CS	CS	CS	CS
AIR SAMPLES							
Organics							
PNAs	✓	✓	✓	✓	✓	✓	✓
Aromatic amines	✓	✓	✓	✓	✓	✓	✓
Phenolics	✓	-	✓	✓	✓	✓	✓
Benzene/Toluene/Xylene	✓	✓	✓	✓	✓	✓	✓
Hexane	✓	✓	✓	-	-	-	-
Gases							
Carbon monoxide (CO)	✓	✓	✓	-	-	-	✓
Hydrogen sulfide (H_2S)	✓	✓	✓	-	-	-	✓
Sulfur dioxide (SO_2)	✓	✓	✓	-	-	-	-
Ammonia	-	-	✓	-	-	-	-
Metal carbonyls	-	-	-	-	-	-	✓[c]
Trace Metals	-	✓[d]	-	✓[d]	-	-	✓[c]
BULK SAMPLES							
Organics							
PNAs	✓	✓	✓	-	-	✓	-
Trace Metals	-	-	-	✓[d]	-	-	-
WIPE SAMPLES							
Organics							
PNAs	-	✓	✓	-	-	✓	✓

[a]WT = walk-through survey. [b]CS = comprehensive survey. [c]Cobalt, molybdenum, nickel.
[d]Arsenic, beryllium, cadmium, copper, mercury, manganese, nickel, strontium, tellurium, magnesium.

SAMPLING AND ANALYTICAL METHODS

The industrial hygiene sampling and analytical protocals used for these studies were standard NIOSH methods; or in the case of PNAs, sampling procedures were those developed by Enviro and analytical procedures developed and validated by the University of Iowa's University Hygienic Laboratory under a subcontract to Enviro.

A complete description of all procedures including the validation testing for PNA sampling and analysis is presented in a companion volume to this document, "A Method for Sampling and Analysis of Polynuclear Aromatic Hydrocarbons in Coal Conversion Plants and Petroleum Refineries" (Dynamac, 1982).

Prior to the survey, all sampling pumps were calibrated to a primary standard with the appropriate sampling train in line. Correct sampling rates were confirmed by periodic checks with a precision rotameter throughout the sampling period. Sampling devices were checked periodically for overloading of sampling media, pump performance, and functioning of the sampling train.

Each sample was given a unique identification number at the start of the sampling period. Sample data sheets were prepared for each sample and identified by a corresponding sample number. Meteorological data taken at the plant were supplemented by data from the local weather bureau or station.

The following sampling procedures were followed as closely as possible at each of the liquefaction plants surveyed.

- Sampling was conducted during each of the three shifts during the survey period, which was about 5 days for each plant. The surveys at Plants A and B were interrupted for several days due to plant shutdown. When the plants came back on stream, the sampling programs were resumed.
- Full-shift sampling was conducted on each worker selected for monitoring. At least two full-shift samples were taken for each job category.
- Two or three area samples were collected during the survey at equipment or process areas suspected to have the highest concentrations of PNAs, hydrocarbon vapors, and gas emissions.

- Plant boundary, or upwind, area samples were collected for all agents sampled within the process area to determine background levels.

After sampling, samples were immediately sealed and protected from light to prevent accidental contamination or sample losses. Samples were packed in dry ice in styrofoam containers specially designed for the shipment of materials under refrigeration. Filters, charcoal tubes, silica gel tubes, and bulk samples were packed in separate containers with styrofoam packing material to prevent breakage.

Polynuclear Aromatic Hydrocarbons (PNAs)

The general principle for collection of PNAs and their aza-analogs from air involves the use of a sampling device consisting of a 37-mm silver-membrane filter with a solid adsorbent backup. The silver-membrane filter is only able to trap particulate-phase PNAs. The C-102 backup captures the vapor-phase PNAs. The two basic assemblies used in this study are shown in Figures 3-2 and 3-3.

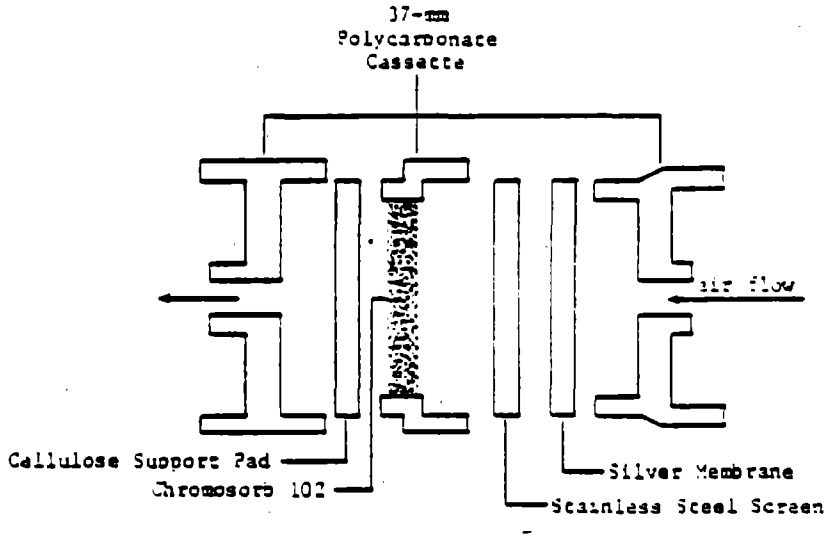

Figure 3-2. Area Monitoring Device for PNAs

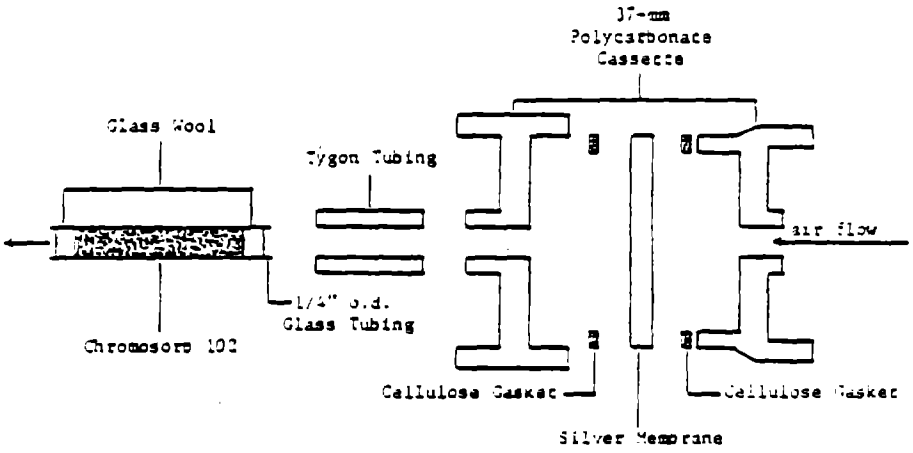

Figure 3-3. Personal Monitoring Device for PNAs

Sampling for airborne PNAs was performed by drawing air through the two-stage sampling unit consisting of a silver-membrane filter followed by Chromosorb 102 (C-102), a porous polymer adsorbent. The commercially available C-102 used for this study was contaminated and required preextraction prior to use. The C-102 cleanup scheme is presented in Table 3-6.

Table 3-6. Chromosorb 102 Cleanup Protocol

Solvent	No. of Solvent Changes	Soxhlet Extraction Time (hr)
Methylene chloride	4	48
Methanol	2	24
Methylene chloride/methanol (1:1; v/v)	2	48

The area sampling cassette contained a silver-membrane filter followed by 3 to 4 grams of C-102 sandwiched in the middle section of a three-piece cassette. A modified sampling unit was used for personal monitoring. Approximately 150 mg of C-102 was packed in a glass tube following the silver-membrane-containing cassette, rather than in the cassette itself. The larger

quantity of solid sorbent in the area cassettes minimized the possibility of sample breakthrough in high-concentration areas. The NIOSH method (P&CAM 183) recommends the use of a glass-fiber filter in front of the silver-membrane filter to prevent clogging; since this was not a problem in this study, the glass-fiber filter was not used.

After collection of personal or area samples, the sampling assemblies were covered with foil and stored at -20°C in the dark until analyzed.

The C-102 solid sorbent and the silver-membrane filter were extracted separately. After extraction and concentration, the extracts were either analyzed separately or combined. The extraction procedure is shown in Figure 3-4.

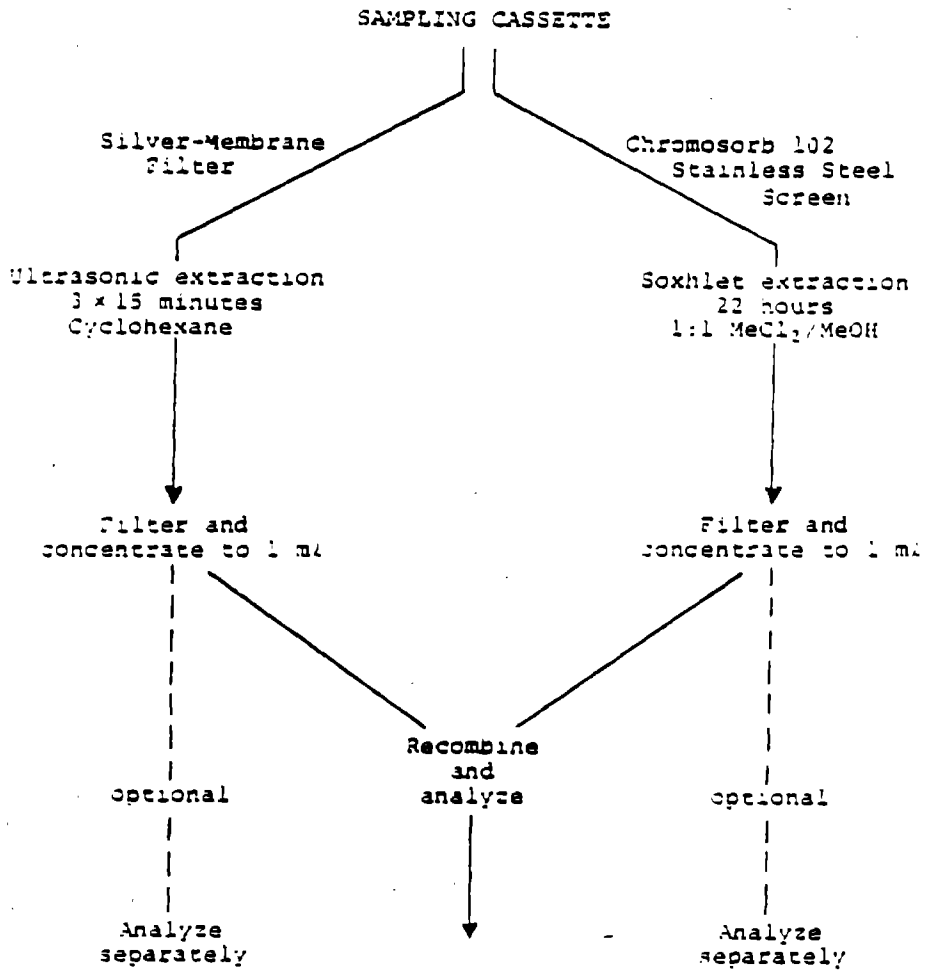

Figure 3-4. Sample Preparation Procedure

The C-102 adsorbent and stainless steel backup screen were placed in a foil-wrapped soxhlet extractor fitted with a 500-mL round-bottom flask and extracted with 300 mL of glass-distilled methylene chloride/methanol (1:1, v/v) for 22 hours (Phillips, 1977). The extracts were processed by concentrating to approximately 10 mL in a round-bottom flask fitted with a 3-ball Snyder column. The concentrate was then filtered through a Millipore sample clarifier (0.45-um Teflon filter) in a 15-mL serum vial fitted with a Teflon-lined rubber septum and crimp cap and stored at -20°C in the dark until analyzed.

The extraction procedure used for the silver-membrane filters is a modification of the NIOSH-validated method P&CAM 217 (NIOSH, 1977). The modification includes multiple extractions instead of a single extraction, and cyclohexane in place of benzene.

The silver-membrane filters were ultrasonically extracted in a 200-watt Branosonic 52 bath for 15 minutes with 5 mL of glass-distilled cyclohexane. The extracts were then placed in a 15-mL centrifuge tube. The process was repeated two additional times, and the extracts were combined, filtered, and then placed in a heating block regulated at 63°C and concentrated to approximately 1 mL.

PNAs were identified and quantified by the use of two internal standards -- d_{10}-anthracene and d_{12}-chrysene. All GC analyses of the referenced PNA compounds produce symmetrical Gaussian peaks, with the exception of quinoline which tails slightly.

Each batch of samples included field blanks and reagent blanks to check for contamination. Desorption efficiencies were determined on each batch of Chromosorb 102.

The GC/MS parameters used for the separations and quantitation of PNAs were as follows:

- GC Column: 6'x 0.079" i.d. glass column packed with 3% OV-17 on 80/100 mesh Supelcort (purchased from Supelco, Inc.)
- Column Temperature: 8°C/min to 260°C, then held at 260°C for 50 min
- Injector Temperature: 240°C
- GC/MS Interface Temperature: 325°C
- Carrier Gas (helium) Flow Rate: 30 mL/min
- MS Ionizer Block Temperature: 250°C
- MS Electron Multiplier Voltage: 1800 V
- MS Electron Energy: 70 eV
- MS Emission Current: 500 mA

The isomers not resolved by this GC column (i.e., numbers 8, 13, 14, 15, and 16 in Table 3-4) but found to be present in quantifiable amounts were quantitated as isomeric groups. If multiple isomers were suspected of contributing to a single peak, additional analysis by either high-pressure liquid chromatography (HPLC) (Thomas and Lao, 1977) coupled with a fluorescence detector (Das and Thomas, 1978) or capillary column gas chromatography was used. These methods were found to separate isomers not resolved with the 6-ft 3% OV-17 column.

The capillary GC parameters are as follows:

- GC Equipment: Varian Model 3700 equipped with an auto-integrator and dual flame-ionization detectors
- GC Column: 15 m x 0.2495-mm i.d. glass capillary column packed with 0.34-um film thickness of SE-52 (from J&W Scientific)
- Column Temperature: 50°C to 250°C at 2°C/min
- Injector Temperature: 300°C
- Detector Temperature: 320°C
- Carrier Gas (helium) Pressure: 20 psig

Aromatic Hydrocarbons

Air samples were collected on 600-mg charcoal tubes and analyzed for: benzene, toluene, and xylene. Sampling and analysis followed the NIOSH-recommended procedures described in Method No. P&CAM 127 (NIOSH, 1977).

Aromatic Amines

Separate samples collected on 800-mg silica gel tubes were analyzed for the two groups of aromatic amines listed below:

Aromatic amines:	aniline
	N,N-dimethylaniline
	o-toluidine
	2,4-dimethylaniline
	o-anisidine
	p-anisidine
	p-nitroaniline
Naphthylamines:	1-naphthylamine
	2-naphthylamine

Analyses followed recommended NIOSH (1977) procedures described in P&CAM 168 for aromatic amines and P&CAM 264 for the naphthylamines.

Phenols

Samples were collected on 800-mg silica gel tubes and analyzed using NIOSH (1977) procedures in S167 for the following phenolics: phenol, o-cresol, m-cresol, p-cresol, o-ethylphenol, p-ethylphenol, 2,3-xylenol, and 2,4-xylenol.

Gases

Sampling for gases such as CO, H_2S, and SO_2 was done by grab sampling techniques using length-of-stain indicator tubes or direct-reading monitoring devices. Because of the intermittent nature of gaseous emissions in the facilities, grab sampling and real-time monitoring were preferred because full-shift personal sampling did not pinpoint emission sources or measure peak concentrations.

DATA ANALYSIS

All analytical results were corrected for desorption efficiencies as determined on each batch or lot of C-102, charcoal tubes, and silica gel tubes. Corrections were also made for the mean field blank values taken during the respective surveys.

The data were analyzed using the following statistical method:

- Lognormal distribution of the measured concentrations in the samples was assumed (NIOSH, 1977).
- The geometric mean (GM) and the geometric standard deviation (GSD) were determined using the formulas:

$$GM = \text{antilog}_{10}\left[\frac{\sum_{i=1}^{n} \log_{10} X_i}{n}\right]$$

$$GSD = \text{antilog}_{10}\sqrt{\frac{n\sum \log_{10} X^2 - \left(\sum \log_{10} X\right)^2}{n(n-1)}}$$

- The lower limit of detection was used for all values of 0.
- The upper and lower confidence limits (UCL, LCL) were calculated from the GM, GSD, and the Student's t according to the formulas:

$$UCL = \text{antilog}_{10}\left[\log_{10} GM + t_{.05}\frac{\log_{10} GSD}{n^{1/2}}\right]$$

$$LCL = \text{antilog}_{10}\left[\log_{10} GM - t_{.05}\frac{\log_{10} GSD}{n^{1/2}}\right]$$

. $t_{.05}$ was chosen from the standard table.

(n-1)	t.05
1	12.7
2	4.3
3	3.2
5	2.6
6-7	2.4
8-9	2.3
10-13	2.2
14-27	2.1
28	2.0

The broad confidence limits on the mean can be attributed to two factors. First, the data were widely dispersed; this probably resulted from the unsteady operating conditions at the plants and inherent variability in the sampling and analytical methods. Second, the number of samples in each category was necessarily low due to the high cost of individual sample analysis for PNAs.

4. RESULTS

RESULTS OF AREA AND PERSONAL SAMPLING

This chapter summarizes the results of all sampling conducted at five coal liquefaction pilot plants. More than 200 area and personal samples were collected and analyzed for up to 34 individual PNAs, or groups of PNAs. In order to present the data in an understandable format, "total PNA" values are reported. The total PNA concentrations represent the sum of the individual PNA concentrations determined for each sample. Individual sample results and the measured concentrations of each PNA species are presented for all plants in Appendix B.

One of the objects of the study was to determine which unit processes or process areas contributed most to worker exposure or had the highest fugitive emissions. To accomplish this, area samples were collected adjacent to equipment in each of the process areas that were expected to be the source of highest emissions. Sampling data from these sites were then combined for comparison to other process area data and personal sampling results (Table 4-1). Similarly, personal sampling data representing similar job responsibilities at the different plants were combined for comparison (Table 4-2).

When groups of data are combined, geometric means (GM) are used along with the geometric standard deviation (GSD) and the 95% upper and lower confidence limits (UCL and LCL).

In most PNA samples, the 2-ring PNAs, primarily naphthalene and its methyl derivatives, comprised the largest contributing mass to the total concentrations. In order to include this information, the percent distribution of PNAs by ring number is also given (Tables 4-1 and 4-2).

Table 4-1. Total PNA Concentrations for Area Samples at Coal Liquefaction Pilot Plants & Percent Distribution of PNAs by Ring Number

Plant	Area Sampled	N[a]	GM[b] (µg/m³)	GSD[c]	LCL[d] (µg/m³)	UCL[e] (µg/m³)	% Distribution of PNAs by Weight					
							2-Ring	3-Ring	4-Ring	5-Ring	6-Ring	7-Ring
A	Coal Preparation & Slurry Mixing	1	16.8	1.9	7.5	181.1	42.6	53.8	3.4	0	0	0
	Dissolving	1	13.7	N/A[f]	N/A	N/A	78.0	19.0	3.0	0	0	0
	Gas Recycling	1	0.6	N/A	N/A	N/A	22.0	75.0	3.0	0	0	0
	Solvent Recovery	1	92.8	N/A	N/A	N/A	78.2	21.0	0.7	0	0	0
	Solids Separation	1	224.3	N/A	N/A	N/A	32.5	53.2	13.7	0.6	0	0
	Residue Separation	1	6.1	N/A	N/A	N/A	66.0	31.7	2.3	0	0	0
	Total In-Plant	8	22.7	6.3	4.7	108.3	59.2	36.2	4.5	0.1	0	0
B	Dissolving (Extraction)	2	52.3	1.3	4.6	591.6	98.5	1.2	0.4	0	0	0
	Distillation (Fractionation)	2	50.3	1.5	1.1	2.2×10^3	97.6	1.7	0.8	0	0	0
	Solvent Recovery	2	68.3	1.0	51.1	79.7	99.0	0.7	0.4	0	0	0
	Solids Separation	2	38.7	2.5	<0.1[g]	1.2×10^3	96.9	3.0	1.0	0	0	0
	Carbonization	2	57.2	1.4	3.1	1.1×10^3	99.7	0.2	0.1	0	0	0
	Hydrogenation	2	42.5	1.7	<0.1	5.6×10^3	97.0	1.9	1.2	0	0	0
	Total In-Plant	12	50.6	1.5	38.9	65.8	98.1	1.5	1.3	0	0	0
C	Slurry Mixing	1	0.7	N/A	N/A	N/A	11.8	80.0	5.7	0	0	0
	Dissolving	1	<0.1	N/A	N/A	N/A	0	0	0	0	0	0
	Distillation	1	2.7	N/A	N/A	N/A	92.6	7.4	0	0	0	0
	Solids Separation	6	3.8	4.0	0.9	16.5	88.0	11.2	0.9	0	0	0
	Product Solidification	3	17.4	1.1	12.8	23.5	83.5	14.8	1.7	0	0	0
	Seal Oil Pump	1	15.3	N/A	N/A	N/A	94.0	5.8	0.3	0	0	0
	Total In-Plant	13	3.9	5.5	1.3	10.9	74.0	23.8	1.7	0	0	0
D	Slurry Mixing (Feed Pump)	3	322.6	2.1	50.0	2.1×10^3	98.0	1.9	0.1	0	0	0
	Dissolving (Reactor Pump)	2	57.0	1.3	7.4	439.1	95.5	4.2	0.3	0	0	0
	Distillation											
	Atmospheric Fractionator											
	Light Gas/Oil Pump	3	554.5	1.4	244.4	1.3×10^3	97.5	2.4	0.1	0	0	0
	Bottoms Pump	3	917.1	2.5	92.2	9.1×10^3	95.5	3.6	0.9	0.1	0	0
	Vacuum Stripper											
	Light Gas/Oil Pump	3	403.5	44.1	<0.1	4.9×10^6	97.3	2.5	0.2	0.1	0	0
	Heavy Gas/Oil Pump	3	4.5	15.2	<0.1	3.9×10^3	83.0	15.3	1.7	0	0	0
	Residue Separation											
	Vacuum Bottoms Pump	3	169.5	1.9	34.1	841.8	70.6	27.3	2.0	0	0	0
	Solvent Fractionation	5	169.0	8.7	11.3	2.5×10^3	99.1	0.8	0.1	0.1	0	0
	Seal Oil Pump	2	56.6	1.5	1.6	2.0×10^3	82.5	15.8	1.7	0	0	0
	Control Room (Main)	3	16.3	2.0	6.5	210.1	97.3	2.7	0	0	0	0
	Control Room (CPU)	2	80.5	1.4	5.2	1.2×10^3	97.4	2.6	0	0	0	0
	Oily Water Sump	2	180.6	14.4	<0.1	4.5×10^{12}	99.7	0.1	0.1	0	0	0
	Perimeter	3	0.7	2.9	<0.1	9.4	100	0	0	0	0	0
	Total In-Plant	34	133.8	7.9	65.8	271.3	93.3	6.1	0.5	0	0	0

[a] Number of samples collected. [b] Geometric mean of concentrations. [c] Geometric standard deviation. (continued)

[d] Lower 95% confidence limit of geometric mean. [e] Upper 95% confidence limit of geometric mean.

[f] N/A = not applicable. [g] "<" indicates value below detection limit.

Table 4-1 (concluded)

Plant	Area Sampled	N[a]	GM[b] (µg/m³)	GSD[c]	LCL[d] (µg/m³)	UCL[e] (µg/m³)	% Distribution of PNAs by Weight					
							2-Ring	3-Ring	4-Ring	5-Ring	6-Ring	7-Ring
E	Slurry Preparation	3	80.3	2.2	10.9	588.7	99.8	0	0.2	0	0	0
	Dissolving (Reactor)	4	61.9	1.8	24.4	157.1	99.5	0.4	0.1	0	0	0
	Distillation											
	Fractionator	2	46.9	2.1	<0.1[f]	3.0×10^{4}	99.0	0.3	0.8	0	0	0
	Vacuum Tower	3	31.1	1.5	11.1	87.0	90.0	2.9	6.8	0	0	0
	Solids Separation (Hydroclone)	3	134.1	1.6	5.4	1.4×10^{3}	95.1	3.4	1.3	0	0	0
	Residue Separation											
	Flaker Belt (empty)	3	11.6	1.4	5.1	26.4	95.6	1.4	3.1	0	0	0
	Waste Oil Recovery	3	26.3	4.4	0.9	1.4×10^{3}	97.3	1.1	1.4	0.2	0	0
	Control Room	3	6.1	19.5	<0.1	9.9×10^{3}	99.7	0	0.3	0	0	0
	Seal Oil Pump	3	26.4	1.5	9.0	77.6	92.2	4.2	3.7	0	0	0
	Perimeter	3	1.2	6.7	<0.1	139.8	100	0	0	0	0	0
	Total In-Plant	27	14.8	4.1	19.7	61.2	96.9	1.4	1.7	0	0	0

[a]Number of samples collected. [b]Geometric mean of concentrations. [c]Geometric standard deviation.
[d]Lower 95% confidence limit of geometric mean. [e]Upper 95% confidence limit of geometric mean.
[f]"<" indicates value below detection limit.

Table 4-2. Total PNA Concentrations for Personal Samples at Coal Liquefaction Pilot Plants & Percent Distribution of PNAs by Ring Number

Plant	Personnel Sampled	N[a]	GM[b] (µg/m³)	GSD[c]	LCL[d] (µg/m³)	UCL[e] (µg/m³)	% Distribution of PNAs by Weight					
							2-Ring	3-Ring	4-Ring	5-Ring	6-Ring	7-Ring
A	OPERATORS											
	Coal Preparation	3	12.6	3.9	0.4	378.1	84.2	16.4	0.5	0	0	0
	Solids Separation	3	32.7	2.3	4.2	252.5	75.8	21.6	2.8	0	0	0
	Solvent Recovery	3	48.3	3.1	6.2	758.5	91.0	8.5	0.5	0	0	0
	Product Solidificat'n	3	70.5	3.9	2.5	2.0×10^3	87.9	10.8	1.3	0	0	0
	Technician Specialist	1	56.7	N/A[f]	N/A	N/A	87.6	11.9	0.5	0	0	0
	Total	13	35.8	3.2	17.6	73.0	85.3	13.8	1.1	0	0	0
	MAINTENANCE PERSONNEL											
	Mechanic	1	84.9	N/A	N/A	N/A	74.0	23.4	2.7	0	0	0
	Welder	1	126.8	N/A	N/A	N/A	86.7	13.2	0.1	0	0	0
	Total	2	103.8	1.3	8.1	1.3×10^3	80.3	18.3	1.4	0	0	0
	LABORATORY TECHNICIANS	1	4.2	4.9	<0.2[g]	211.1	79.7	19.5	0.8	0	0	0
B	OPERATORS											
	Extraction	3	0.2	1	<0.2	0.3	100	0	0	0	0	0
	Fractionation/ Solvent Recovery	3	<0.2	2.5	<0.2	1.1	100	0	0	0	0	0
	Solids Separation/ Carbonization	3	<0.2	1.5	<0.2	0.34	100	0	0	0	0	0
	Hydrogenation/ Utilities	3	<0.2	3.9	<0.2	2.5	100	0	0	0	0	0
	Total	12	<0.2	2.2	<0.2	0.2	100	0	0	0	0	0
	MAINTENANCE PERSONNEL											
	Millwright	4	<0.2	2.4	<0.2	0.6	100	0	0	0	0	0
	Pipefitter	2	<0.2	1.6	<0.2	1.2	100	0	0	0	0	0
	Total	6	<0.2	4.0	<0.2	0.3	100	0	0	0	0	0
	LABORATORY PERSONNEL											
	Chemist	3	<0.2	4.8	<0.2	1.7	100	0	0	0	0	0
	Technician	3	<0.2	3.9	<0.2	2.4	100	0	0	0	0	0
	Total	6	<0.2	4.0	<0.2	0.2	100	0	0	0	0	0
	SHIFT SUPERVISOR	2	<0.2	1.9	<0.2	42.6	100	0	0	0	0	0
C	OPERATORS											
	"C"	2	1.3	72.6	<0.2	5.3×10^{16}	97.3	2.7	0.05	0	0	0
	"D"	2	9.0	1.1	2.7	29.8	89.9	9.7	0.6	0	0	0
	Total	4	3.1	16.0	<0.2	257.8	93.6	6.2	0.3	0	0	0
	MAINTENANCE PERSONNEL											
	Pipefitter	1	21.5	N/A	N/A	N/A	93.5	6.1	0.4	0	0	0
	Insulator	2	18.0	2.0	<0.2	8.6×10^3	94.1	5.5	0.3	0	0	0
	Oiler	1	4.7	N/A	N/A	N/A	91.5	7.9	0.9	0	0	0
	Instrument/Mechanic	1	11.2	N/A	N/A	N/A	93.2	6.0	0.4	0	0	0
	Millwright	2	14.6	2.5	<0.2	4.7×10^4	93.5	6.2	0.3	0	0	0
	Total	7	13.4	2.0	7.2	24.9	93.2	6.3	0.5	0	0	0
	LABORATORY PERSONNEL											
	Chemists	3	12.4	1.2	0.7	222.4	95.4	4.5	0.2	0	0	0

[a]Number of samples collected. [b]Geometric mean of concentrations. [c]Geometric standard deviation. (continued)

[d]Lower 95% confidence limit of geometric mean. [e]Upper 95% confidence limit of geometric mean.

[f]N/A = not applicable. [g]"<" indicates value below detection limit.

Table 4-2 (concluded)

Plant	Personnel Sampled	N[a]	GM[b] (μg/m³)	GSD[c]	LCL[d] (μg/m³)	UCL[e] (μg/m³)	% Distribution of PNAs by Weight					
							2-Ring	3-Ring	4-Ring	5-Ring	6-Ring	7-Ring
D	OPERATORS (PROCESS TECHNICIANS)											
	Coal Preparation Area	3	51.4	1.9	10.6	249.8	95.5	4.5	0	0	0	0
	Liquef/Distil Area #1	3	67.8	1.9	12.9	354.4	97.1	2.9	0	0	0	0
	Liquef/Distil Area #2	3	217.6	3.8	7.9	5.9×10^3	97.5	1.9	0	0	0	0
	Liquef/Distil Area #3	3	40.1	1.6	1.8	931.4	96.5	3.5	0	0	0	0
	Solvent Hydrogenation	3	299.7	4.4	7.5	1.2×10^4	99.2	0.8	0	0	0	0
	Offsite & Utilities	2	88.3	1.6	1.1	7.4×10^3	97.0	2.9	0	0	0	0
	Total	17	96.9	3.3	52.7	178.2	97.1	2.8	0	0	0	0
	MAINTENANCE PERSONNEL											
	Welder	3	15.7	1.8	3.6	69.1	87.6	12.4	0	0	0	0
	Millwright	3	188.3	5.5	2.8	1.2×10^4	98.9	1.1	0.03	0	0	0
	Pipefitter	4	51.1	1.2	37.2	70.1	98.2	1.8	0	0	0	0
	Insulator	2	24.5	1.9	<0.2[f]	7.0×10^3	96.3	3.7	0	0	0	0
	Electrician	2	34.3	1.5	0.9	1.3×10^3	92.6	6.6	0.8	0	0	0
	Instrument Technician	3	41.5	2.1	6.4	270.4	98.6	1.4	0	0	0	0
	Laborer	3	19.0	1.4	8.0	45.0	96.6	3.4	0	0	0	0
	Total	20	38.8	2.8	23.8	63.5	96.3	3.6	0.01	0	0	0
E	OPERATORS											
	Liquefaction (dissolving)	3	8.0	20.6	<0.2	1.4×10^4	99.1	0.3	0.5	0	0	0
	Fractionation	3	29.1	1.5	9.9	85.0	97.4	2.1	0	0	0	0
	Solids Separation	1	9.6	N/A[g]	N/A	N/A	100	0	0	0	0	0
	Wastewater Treatment	2	47.5	3.4	<0.2	2.6×10^6	100	0	0	0	0	0
	Total	9	18.7	5.9	4.8	72.7	99.1	0.6	0.1	0	0	0
	MAINTENANCE PERSONNEL											
	Pipefitter/Welder	5	12.3	10.6	0.7	244.2	100	0	0	0	0	0
	Machinist	3	1.8	11.5	<0.2	795.1	100	0	0	0	0	0
	Insulator	2	121.3	2.8	<0.2	1.1×10^6	98.7	0.6	0.7	0	0	0
	Laborer	5	15.9	8.4	1.1	230.4	98.2	1.3	0.3	0	0	0
	Total	15	12.6	10.1	3.6	44.2	99.2	0.5	0.3	0	0	0

[a]Number of samples collected. [b]Geometric mean of concentrations. [c]Geometric standard deviation.
[d]Lower 95% confidence limit of geometric mean. [e]Upper 95% confidence limit of geometric mean.
[g]N/A = not applicable. [f]"<" indicates value below detection limit.

Other samples were collected to assess worker exposure to aromatic amines, and simple aromatics such as benzene, toluene, and xylene. These data are summarized in this chapter, and individual sample results are presented in Appendix B.

Qualitative results of the PNA wipe samples collected at the coal liquefaction plants is shown in Table 4-3.

Sampling results for aromatic amines and other organics are shown as the highest measured concentration at each area and personal category (Tables 4-4 - 4-7). Since most samples analyzed for these compounds had no detectable concentration, the calculated mean value would, in most cases, fall below the minimum detectable level of the analytical method.

Although "highest measured concentrations" are infrequently used in displaying large amounts of sampling data, the results presented are instructive in showing that even the highest measured concentrations are well below concentrations recognized as having health hazard significance.

Table 4-3. Wipe Sample Qualitative Results for PNAs at Four Coal Liquefaction Pilot Plants (no wipe samples collected at Plant C)

Plant	Site Sampled	PNAs					
		2-Ring	3-Ring	4-Ring	5-Ring	6-Ring	7-Ring
A	Solvent recovery area, pump motor	•[a]	•	•	•	--[b]	x[c]
	Process solvent	•	•	•	•	--	x
B	Tank farm fuel oil pump	•	•	•	--	--	x
	Process solvent	•	•	•	•	•	x
D	Wrench handle	•	•	•	•	--	--
	Instrument cover	•	•	•	•	--	--
	Valve handle	•	•	•	•	--	--
	Control house door handle	•	•	•	•	--	--
	Control house lunchroom	•	•	•	--	--	--
	North flaker staircase - ground	•	•	•	•	--	--
	Bench and lockers/dirty change room	•	•	•	•	--	--
E	Slurry pump	•	•	•	•	•	--
	Seal oil pump	•	•	•	•	--	•
	Control room	•	•	•	--	--	--

[a] "•" indicates compound detected.
[b] "--" indicates compound not detected.
[c] "x" indicates sample not analyzed for this group of PNAs.

Table 4-4. Measured Concentrations (mg/m^3) of Aromatic Amines Measured in Area Samples at Coal Liquefaction Pilot Plants

Plant	Process Area	N[a]	Aromatic Amines					
			Aniline	N,N-Dimethyl-aniline	2,4-Dimethyl-aniline	o-Toluidine	Anisidine[b]	Naphthyl-amine[c]
A	Coal Preparation	1	—[d]	—	—	—	s[e]	s
	Solids Separation	1	—	—	—	—	s	s
	Solvent Recovery	1	—	—	—	—	s	s
	Residue Separation	1	—	—	—	—	s	s
B	Solvent Extraction	2	—	—	s	s	—	s
	Solids Separation	2	—	—	s	s	—	s
	Solvent Recovery	2	—	—	s	s	—	s
	Carbonization	1	—	—	s	s	—	s
	Waste Treatment	1	—	—	s	s	—	s
	Stretford Unit	2	—	—	s	s	—	s
C	Slurry Blend	1	—	—	—	—	—	s
	Reactor	1	—	—	—	—	—	s
	Solids Separation	6	—	—	—	—	—	s
	Distillation	1	—	—	—	—	—	s
	Seal Oil Pump	1	—	—	—	—	—	s
	Product Solidification	1	—	—	—	—	—	s
D	Control Rooms	5	—	—	—	—	—	—
	Slurry Feed	2	—	—	—	—	—	—
	Reactor	2	—	—	—	—	—	—
	Atmospheric Stripper	4	0.4	—	—	0.1	—	—
	Vacuum Stripper	8	0.4	0.1	0.3	—	0.6	—
	Solvent Fractionation	6	0.3	—	—	—	—	—
	Flush Oil Pump	2	—	—	—	—	—	—
	Oily Water Sump	2	—	—	—	—	—	—
E	Control Room	3	—	—	—	—	—	—
	Slurry Pump	4	—	—	—	—	—	—
	Reactor	3	—	—	—	—	—	—
	Solvent Recovery	4	—	—	—	—	—	—
	Distillation	9	—	—	—	—	—	—
	Residue Separation	4	—	—	—	—	—	—
	Waste Oil Recovery	4	—	—	—	—	—	—
	Seal Oil Pump	3	—	—	—	—	—	—

[a] Number of samples collected.
[b] Includes o- and p-anisidine.
[c] Includes 1- and 2-naphthylamine.
[d] "—" indicates compound not detected.
[e] "s" indicates sample not analyzed for this compound.

Table 4-5. Maximum Concentrations (mg/m^3) of Aromatic Amines Measured in Personal Samples at Coal Liquefaction Pilot Plants

Plant	Job Category	N[a]	Aromatic Amines						
			Aniline	N,N-Dimethyl-aniline	2,4-Dimethyl-aniline	Anisidine[b]	o-Toluidine	p-Nitro-aniline	Naphthyl-amine[c]
A	Unit Operator	17	0.08	0.1	—[d]	—	—	s[e]	s
	Laboratory Technician	1	—	—	—	—	—	s	s
B	Unit Operator	12	—	—	0.49	—	—	s	s
	Laboratory Technician	4	—	—	—	—	—	s	s
	Maintenance Personnel	5	—	—	—	—	—	s	s
	Supervisor	1	—	—	0.40	—	—	s	s
C	Unit Operator	1	—	—	—	—	—	—	—
	Laboratory Technician	4	—	0.35	—	—	—	—	—
	Maintenance Personnel	5	—	—	—	—	—	—	—
D	Unit Operator	11	—	—	—	—	—	—	—
	Maintenance Personnel	12	—	—	—	—	—	—	—
E	Unit Operator	11	—	—	—	—	—	—	—
	Maintenance Personnel	14	—	—	—	—	—	—	—

[a] Number of samples collected. [b] Includes o- and p-anisidine. [c] Includes 1- and 2-naphthylamine.
[d] "—" indicates compound not detected. [e] "s" indicates sample not analyzed for this compound.

Table 4-6. Maximum Concentrations (ppm) of Organic Compounds Measured in Area Samples at Coal Liquefaction Pilot Plants

Plant	Process Area	N[a]	Organics					
			Benzene	Toluene	Xylene	Phenols[b]	Cresols[c]	Xylenols[d]
A	Coal Preparation	1	0.02	0.03	0.03	x[e]	x	x
	Solids Separation	1	0.04	0.09	0.06	x	x	x
	Solvent Recovery	1	0.02	0.08	0.12	x	x	x
	Residue Separation	1	—[f]	—	—	x	x	x
B	Coal Preparation	1	—	—	—	—	—	—
	Solids Separation	11	—	—	—	—	—	—
	Solvent Extraction	13	—	—	—	—	—	—
	Solvent Recovery	6	—	—	—	0.1	—	—
	Carbonization	7	—	—	—	—	—	—
	Fractionation	2	—	0.03	—	—	—	—
	Hydrogenation	2	—	0.06	—	—	—	—
	Stretford Unit	2	x	x	x	—	—	—
C	Slurry Blend	2	—	—	—	x	x	x
	Reactor	1	—	—	—	x	x	x
	Solids Separation	6	—	—	—	x	x	x
	Distillation	1	—	—	—	x	x	x
	Seal Oil Pump	1	—	—	—	x	x	x
	Caustic Pump	1	x	x	x	—	—	—
	Hot Well	1	x	x	x	—	—	—
D	Control Rooms	5	0.19	0.11	0.13	x	x	x
	Slurry Feed	4	0.04	—	0.02	—	—	—
	Reactor	2	—	—	—	x	x	x
	Atmospheric Fraction.	6	0.03	0.06	0.21	—	—	—
	Vacuum Stripper	8	0.13	0.14	0.26	—	—	—
	Solvent Fractionation	6	0.04	0.04	0.17	x	x	x
	Flush Oil Pump	3	0.04	0.08	0.52	x	x	x
	Oily Water Sump	2	0.32	0.54	0.85	x	x	x
E	Control Room	5	0.02	0.01	—	—	—	—
	Slurry Preparation	4	0.01	0.01	0.01	—	—	—
	Reactor	5	0.03	0.01	0.01	—	—	—
	Solvent Recovery	7	—	0.01	—	—	—	—
	Distillation	8	0.06	0.02	0.01	—	—	—
	Residue Separation	6	0.01	0.01	—	—	—	—
	Waste Oil Recovery	5	—	0.02	—	—	—	—
	Seal Oil Pump	2	—	—	—	—	—	—

[a] Number of samples collected. [b] Includes o- and p-ethylphenol. [c] Includes o-, m-, and p-cresol.
[d] Includes 2,3- and 3,5-xylenol. [e] "x" indicates sample not analyzed for this compound.
[f] "—" indicates compound not detected.

Table 4-7. Maximum Concentrations (ppm) of Organic Compounds Measured in Personal Samples at Coal Liquefaction Pilot Plants

Plant	Job Category	N[a]	Organics					
			Benzene	Toluene	Xylene	Phenols[b]	Cresols[c]	Xylenols[d]
A	Unit Operator	12	0.08	0.39	0.07	x[e]	x	x
	Laboratory Technician	3	—[f]	—	—	x	x	x
B	Laboratory Technician	3	—	0.08	—	x	x	x
C	Unit Operator	4	—	—	—	x	x	x
	Laboratory Technician	3	—	—	—	x	x	x
	Maintenance Personnel	3	—	—	—	x	x	x
D	Unit Operator	15	0.13	0.05	0.18	—	—	—
	Maintenance Personnel	16	0.34	0.10	0.05	—	—	—
E	Unit Operator	5	x	x	x	—	—	—
	Maintenance Personnel	5	x	x	x	—	—	—

[a] Number of samples collected. [b] Includes o- and p-ethylphenol. [c] Includes o-, m-, and p-cresol.
[d] Includes 2,3- and 3,5-xylenol. [e] "x" indicates sample not analyzed for this compound.
[f] "—" indicates compound not detected.

REVIEW OF INDUSTRIAL HYGIENE/OCCUPATIONAL MEDICINE PROGRAMS

The industrial hygiene and medical surveillance programs reviewed here are divided into three components:

- those elements designed to minimize physical contact between the worker and the plant environment (personal hygiene and educational programs);
- elements aimed at the detection of medical changes caused by the industrial environment (medical surveillance and epidemiological studies); and
- industrial hygiene monitoring programs designed to measure chemical pollutants in the plant environment.

Work practices and controls are discussed in the following section of this chapter.

With some exceptions, all five coal liquefaction plants in this study maintained programs containing the basic components of comprehensive occupational health programs. The components of the individual programs at each plant are summarized in Table 4-8.

Subjective differences in the efficacy of these programs were observed, but it proved difficult to quantitate or even to substantiate these differences which can probably be attributed to differences in motivation, expertise, and interest of the personnel responsible for the management of the programs and plant employees in cooperating with prescribed programs.

Personal Hygiene and Educational Programs

Recommended personal hygiene procedures designed to protect the coal conversion worker against dermal, inhalational, and ingestive exposures to hazardous chemicals include four major elements:

- protective clothing/equipment programs
- clean clothing programs
- shower facilities with clean/dirty area separation
- barrier creams and cleansing agents

Table 4-8. Industrial Hygiene and Occupational Medicine Programs at Coal Liquefaction Pilot Plants

PROGRAM ELEMENT	PLANT A	PLANT B	PLANT C	PLANT D	PLANT E
PERSONAL HYGIENE AND SAFETY					
Protective Clothing/Equipment Program					
coveralls	✓	✓	✓	✓	✓
shoes/boots	✓	✓	✓	✓	✓
underwear	✓	-	-	-	-
rainsuits/coats	✓	-	✓	✓	✓
gloves	✓	✓	✓	✓	✓
safety glasses	-	✓	✓	✓	✓
hardhats	✓	✓	✓	✓	✓
earmuffs	-	-	-	-	-
respirators	✓	✓	✓	✓	✓
Clean Clothing Program					
clean coveralls	daily	daily	daily	daily	✓
protective shoes	✓	-	-	✓	✓
clean underwear	daily	-	-	-	-
Hygiene Facilities (Shower Room)	✓	✓	✓	✓	✓
single locker	-	✓	-	-	-
dual lockers	-	-	✓	-	-
clean/dirty separation	✓	-	-	✓	-
barrier creams/agents	✓	-	✓	✓	✓
EDUCATIONAL PROGRAM					
Prejob training	✓	✓	✓	✓	-
Brochures/manuals	✓	✓	✓	✓	-
Continuing education	✓	-	✓	✓	-
Posted signs	-	-	-	✓	-
Respirator training	✓	✓	✓	✓	✓
WORK PRACTICES AND PERMIT SYSTEM	✓	✓	✓	✓	✓
INDUSTRIAL HYGIENE MONITORING					
Informal schedule	-	✓	-	-	-
Uniform program	✓	-	✓	✓	✓
MEDICAL SURVEILLANCE					
Clinical monitoring	✓	✓	✓	✓	✓
Epidemiological program	✓	-	-	✓	-

The range of protective clothing required or provided by the five plants for protection against dermal exposure to coal-derived materials includes:

- shoes -- oil-resistant leather or rubber coverings required and provided by some plants
- underwear and socks -- daily changes provided by one plant
- coveralls -- provided by all plants
- raincoats, rainsuits, aprons, hoods -- provided by all plants on an as-needed basis or on an assigned basis for high-exposure jobs in the process area
- gloves: cotton, asbestos, leather, rubber -- variously available or required in all plants for specific jobs.

Safety equipment is required for everyone entering the process areas of all plants and includes safety glasses and hardhats. Earmuffs are usually available as well.

Protection of workers from inhalation of potentially dangerous gases and airborne particulates is provided by disposable respirators and full-face respirators with acid gas/organic vapor cartridges; in addition, supplied-air respirators include 5-minute, self-contained escape packs, and 30-minute, pressure-demand, self-contained breathing apparatus (SCBA).

The purpose of the clean clothes programs is to minimize exposure to coal-derived materials and prevent their spread outside the dirty areas of the plant. Four of the five surveyed liquefaction plants provide daily changes of clean coveralls for workers. These plants also provide laundry service for this clothing, either on the premises or at commercial laundries. However, there was no evidence of systematic programs in any of the plants for cleaning nonlaunderable articles, such as gloves and rubber items. Worker contact with heavily soiled articles of this nature was noted frequently.

All the plants mandate postshift showers which are taken during the last 20 to 30 minutes of the shift; cleansing materials are provided as well. Three of the five plants also provide either dual lockers or effective clean/dirty area separation in the shower/changing rooms. Barrier creams are generally available in the wash areas of the plants.

The UV fluorescent examination of skin for the detection of PNA contamination before and after showering, and of clothing after laundering, and of tools has only been done on an experimental basis. One plant uses UV fluorescence for determination of tool contamination. No plant provides routine spot-checking of this nature for monitoring the efficacy of personal hygiene programs.

Educational programs for employees of the coal liquefaction plants were observed to contain various elements consisting mainly of:

- orientation and training sessions including audiovisual presentations, tours, discussions, and testing for understanding of job hazard and health information;
- health and safety brochures and manuals;
- periodic continuing education sessions for refreshing and updating job hazard and health information, and providing classes or courses in specialized subjects such as CPR; and
- posting of signs and labels to indicate hazardous situations or to encourage hygienic work habits.

All the plants provide training in the use of respirators.

Medical Surveillance and Epidemiological Studies

Routine medical surveillance protects the health of the individual by detection of incipient health problems, and the health of all workers by the provision of long-term health information which may identify plant and industrial hazards requiring process or work practices modifications. Effective programs include medical monitoring of individual workers for immediate evaluation, and a system for continuous recording of both medical and exposure data for future study.

Table 4-9 lists the coal liquefaction plants included in this study and the components of the medical surveillance program at each. All currently operating plants provide at least periodic medical history and physical examinations and one or more auxiliary tests, including pulmonary function tests, chest X-rays, electrocardiograms, and a standardized battery of serum

chemistry tests. They also include special skin examinations: annual visual examination of the skin by a physician (all plants); quarterly examination of the skin by a nurse (Plants A, B and C); charting of skin lesions (Plants A and E); color photography of the face and hands (Plant D); and semi-quantitative estimations of a "black speck" index for later correlation with pathology (Plant A). In addition, cytological examinations of sputum and urine are provided at Plant D.

Table 4-9. Medical Programs in Effect at Coal Liquefaction Plants

	PLANT A	PLANT B	PLANT C	PLANT D	PLANT E
No. of Employees:[1]	184	38[2]	121	200-250	150[2]
MINIMAL WORK-UP					
Preplacement History and Physical	✓	✓	✓	✓	✓
Annual Follow-up	✓	✓	✓	✓	✓
Urinalysis	✓	-	✓	✓	-
Blood Count	✓	-	✓	✓	-
ROUTINE WORK-UP					
Blood Chemistries	✓	-	✓	-	✓
AUXILIARY TESTS					
Chest X-ray	✓	-	-	✓	-
Pulmonary Functions	✓	-	✓	✓	-
EKG	-	-	-	✓	-
SPECIALIZED TESTS					
Audiogram	✓	-	-	✓	-
Sputum Cytology	-	-	-	✓	-
Urine Cytology	-	-	-	✓	-
Skin Examination	✓	✓	✓	✓	✓
MISCELLANEOUS					
Medical Work-up	hemoccult	-	-	ongoing exposure histories	-
Epidemiological Program	✓			✓	

[1]Not all tests given to all personnel. [2]Process workers only.

Industrial Hygiene Monitoring Programs

All five coal liquefaction plants conduct periodic air sampling for chemical and physical hazards; three of the five have comprehensive monitoring programs. Table 4-10 summarizes the pollutants monitored in the surveys of each individual plant. However, results from only one of the comprehensive programs (Plant A) were available at the time of this study.

Table 4-10. Summary of Industrial Hygiene Monitoring Programs at Coal Liquefaction Plants

Monitoring Program	Plant A	Plant B	Plant C	Plant D	Plant E
Coal Dust/Respirable Particulates	✓	-	-	✓	-
Aromatic Hydrocarbons	Benzene solubles/ PNAs	-	Benzene solubles	Benzene solubles	Benzene solubles
Gases	✓	CO, H_2S	-	✓	-
Benzene, Toluene, Xylene	✓	-	✓	-	-
Phenolics	✓	-	✓	✓	-
Noise	✓	✓	✓	✓	-

An extensive industrial hygiene monitoring program is being conducted by the Pittsburg and Midway Coal Mining Co. at one of the coal liquefaction pilot plants (Plant A) (DOE, 1980). Highlights of the program and results to date include:

WORK PRACTICES AND CONTROLS

Coal liquefaction processes are primarily closed systems; therefore, this design feature serves to contain process constitutents within the system. In a properly maintained system, worker exposure to process constituents can occur only:

- at feedstock, product or by-product entry and exit points,
- during upset conditions,
- during activities that circumvent the closed system, and
- as a result of catastrophic equipment or vessel failure.

Supplemental engineering controls, such as local exhaust ventilation, have been employed at entry and exit points to control emissions at these sites. For upset conditions and for activities that circumvent the closed system, work practices and personal protective clothing and equipment are relied upon to provide workers with additional protection.

Work Practices

The principal objectives of work practices found at the five coal liquefaction plants were to minimize skin contact with process constituents through the use of protective clothing, and to minimize inhalation exposure through the use of respiratory protection. This was accomplished through the development of work procedures that would reduce exposures to any constituents encountered during upset conditions or in the performance of activities which circumvented the closed system. The situations requiring special work procedures had been identified by the plants as being mainly related to maintenance activities, process stream sampling, and emergencies.

Chemical hazards which the plants had identified as the greatest hazards, requiring special procedures, include PNAs and hydrogen sulfide. The PNAs were selected because of the carcinogenic properties of a number of species in this group. Plant concern regarding bodily contact with PNAs is supported by data obtained in this industrial hygiene study which showed the presence of PNAs on work surfaces, tools, and clothing.

Hydrogen sulfide is considered a hazard because of its presence in coal liquefaction process streams in the parts-per-million range (by volume). At these levels, hydrogen sulfide can be an acute hazard in enclosed areas (e.g., a vessel) or in emergency situations involving major process leaks.

Maintenance workers have duties which routinely involve contact with process stream constituents. These workers, therefore, have a higher potential risk of being exposed to process materials relative to workers in other job categories found in liquefaction plants. These maintenance activities are related to work on on-line equipment, such as breaking into process lines, repairing and removing process equipment, and entering vessels.

Work procedures in the liquefaction plants were designed to minimize worker contact with process materials, especially the coal liquids (tars), and to prevent the formation of an acute hazard condition from toxic gases such as hydrogen sulfide. The key elements of these work practices are isolation of the system, draining the system of process material, and cleaning of the work site. Only Plant D has formalized these three elements within its safety manual. Other facilities reportedly follow these procedures, but they did not have written procedures available at the time of this study.

It was noted at the liquefaction facilities that the plant operators generally perform the premaintenance activities of isolation, draining, and cleaning because they are more familiar with the process design than are the maintenance crews. This transfers some of the risk of exposure to process materials from the maintenance crews to the operators. Protection of the operators is accomplished by the development of formalized work procedures for these three activities; by the use of a permit system to monitor these procedures; and by the use of personal protective clothing and equipment.

Isolation--

In the isolation step, the flow of process material into the process segment being repaired is stopped by blanking off all process lines entering and leaving the segment. Blanking off of the process segment is accomplished by the use of valves, caps, or plugs. Valving is the simplest technique, and

involves the closing of valves on all lines entering and leaving the segment being repaired; valving is also the least reliable method of isolation because of the possibility of valve failure. Valving is the most common technique being used at all of the liquefaction facilities; however, Plant D uses caps and plugs whenever feasible when working on equipment and vessels. Caps and plugs are more reliable because they involve the actual removal of a segment of piping, thereby physically isolating the vessel or equipment from the rest of the process.

Draining--

Once the system is isolated, it is drained of process material to permit maintenance work. Drained solid or liquid materials are routed to receptacles, such as covered containers or drains, for disposal; vapor and gases are vented to the thermal oxidizers. Health and safety problems are present in the draining of isolated systems that are under high temperatures and pressures. Where pressurized or high-temperature systems exist, bleed valves are used to reduce pressures to atmospheric level.

Cleaning--

Cleaning operations are used to remove surface contamination -- primarily coal tars -- from work surfaces. Steam-cleaning is the most commonly used method and was used in all of the liquefaction facilities. Hydroblasting and industrial-strength caustic detergents are used in combination with steam-cleaning at Plants D and E. Observations at these facilities indicated that the use of detergents increases the efficiency of the cleaning operation.

Vessel Entry--

All liquefaction plants have developed vessel entry procedures which are patterned after NIOSH recommendations. These procedures follow the cleaning step, and they involve:

- purging the vessel with air,
- checking combustible gas and oxygen levels,
- measuring concentration of toxic gases, such as hydrogen sulfide, likely to be present, and
- employing a buddy system, whereby one person fully equipped with the necessary protective clothing and equipment is stationed outside the vessel to provide assistance in an emergency.

Housekeeping--

Different approaches have been developed in the five liquefaction plants to handle routine housekeeping duties. The technique most commonly employed is to conduct cleanup activities on an as-needed basis. At Plant C, spills are cleaned as soon as possible by the persons responsible for the spill. Strict adherence to this policy, especially the as-soon-as-possible clause, at Plant C has produced the cleanest work environment of the liquefaction facilities visited.

Plants D and E clean the process area on a daily basis with assigned personnel. One unit process area is cleaned each day by the maintenance labor force because plant size makes it impractical to clean the entire plant area in a single day. This procedure permits tars time to solidify so that a more rigorous procedure is needed to clean up the area.

Cleanup is conducted on an as-time-permits basis at Plants A and B. Responsibility for cleanup was held by operators who had other assigned duties that took precedence over cleanup. Under this setup, cleaning of areas in the plants was intermittent, and as a result Plants A and B had the greatest amount of tar deposition of all facilities visited.

Plants D and E provide for the cleaning of contaminated tools at specially designated sites. An additional precaution is taken at Plant D by inspecting cleaned tools under ultraviolet light for residual tar contamination.

Steam-cleaning is used at all five facilities to remove tar deposits. At Plant C, where spills are handled on an individual basis, an absorbent such

as vermiculite is immediately spread on the spill. After the tar is absorbed, the vermiculite is placed in a closed container for disposal, and the area is steam-cleaned; this procedure has proven to be most effective in keeping the work area free of tar deposits. At Plant B, spills were handled by simply flushing the area with water, with the wastewater going to a wastewater treatment site. The area was cleaned with steam later when time permitted. Under this procedure, Plant B had one of the highest levels of tar deposits of all facilities visited.

Hydroblasting, and a combination of hydroblasting and industrial-strength caustic detergents, serve as alternates to steam-cleaning at Plants D and E. It was noted during the surveys that this combination is very effective in removing tar deposits. Plant A use a jackhammer to loosen tar deposits prior to steam-cleaning; however, this technique was not as effective as hydroblasting and detergent cleaning noted at Plant D and E, where it was done on a routine, scheduled basis.

Administrative Controls

Most of the liquefaction plants surveyed in this project do not consider administrative controls to be a significant method in controlling worker exposures, preferring instead the use of protective clothing and equipment and the use of safe work procedures. In the facilities where administrative controls are used, they serve as supplements to the other methods.

The most commonly used administrative control observed was barricading, whereby a person's access to a restricted area is physically restricted by barriers. Entry is permitted on the basis of formal training in recognizing and handling hazards within the area. In temporary situations -- where process upsets or the performance of specific activities such as repair can create hazardous conditions -- colored barrier tapes are often used to erect a temporary barrier to keep untrained personnel out of the area. At Plant D, permanent barriers were erected at the sour water/sour gas system.

Process areas of plants A, B, D, and E have been designated as "limited access" areas in their entirety. Visitors entering the facility are assumed to be untrained and unfamiliar with the plant's safety measures. A sign-in/sign-out system is being used at these plants to monitor visitors while they are in the facility: visitors entering the facility must sign a logbook, noting time of arrival; upon departure, visitors must sign out, logging time of departure.

While in the facility, visitors are provided with company escorts who are familiar with the plant's safety policies. This procedure provides an effective means of monitoring visitors and their location in the facility, and ensures that visitors are not endangered by accidental violation of safety procedures. At Plants D and E, all visitors planning to enter the main process area must take part in a brief training program outlining the basic safety program.

5. ANALYSIS AND DISCUSSION OF RESULTS

POLYNUCLEAR AROMATIC HYDROCARBONS (PNAs)

PNA samples collected at each of the five liquefaction facilities were divided into four major groups: all combined area samples (excluding plant perimeter), and personal samples for: operators, maintenance personnel, and laboratory technicians. The worker groups were derived on the basis of job descriptions obtained at the individual plants and observations of worker activities made at the time of the surveys. Selections were made to ensure that the workers placed in each group had similar duties at all five facilities. For each of the four groups, the geometric mean (GM), geometric standard deviation (GSD), and 95% lower and upper confidence limits (LCL and UCL) have been calculated (Table 5-1). Table 5-2 contains the breakdown of the PNA results into common unit operations at each plants.

Statistical analysis of the geometric means of the four groups were performed on an intraplant and an interplant basis using the Student's t-test. The equation used assumes that the variances (S^2) of the groups being compared are different (Sokal and Rohlf, 1969). The equation is:

$$\left| t'_s \right| = \text{antilog} \left| \frac{\log GM_1 - \log GM_2}{\sqrt{\frac{\log S_1^2}{n_1} + \frac{\log S_2^2}{n_2}}} \right|$$

Table 5-1. Geometric Mean PNA Concentrations and 95% Confidence Limits for Major Sample Groups at Five Coal Liquefaction Pilot Plants

Group	Parameter	Plant A	Plant B	Plant C	Plant D	Plant E
Combined Area Samples	Number of Samples Collected	8	12	13	34	27
	Geometric Mean ($\mu g/m^3$)	22.7	50.6	3.9	133.8	34.8
	Geometric Standard Deviation	6.3	1.5	5.5	7.9	4.1
	Lower 95% Confidence Limit ($\mu g/m^3$)	4.7	38.9	1.1	65.8	19.7
	Upper 95% Confidence Limit ($\mu g/m^3$)	108.3	65.8	10.9	271.8	61.2
Operator (Personal Samples)	Number of Samples Collected	13	12	4	17	9
	Geometric Mean ($\mu g/m^3$)	35.8	<0.2[a]	3.1	96.9	18.7
	Geometric Standard Deviation	3.2	2.2	16.0	3.3	5.9
	Lower 95% Confidence Limit ($\mu g/m^3$)	17.6	<0.2	<0.2	52.7	4.8
	Upper 95% Confidence Limit ($\mu g/m^3$)	73.0	0.2	257.8	178.2	72.7
Maintenance (Personal Samples)	Number of Samples Collected	2	6	7	20	15
	Geometric Mean ($\mu g/m^3$)	103.8	<0.2	13.4	38.8	12.6
	Geometric Standard Deviation	1.3	4.0	2.0	2.8	10.1
	Lower 95% Confidence Limit ($\mu g/m^3$)	8.1	<0.2	7.2	23.8	3.6
	Upper 95% Confidence Limit ($\mu g/m^3$)	1,300	0.3	24.9	63.5	44.2
Laboratory Technician (Personal Samples)	Number of Samples Collected	3	6	3	0	0
	Geometric Mean ($\mu g/m^3$)	4.2	<0.2	12.4	N/A[b]	N/A
	Geometric Standard Deviation	4.9	4.0	3.2	N/A	N/A
	Lower 95% Confidence Limit ($\mu g/m^3$)	<0.2	<0.2	0.7	N/A	N/A
	Upper 95% Confidence Limit ($\mu g/m^3$)	211.1	0.2	222.4	N/A	N/A

[a] "<" indicates value below detection limit.

[b] N/A = not applicable.

Table 5-2. Total PNA Concentrations at Process Areas of Five Coal Liquefaction Plants

Plant	Process Area Sampled	N[a]	GM[b] (µg/m³)	GSD[c]	LCL[d] (µg/m³)	UCL[e] (µg/m³)
A	Coal Preparation, Slurrying, and Dissolving	4	31.3	1.9	11.3	86.2
	Solids Separation	1	224.3	N/A[f]	N/A	N/A
	Fractionation	2	23.2	6.8	<0.1[g]	6.4×10^8
B	Coal Preparation, Slurrying, and Dissolving	2	52.3	1.3	4.6	591.6
	Solids Separation	4	47.0	1.8	18.1	121.9
	Fractionation	6	52.6	1.5	35.3	78.3
C	Coal Preparation, Slurrying, and Dissolving	2	0.3	4.0	<0.1	6.1×10^{-4}
	Solids Separation	6	3.8	4.0	0.9	16.5
	Fractionation	5	11.7	2.3	4.2	32.8
D	Coal Preparation, Slurrying, and Dissolving	5	161.2	3.0	41.0	634.5
	Fractionation	22	155.7	11.1	52.9	457.7
	Control Room	5	50.4	2.0	21.7	116.9
	Perimeter	3	0.7	2.9	<0.1	9.4
E	Coal Preparation, Slurrying, and Dissolving	7	69.2	1.9	38.9	123.1
	Solids Separation	3	135.4	3.7	5.4	3.4×10^3
	Fractionation	11	24.5	1.9	16.0	37.6
	Control Room	3	6.2	19.5	<0.1	9.9×10^3
	Perimeter	3	1.2	6.7	<0.1	139.8

[a]Number of samples collected. [b]Geometric mean of concentrations.
[c]Geometric standard deviation. [d]Lower 95% confidence limit of geometric mean.
[e]Upper 95% confidence limit of geometric mean. [f]N/A = not applicable.
[g]"<" indicates value below detection limit.

where "n" is sample size. The t'_s value is compared with the t' value at P = 0.05 obtained through extrapolation using the following equation:

$$t'_{.05} = \frac{t_{.05[n_1-1]}\left(\frac{S_1^2}{n_1}\right) + t_{.05[n_2-1]}\left(\frac{S_2^2}{n_2}\right)}{\frac{S_1}{n_1} + \frac{S_2}{n_2}}$$

where "n-1" is the degrees of freedom.

Plant A

A comparison of all area samples collected at Plant A (GM = 21.4 ug/m^3; Table 5-1) with the GM of each of the three worker groups shows a significant difference ($P < 0.01$) in the mean concentrations of the worker groups relative to the area samples (Figure 5-1). The maintenance group mean (GM = 103.8 ug/m^3) was five times the area mean, and the operator mean (GM = 35.8 ug/m^3) 1.5 times higher. These results indicate an additional source of exposure to these groups other than average PNA levels present in the process area environment. Observation of worker activities at Plant A indicates that specific activities involving repair of process equipment were a source of additional exposure. The operator levels are not as high as the maintenance because operators did not actively participate in most repair activities.

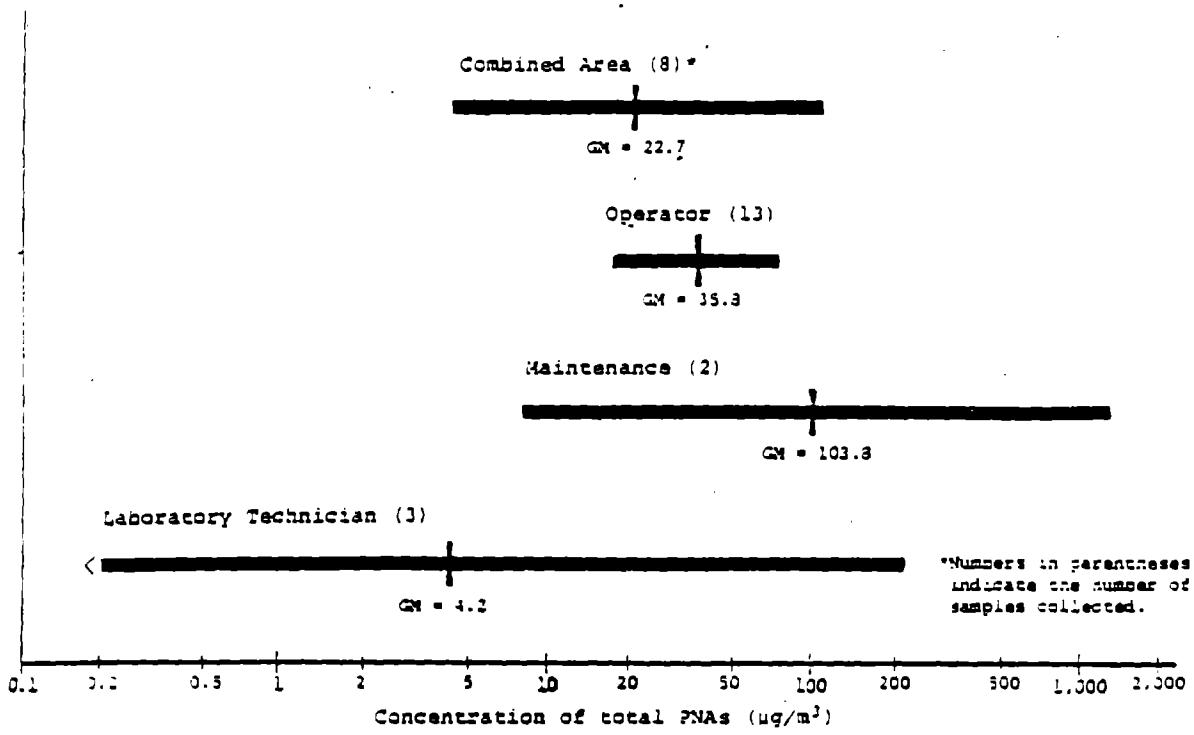

Figure 5-1. Plant A Geometric Mean PNA Concentrations and 95% Confidence Limits for Combined Area, Operator, Maintenance, and Laboratory Technician Samples

The laboratory technicians had a geometric mean exposure of 4.2 $\mu g/m^3$ which was 20% of the average PNA levels determined for the area samples. The low exposure for the technician group is attributed to the fact that the technicians' duty stations are outside of the process area. The technicians at Plant A are not required to enter the process area because their duties primarily involve the preparation and analysis of process stream samples which are collected by the operators. Since the technicians' work is performed under laboratory hoods, lower PNA exposure is associated with this group.

Significant differences ($P < 0.001$) are evident among the three worker groups, with the laboratory technician group having the lowest level of exposure (Table 5-1). The mean for the operator group was nine times that

of the laboratory technician group and for the maintenance group 25 times. The low level of exposure of the laboratory technicians can be attributed to their minimal contact with the process areas; the high levels of the maintenance group can be attributed to repair activities that place them in direct contact with process material; and the operators' intermediate exposure level is because their duties require lengthy periods in the process area monitoring equipment and providing occasional assistance to maintenance personnel.

Figure 5-2 is a graphical presentation of the PNA results by unit operations for Plant A. Statistical comparison is difficult because of the low number of samples. However, no difference ($P > 0.05$) was observed between the mean PNA levels of the dissolver/coal preparation area (GM = 31.3 ug/m^3) and the fractionation (GM = 23.2 ug/m^3) area despite the fact that the dissolver/coal preparation system is in an enclosed, three-story structure, while the fractionation system is in an open structure.

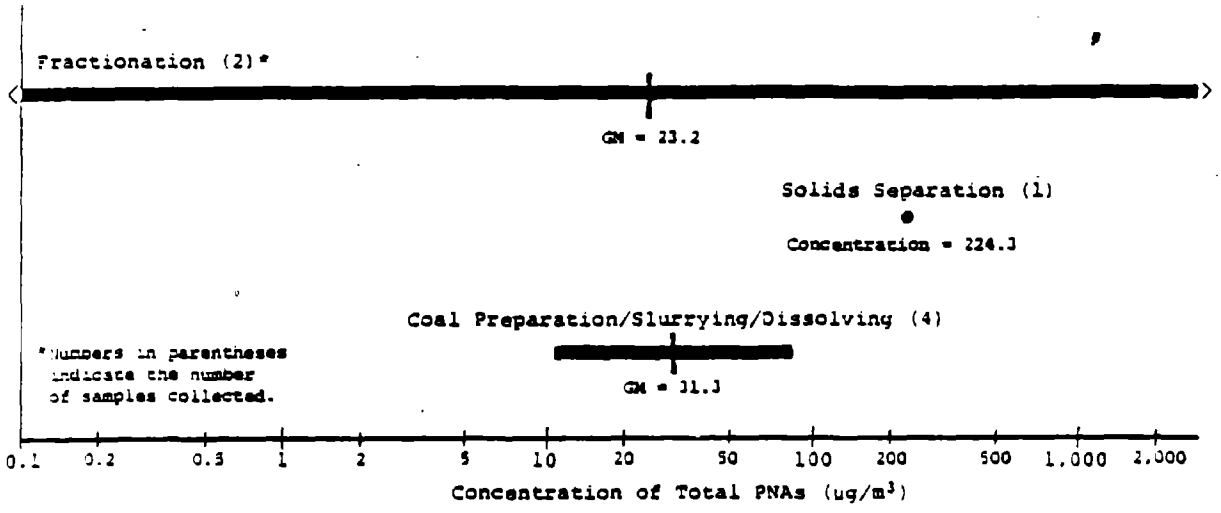

Figure 5-2. Plant A Geometric Mean PNA Concentrations and 95% Confidence Limits for Major Unit Operations

The ground level of the solids separation area contains most of the pumps used in this liquefaction facility. It has been noted at this and other liquefaction facilities that pumps are usually a major source of fugitive emissions. Therefore, the high PNA level (224.3 ug/m^3) measured in a single sample taken from this area may be due to the close proximity of the sampler to these pumps. This high value, relative to the means of the other two process areas, is suggestive of potentially higher exposures occurring within this area.

Plant B

A significant difference (P 0.01) was observed between the combined area samples (GM = 50.6 ug/m^3) and the three worker groups (GM = 0.2 ug/m^3 for each worker group) in Plant B (Figure 5-3). All three worker groups had mean PNA levels below the limit of detection, indicating negligible exposures to PNAs. It is apparent from observations made during the surveys that most workers were not in the process area long enough to accumulate PNA exposures equivalent to levels measured in the process area. Observations made during the survey showed that the operators averaged 80 percent of their time in the control room because frequent upset conditions during the survey precluded their conducting normal activities. The laboratory technicians spent 100 percent of their time analyzing samples in the laboratory which is well outside of the process area. Maintenance workers spent 80 percent of their time in the maintenance shop which is also located outside of the process area.

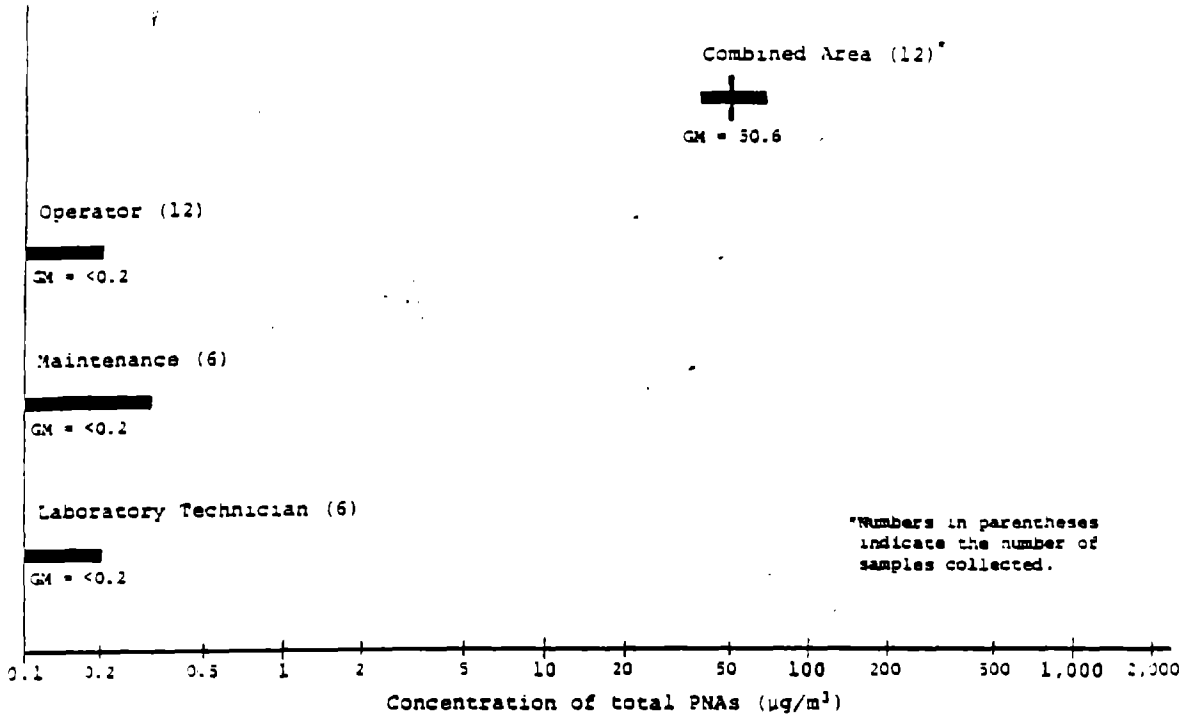

Figure 5-3. Plant B Geometric Mean PNA Concentrations and 95% Confidence Limits for Combined Area, Operator, Maintenance, and Laboratory Technician Samples

No significant differences ($P > 0.05$) were found between the mean concentrations of the major unit operations (Table 5-2; Figure 5-4) at Plant B, indicating uniform PNA levels throughout the facility. The major factor for the uniformity in PNA levels is the close proximity of all unit operations to one another.

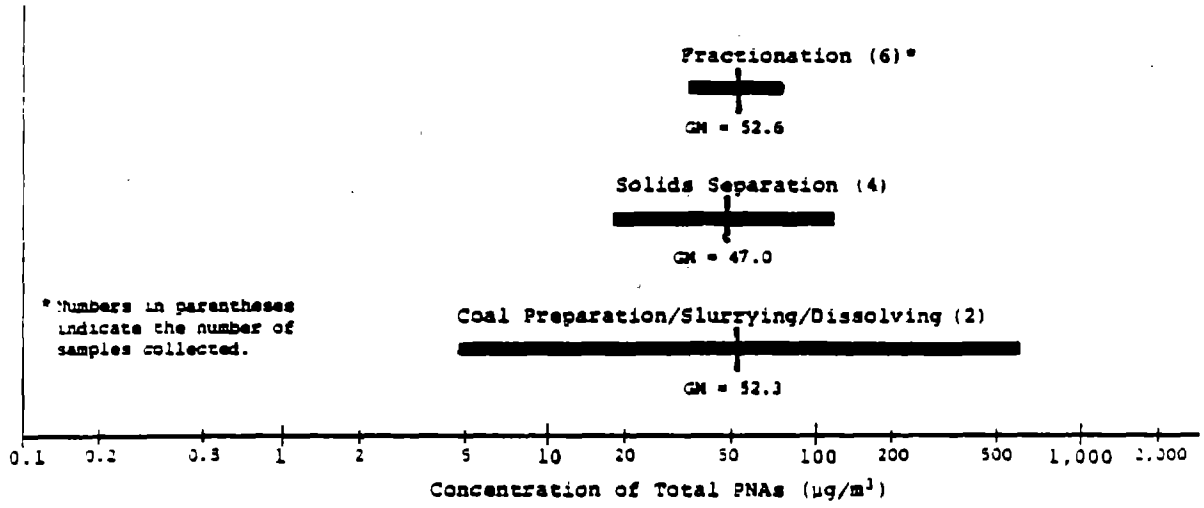

Figure 5-4. Plant B Geometric Mean PNA Concentrations and 95% Confidence Limits for Major Unit Operations

Plant C

The operators at Plant C work throughout the process area. When the mean for this group (GM = 3.1 ug/m^3) is compared with the mean of combined area samples (GM = 3.9 ug/m^3) (Figure 5-5), the difference is not significant ($P > 0.05$). This indicates that PNA exposure for this group closely reflects PNA concentrations in the process area as a whole. Since the operators perform minor repair activities (e.g., fixing a leaking valve), it appears that such activities did not add significantly to the operators' overall exposure.

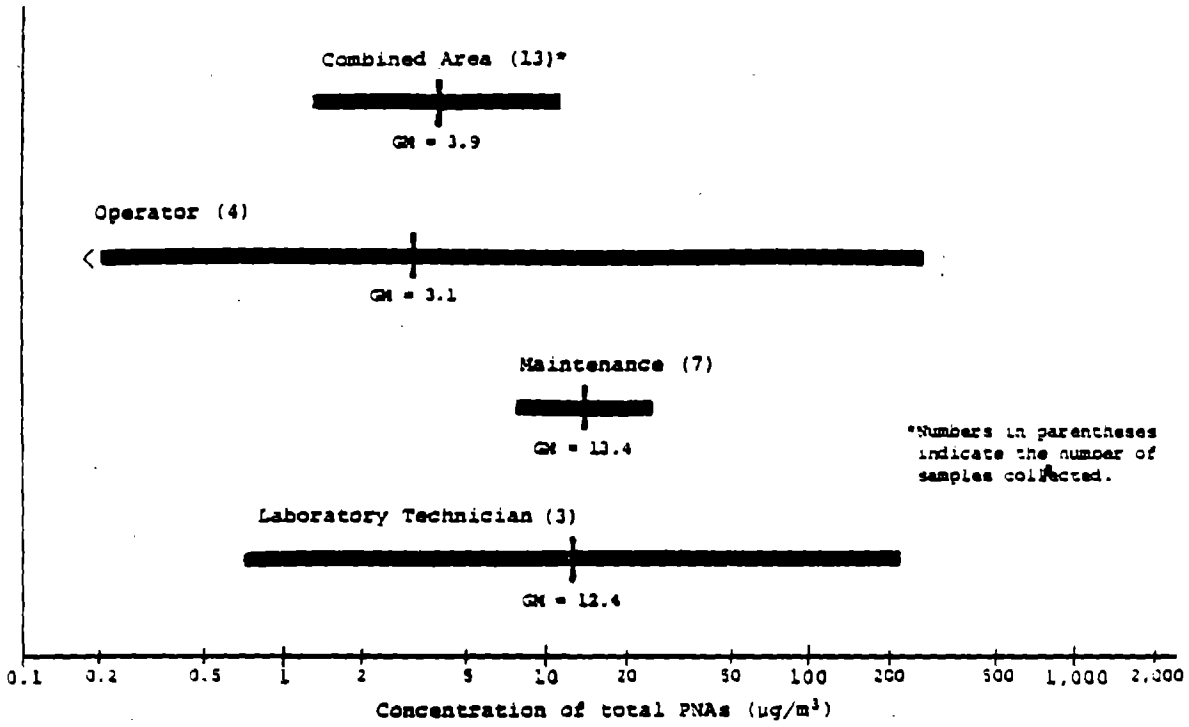

Figure 5-5. Plant C Geometric Means and 95% Confidence Limits for Combined Area, Operator, Maintenance, and Laboratory Technician Samples

No significant different ($P > 0.05$) existed between the means of the maintenance group (GM = 13.4 ug/m^3) and the laboratory technician group (GM = 12.4 ug/m^3), indicating that their duties result in similar levels of exposure. The Plant C laboratory technicians differ from those at the four other plants, in that they collected their own process samples. Since the

duties of the maintenance workers at Plant C are similar to those of maintenance workers at the other plants, it appears that the equivalent exposure for the laboratory technicians and the maintenance workers is related to the collection of process samples. These results indicate the importance of process stream sample collecton as a contributing factor to PNA exposure.

Significant differences in PNA concentrations ($P < 0.05$) exist between both the maintenance and laboratory technician groups and the combined area samples and operator groups (Table 5-1; Figure 5-5). The maintenance personnel and laboratory technicians have PNA exposures which are about four times the mean concentrations measured for the area samples and operator groups. This indicates that the maintenance staff and laboratory technicians are exposed to additional sources besides those of the general process area environment. Observations during the survey of Plant C indicate that these sources are activity-related, with the technicians' exposure linked to process sampling activities and maintenance workers' exposures related to repair of on-line equipment.

A comparison of means of the major unit operations at Plant C is shown in Table 5-2 and Figure 5-6. The fractionation area had the highest level (GM = 11.7 ug/m^3) with that of the solids separation area and the coal dissolving area being significantly lower.

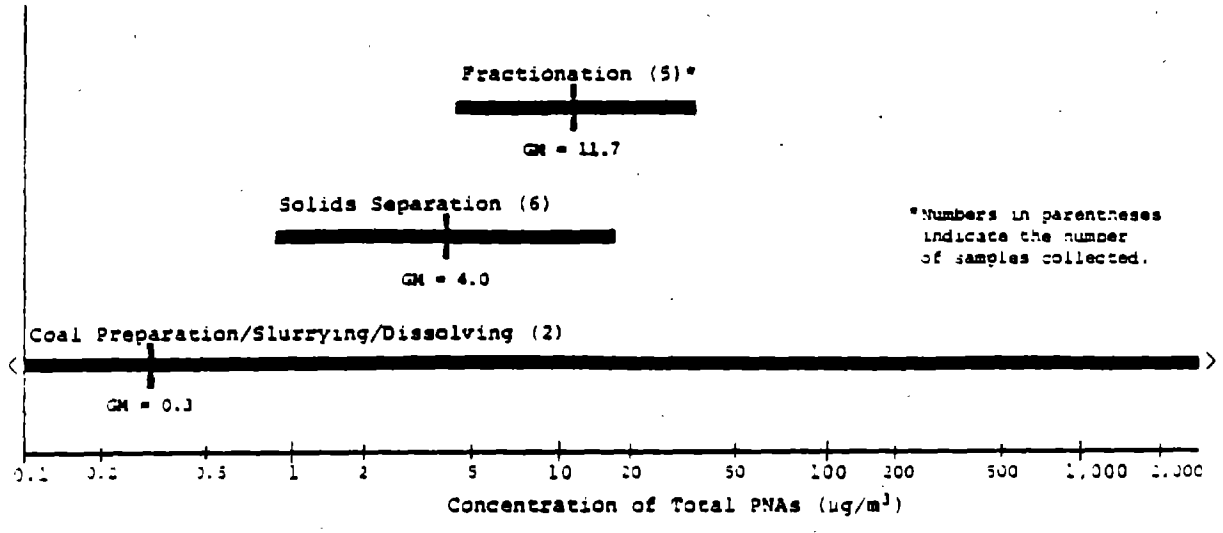

Figure 5-6. Plant C Geometric Mean PNA Concentratons and 95% Confidence Limits for Major Unit Operation Samples

Plant D--

The combined in-plant area sample mean (GM = 133.8 ug/m^3) at Plant D was significantly higher ($P < 0.001$) than the mean of the personal samples collected on operators and maintenance workers (Table 5-1; Figure 5-7). The mean area PNA level was 40 percent higher than that of the operators (GM = 96.9 ug/m^3) and 240 percent higher than that of the maintenance staff (GM = 38.8 ug/m^3).

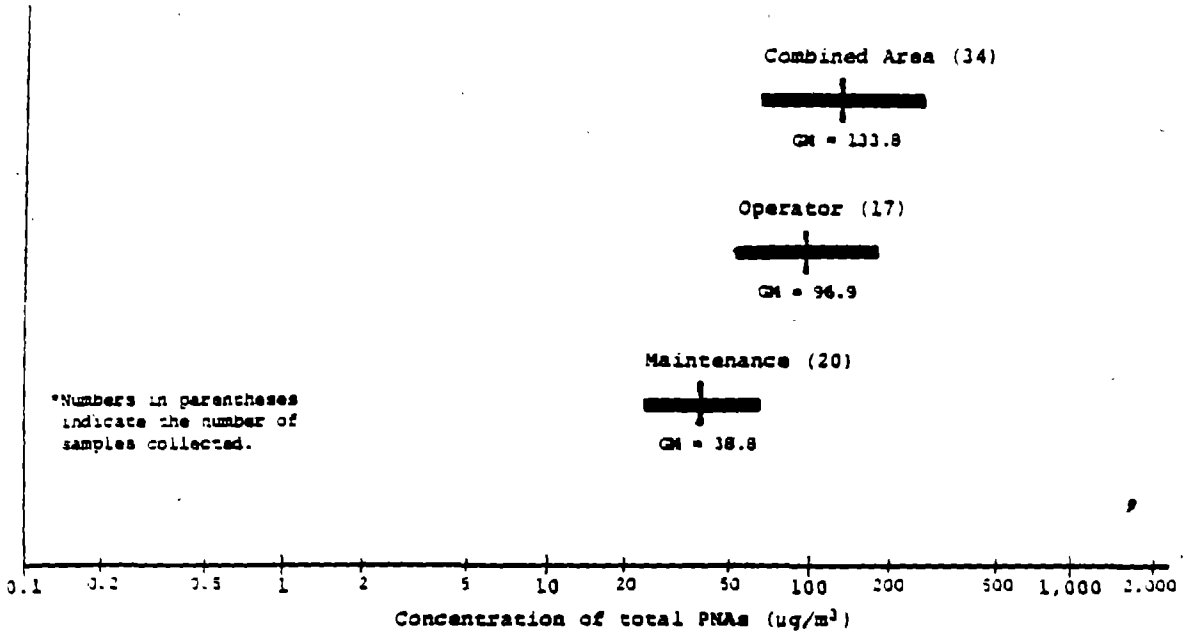

Figure 5-7. Plant D Geometric Means and 95% Confidence Limits for Combined Area, Operator, and Maintenance Samples

The significantly lower levels of PNA exposures for the two worker groups is an indication that they were not exposed to sources of PNAs other than that found in the general work environment and were not in the process area long enough to receive the full burden of PNAs from the process area environment. The operators were observed to spend only about 60 percent of their time in the process area monitoring equipment, which would account for their lower level of exposure relative to the concentration of PNAs in the area samples.

The maintenance crew did not work on onstream equipment during the survey period; instead, their time in the field was minimal, primarily spent on

repair of support equipment and cleanup of the process area. A majority of their time was spent in the shop areas which are remote from the main process area.

The operators had exposures significantly higher (P 0.001) than those of the maintenance group. This is different from the pattern noted at Plants A, B, and C, where the maintenance group had the highest level of exposure. This difference is attributed to the absence of repair activities on on-line process equipment during the survey period; in the other plants, this type of activity was found to be a major contributor to the overall exposure of the maintenance group workers. It is, therefore, expected that sampling of maintenance workers during shutdown when on-line equipment repair activities are in progress would show higher PNA exposure levels.

All major unit operations had means significantly higher (P 0.05) than the perimeter (GM = 0.7 ug/m^3) (Table 5-2; Figure 5-8). The PNA level for the control room (GM = 50.4 ug/m^3) was 71 times, and the levels of the dissolver/coal preparation (GM = 161.2 ug/m^3) and the fractionation (GM = 155.7 ug/m^3) areas more than 220 times the perimeter PNA levels.

There was no significant difference (P 0.05) between PNA levels for the dissolver/coal preparation area and the fractionation area. However, these two areas had means significantly higher (P 0.05) than that of the control room by a factor of 3. The control room at Plant D is about 75 meters from the main process area, which may account for the lower levels measured there relative to the process area.

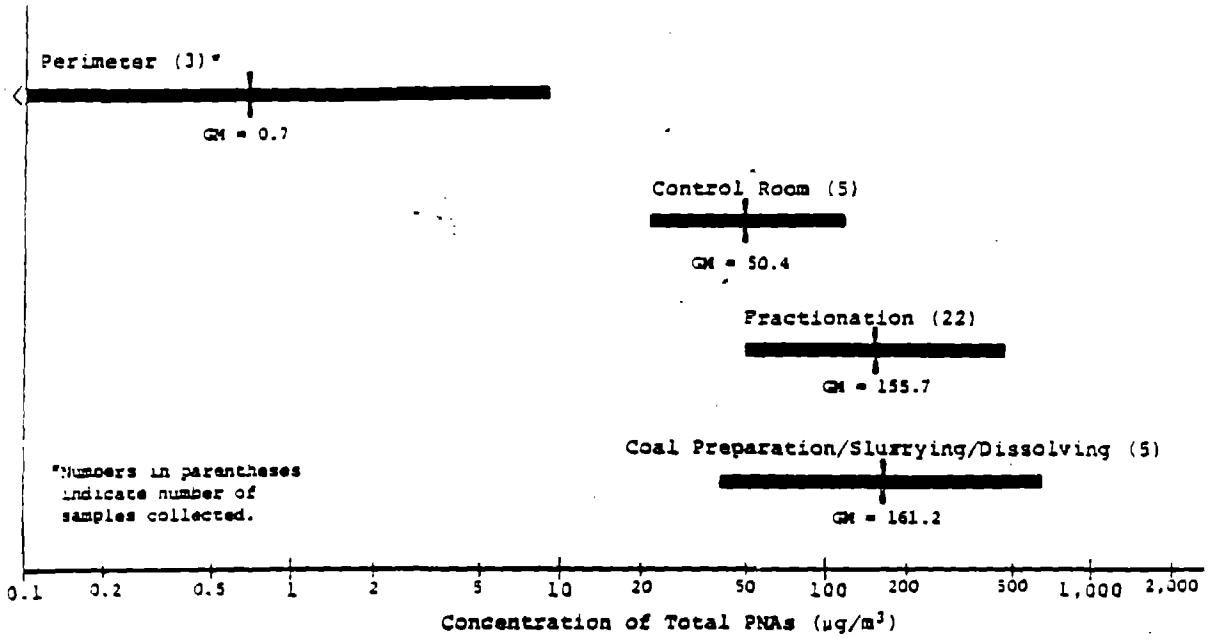

Figure 5-8. Plant D Geometric Mean PNA Concentrations and 95% Confidence Limits for Major Unit Operations, Control Room, and Perimeter Samples

Plant E—

Significant differences ($P < 0.05$) exist between the mean PNA level in the combined area samples and the individual worker groups (Table 5-1; Figure 5-9). The mean area PNA level (GM = 34.8 ug/m^3) was three times the mean measured on maintenance workers (GM = 12.6 ug/m^3) and two times that of the operators (GM = 18.7 ug/m^3). The significantly higher ambient PNA levels of the process areas relative to the worker groups are an indication that workers from these groups did not spend sufficient time in the process areas during the survey to receive an equivalent time-weighted average exposure to PNAs.

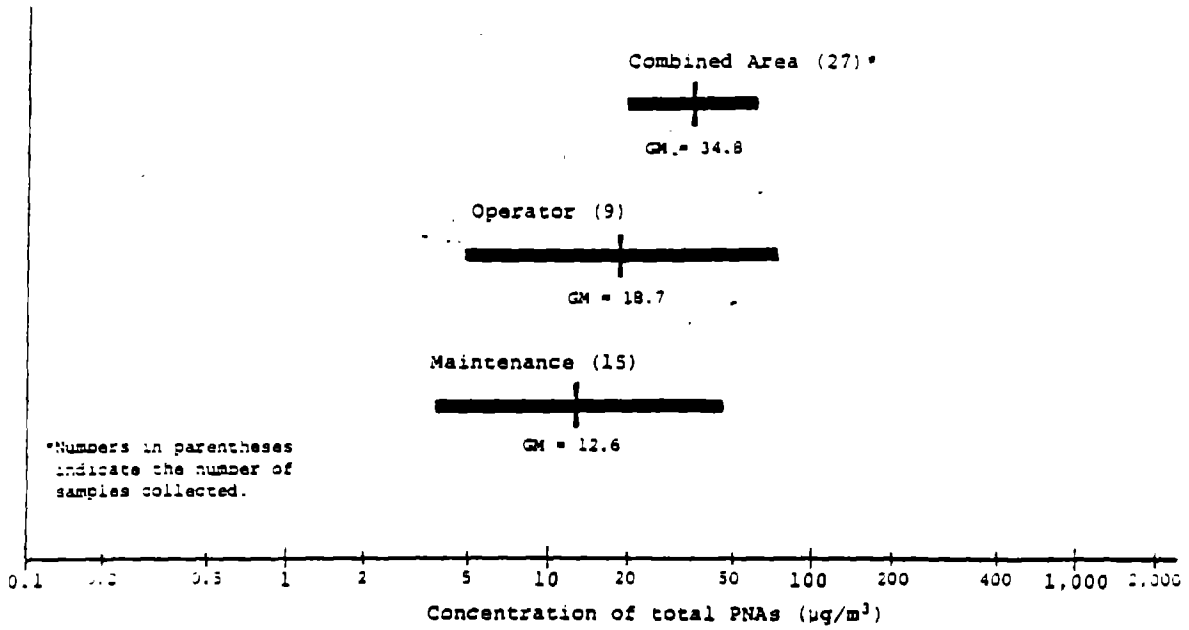

Figure 5-9. Plant E Geometric Mean PNA Concentrations and 95% Confidence Limits for Combined Area, Operator, and Maintenance Samples

The operators at Plant E were observed to spend more than 50 percent of their time in the control room. A comparison of means showed no significant difference ($P > 0.05$) between operator and control room samples but a significant difference between operator and ($P < 0.05$) other unit operation samples--the operator mean being 50 to 750 percent lower than that of the areas (Tables 5-1 and 5-2). The results indicate that the operators' PNA exposures were equivalent to ambient PNAs in the control room. Activities performed by the operators during the survey of Plant E represented routine operations.

Maintenance personnel in Plant E do not work on onstream equipment during test runs unless upset conditions occur. Their normal workload during a test run consists of work on support equipment, work on unit operations that are down, new construction, remodeling, cleanup of the process area, and making preparations for shutdown activities. There were not major process upsets and all but one unit operation were running during the survey of Plant E; thus, maintenance activities were primarily in other work areas which did not require extensive time within the process area. An estimated 60 to 80 percent of maintenance staff time was spent in the maintenance ops which are outside of the process area.

A comparison of the maintenance group with the major process areas of the plant (Tables 5-1 and 5-2) shows no significant difference (P 0.05) from the control room mean. However, the maintenance group had a significantly lower (P 0.05) mean PNA exposure than the combined PNA concentration levels measured at the unit operations, ranging from 50 to 90 percent (Figure 5-9).

Survey results at Plants A, B, and C indicated that activities involving on-line process equipment are the major source of PNA exposures for maintenance workers; at Plant E, work on on-line equipment is scheduled for shutdown periods. It is expected that if sampling were conducted during shutdown it would produce exposure results more in line with those noted at the other liquefaction facilities.

The four major unit operations at Plant E had PNA concentrations ranging from 50 to 100 times higher (P 0.05) than the perimeter samples (GM = 1.2 ug/m^3) (Table 5-2; Figure 5-10). Significant differences (P 0.05) also exist in PNA concentrations among the four major unit operations. The control room had the lowest level (GM = 6.2 ug/m^3); the fractionation section was 400 percent higher (GM = 24.5 ug/m^3); the dissolver/coal preparation area (GM = 69.2 ug/m^3) was 400 percent higher than the fractionation area; and the solids separation section posted the highest level (GM = 135.4 ug/m^3) which was twice that of dissolver/coal preparation area.

The solids separation section is located 50 feet north of the fractionation section and 20 feet west of the dissolver/coal preparation section. During the survey, this was downwind of the fractionation and upwind of the dissolver/coal preparation area. Based on the ranking of these areas by PNA concentrations, it appears that the solids separation area is a major source of PNA emissions. Ambient PNA concentrations decrease with an increase in distance from this section. The control room is located outside the process area and had the lowest PNA levels.

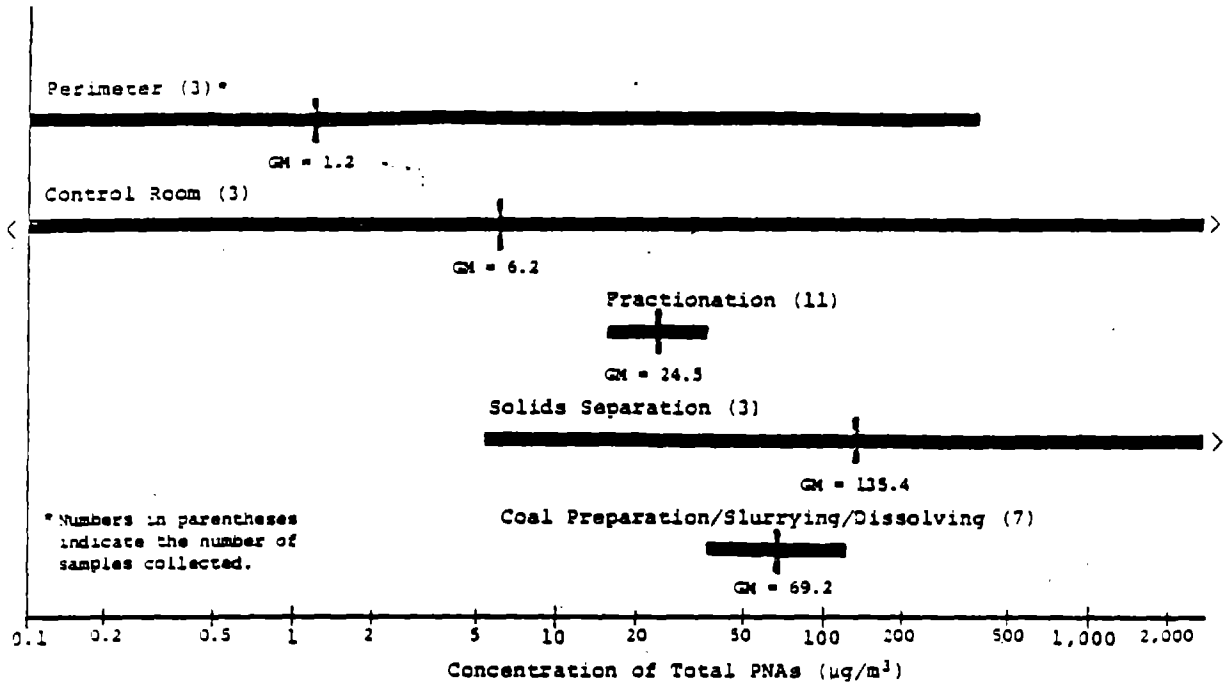

Figure 5-10. Plant E Geometric Mean PNA Concentrations and 95% Confidence Limits for Major Unit Operation, Perimeter, and Control Room Samples

Interplant Comparison

Combined Area Samples--

Significant differences were found in the overall average total PNA concentrations measured in area samples at the five coal liquefaction plants ($P < 0.05$) (Table 5-1; Figure 5-11).

These differences could not be correlated with plant size or liquefaction process. Other factors including operating conditions at the time of the survey were felt to have a greater influence on the values.

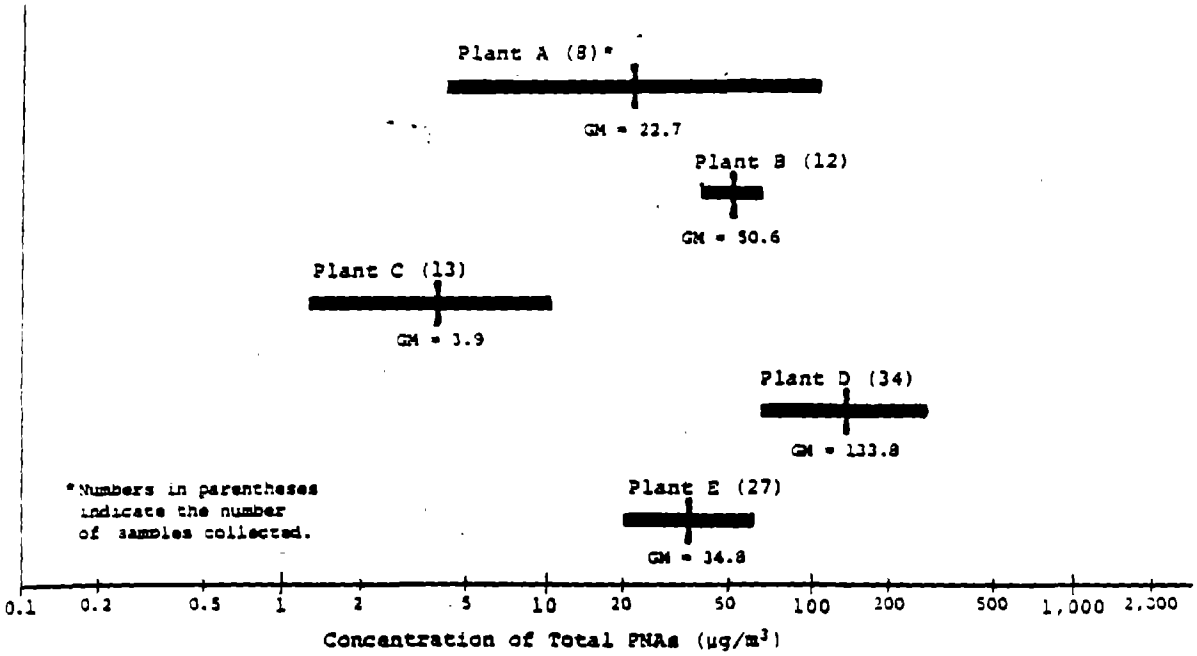

Figure 5-11. Geometric Mean PNA Concentrations with 95% Confidence Limits for (combined) Area Samples from Five Liquefaction Facilities

Plants A and C are very similar in their operating specifications. Comparison of these two plants indicates that an increase in the size of the plant does not lead to a corresponding increase in the ambient PNA levels. This result suggests that PNA levels in these plants can not be extrapolated to large commercial facilities.

Worker Groups—

The analyses of data from each of the five plants showed significant differences in the means of each of the three worker groups for all five plants (Figures 5-12, 5-13, and 5-14). However, evidence of the existence of a relationship between plant size, or process type, and worker group exposure was not found (Tables 5-3 and 5-4). Exposure levels of the operator, maintenance, and laboratory technician groups were found to be dependent upon time spent in the process area and upon the type of activity being performed. These factors have no relationship to plant size and to the type of process being used at each facility.

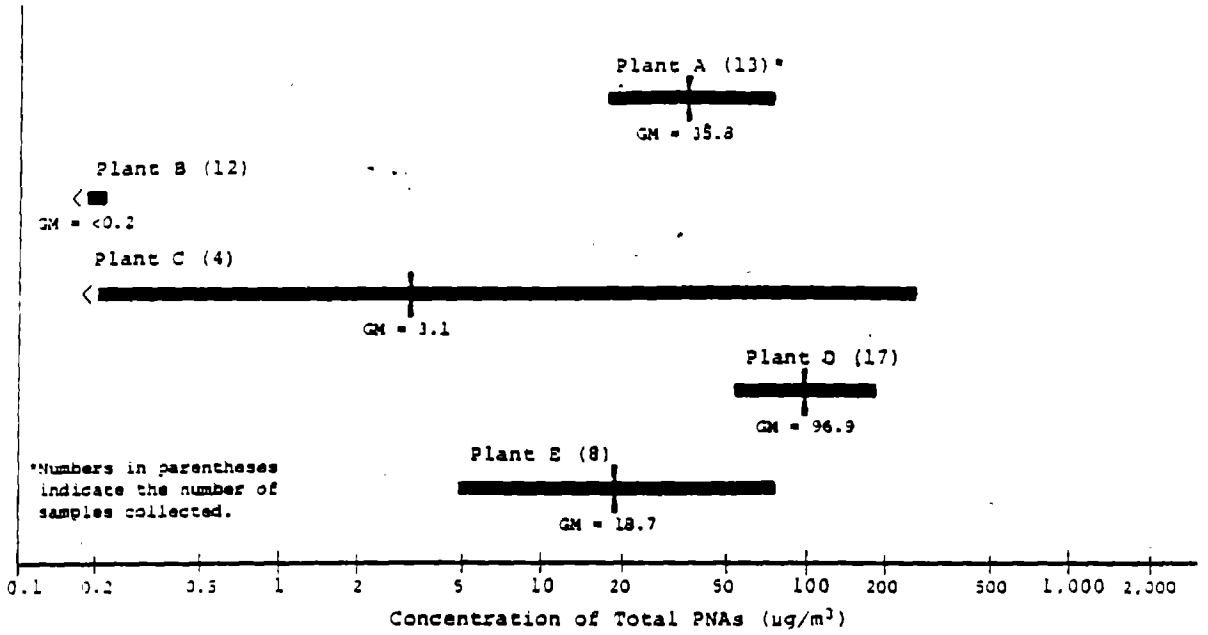

Figure 5-12. Geometric Mean PNA Concentrations and 95% Confidence Limits for Operators at Five Liquefaction Plants

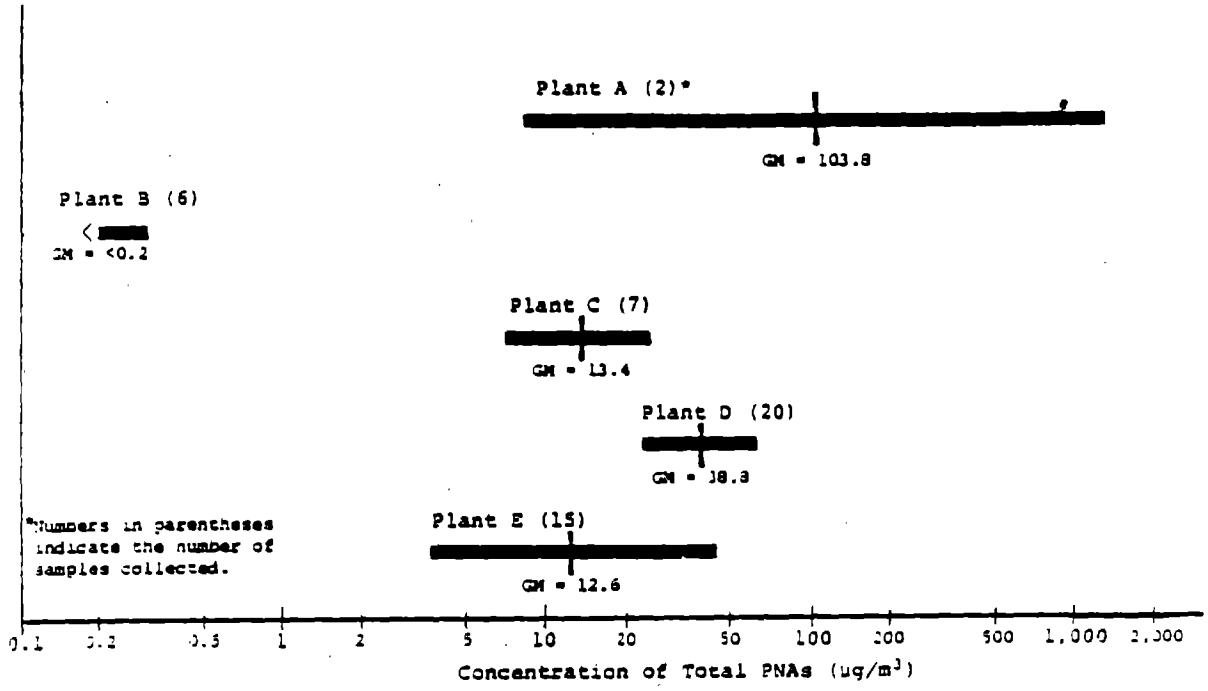

Figure 5-13. Geometric Mean PNA Concentrations with 95% Confidence Limits for Maintenance Workers at Five Liquefaction Plants

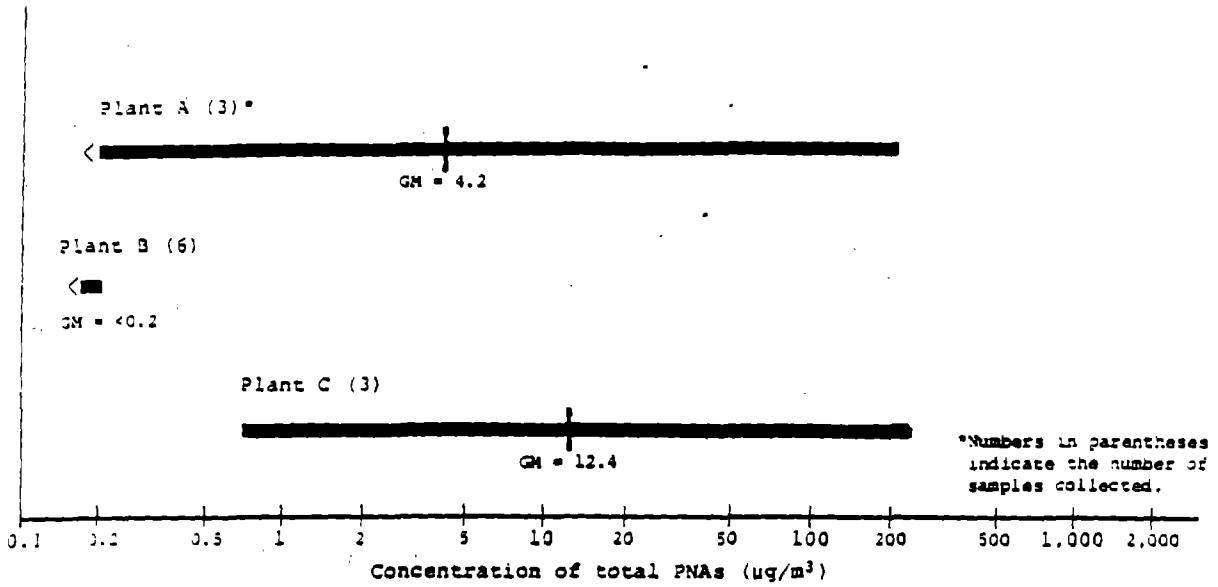

Figure 5-14. Geometric Mean PNA Concentrations with 95% Confidence Limits for Laboratory Technicians at Three Liquefaction Plants

Table 5-3. Comparison of Plant Size With Geometric Mean PNA Exposures for Three Worker Groups

Plant	Rank by Size	Rank of Geometric Mean of Groups[a]		
		Operator	Maintenance	Laboratory Technician
A	3	2 (35.8)	1 (103.8)	2 (4.2)
B	4	5 (<0.2)[b]	5 (<0.2)[b]	3 (<0.2)[b]
C	5	4 (3.1)	4[c] (12.6)	1 (12.4)
D	1	1 (96.9)	2 (38.8)	[d]
E	2	3 (18.7)	3[c] (13.4)	[d]

[a]Geometric mean concentration (μg/m³) given in parentheses.
[b]Limit of detection of analytical procedure.
[c]No significant difference between Plants C and E ($P > 0.05$).
[d]No sampling at these plants for laboratory technician group.

Table 5-4. Comparison of Coal Liquefaction Process Type with Geometric Mean PNA Exposures for Three Worker Groups

Process Type	Plant	Rank by Group Geometric Mean[a]		
		Operator	Maintenance	Laboratory Technician
Donor Solvent	D	1 (96.9)	2 (38.8)	[b]
	B	5 (<0.2)[c]	5 (<0.2)[c]	3 (<0.2)[c]
Catalytic Hydrogenation	E	3 (18.7)	3[d] (13.4)	[b]
Noncatalytic Hydrogenation	A	2 (35.8)	1 (103.8)	2 (4.2)
	C	4 (3.1)	4[d] (12.6)	1 (12.4)

[a]Geometric mean concentration (μg/m³) given in parentheses.
[b]No sampling conducted at these plants for laboratory technician group.
[c]Limit of detection of analytical procedure.
[d]No significant difference between Plants C and E ($P > 0.05$).

Although no relationship was found between plant size and worker group exposure, an internal consistancy of exposures for all three worker groups is evident from the data given in Table 5-3. Plants D and A consistently ranked at the top for all the three worker groups. Plant B's worker population had the lowest level of exposure in all three groups, while Plant E ranked in the middle of the five plants.

Contamination of process equipment and tools with PNAs was detected by collection and qualitative analysis of wipe samples (Table 4-3, page 4-7). Most samples were found to contain PNAs with up to 5-rings. Although no quantitative exposure estimate is possible to this type of exposure, it is apparent that continued dermal contact with contaminated equipment is occurring at all plants. This emphasizes the need for an effective protective clothing program and periodic decontamination and cleaning of items frequently contacted by plant employees.

The strongly suspected carcinogen phenanthrene/anthracene (coelutents) appeared to serve as a reliable indicator of the presence of high molecular weight PNAs in these wipe samples. They were present in all samples in which PNAs with more than four rings were found.

In order to relate the PNA exposures measured in the five coal liquefaction pilot plants to a familiar industry segment, Figure 5-15 was developed from data obtained in two other NIOSH-sponsored studies conducted by Enviro (Futagaki, 1981, and Cubit and Tanita, 1982). Figure 5-15 shows the results (GM and 95% confidence limits) of personal sampling conducted in this study, in nine petroleum refineries (fluid catalytic cracking units and delayed coking units), and in three coal gasification plants. The sampling and analytical methods for PNAs were identical for each study. Since personnel activities differ widely in the three industries exact analogies are not possible, but the data do show that the range of personal exposures in coal liquefaction plants is equivalent to the exposure ranges found in the nine petroleum refineries.

As in the case of the liquefaction plants, most of the PNAs collected in the petroleum refinery and gasification plant samples were naphthalene and its

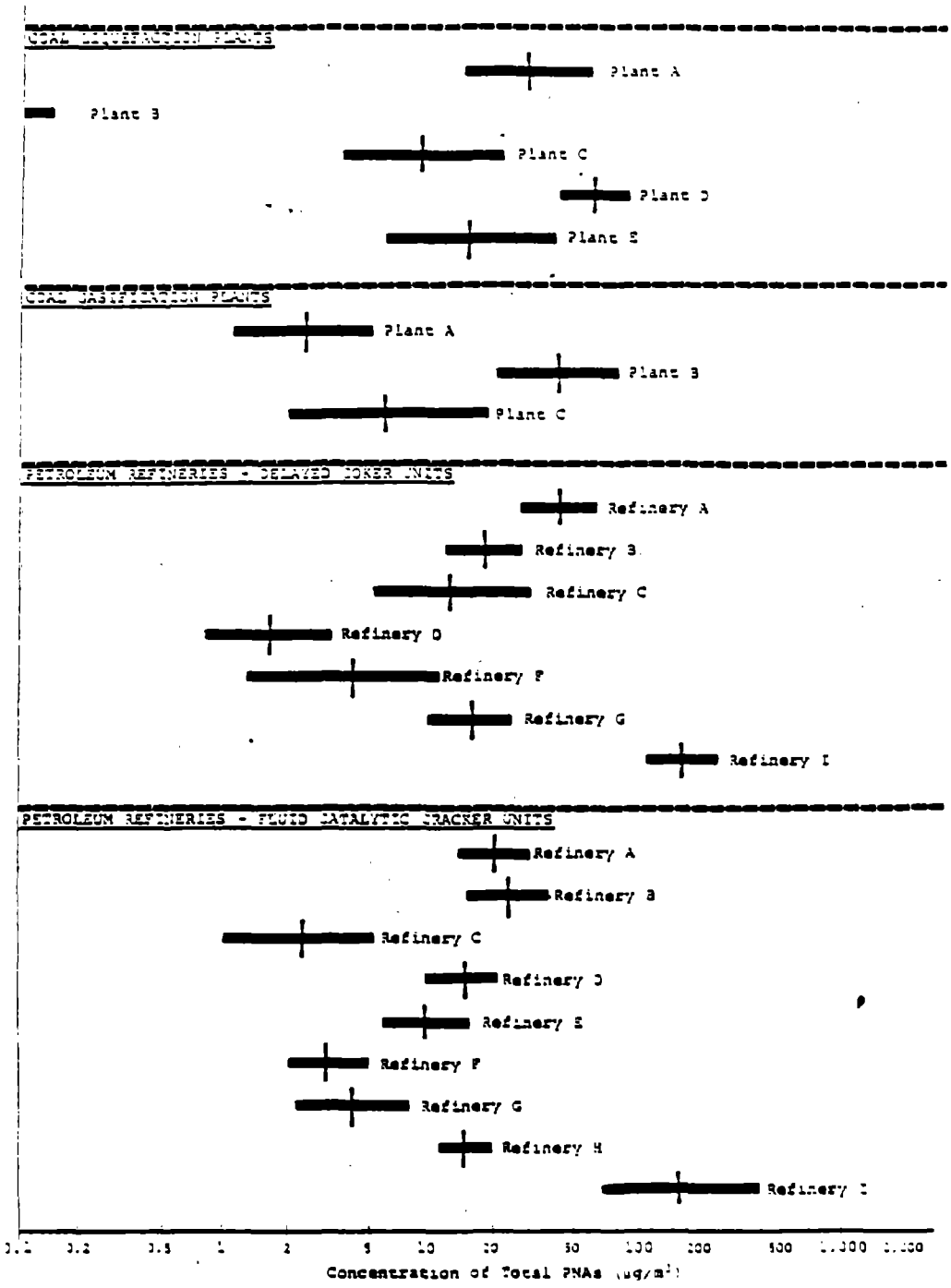

Figure 5-15. Geometric Mean PNA Concentrations with 95% Confidence Limits for Personal Samples Collected at Coal Liquefaction and Coal Gasification Plants, and Petroleum Refineries

methyl derivatives. However, the liquefaction plants tended to have greater concentrations of the 3- and 4-ring PNA species.

AROMATIC AMINES

In the 90 area samples and 94 personal samples collected for analysis of aromatic amines in the five coal liquefaction plants only 12 (13% of the samples) had detectable quantities. Tables 4-4 and 4-5 show that the highest concentrations measured were all below 1 mg/m^3 for the seven aromatic amines. The results conclusively demonstrate that employee exposure to simple aromatic amines was not a common occurrence in the five plants and that concentrations measured were all well below current health standards. These data cannot be used as evidence that polynuclear aromatic amines (PAAs) are not present in the plant environments, however.

The PAAs, as discussed in Chapter 3 of this document, have been shown to be associated with the mutagenic and carcinogenic activity of high boiling point fractions of coal-derived liquids. A suitable method for sampling PAAs has not been developed and the methods used in this study (P&CAM 168 and 264) for the simple aromatic amines are not applicable to PAAs.

OTHER ORGANICS

Over 200 area and personal samples were collected and analyzed for benzene, toluene, xylene, phenols, cresols, and xylenols. None of the samples had concentrations exceeding 1 ppm for any of the analytes measured (Table 4-6 and 4-7). Benzene was found in 35 of 208, toluene in 35, xylene in 25, and phenols in only 1 of the 298 samples collected. Cresols and xylenols were not detected in any of the personal or area samples.

The results are a strong indication that exposure to these chemicals does not present a health hazard to maintenance or operator personnel performing routine duties during normal plant operations.

MEDICAL AND INDUSTRIAL HYGIENE PROGRAMS

The Industrial Hygiene and Occupational Medicine Programs of the coal liquefaction pilot plants in this study have been developed to minimize the risks of fire, accidents, explosions, and exposure to toxic chemicals. Programs designed to minimize the first three hazards are modeled after industrial programs in related industries, and they comply with industrial standards and mandatory requirements. Unique programs to minimize exposure to toxic chemicals in the coal liquefaction environment are being developed, and they are the subject of this discussion.

The personal hygiene measures discussed in Chapter 4 provide some degree of protection from pollutants; however, the following deficiencies have been identified:

- failure to identify optimal materials for protective clothing manufacture,
- lack of guidelines for discarding nonlauderable, contaminated clothing including shoes, boots, gloves, slickers, etc.,
- lack of provision for clothing change before meals, and
- lack of a program for routinely determining the effectiveness of the personal hygiene program by checking for residual contamination of personnel after showers, and of clothing after laundering, drycleaning, etc.

Educational programs generally depend upon initial and continuing verbal instruction from plant supervisors supplemented by written and audiovisual aids; this format provides information and instruction to regular plant employees. However, an active program to include all plant maintenance workers employed by outside contractors needs to be developed in the plants. Only in this way will this high-exposure group of workers be kept continuously aware of the potential hazards and special work practices necessary in coal liquefaction plants.

Most occupational health programs provided by the plants include a pre-employment physical, annual checkups, and a termination physical. Together with a blood count and urinalysis, this constitutes a minimal program for

the detection of health changes in essentially normal workers. Because many industrial exposures, including those in coal conversion plants, are to multiple chemicals whose toxic effects cannot always be predicted, a more complete screening program should include more specific heart and lung tests (EKG, and FVC and FEV_1 pulmonary function tests), as well as a standardized battery of serum chemistry tests which can detect a broad spectrum of organ dysfunctions, often before other signs and symptoms of disease become apparent.

For the coal conversion industry, this "routine" screening program may not be adequate to protect the health of the worker. Preliminary epidemiologic and toxicologic testing data have indicated an increased risk of cancer from chronic exposure to some coal-derived materials. Furthermore, these studies have pinpointed the skin, lungs, and urinary tract as organs at special risk from such exposure. For this reason, more extensive examination of these target organs has been recommended and is being practiced in some coal liquefaction plants.

Urinary cytology is the most widely used and accepted screening test for cancer of the bladder. Because early detection of this lesion significantly enhances survival, the routine use of this examination as a screening tool in high-risk workers would seem obvious. However, from its institution in 1956 by Crabbe as a systematic screening tool among dyestuff workers in Great Britain to the present, controversy has waxed and waned concerning its record of positive correlation with proven bladder cancer. Difficulties associated with the preparation of cells suspended in urine, as well as in the interpretation of results have resulted in widely varying reports on its efficacy in detecting bladder cancer.

A recent study at the Mayo Clinic, reporting on 8,140 patients undergoing this procedure, cites a sensitivity of the procedure for bladder cancer of 66.6 percent with 5 percent false positives (Rife et al., 1979). A range of 26 to 100 percent positive correlation is reported from different laboratories by Betkerur et al. (1980).

The current standard of practice in most laboratories is to have all, or almost all, sputum and urine material reviewed and interpreted by a pathologist (Ng, 1980). The most important factor determining the quality of the results is the pathologist's expertise, motivation, and interest. It must be recognized, however, that in a mass screening program economic considerations dictate that this material be screened by less highly trained professionals (cytotechnologists) with only positive results being reviewed by the pathologist. Whether acceptable correlations of these results with proven cancer can be obtained is unclear.

The cytological diagnosis of cancer of the lung from sputum is a diagnostic test with a correct detection of about 68 percent (Springs, 1977). Its use as a complement to chest X-ray in the detection of lung cancer would seem desirable because those tumors most likely to shed cells into the sputum are often the most difficult to detect radiologically. However, while preliminary findings from early lung cancer detection programs supported by the NCI have tended to show that combined screening for lung cancer by annual sputum cytology and chest X-ray is more effective than chest X-ray alone (Melamed et al., 1977), they have not shown that this screening program significantly influences lung cancer mortality (Fontana et al., 1975). The rationale for the routine use of this test in high-risk, asymptomatic workers would then depend upon the identification of premalignant cells in sputum. Saccomanno et al. (1965) described such a finding in 24 uranium miners who subsequently developed lung cancer. Confirmation of these findings and the possible institution of examinations aimed at detecting these early cell changes represent an important avenue for research.

Two of the coal liquefaction plants have ongoing epidemiology programs; however, pilot plants by definition are small. If they are to supply the health information demanded from them that will stand up to statistical analysis and extrapolation to commercial facilities, pooling of information from similar plants, both now and in the future, is necessary. Therefore, a standardized and central reporting system with uniform data bases is essential.

6. CONCLUSIONS

Coal liquefaction plants were shown to be sources of worker exposure to PNAs. The levels measured at Plant D may be the most predictive of exposures in commercial plants because Plant D was the only plant to run continuously at normal operating conditions during the surveys. The major PNAs present in all plants were naphthalene and its methyl derivatives. Air sampling data showed very low levels of 4- and 5-ring PNAs present as particulate or vapor, hence inhalation exposure to PNAs known to be carcinogens may not present a significant hazard in the plants.

Plant size, design, unit process, and operating conditions could not be directly related to the concentrations of PNAs found in area and personal samples.

Employee activities were directly related to PNA exposure levels. Maintenance activities involving breaking into process equipment or handling contaminated equipment resulted in higher exposures to airborne PNA concentations. Routine plant operator activities did not result in PNA exposures comparable to maintenance operations. Mean operator levels of exposure were generally lower than the mean of area samples. This finding was related to the fact that operators spend considerable amounts of time in control rooms where PNA levels are generally lower than in process areas.

Dermal contact with process liquids is a significant source of chronic PNA exposure in these plants. This exposure is not easily quantifiable but may represent a significant hazard in light of the available health information concerning adverse effects of coal tar derivatives.

Aggressive equipment cleaning and decontamination programs combined with appropriate personal protective equipment and personal hygiene programs are

necessary to reduce the dermal exposure risk. Since there is no standard method for assessing this risk, the effectiveness of programs is difficult to estimate. Visual inspection of equipment or clothing surfaces is not a reliable indicator of PNA contamination.

Employee exposure to other organic chemicals resulting from plant emissions of benzene, toluene, xylene, phenols, cresols, and the nine aromatic amines included in the study does not constitute a significant health hazard in the five coal liquefaction plants studied. Samples collected for these groups of chemicals rarely showed measureable concentrations. This negative finding is particularly important in the case of phenol -- a known promoter of the carcinogenic effects of many chemicals including PNAs.

The medical surveillance programs established by the plants reflect their awareness of the occupational hazards associated with the facilities. Although no standard medical surveillance or battery of tests has been widely accepted for these types of facilities, each of the plants has based its program on those recommended by NIOSH and its corporate medical offices.

7. RECOMMENDATIONS

Dynamac's recommendations are:

- Additional toxicology studies should be conducted to assess the occupational health hazard of long-term inhalation exposure to low levels of 2-, 3-, and 4-ring PNAs.

- Standardized sampling methods should be developed for assessing the dermal exposure factor to PNAs in residues on equipment surfaces.

- Methods should be developed for cleaning or decontaminating equipment and protective clothing of coal tar residues.

- Additional studies should be conducted on the permeability and protection factor for PNAs afforded by various materials used in protective clothing, particularly gloves.

- A PNA indexing system for selection of "proxy" PNAs for assessment of total PNA exposures needs to be developed. This method should be able to utilize analytical instrumentation other than mass spectrometry because of its high cost and inherent variability.

- The feasibility of organic vapor sampling badges for light weight (2-, 3-ring) PNAs should be investigated.

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APPENDIX A

PROCESS/FACILITY DESCRIPTIONS OF COAL LIQUEFACTION PILOT PLANTS

PLANT A

PROCESS DESCRIPTION

The Plant B process , as used at the Fort Lewis facility, has two variations. In the first variation, (I), the product is a solid material with an approximate melting point of 177-205°C (350-400°F). In the second variation, (II), the product is a liquid approximately of crude oil consistency. A schematic showing the (II) process mode is presented in Figure A-1.

In the (I) mode, coal is ground to 100 percent minus 20 mesh, and 70 percent minus 200 mesh; then the pulverized coal is mixed with recycled coal-derived solvent. The coal slurry is fed through the Wilson-Snyder reciprocating pump to be pressurized to approximately 1,500-2,000 psig. Carbon dioxide is available for use in the coal storage bin to prevent conditions which could lead to a fire. High-pressure hydrogen gas is added to the slurry. The three-phase stream is pumped through the preheater and heated to approximately 400-425°C (750-800°F); then it flows from the preheater to the dissolver -- an upright cylinder with liquid feed in the bottom and total stream takeoff at the top.

The gas, solvent, dissolved coal, and undissolved residue pass from the dissolver through a series of pressure letdown drums which separate the gas and the slurry. The slurry temperature is dropped to about 288°C (550°F), and the pressure is dropped to approximately 500 psig. The high-pressure gas recovered from the letdown drums is passed to the high-pressure gas purification system (diethanolamine unit). The purified gas is scrubbed to remove light hydrocarbons, is recompressed, has fresh hydrogen added, and is returned to the preheater inlet. The sour gas, primarily carbon dioxide and hydrogen sulfide, is sent to the Stretford unit.

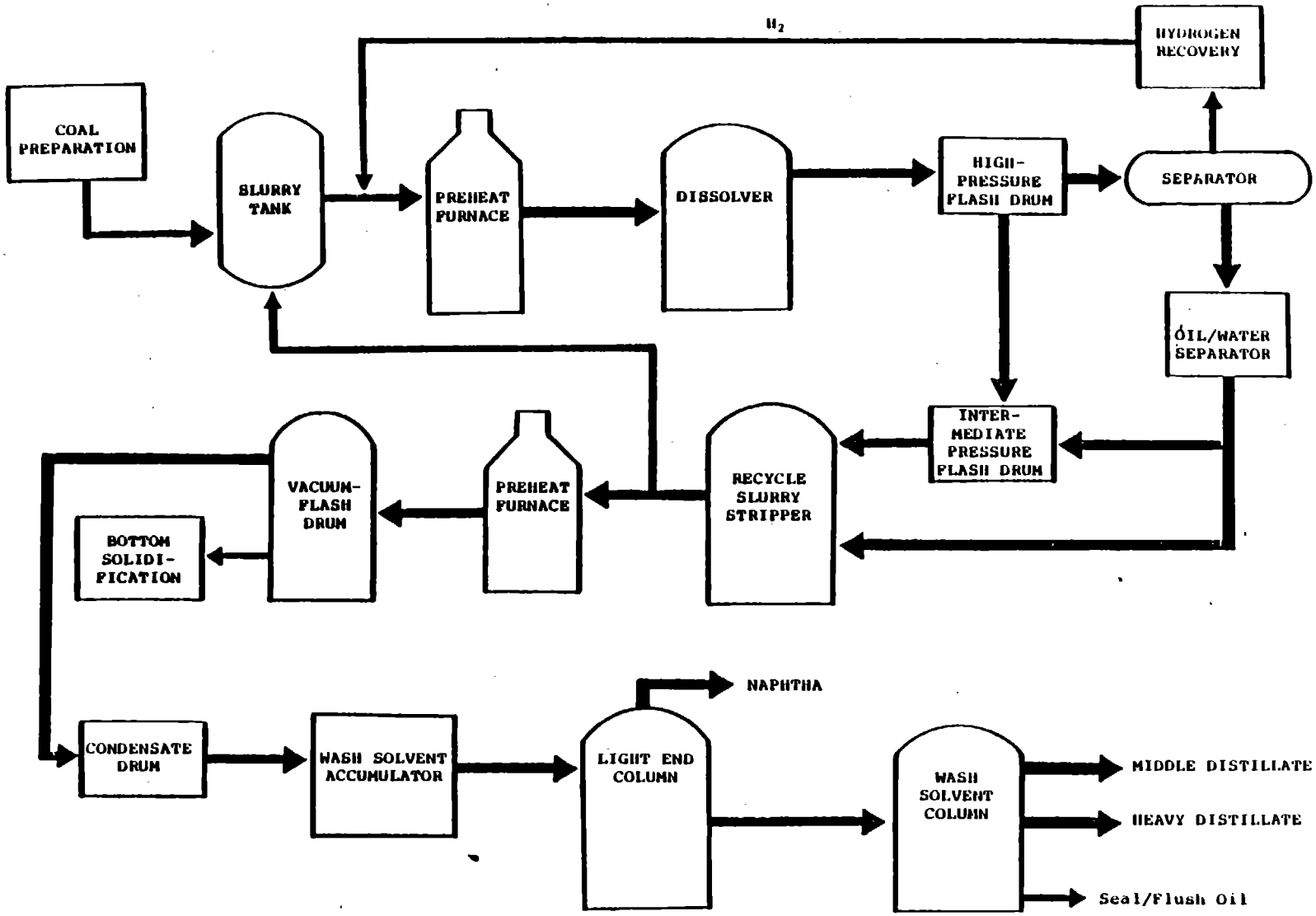


Figure A-1. Plant A Process Schematic SRC-II Mode

the liquid -- including the solvent-dissolved coal, undissolved solids, and dissolved gases -- is sent to the low-pressure flash vessel where the dissolved gases are released. The liquid is then filtered. The filter cake -- containing coal mineral matter, undissolved coal, and filter precoat -- is sent to a rotary-drum kiln where solvent from the filer cake is recovered. The solid residue is transported to a bin from which it is removed from the plant by truck.

The filtrate is pumped to a vacuum-flash preheater, heated to approximately 316°C (600°F), and then flashed from 130 psig to approximately minus 11 psig. The vacuum-flashed liquid for solvent refined coal contains approximately 10 to 20 percent solvent. This product is pumped onto a Sandvik belt (a continuous, water-cooled, stainless steel belt), solidified, and then delivered either to a waiting truck or to a storage pad.

The vacuum-flashed vapor is sent first to a distillation column for removal of light ends. The heavier liquid is then sent to a second column for recovery of the wash solvent and process solvent. The wash solvent is returned to the filter section; the process solvent is recycled back to the slurry mix tanks. Excess solvent or wash liquid generated during the processing of the coal is stored to the west of the plant in storge tanks.

The (II) process is a slight modification of the (I) process. In the (II) process, a portion of the whole product from the dissolvers is cooled to approximately 232°C (450°F) and recycled back to the slurry mix tanks. This material -- which contains solvent, dissolved coal, undissolved coal, and undissolved mineral matter -- is then used as the solvent to slurry the coal. The slurry is sent through the preheater and back to the dissolvers.

(II) has a longer residence time at reactor conditions than does (I), which results in further conversion. Also, during the first pass through the dissolver, the pyrite (FeS_2) undergoes reaction with the hydrogen in the dissolver to form ($FeS + H_2O$). FeS_2 is known to have catalytic properties and apparently helps to catalyze the hydrogenation reaction.

Dissolver liquid product is not filtered (although the mineral separation tankage, 03 Area, is used to increase dissolver product surge capacity); instead, the dissolver product is vacuum-flashed and the ash-containing liquid is the residue. This residue is cooled on the Sandvik belt as described above. (II) product is recovered in the same manner as the (I) process solvent.

FACILITY DESCRIPTION

The Fort Lewis Pilot Plant is laid out as a rectangle with a panhandle (Figure A-2). A railroad track is located along most of the southern boundary of the plant. The railroad is used both to bring in coal and remove the solvent refined coal product.

The coal preparation section (01 Area) is located at the southeastern corner of the plant rectangle. This totally enclosed unit is located about 30 meters from all other portions of the plant. The maintenance building is located directly north and slightly to the east of the coal preparation section; and the preheating and dissolution section (02 Area) is located to the north and to the west of the coal preparation unit. The coal pile is located to the west of the coal preparation area, within approximately 10 meters of it, and to the south of the control building. The high-pressure preheating and dissolution sections are separated from the remaining portions of the plant, and most of the high-pressure work area is located in this one section.

Directly west of and 10 to 15 meters away from the high-pressure area is the mineral separation building (03 Area). The top floor of this building is totally enclosed and includes filtration equipment; tanks and piping are on the second floor; and tanks and pumps are on the bottom floor. The 03 Area also includes all the equipment used to recover solvent from the filter cake. The main kiln is located on the second floor of the building.

Directly west of the adjacent to the mineral separation building is the open framework for solvent recovery (04 Area). The solvent recovery area has

Area No.	Description
01	Coal preparation area
02	Preheater and dissolver area
03	Mineral separation area
04	Solvent recovery area
05	Gas recovery and recompression area
06	Partially paved storage area
07	Paved storage area
08.1	Product solidification area
08.2	Solid product storage bin
09.1	Process wastewater disposal system
09.2	Tank farm
09.3	Cooling water
09.4	Boilers
09.5	Hydrogen/synthesis gas and inert gas generation and desulfurization units
09.6	Control building
09.7	Shop and warehouse building
09.8	Dowtherm system
09.9	Dry chemical storage building
10.0	Deashing unit

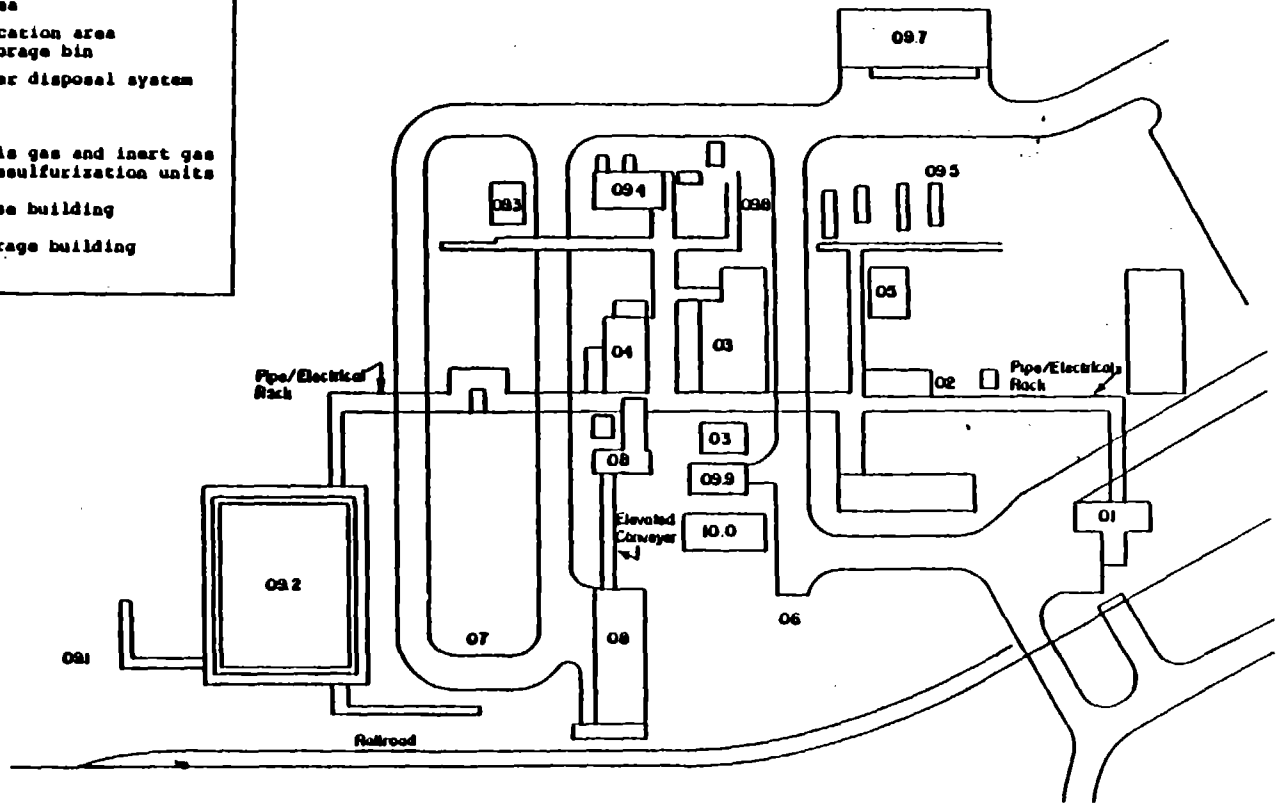


Figure A-2. Plant A Plant Layout

eight floors of equipment including the distillation towers, the vacuum-flash preheater, and the section surge tanks.

All rotating equipment is located on the ground floor of the solvent recovery structure. The Sandvik belt, which is used for final cooling of the product, and the conveyor that unloads the product either onto trucks or onto the product pile are also located on the ground floor. The product pile is located to the west and slightly south of the product solidification section.

The utilities -- including cooling tower, boiler, Stretford unit, and natural-gas reformer for the production of hydrogen -- are located north of the 03, 04, and 08 Areas and adjacent to them.

The tank farm -- consisting of variously-sized tanks and the liquid nitrogen tank -- is located to the west of the 08 Area and some 30 meters from it. This area is semi-isolated from the rest of the plant and is diked to prevent spillage of product liquid into the adjacent areas.

The water treatment plant is located to the west of the tank farm, and somewhat downhill from it in the panhandle. The accumulation pond contains water at a temperature above 38°C (100°F); the odor from this pond is quite strong. Water from the pond goes through a biotreatment unit (Trickle-filter type) which gives a product that can be returned to the local streams. After biotreatment, the water can be passed through a sand filter and through activated-carbon filters; the water product coming from the biotreatment unit has no odor.

PLANT B

PROCESS DESCRIPTION

The Plant B Test Facility used a commercial process to produce low-sulfur liquids of different boiling ranges. A simplified process schematic is presented in Figure A-3. The operating parameters of the process are shown below:

Coal Feed: 20 tons/day
Extractor Temperature: 385 to 450°C (725 to 850°F)
Extractor Pressure: 450 psig
Hydrogenation pressure: 3,000 to 3,500 psig
Extractor Residence Time: 30 minutes

Coal is trucked to the plant and deposited in either of two 10-ton bins located below ground level. The coal is transferred from the unloading bins to a bucket elevator which dumps the coal into a hammer mill for coarse grinding.

Ground coal is conveyed with flue gas to a spinner separator and cyclone where drying occurs. Coal from the cyclone is sized and delivered to a 70-ton storage bin. The storage bin and conveyance systems are purged with nitrogen to eliminate the danger of fire or explosion.

Coal is dropped from the storage bin through a rotary valve into a slurry mix tank, where it is blended with recycle solvent and fresh hydrogenated solvent. In the tank, the slurry is mixed with an agitator, and blended from bottom to top with a centrifugal recycle pump; residence time in the slurry mix tank is 30 minutes. The mixed slurry usually consists of from

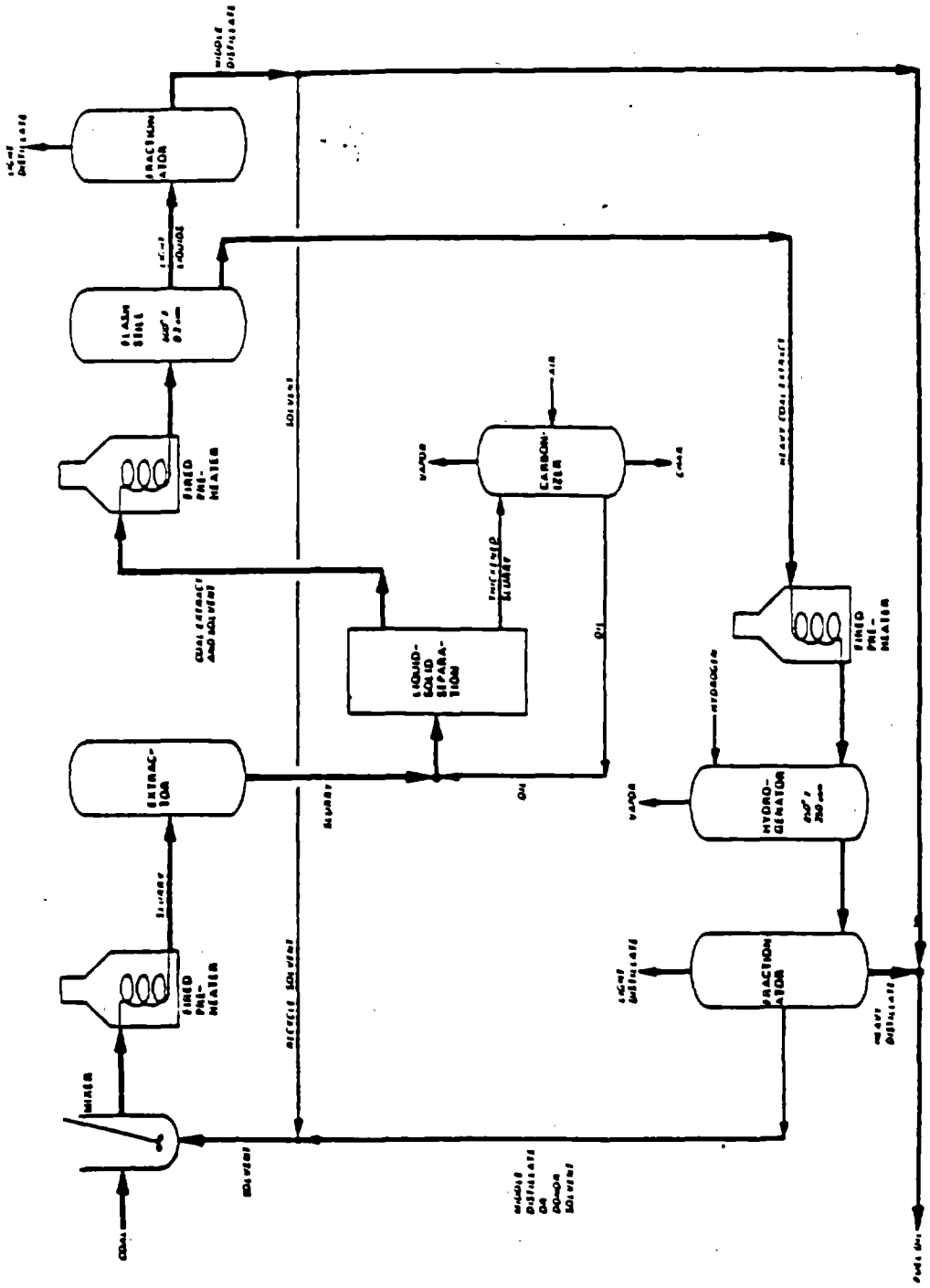


Figure A-3. Plant B Process Schematic

15 to 25 percent coal. Once it is mixed, the slurry is fed to the continuous withdrawal system feed tank.

The slurry is continuously pumped to a preheater which heats the slurry to about 425°C (800°F). From the preheater, the slurry passes to the top of the extractor (dissolver) and flows downward to the bottom of the vessel. The residence time in the vessel is normally sufficient to complete all dissolution that will take place at the particular conditions of operation and thus stabilize the slurry. Downstream from the extractor, the slurry flows through a knockout pot for removal of agglomerated solids. After the knockout pot removes the solids, the slurry is passed through a flow control/pressure reduction valve, where pressure is reduced to approximately 150 psig. This pressure reduction permits some of the dissolved gas to flash at the valve and may also cause some solvent flashing.

Hydrocarbon vapors and noncondensable gases are formed as a result of thermal cracking and hydrogenation of the dissolved coal/solvent mixture in the extractor. This gas-vapor mixture includes methane, the higher hydrocarbons, hydrogen sulfide, carbon monoxide, and carbon dioxide, and amounts of about 3 weight percent of the coal fed to the extractor on a moisture-/ash-free basis. It also includes 2 to 5 percent water.

These gases, water vapor, and light hydrocarbon solvent vapors are exhausted from the top of the reactor and cooled. The gases go to the Stretford unit, and the condensed light oil and water form an emulsion which is sent to the carbonization section.

The slurry from the extraction section flows to the feed surge tank in the solids separation section, where dissolved gas is separated from the slurry. Slurry from the feed surge tank is fed to the 4,200-gallon settling tank. The solids agglomerate as they settle, thus speeding the settling action. Clear product -- a mix of about 20 percent liquefied coal and 80 percent solvent, containing less than 1 percent solids -- is decanted from the overflow weir at the top of the vessel. This clear product flows

to the solvent recovery product feed tank. The underflow material -- containing approximately 25 percent solids -- is fed to the low-temperature carbonization section.

The liquefied coal/solvent product is pumped to the extract solvent recovery section, where the material is first preheated to 325°C (600°F) at 80 psig and then flashed across a pressure control valve into a flash still at minus 5 inches of water pressure (14.5 psig). A part of the unflashed liquid, now rich in dissolved coal, is recycled back to the flash still heater; and the remainder is pumped to the catalytic hydrogenation section.

Flashed vapor is fed to a fractionator column where a light and middle distillate are separated. Light distillate removed from the fractionator top is sent to tankage. Middle distillate may be recycled to the slurry mixing operation or sent to tankage and ultimately blended into a fuel oil product.

Unflashed vapor from the flash still is pumped through a preheater to a catalytic hydrogenation system. The system employs two reactors: the first is a noncatalytic preconditioner; and the second is an ebullated-bed, cobalt-molybdenum catalytic reactor. Hydrogen is added at the first reactor, and some hydrogenation occurs. Light ends are removed from this reactor, and the remaining liquid continues on to the catalytic reactor. More light ends are taken from the second reactor, combined with the first, and treated for separation of gases and condensable hydrocarbons. Gases are subsequently treated to remove hydrogen sulfide.

The primary liquid stream from the reactors is sent for final fractionation into light-, middle-, and heavy-distillate cuts. Fractionation uses two columns: the first column serves to stabilize the reaction product; and the second column separates the three distillate cuts. The light distillate is stored in tankage. The remaining cuts may provide a portion of the recycle solvent for slurry mixing, including donor solvent component. A portion of these cuts also comprises the main fuel oil product of the process.

The low-temperature carbonization section is designed to recover solvent from the mineral residue which was separated from the extract product in the solids separation section. This residue -- containing solvent, coal extract, and very fine coal particles -- is sprayed into the fluid bed of char. The heat of the bed causes the solvent to flash off. The extract and minus 325 mesh particles coat the particles in the fluid bed. The large surface area of the bed particles means that each particle receives only a thin coating of extract which rapidly pyrolyzes, leaving behind char particles.

Flashed product gas and vapors pass through two internal cyclones and are immediately quenched with condensate oil. The gas is cooled further and then separated from condensed light oil and water. The water is pumped to process water cleanup, and the light oil is returned to the settler in the solids separation section. A portion of the off-gas -- which contains carbon monoxide, carbon dioxide, nitrogen, and some hydrogen sulfide and sulfur dioxide -- is purged to the Stretford unit. Char is removed from the process and disposed of.

FACILITY DESCRIPTION

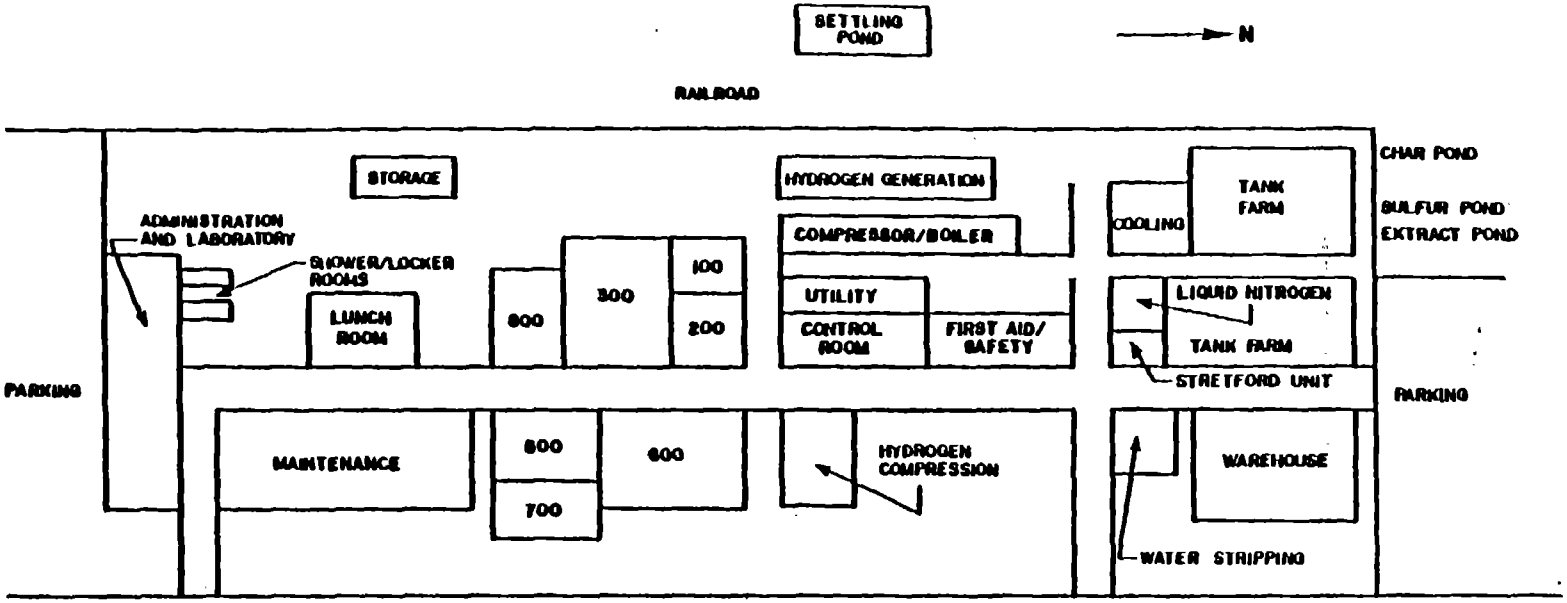
The Plant B Test Facility is located in Cresap, West Virginia, approximately 20 miles south of Wheeling, West Virginia, and next to the Ohio River. The plant has a north-south, east-west orientation, with the Administration Building at the south end of the plant and the holding ponds for char, solvent refined coal, and sulfur at the north end. The plant itself is divided roughly in half by a service road.

The primary or main control room is located to the north of the operations area, and adjacent to the utilities and electrical control room. Coal storage, coal preparation, solids separation, and solvent recovery areas are located in the western half of the plant, to the south of the control building. Solvent distillation, extract hydrogenation, and hydrogenated product distillation are located in the eastern half of the plant, to the south of the control room. Hydrogen recycle and hydrogen compression are located on the east side of the plant, directly opposite the control room. Methane reformation to produce hydrogen, the utilities, cooling tower, and boiler

areas are located on the west side of the plant, in back of the control room. The sour-water tank and water purification sections are north of the control room and to the east; the Stretford unit is located on the west side of the plant, and to the north of the control room.

Figure A-4 show the plant layout of the Cresap Test Facility, including locations of the unit operations. Unit operations at the Cresap pilot plant are segregated into two groups which are separated by the service road, which is about 20 feet wide. The two sections are housed in open, multi-level structures. The two sections are each approximately 150' x 120' in area with vessels and superstructure about 60' high. Most process equipment is unenclosed; an exception is the third level of the 300' area which is enclosed and contains the filtration system (the filtration units were not in use at the time of the comprehensive survey).

The ground level of all units is constructed of concrete which simplifies cleanup of spills; in addition, all flooring is diked to contain solvent spills. Most of the pumps are located on the ground level which simplifies monitoring and maintenance of the pumps.



Area	Description	Area	Description
100	Coal preparation	700	Fractionation
200	Solvent extraction	800	Carbonization
300	Solids separation	900	Support/Utilities
500	Solvent recovery	1100	Tank farm
600	Hydrogenation	1200	Environmental units

Figure A-4. Plant B Plant Layout

PLANT C

The Wilsonville Pilot Plant uses the (I) process to produce a low-sulfur, low-ash solid fuel. A schematic of the (I) process is presented in Figure A-5.

Coal, which has been pulverized offsite so that 95 percent is smaller than 200 mesh (74 x 74 microns), is mixed in a slurry blend tank with process-generated solvent which has a boiling range of 232-427°C (450-800°F). Hydrogen-rich feed gas is added to the coal slurry upstream of the slurry preheater. The feed gas stream is composed of scrubbed recycle gas plus fresh makeup hydrogen sufficient to bring the overall gas composition to 85 percent hydrogen by volume.

The coal slurry and gas mixture leaving the slurry preheater flows upward through the dissolver. The dissolver is 23 feet in height and 1 foot in diameter. The dissolver operates at 427-454°C (800-850°F) and at 1,400 to 2,100 psig. Depending upon the dissolver outlet being used, the residence time in the dissolver can vary from 10 to 60 minutes. The product from the dissolver is cooled by the dissolver product cooler to 260-343°C (500-650°F).

The vapor and slurry phases are separated in the high-pressure separator. Vapor from the separator is cooled to about 56°C (150°F) by the high-pressure cooler and passed to the high-pressure vent separator. The water and organic compounds condensed in the dissolver product cooler are fed through the letdown valves to the flash tank, the flash condensor, and into the solvent decanter. Gases from the high-pressure vent separator include unreacted hydrocarbons, light hydrocarbons, hydrogen sulfide, and carbon oxides.

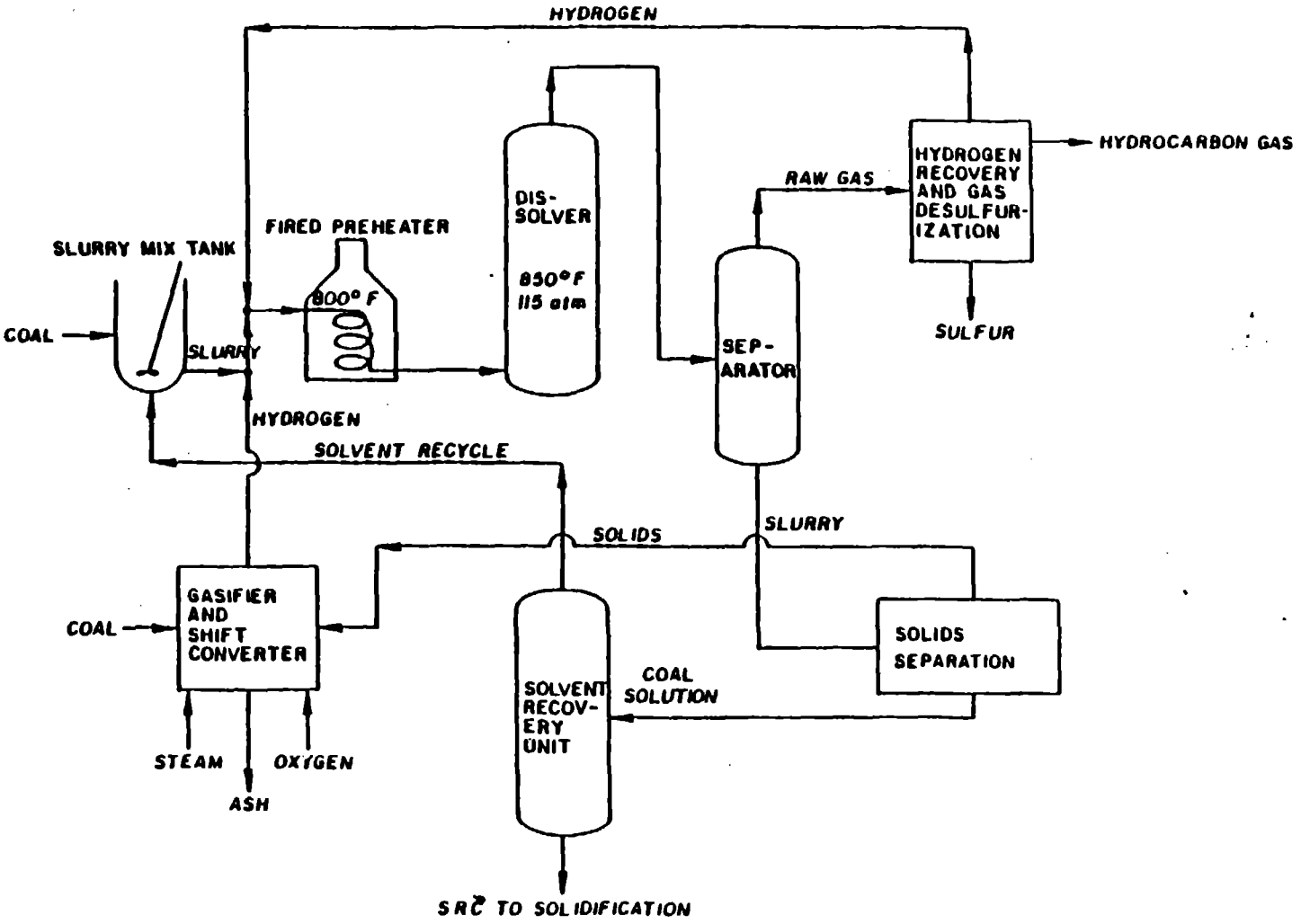


Figure A-5. Plant C Process Schematic

The slurry which is flashed through the high-pressure valves flows to the reclaim tank which serves as a feed reservoir for the batch filtration system. The flashed vapor is condensed and separated. The slurry from the reclaim tank is pumped to a pressure-leaf filter where the undissolved solids are removed.

Filtered product solution is pumped though the vacuum column preheater to the vacuum column. Recirculated liquid product is mixed with material from the vacuum preheater surge drum. The vacuum column overhead pressure is main- tained at 28 to 30 inches of vacuum. The material in the column is sep- arated into liquid product and vapors in the overhead. The condensed organic vapors are pumped to the feed tank and then to the light solvent recovery column.

Liquid product from the vacuum column is fed to the product cooler, which is a water-cooled vibrating conveyor. The product solidifies into brittle 1/8- to 1/4-inch-thick sheets which shatter into small fragments upon vibration; the fragmented product is drummed for storage. A portion of the liquid product is fractionated and used as recycle solvent.

Vapor from the high-pressure vent separator contains hydrogen, hydrocarbon gases, hydrogen sulfide, and carbon dioxide. At Wilsonville, the hydrogen sulfide and carbon dioxide are removed in the hydrogen scrubber by a dilute solution of caustic soda. To provide a feed gas containing 85 percent hydrogen, scrubbed recycle gas is blended with pure hydrogen. Pure hydrogen from storage is compressed by the fresh hydrogen compressor, and flows to the hydrogen recycle compressor which boosts the feed gas stream to the inlet pressure of the slurry preheater.

FACILITY DESCRIPTION

A numerical identification system is used at the Wilsonville facility to identify the individual equipment. This designation system is given in Table A-1 and is used in Figure A-6 and A-7, the plant layout and the layout of the main process areas, respectively.

Table A-1. Numerical Identification System for Process Equipment: Plant C

I.D. # System	Process Equipment
P102 A/B	Slurry Blend Tank Pumps
P103 A/B	Slurry Preheater Feed Pumps
P106	Caustic Scrubber Pump
P108 A/B	Water Circulating Pump Scrubbers
P110 A/B	Reclaim Tank Pumps
P111 A/B	Filter Feed Pumps
P116 A/B	Preheater Surge Drum Pumps
P119 A/B	Liquid Coal Pumps
P125 A/B	Filter Scrubber Pumps
P139 A/B	Reflux Pumps
P142 A/B/C	Preheat Tank Pumps
P143	Wash Tank Circulating Pump
P169 A/B	Wash Solvent Pumps
P178	Sluice Pump
P203	Flush Solvent Pump
P205 A/B	Dowtherm Circulating Pumps
P206	Dowtherm Surge Pump
B102	Slurry Preheater
B103	Distillation Column Preheater
B203	Dowtherm Heater
C102	Hydrogen Recycle Compressor
C104	Fresh Hydrogen Compressor
E102	Dissolver Product Cooler
E103	High-Pressure Cooler
E107	Flash Condenser
E122	Solvent Draw Cooler
F103	Pressure Leaf Filter
K111	Vacuum Jet
K125	Product Cooler

I.D. # System	Process Equipment
R101	Dissolver
T101	Hydrogen Caustic Scrubber
T102	Vacuum Column
T104	Light Solvent Recovery Column
T105	Fractionating Column
V101 A/B	Slurry Blend Tanks
V103	High-Pressure Separator
V104	High-Pressure Vent Separator
V105	Solvent Decanter
V106	Recycle Hydrogen Water Scrubber
V110	Flash Tank
V111	Reclaim Tank
V120	Vacuum Preheater Surge Drum
V123	Process Solvent Storage Tank
V124 A	Light Oil Product Tank
V124 B	Wash Solvent Storage Tank
V129	Caustic Tank
V131	Recovered Solvent Tank
V140	Precoat Makeup Tank
V141	Wash Tank
V144	High-Pressure Blowdown Tank
V147	Precoat Tank
V164	Feed Tank for T104
V170	T104 Overhead Holding Tank
V178	Wash Solvent Storage Tank
V206	Dowtherm

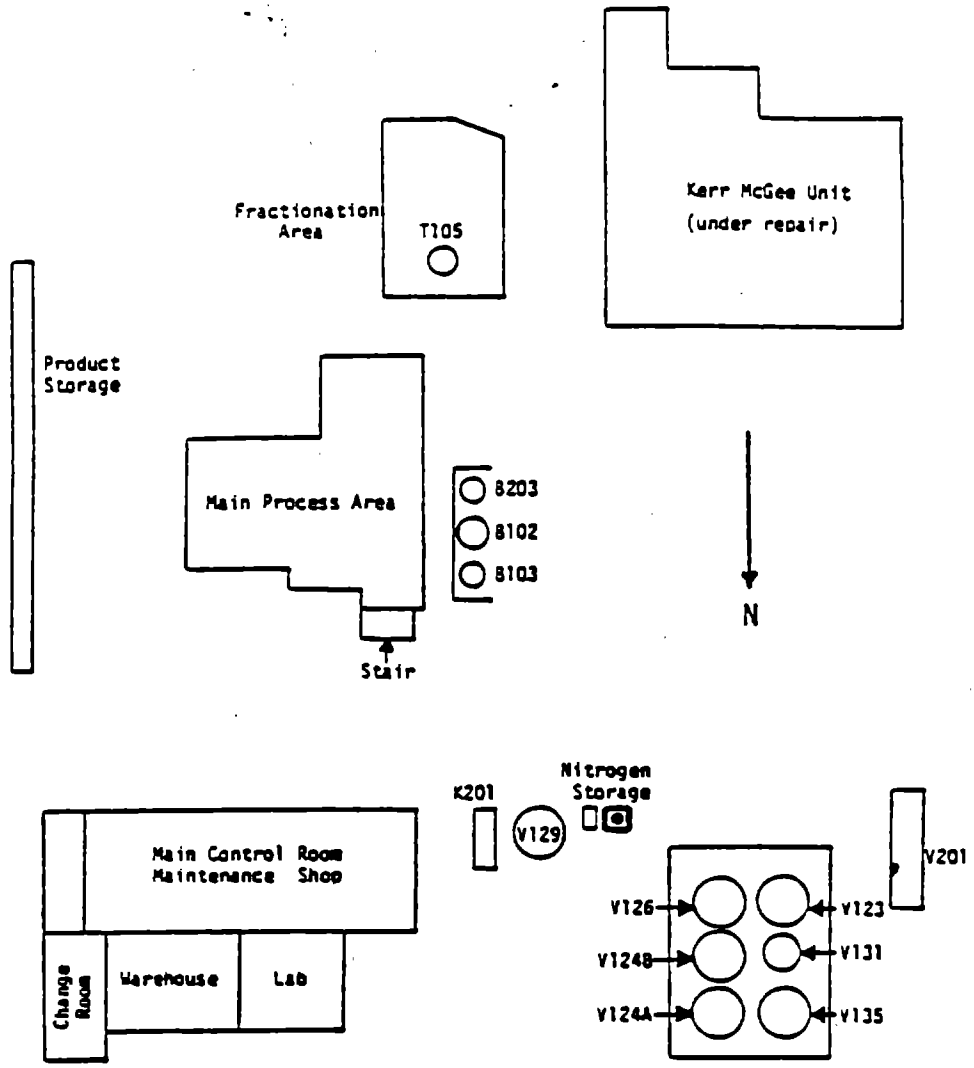


Figure A-6. Plant C Layout

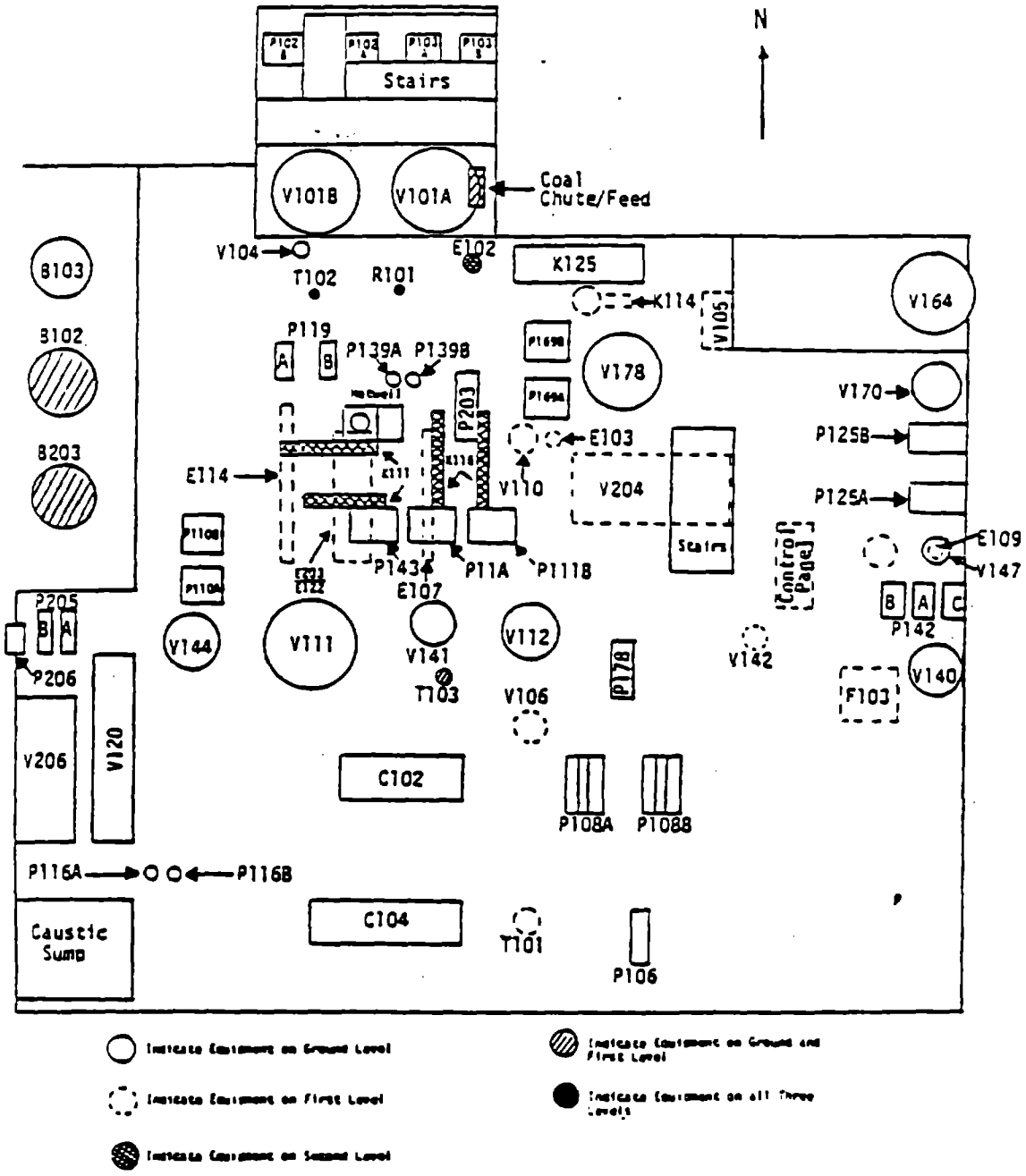


Figure A-7. Plant C Layout of Main Process Area

The Wilsonville process is housed in an open, multilevel structure. The open structure reduces the likelihood of localized accumulation of pro- cess emissions. However, the close proximity of the individual pieces of equipment is expected to enhance the degree of cross-contamination between the equipment, thereby masking the contribution of the individual components of the process to the measured levels.

The grade level floor of the process structure is constructed of concrete which simplifies cleanup procedures. The flooring is diked to contain major spills. Most of the pumps and equipment prone to leakage are located at this level.

PLANT D

PROCESS DESCRIPTION

The Plant D system is a unique noncatalytic coal liquefaction process utilizing prehydrogenated "donor" solvent to facilitate hydrocracking of coal. The system uses crushed bituminous, subbituminous, or lignite coal and reacts it with donor solvent and hydrogen at elevated temperature and pressure. The donor solvent is a recycled distillate of the liquefaction stream and is catalytically hydrogenated in a separate process. Several liquid fractions are produced by the Plant D process, as well as an internally consumed fuel gas.

Pilot Plant D was built to test the major process steps involved in the system. A process schematic of the Plant D facility is presented in Figure A-8. For dicussion purposes, the facility may be divided into the following process areas:

- coal preparation
- slurry drying
- liquefaction
- product recovery
- solvent hydrogenation
- support processes.

Coal Preparation

Raw coal is delivered to Plant D by rail and stored on site in a 5,000-ton-capacity storage silo. Coal from the storage silo is fed to one of two coal preparation systems. The first system is a gas-swept roller mill, in which the coal is crushed to a size of minus 8 mesh or minus 30 mesh and dried to

a moisture content of less than 4 percent. Drying is accomplished by contacting the coal with hot flue gas. Prepared coal from the gas-swept mill is placed in a 290-ton-capacity storage bin before being transported to the slurry drier unit (D-101).

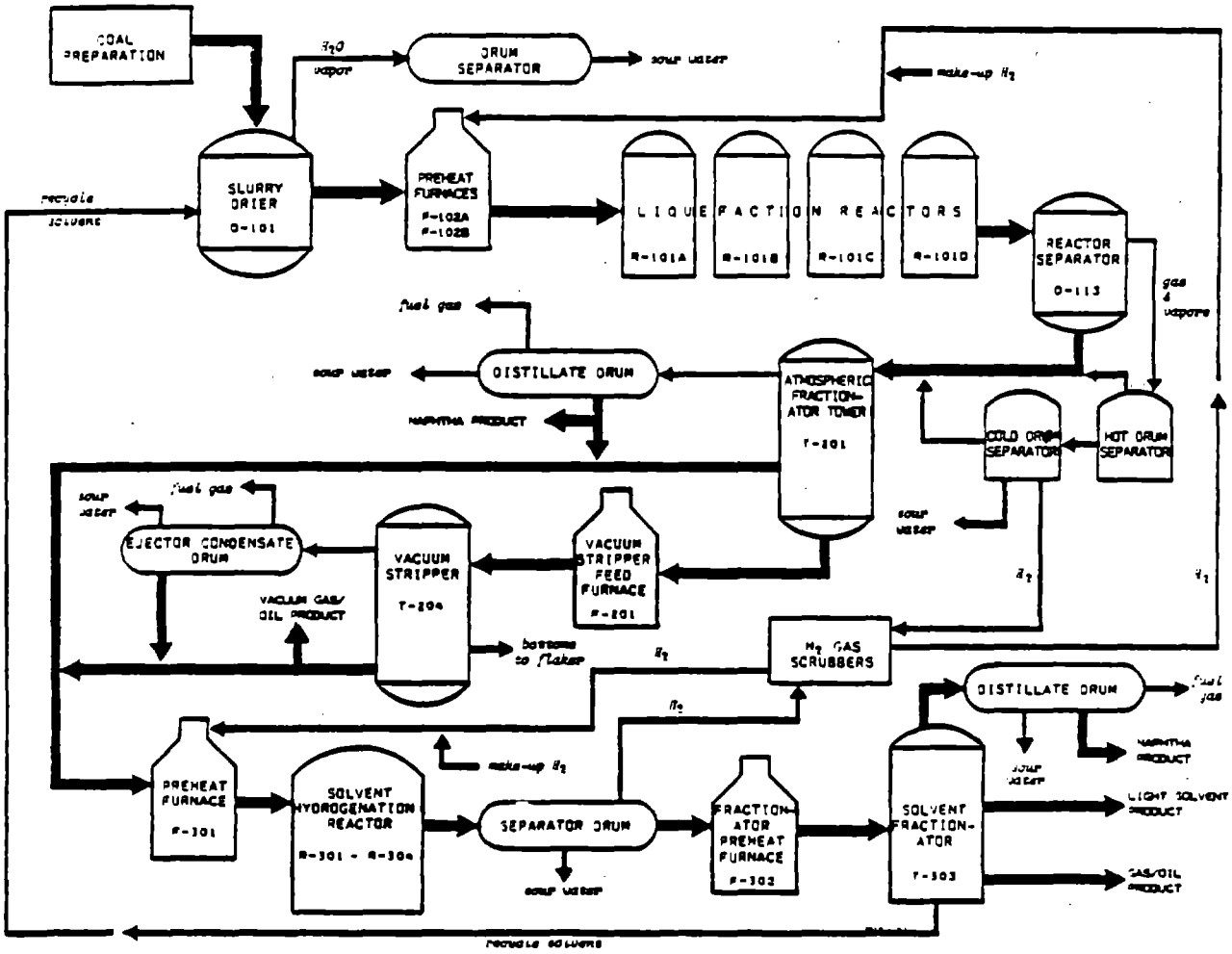


Figure A-8. Plant D Process Schematic

The other coal preparation system is an impact mill which will crush coal only to minus 8 mesh. When the impact mill is used, the received coal moisture (16-30%) is removed by heating the feed coal slurry to about 135°C (275°F) and boiling off the moisture.

Several control mechanisms are in use for dust suppression and explosion-proofing for the coal preparation processes. For dust suppression, control mechanisms include: covers for all conveyors and for railcar unloading; a water spray system for the railcar hopper and coal preparation area; and venturi scrubbers and bag filters for the drying gas streams. Explosion-proofing in the coal storage silo and bins is provided by a constant nitrogen-inerting system.

Slurry Mixing and Drying

The slurry drying tank (D-101) is located on the coal preparation block where it receives crushed coal from both mills and mixes it with hot donor solvent from the liquefaction/distillation unit. Donor solvent recycled from the solvent fractionator enters at approximately 230°C (450°F), and the slurry tank operates at about 120°C (250°F) and at slightly positive pressure (3 psig).

Coal from the impact mill is dried by the hot slurry, the moisture being removed as vapor. The vapor containing some light organics is condensed and separated, organics recycled to the slurry tank and water directed to sour water treatment. Coal from the gas-swept roller mill does not require drying, and sour water is not produced from the slurry.

Liquefaction

The coal slurry is pumped via high-pressure slurry pumps (P-102A&B) to the reactor feed furnace (F-102), where the slurry is heated to about 455°C (850°F). Molecular hydrogen is added to the stream which continues to the liquefaction reactors (R-101A to R-101D).

These reactors are vertical upflow reactors, 2 feet in diameter and 55 feet tall. Although four reactors are available, the number in use can be varied according to the residence time needed to achieve proper conversion. The reactors are noncatalytic and depend on the dissolving properties of the solvent and hydrocracking to achieve liquefaction. Hydrocracking of the coal is produced at operating temperature and pressure with hydrogenated donor solvent and molecular hydrogen. The operating parameters of the pilot plant are presented below:

Coal feed rate:	160 to 200 tons/day
Reactor temperature:	441 to 451°C (825 to 844°F)
Design temperature range:	427 to 460°C (800 to 860°F)
Reactor pressure:	2,009 to 2,198 psig
Design pressure range:	1,900 to 2,600 psig
Reactor residence time:	Up to 80 minutes

Reactor product consists of gas, vapor, liquefied coal, recycle solvent, unreacted coal, and mineral matter. This stream is fed to the reactor separator drum where it is split into a vapor stream and a slurry stream. The vapor phase passes through hot and cold separator drums where condensable hydrocarbons, sour water, and unused hydrogen gas are separated. Condensed hydrocarbons reenter the slurry stream, and sour water is removed for treatment. Unused hydrogen is recycled to the reactors after purification in gas scrubbers. The main slurry stream passes directly from the reactor separator to distillation.

Distillation

Preliminary distillation occurs in the atmospheric fractionator tower (T-201) where the slurry stream is flashed and steam-stripped. Fractionator temperatures of up to 345°C (650°F) are regulated by the input rate of cooler liquids from the drum separators. Flashed vapor consisting of naphtha, sour water, and fuel gas is condensed and separated in a distillate drum.

In addition to naphtha, the fractionator produces a light gas/oil, a heavy gas/oil, and bottoms. Both gas/oils are pumped (P-202) to the hydrogenation unit. Naphtha may be blended with the gas/oil stream or taken as product. Bottoms are sent to a vacuum stripper.

Bottoms are first pumped (P-204) through a preheat furnace (F-201) and then to the vacuum stripper (T-204). The vacuum stripper yields an overhead stream, two side streams, and a solids-containing bottoms residue. The overhead stream is condensed and separated into liquid hydrocarbons, sour water, and fuel gas. Hydrocarbons are sent to the solvent hydrogenation section. The vacuum stripper side streams include a light vacuum gas/oil (LVGO) and a heavy vacuum gas/oil (HVGO). The HVGO can be withdrawn as product or can be combined with the LVGO stream and pumped (P-207, P-208) to the solvent hydrogenation section. Vacuum bottoms are pumped (P-210) to the flaker belt where they are cooled and solidified on a stainless steel conveyor belt, and discharged into bins. Bottoms still contain potentially valuable hydrocarbon material and are presently stored in a building on site.

The fumes from the cooling belt are completely withdrawn and sent through a high-energy water venturi scrubber. In addition, the discharge end of the conveyor, where the solidified bottoms are loaded into transport conveyors, is enclosed with a hood that sends fines-containing air through a bag filter.

Solvent Hydrogenation

The solvent hydrogenation section serves to replenish the donor hydrogen in the recycle solvent and to obtain the proper boiling-range solvent. In effect, solvent hydrogenation is a middle distillate hydrotreating plant. The feed to solvent hydrogenation is normally comprised of the light and heavy atmospheric gas/oils and the light vacuum gas/oil; however, the distillate naphtha and heavy vacuum gas/oil can also be included. The solvent is hydrogenated in fixed-bed, nickel-molybdate catalytic reactors (R-301 to R-304).

The liquid feed is mixed with hydrogen gas and pumped (P-301) to the reactor preheat furnace (F-301) and to the reactor. The replenished solvent flows

through separator drums where unconsumed hydrogen is recovered, and sour water and organic vapors are condensed and removed. Hydrocarbons from the separator drums and the solvent stream are combined and sent to the solvent fractionator (T-303) via a preheat furnace (F-302). The fractionation process separates the hydrogenation products into three streams: fuel gas, naphtha, and recycle donor solvent. Fractionator overhead is directed to a distillate drum where sour water, fuel gas, and the naphtha product are separated. Solvent comes directly off the fractionator and is pumped (P-306, P-307, P-308) to storage in the tank farm. Donor solvent possessing the proper characteristics is cycled back to the liquefaction section and mixed with coal in the slurry drier.

Support Processes

Three integral support processes are critical to Plant D operations: hydrogen (H_2) recovery, fuel gas recovery and use, and sour water removal. Certain of these processes are linked to a nearby refinery.

Hydrogen is initially piped to the Plant D from the refinery and is introduced at both the liquefaction and the hydrogenation reactors. Hydrogen not con- sumed in reactions is recovered from the separator drums after the process stream leaves the reactors. The impure gas is scrubbed with water and die- thanolamine (DEA) to remove ammonia, hydrogen sulfide, and carbon dioxide. Clean hydrogen is recompressed and recycled to the reactors along with make- up hydrogen from the refinery.

Fuel gas is similarly recovered from the separator drums which process distillate streams from the atmospheric tower, vacuum stripper, and solvent fractionator. Fuel gas is composed of light hydrocarbons (C_4 and less) and impurities. It is treated in a system similar to hydrogen scrubbing to remove impurities, and is subsequently used for heating purposes. Fuel gas, along with makeup natural gas, supplies fuel for the several preheat and feed furnaces used in the process.

Sour water is removed from the process at various separator and distillate drums, and is also produced from water scrubbing of fuel gas and hydrogen.

Sour water contains large amounts of sulfur compounds and is sent via pipeline to a nearby refinery for treatment.

The DEA used for gas scrubbing is regenerated on site, producing a stream of hydrogen sulfide and carbon dioxide. This gas is also sent to the refinery for treatment. The treatment of sulfur-containing wastes results in the formation of elemental sulfur as a by-product.

Plant D has a flush oil system to provide solids-free solvent for flushing lines, instrument taps, and solids-handling valves. Flush oil is provided by high-pressure pumps (P113A and B, and P-105) and low-pressure pumps (P-115A and B). This flush oil is a hydrogenated distillate. Solids-handling pumps are externally flushed with process sidestreams. For example, P-204 atmospheric bottoms pumps is flushed with light vacuum gas/oil from the vacuum tower T-204.

The process yields five separate products: fuel gas, naphtha, solvent, gas/oil distillate, and bottoms residue. The major by-product of the process is elemental sulfur.

FACILITY DESCRIPTION

The Plant D Coal Liquefaction Pilot Plant is located north of Baytown, Texas, and is situated on level ground. Directly south of the unit is a large petroleum refinery which provides chemical feedstock and waste treatment services for the liquefaction process by pipeline. The refinery was operating during the survey, and the wind blew periodically from the direction of the refinery.

The facility is divided into several units containing equipment for different phases of the process. A checklist of the process units and associated equipment is presented in Table A-2. A diagram showing the layout of the pilot plant is presented in Figure A-9; and the main process units involved in liquefaction are detailed in Figure A-10.

Table A-2. Equipment Checklist for Plant D Process Units

ECLP Unit	Equipment
Liquefaction/Distillation Unit #1 (LDU #1) (100 area)	slurry drier (D-101); high-pressure slurry feed pumps (P-102A&B); slurry preheat furnaces (F-102A&B); liquefaction reactors (R-101A to R-101D); high-pressure separation drum (D-103); reactor separator pumps (P-106A&B)
Liquefaction/Distillation Unit #2 (LDU #2) (200 area)	atmospheric fractionator (T-201); light gas/oil pumps (P-202A&B); bottoms pumps (P-204A&B); vacuum preheat furnace (F-201); vacuum stripper tower (T-204); light vacuum gas/oil pumps (P-207A&B); heavy vacuum gas/oil pumps (P-208A&B); vacuum bottoms pump (P-210)
Liquefaction/Distillation Unit #3 (LDU #3)	solids handling; flaker belt; Dowtherm facilities; high-pressure flush oil pumps (P-113A&B); blowdown drum (D-121)
Solvent Hydrogenation Unit (SHU) (300 area)	solvent feed pumps (P-301A&B); feed filter (D-308); solvent preheat furnace (F-301); solvent hydrogenation reactors (R-301 to R-304); solvent fractionator preheat furnace (F-302); solvent fractionator (T-303); sour water system; fuel gas scrubbing; acid gas compressors; hydrogen compressors
Coal Preparation Unit (CPU)	railcar unloading; coal conveyors; storage silo and bins; impact mill; gas-swept mill
Offsite and Utilities (OSU)	tank farm; cooling tower; wastewater systems; steam supply; oily water sump; compressed air system; low-pressure flush oil pumps

Primary pipelines interconnecting the process areas are elevated above grade level. Several multilevel structures are present in the process area including those which house the towers. These contain equipment and workspace, and are open to the air.

The process sections containing equipment susceptible to liquid leakages have concrete floors and are diked. Specific equipment and subsections are diked within the sections to further isolate any spills. The tank farm area is covered with crushed stone, and equipment is supported on concrete pads or piers. Most pumps are located on ground level within the diked areas. Several units in the liquefaction and hydrogenation sections rise from grade

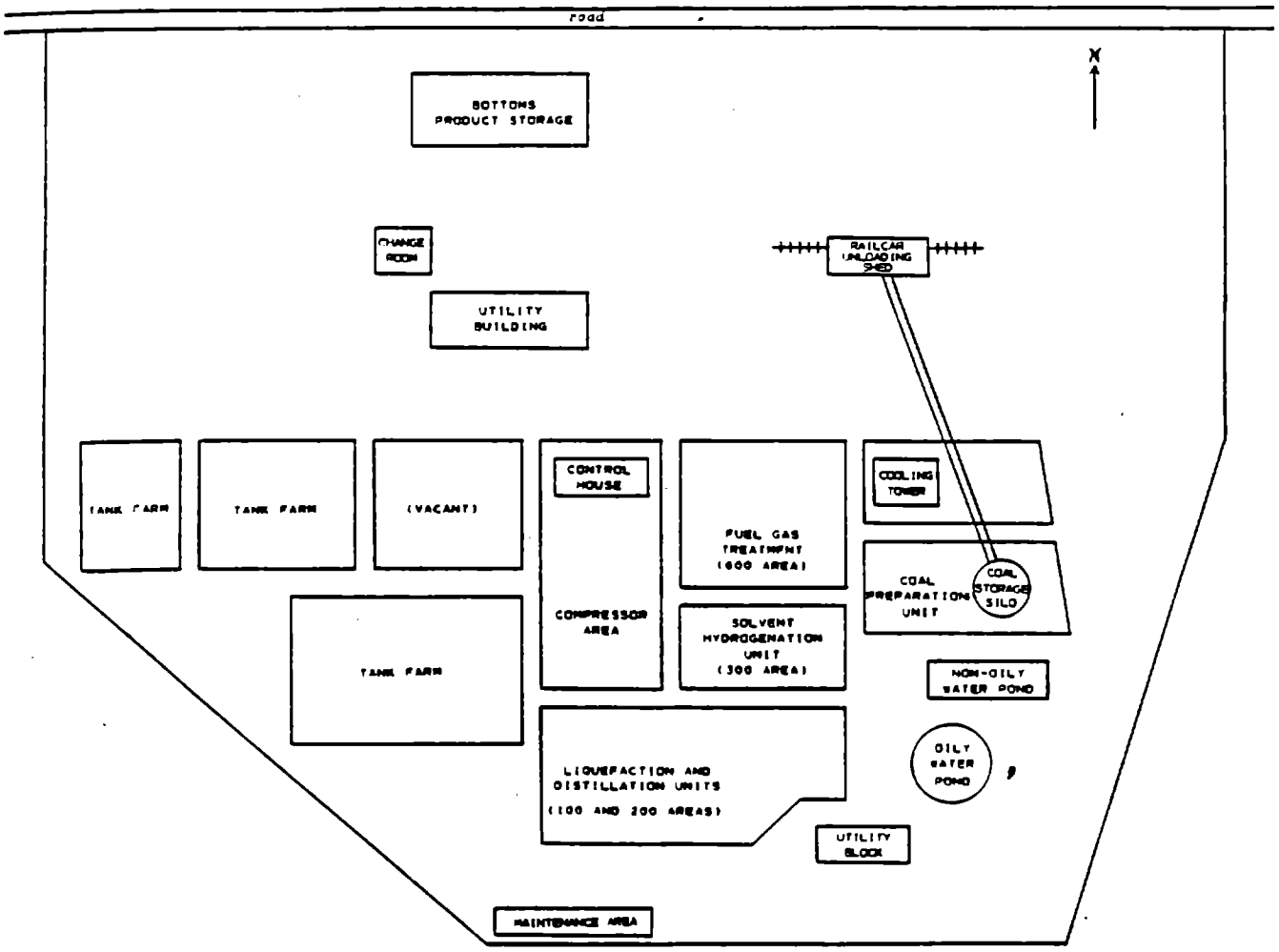


Figure A-9. Plant D Plant Layout

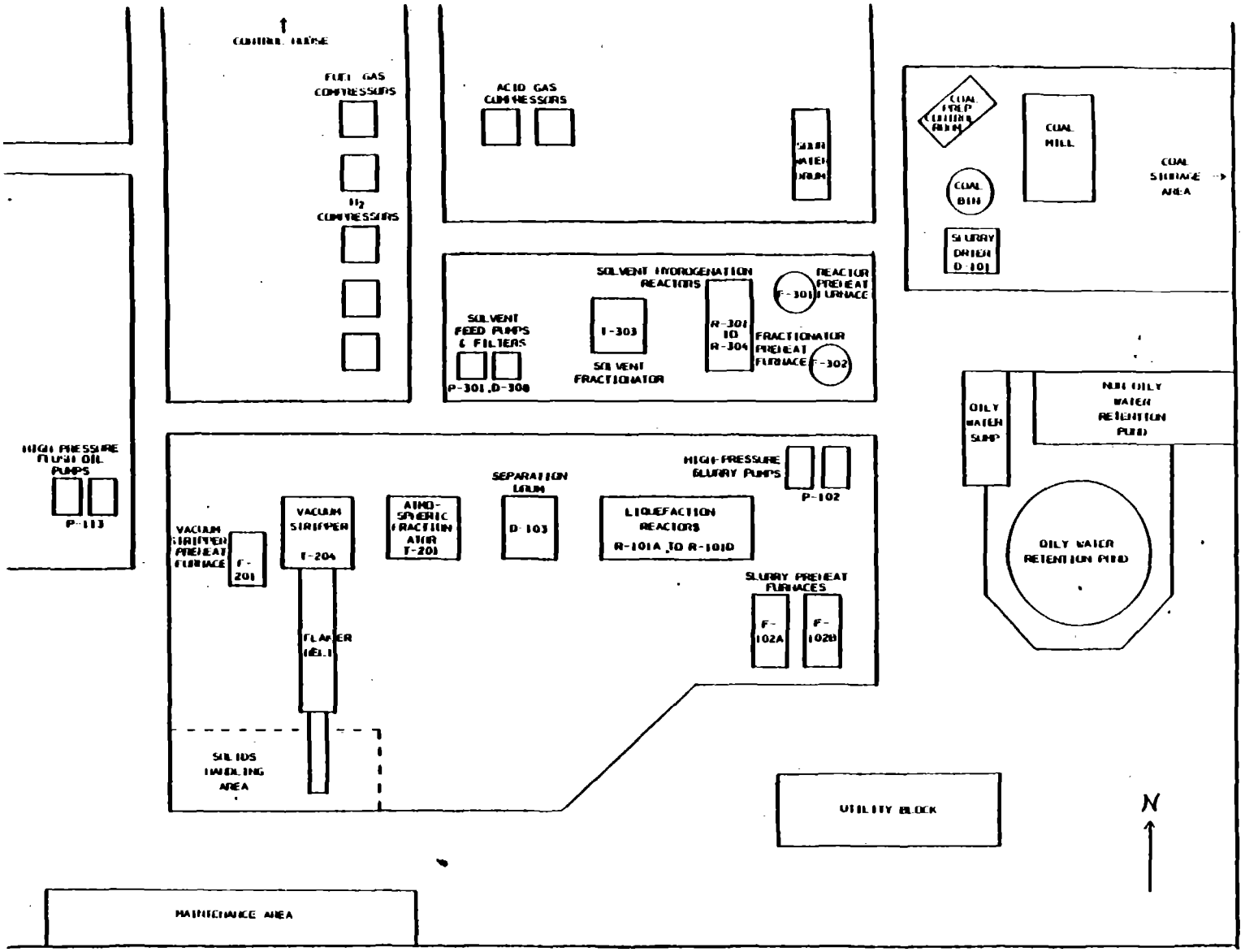


Figure A-10. Plant D Process Area Layout

level to 4th and 5th levels. The reactors, preheat furnaces, atmospheric and vacuum towers, and solvent fractionator have attendant steel superstructures with workspace for testing, sampling, and maintenance activities. Flooring on these structures is steel grating. Numerous areas had visible accumulations of process liquids, although these were usually confined. Areas of high foot traffic were observed to be clean and relatively free of process emissions.

Coal is delivered by rail to a building northeast of the process area, where it is unloaded and mechanically conveyed to the 5,000-ton raw coal storage silo. The process stream is initiated at the slurry drier in the coal preparation unit, and moves to the liquefaction and distillation section. Recycle solvent hydrogenation occurs in the hydrogenation area. Products removed during distillation or solvent fractionation are stored in the tank farm areas located east of the process area. A flaker belt for solidifying vacuum bottoms residue is located in the liquefaction section. Solid bottoms product is collected and transported from there to a storage building north of the process area.

The process is monitored and regulated from a main control house located north of the compressor area. Employees pass through the control house going to and from the process area, and it therefore receives heavy foot traffic. A secondary control room is located in the coal preparation area and controls processes for this section; it receives little foot traffic.

Utility buildings used by maintenance personnel for various activities are located on the extreme south side of the process area, and to the north outside of the area. These buildings receive fairly heavy use.

PLANT E

PROCESS DESCRIPTION

The Plant E process is a catalytic coal liquefaction process capable of producing either synthetic crude oil suitable for refining or heavy fuel oil. The process can use either bituminous or subbituminous coals. Coal is hydrogenated and liquefied in a catalytic ebullated-bed reactor. The hydroliquefaction product is then separated by distillation into liquid fractions of different boiling temperatures. The process also produces a fuel gas which is consumed onsite for heating purposes.

The Catlettsburg facility was originally built to conduct experimental runs to produce both syncrude and fuel oil. The fuel oil mode of operation and its associated deashing unit have never been used. The syncrude mode with its greater hydrogen requirements and increased reactor residence time, on the other hand, has produced several distillate cuts which can be blended into a refinable oil. The syncrude mode is presented schematically in Figure A-11.

The process can be divided into the following component process units:

- coal preparation
- hydrogenation and liquefaction
- primary separation
- product recovery
- support processes

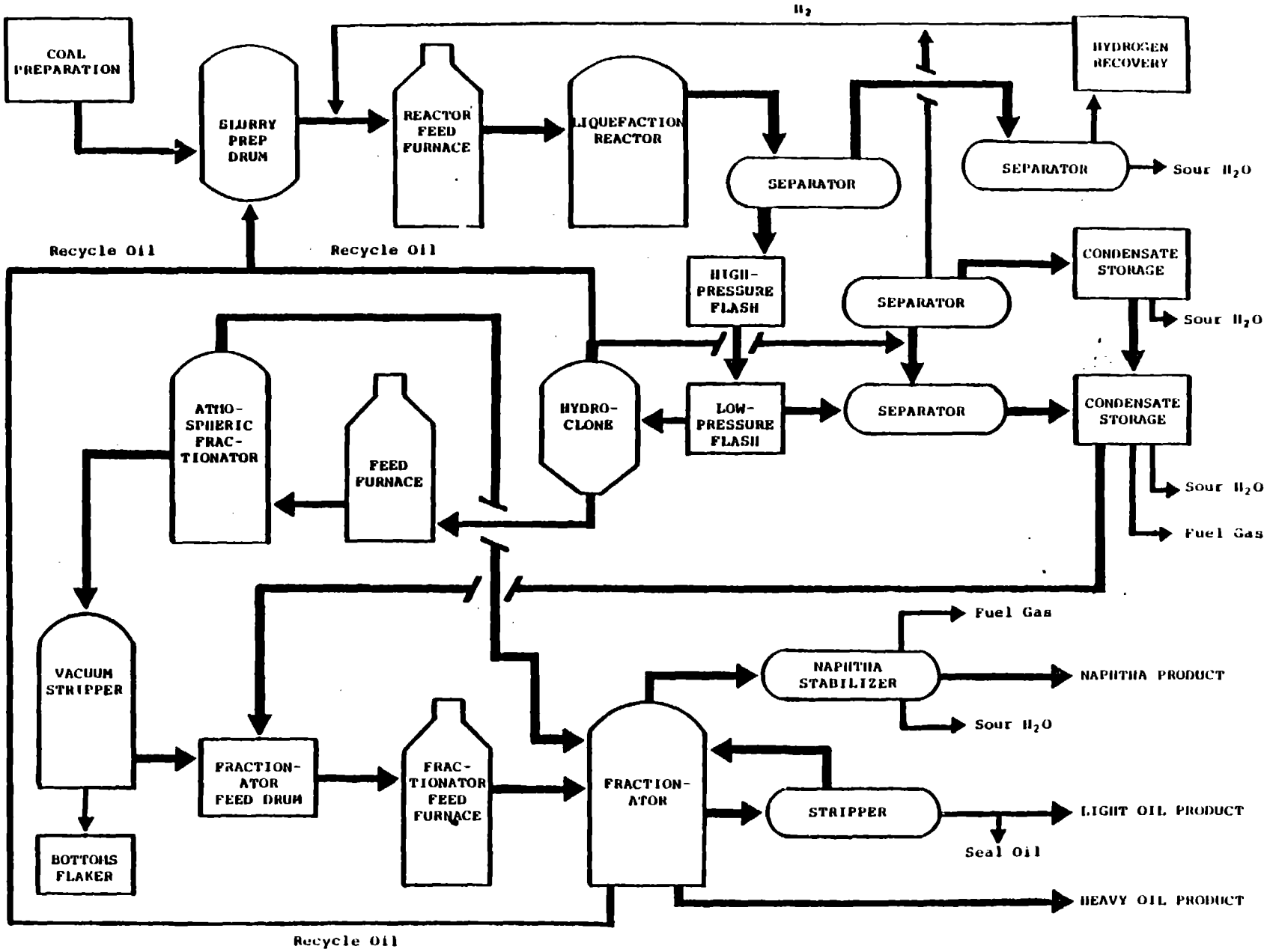


Figure A-11. Plant E Process Schematic (syncrude mode)
Source: Ashland Synthetic Fuels, Inc.

Coal Preparation

Raw coal is delivered by railcar and is mechanically conveyed to two open piles with a combined storage capacity of 12,000 tons. Coal from these piles is reclaimed with front-end loaders and fed into a crusher which reduces the coal to minus 3/4-inch size. Crushed coal is conveyed to two 900-ton storage bins. This coal is removed with a weigh feeder and conveyed through a dryer feed bin to a bowl mill where it is pulverized to minus 100 mesh.

The pulverized coal is dried to 2 percent moisture and simultaneously conveyed with hot flue gas to a cyclone where most of the coal is separated. The dry coal then passes through a rotary gas lock to a screw conveyor where it is distributed to two 250-ton bins.

All phases of coal preparation are protected against dust emissions and explosions. Baghouse filters are used at every step of the operation, with coal dust being recirculated to the coal stream. Variable height boom conveyors are used to distribute coal to open piles and to reduce dust at this stage. Nitrogen (N_2) inerting and blowout panels are used in the bins to prevent and control explosions.

Hydrogenation and Liquefaction

Prepared coal enters a slurry preparation drum via a weigh feeder, and is mixed with recycled slurry oil. Slurry oil comes from the hydroclone overflow stream and additional product oil from fractionation. The slurry is pumped at approximately 3,000 psig to a gas-fired preheater where it is heated to about 400°C (750°F). Hydrogen (H_2) is introduced as the stream enters the preheater. The hot slurry is fed to the reactor bottom along with additional preheated hydrogen.

The Plant E reactor utilizes a cobalt-molybdenum catalyst in an ebullated bed. An ebullating pump recirculates the catalyst-free slurry from the top of the reactor to the bottom and up through the catalyst bed. Bed expansion is controlled by varying the circulation rate through the ebullating pump.

Reactor temperature is maintained at approximately 445°C (850°F) and kept uniform throughout the reactor by the recirculating slurry. The temperature of the exothermic hydrogenation reaction is controlled by regulating the feed which is about 38°C (100°F) lower than the reactor. Catalyst activity is maintained by daily addition of fresh catalyst and withdrawal of spent catalyst in a batch operation.

Primary Separation

The reaction product is withdrawn from the top of the ebullating bed and depressurized in a series of flash vessels. Reactor effluent -- consisting of gaseous and liquid products, unconverted coal, and mineral matter -- is separated into a vapor phase and a solid/liquid phase in the reactor effluent separator. The vapor phase, containing unreacted hydrogen and gaseous hydrocarbons, is cooled and the heavier hydrocarbons are condensed. Gaseous hydrocarbons are absorbed in a lean oil scrubbing tower. The solid/liquid phase is flashed in two steps from 3,000 psig to 50 psig. Flashed vapor is condensed, sent to condensate storage, and ultimately delivered to the fractionator. Some hydrogen is recovered from the flash vessels and is recycled. Bottoms material from the flash steps is directed to a set of hydroclones (liquid-phase cyclones).

Hydroclones are used to separate solids from the slurry stream and produce a solids-free oil for recycling to slurry preparation. Recycling of this oil containing unreacted coal (hydrocarbons boiling above 524°C, 975°F) improves yield structure. Solids-free hydroclone overflow not used for recycling is sent to fractionation. Hydroclone bottoms containing all the solids are pumped to the atmospheric and vacuum strippers. Overhead from the vacuum stripper is sent to fractionation.

Product Recovery

Process streams enter the fractionation unit at two points. The solid/liquid slurry stream is pumped through a preheater furnace to the atmospheric stripper and the vacuum stripper. Condensed liquids from the flash steps and hydroclone overhead move directly to the fractionator feed tank.

The solid/liquid stream (hydroclone bottoms) is flashed and steam-stripped at the atmospheric stripper. Bottoms from the atmospheric stripper are directed to the vacuum stripper and are flashed and steam-stripped again. Overhead from the vacuum stripper is separated from water in the collector drum. Water is sent for sour water treatment. Hydrocarbon is pumped to the fractionator feed drum, where it is combined with liquids from primary separation. Bottoms from the vacuum stripper -- consisting of residuum, unreacted coal, and mineral material -- is delivered to the flaker solidification process. Here, a fully enclosed and exhausted belt cools the liquid and delivers the solidified material to storage piles. The flaker material is later trucked offsite for disposal.

The combined liquids from the strippers and the flash steps are fed to the fractionator through a preheater furnace. The process stream is partially vaporized in the preheater furnace before being introduced to the flash zone of the fractionator. The overhead product from the fractionator is sent to a stabilizer tower where the light ends (C_4 and lighter) are removed. The light ends are suitable for use as fuel gas. The bottoms product is stabilized naphtha. The fractionator produces two other streams -- light oil and heavy oil.

Both streams are steam-stripped to remove light ends which are returned to the fractionator. The heavy oil stream is recycled with hydroclone overhead to slurry preparation. A portion of this stream may be blended with the other streams to produce a synthetic crude oil.

Support Processes

Three other processes are critical to operation of Plant E: hydrogen recovery, fuel gas recovery and use, and sulfur removal. Fuel gas is recovered and used onsite, while the other processes are linked to systems in the nearby refinery.

Fuel gas, composed of gaseous hydrocarbons, is recovered from the process at the last condensate storage tank and from the naphtha stabilizer. The gas

is cleaned of contaminants, such as hydrogen sulfide (H_2S), and is used in the preheater furnaces and feed furnaces in the process.

Hydrogen makeup gas (H_2) is obtained from a nearby refinery, and introduced into the process at the reactor feed preheater. Hydrogen not consumed by the hydrogenation reaction is removed from the process stream at the reactor effluent separator and subsequent flash steps. Hydrogen is separated from other gases and is recycled to the reactor.

Sulfur-containing contaminants are removed at several stages of the process. Hydrogen sulfide is removed with the fuel gas stream and with the sour water produced at various steps in primary separation and fractionation. Hydrogen sulfide is removed from the fuel gas with diethanolamine (DEA). The H_2S is then stripped from the DEA. The DEA is regenerated onsite. Sour water is steam-stripped of its hydrogen sulfide. A concentrated stream of hydrogen sulfide from the fuel gas stream and sour water is piped to the nearby refinery, where a Claus sulfur recovery unit is used to convert the hydrogen sulfide to elemental sulfur.

The Plant E process in the syncrude mode yields five products: fuel gas, naptha, light oil, heavy oil, and a solid bottoms residue. The solid bottoms material is a combination of unreacted carbon, ash, and residuum, and is currently a waste product that must be shipped offsite for disposal. The single major by-product of the process is elemental sulfur.

FACILITY DESCRIPTION

The Plant E pilot plant in Catlettsburg, Kentucky, is sited alongside the Big Sandy River just north of its parent corporation's oil refinery. Coal is delivered by rail and hydrogen by pipeline from the refinery. Process-produced hydrogen sulfide gas is piped back to the refinery for sulfur recovery, and product oil for refining. Liquid wastes are discharged into the Big Sandy River 2 miles upstream from its juncture with the Ohio River. A nearby interstate highway is used for trucking solid waste offsite. Fog and variable winds are frequent weather conditions in this low-lying valley.

Enclosed by chain link fencing and protected from unauthorized access by a guard house, the Plant E facility is roughly divided into five functional areas: coal preparation (100); hydrogenation/liquefaction (200); waste oil recovery (600); sour water and acid gas treatment (400); and deashing (500). The first two areas and the deashing area with the adjacent flaker belt comprise most of the physical plant. Figure A-12 depicts the overall layout of the plant; and Figure A-13 is a more detailed diagram of the hydrogenation/liquefaction area.

The coal preparation area is itself divided into three functional units. Coal receiving includes a covered hopper and conveyor system which delivers coal to a tall transfer tower and then to open stockpiles on cement slab. An above-grade control shed located nearby is used to direct this operation. Coal reclaiming -- including conveyers, a primary crusher, and large storage bins -- is housed in a tall, open structure. The pulverizer drying area, dominatd by the Raymond bowl mill, is housed in a semienclosed, circular building. Catch basins around the perimeter of the area divert rain water to a settling pond at its northern edge. Elaborate dust collectors keep the area relatively free of dust and soot.

The hydrogenation/liquefaction area, located roughly in the middle of the facility, contains the bulk of process and support equipment. As in the other areas, the general flooring is crushed stone. Concrete pads support major equipment. The atmospheric stripper and vacuum towers rise several stories above the other equipment including the hydroclone, reactor, hydrogen compressor, seal oil pumps, and high-pressure slurry pumps. This equipment is open to the air and connected by above-grade pipeline. Equipment susceptible to liquid leakage is floored and diked with concrete. Oil stains and small spills are present in these isolated areas. Products removed during fractionation are stored in the tank farm, which occupies the eastern tip of the facility just inside the perimeter road.

The deashing area of the plant contains a nonoperational, partially dismantled deashing unit. It is located immediately south of the hydrogenation unit and adjacent to the stainless steel, water-cooled flaker belt. This

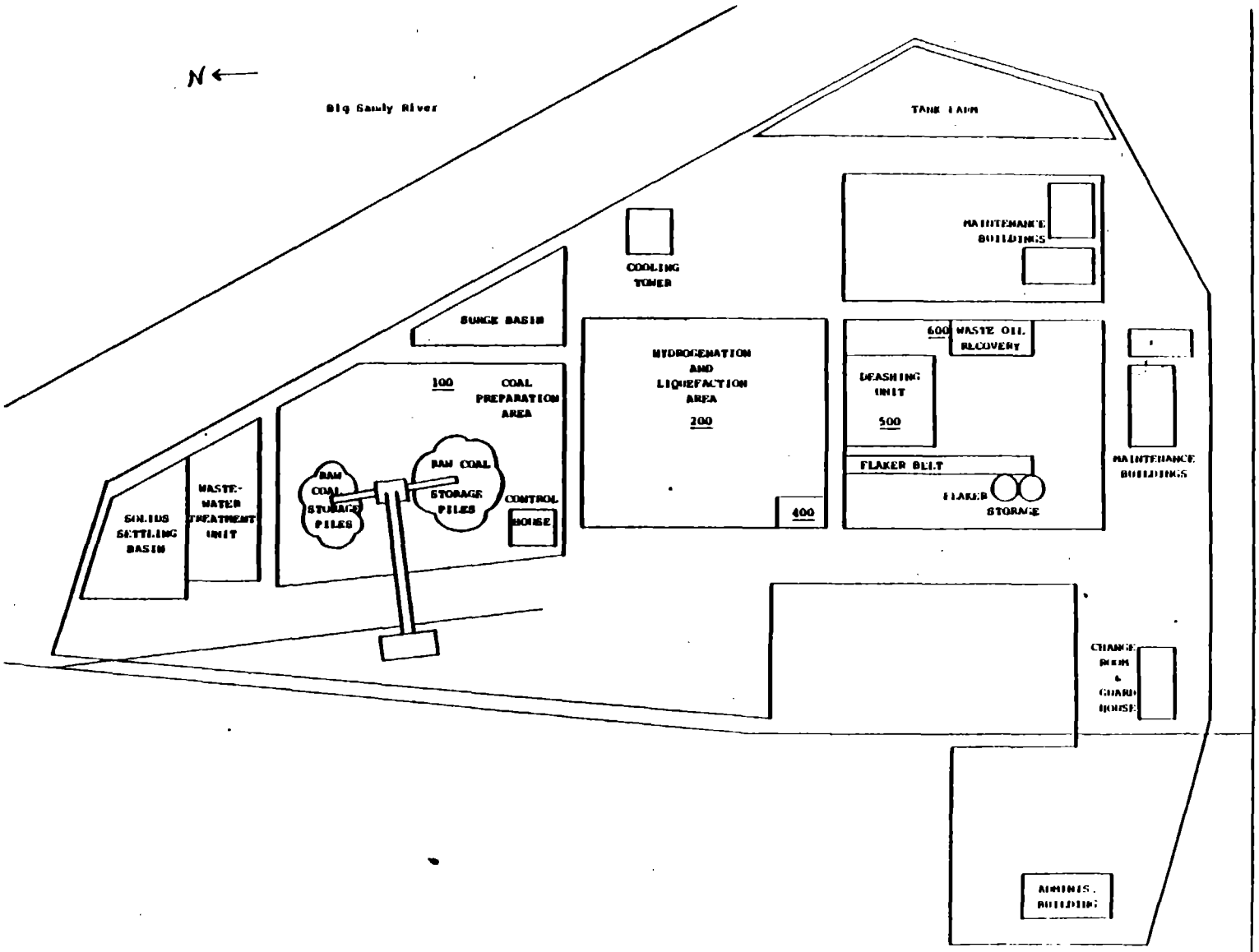


Figure A-12. Plant E Plant Layout
Source: Ashland Synthetic Fuels, Inc.

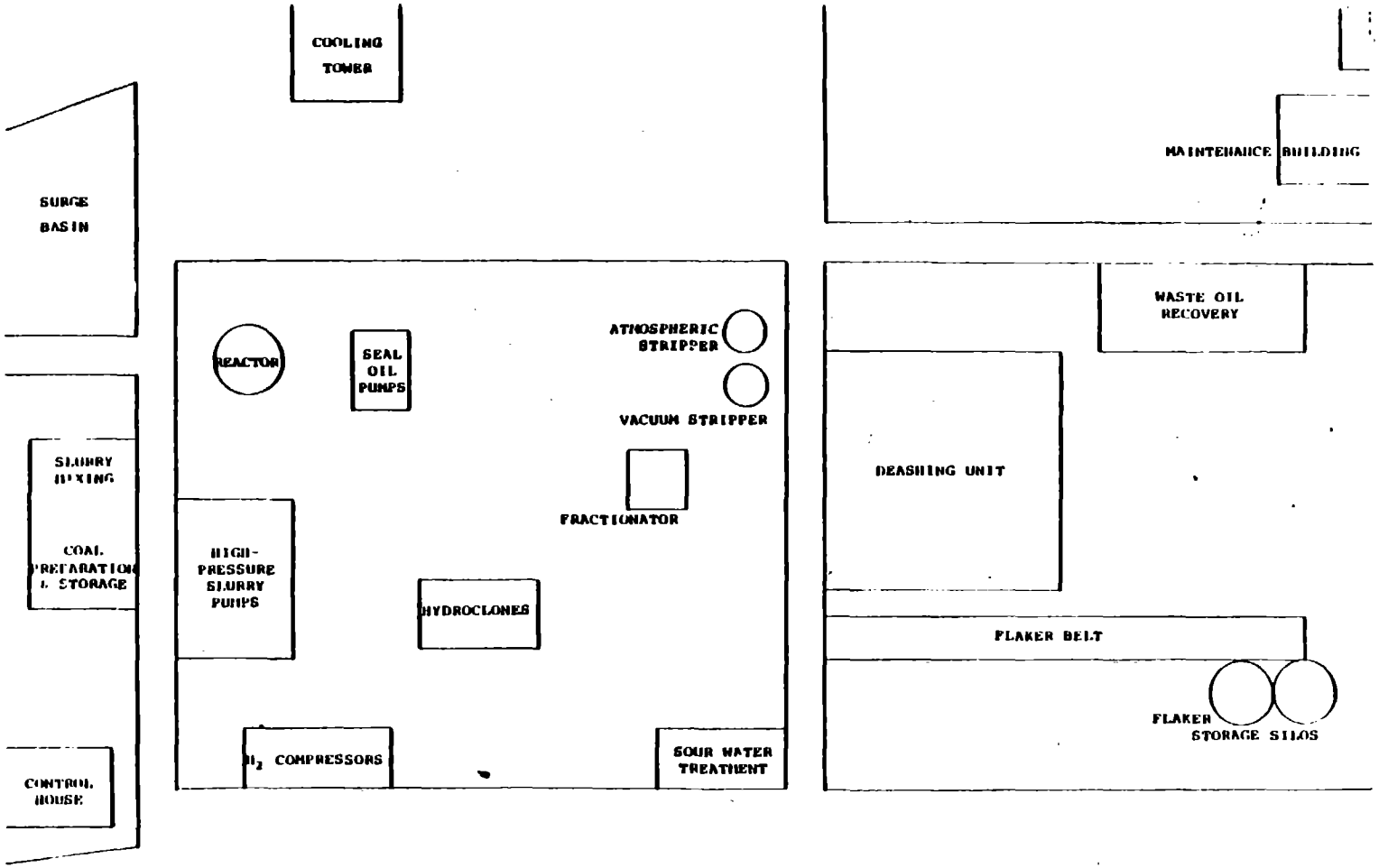


Figure A-13. Plant E Detailed Layout of Hydrogenation/Liquefaction Area (not to scale)

belt, located above grade in a 2-story sturcture equipped with an extensive hood, delivers solidified waste material to a stockpile at its base.

Located at the extreme north end of the plant, the enclosed wastewater treatment plant is connected by pipeline to the surge basin and solids settling pond. Cooling tower blowdown, coal pile runoff, boiler blowdown, and process wastewater from foul water stripping are processed here, before being discharged into the river.

The control house, from which the major parameters of the liquefaction process are monitored and regulated, is located in the southwest corner of the coal preparation area. It is a self-contained, concrete block building, and it houses a large control room, a lunchroom, bathrooms, and individual offices.

Appendix B

RESULTS OF SAMPLING PROGRAMS AT FIVE COAL LIQUEFACTION PLANTS

PLANT A

FORT LEWIS, WASHINGTON

Table B-1. Plant A Area Sampling Analytical Results ($\mu g/m^3$) for PNAs (February 8-14, 1979)..... B-3

Table B-2. Plant A Personal Sampling Analytical Results ($\mu g/m^3$) for PNAs (February 7-17, 1979)..... B-4

Table B-3. Plant A Area Sampling Analytical Results ($\mu g/m^3$) for Aromatic Amines (June 15-20, 1978)..... B-6

Table B-4. Plant A Area Sampling Analytical Results (mg/m^3) for Aromatic Amines (February 11-17, 1979)..... B-7

Table B-5 Plant A Personal Sampling Analytical Results (mg/m^3) for Aromatic Amines (February 10-18, 1979)..... B-8

Table B-6. Plant A Area Sampling Analytical Results (ppm) for Benzene, Toluene, and Xylene (June 15-20, 1978)..... B-9

Table B-7. Plant A Area Sampling Analytical Results (ppm) for Benzene, Toluene, and Xylene (February 11-15, 1979)..... B-10

Table B-8. Plant A Personal Sampling Analytical Results (ppm) for Benzene, Toluene, and Xylene (February 9-18, 1979)..... B-11

Table B-1. Plant A Area Sampling Analytical Results (μg/m^3) for PNAs (February 8-14, 1979)

Location Sampled:	Slurrying			Dissolving	Mineral Separation	Fraction-ation	Solidifi-cation	Gas Recycle	Blanks (μg/sample)	
	Between Crusher & Pumps	Between Crusher & High-Pressure Pumps	Slurry Mix Tank	High-Pressure Flash Drum	Slurry Pump	Wash Solvent Bottoms Pump	Sandvik Belt	At Reformer		
Sample Number:	006	007	010	040	041	025	026	066	029	077
Sample Volume (l):	1,312	1,146	1,395	5,051	5,078	4,407	4,361	4,269		
Sampling Time:	0820-1420	1230-1812	1306-1815	1827-0336	1829-0341	0912-1711	0910-1704	1847-0231		
Date Collected:	2/8/79	2/9/79	2/9/79	2/11/79	2/11/79	2/10/79	2/10/79	2/12/79	2/11/79	2/14/79
Compound (detection limit, μg/m^3)[a]										
Naphthalene (0.01)	5.7	0.3	5.2	5.3	8.9	10.6	0.8	--[b]	0.1	0.3
1-Methylnaphthalene (0.01)	1.0	0.7	0.6	0.3	1.1	6.7	0.2	0.02	0.02	0.05
2-Methylnaphthalene (0.01)	8.1	0.2	4.6	2.0	34.9	10.5	0.6	--	0.1	0.2
Quinoline (0.01)	13.7	0.6	0.5	6.4	14.5	40.0	1.8	--	--	--
Acenaphthalene (0.01)	0.6	--	--	--	--	0.1	--	--	--	--
Acenaphthene (0.01)	--	0.4	1.0	0.06	4.9	1.2	0.2	--	--	--
Fluorene (0.01)	4.4	4.0	2.6	0.6	8.5	3.6	0.4	0.1	--	0.04
Phenanthrene/Anthracene (0.01)	13.7	9.6	26.6	3.03	43.3	16.1	1.8	0.4	0.2	--
Acridine (0.01)	1.8	--	--	--	--	--	--	--	--	--
Carbazole (0.01)	3.8	0.2	4.6	0.2	28.9	0.2	0.04	0.02	--	0.02
Fluoranthene (0.01)	1.7	0.5	2.7	0.2	23.0	0.6	0.07	0.02	0.1	0.03
Pyrene (0.01)	1.5	0.2	1.6	0.2	24.9	0.7	0.1	0.02	0.1	0.04
Benzo(a)fluorene/ Benzo(b)fluorene (0.01)	0.8	0.8	0.8	0.07	27.3	2.6	--	--	--	--
Benz(a)anthracene/Chrysene/ Triphenylene (0.01)	0.3	--	0.4	0.3	5.8	--	--	--	--	--
Benzo(e)pyrene/ Benzo(a)pyrene (0.01)	--	--	--	--	1.3	--	--	--	--	--
Perylene (0.01)	--	--	--	--	--	--	--	--	--	--
Dibenz(a,j)acridine (0.01)	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)carbazole (0.01)	--	--	--	--	--	--	--	--	--	--
Indeno(1,2,3-cd)pyrene (0.01)	--	--	--	--	--	--	--	--	--	--
Dibenz(a,h)anthracene (0.01)	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene (0.01)	--	--	--	--	--	--	--	--	--	--
Anthanthrene (0.01)	--	--	--	--	--	--	--	--	--	--
Coronene (0.06)	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)pyrene (0.06)	--	--	--	--	--	--	--	--	--	--
Dimethylbenz(a)anthracene (0.01)	--	--	--	--	--	--	--	--	--	--
TOTAL	57.1	17.5	51.2	18.7	227.3	92.8	6.0	0.6	0.6	0.7

[a] Assuming a sample volume of 4,000 liters.

[b] "--" indicates not detected.

Table B-2. Plant A Personal Sampling Analytical Results ($\mu g/m^3$) for PNAs (February 7-17, 1979)

Personnel Sampled	Laboratory Technicians			01 Area Personnel					
				Welder	Operator	Technician	Technician	Mechanic	Operator
Sample Number:	053	054	056	003	011	012	020	073	103
Sample Volume (l):	304	251	450	220	352	245	241	182	275
Sampling Time:	0828-1655	0831-1653	0830-1650	0955-1335	1235-1825	1234-1824	0821-1625	0056-1400	0837-1312
Date Collected:	2/12/79	2/12/79	2/12/79	2/7/79	2/9/79	2/9/79	2/10/79	2/14/79	2/17/79
Compound									
Naphthalene	--[a]	2.7	0.4	76.1	0.1	8.2	--	36.02	7.1
1-Methylnaphthalene	--	1.3	1.0	13.8	1.03	0.4	0.4	1.2	0.8
2-Methylnaphthalene	--	13.1	0.8	2.3	9.4	31.7	--	15.2	18.9
Quinoline	--	--	--	4.9	3.6	0.2	0.2	--	--
Acenaphthalene	--	--	--	3.9	2.6	0.02	--	--	--
Acenaphthene	--	0.4	--	--	0.07	1.7	0.07	2.4	1.3
Fluorene	--	1.2	0.6	8.9	0.6	7.4	0.8	8.0	4.0
Phenanthrene/Anthracene	1.0	3.4	0.6	15.8	--	6.6	2.0	17.8	--
Acridine	--	0.2	--	0.06	0.06	0.07	--	0.04	6.1
Carbazole	--	--	--	--	0.1	--	--	1.0	--
Fluoranthene	--	--	--	0.9	1.3	0.1	--	0.8	--
Pyrene	--	0.1	--	0.2	--	0.3	0.07	2.2	0.2
Benzo(a)fluorene/ Benzo(b)fluorene	--	--	--	0.04	0.1	--	--	0.2	--
Benz(a)anthracene/ Chrysene/Triphenylene	--	--	0.09	--	--	--	--	--	0.2
Benzo(e)pyrene/ Benzo(a)pyrene	--	--	--	--	--	--	--	--	--
Perylene	--	--	--	--	--	--	--	--	--
Dibenz(a,j)acridine	--	--	--	--	--	--	--	--	--
Dibenz(a,i)carbazole	--	--	--	--	--	--	--	--	--
Indeno(1,2,3-cd)pyrene	--	--	--	--	--	--	--	--	--
Dibenz(a,h)anthracene	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene	--	--	--	--	--	--	--	--	--
Anthanthrene	--	--	--	--	--	--	--	--	--
Coronene	--	--	--	--	--	--	--	--	--
Dibenz(a,i)pyrene	--	--	--	--	--	--	--	--	--
Dimethylbenz(a)anthracene	--	--	--	--	--	--	--	--	--
TOTAL	1.0	22.4	3.5	126.9	18.9	56.7	3.5	84.1	38.6

"--" indicates not detected.

(continued)

Table B-2 (concluded)

Personnel Sampled:	03 Area Personnel			04 Area Personnel			08 Area Personnel			Blanks (µg/sample)	
	Operator	Operator	Operator	Operator	Operator	Operator	Operator	Operator	Operator		
Sample Number:	033	088	090	016	021	035	013	022	034	030	082
Sample Volume (ℓ):	439	242	438	227	292	300	202	483	287		
Sampling Time:	0816-1624	0834-1637	0838-1645	1303-1821	0824-1630	0814-1634	1246-1822	0823-1626	0817-1615		
Date Collected:	2/11/79	2/15/79	2/16/79	2/9/79	2/10/79	2/11/79	2/9/79	2/10/79	2/11/79	2/11/79	2/14/79
Compound											
Naphthalene	6.6	6.5	9.3	--[a]	14.6	19.5	--	14.1	38.9	--	--
1-Methylnaphthalene	5.1	3.8	1.0	0.8	--	--	0.06	0.5	0.02	--	--
2-Methylnaphthalene	--	--	45.1	4.3	57.9	63.3	--	48.2	180.0	--	--
Quinoline	0.1	0.04	0.2	--	0.2	0.3	--	0.2	0.9	--	--
Acenaphthalene	--	--	--	--	--	--	--	--	--	--	--
Acenaphthene	0.01	0.9	1.9	0.6	3.5	2.4	0.03	1.9	8.4	--	--
Fluorene	6.2	0.3	4.4	2.5	5.9	3.2	--	4.3	16.3	--	--
Phenanthrene/Anthracene	12.7	2.2	7.8	4.6	6.0	5.8	8.2	5.2	19.8	0.2	0.01
Acridine	--	--	--	0.04	0.02	0.02	0.1	--	--	--	--
Carbazole	0.08	--	--	--	--	0.04	0.4	0.09	--	--	--
Fluoranthene	1.0	--	0.3	0.06	--	0.5	1.0	0.1	--	--	--
Pyrene	0.6	--	0.2	0.4	0.09	--	4.5	0.07	--	--	--
Benzo(a)fluorene/ Benzo(b)fluorene	2.3	0.1	0.8	--	--	--	3.4	0.1	--	--	--
Benz(a)anthracene/ Chrysene/Triphenylene	1.0	--	0.2	--	--	0.08	--	0.2	--	--	0.1
Benz(e)pyrene/ Benz(a)pyrene	--	--	--	--	--	--	--	0.03	--	--	--
Perylene	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,j)acridine	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)carbazole	--	--	--	--	--	--	--	--	--	--	--
Indeno(1,2,3-cd)pyrene	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,h)anthracene	--	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene	--	--	--	--	--	--	--	--	--	--	--
Anthanthrene	--	--	--	--	--	--	--	--	--	--	--
Coronene	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)pyrene	--	--	--	--	--	--	--	--	--	--	--
Dimethylbenz(a)anthracene	--	--	--	--	--	--	--	0.04	--	--	--
TOTAL	35.7	13.8	71.2	13.3	88.2	95.1	17.7	75.0	264.3	0.2	0.1

[a] "--" indicates not detected.

Table B-3. Plant A Area Sampling Analytical Results ($\mu g/m^3$) for Aromatic Amines (June 15-20, 1978)

Location Sampled	Sample Number	Sample Volume (ℓ)	Sampling Time	Date Collected	Aromatic Amines[a] (detection limit, $\mu g/m^3$)[b]			
					A (0.13)	B (0.05)	C (0.05)	D (0.05)
Slurry Mix Tank	005	27.1	0928-1404	6/15/78	--[c]	--	--	--
Pulverizer Recycle Gas Water Scrubber	010	12.3	1410-1615	6/15/78	--	--	--	--
Filter	007	25.8	0943-1415	6/15/78	--	--	--	--
Filter	012	12.0	1420-1624	6/15/78	--	--	--	--
Downwind of Surge Reservoir	019	18.0	0855-2340	6/16/78	--	--	--	--
Downwind of Surge Reservoir	024	24.0	1140-1515	6/16/78	--	--	--	--
Blanks (ug/sample)	036			6/20/78	--	--	--	0.09
	037			6/20/78	--	--	--	0.07

[a] Aromatic amines: A = Aniline; B = N,N-Dimethylaniline; C = o-Anisidine; D = p-Anisidine.

[b] Assuming a sample volume of 25 liters.

[c] "--" indicates not detected.

Table B-4. Plant A Area Sampling Analytical Results (mg/m^3) for Aromatic Amines (February 11-17, 1979)

Location Sampled	Sample Number	Sample Volume (l)	Sampling Time	Date Collected	Aromatic Amines[a] (detection limit, mg/m^3)[b]					
					A (0.1)	B (0.1)	C (0.1)	D (0.1)	E (0.1)	F (0.1)
Slurry Mix Tank	097	47.5	0857-1651	2/16/79	--[c]	--	--	--	--	--
03 Area Circulating Pump for Filter Feed Surge Vessel	084	47.7	0845-1641	2/15/79	--	--	--	--	--	--
04 Area Hot Well Tank Pump	108	49.5	0853-1643	2/17/79	--	--	--	--	--	--
Sandvik Belt	117	49.8	0823-1640	2/11/79	--	--	--	--	--	--
08 Area Sandvik Belt	058	47.1	0842-1634	2/12/79	--	--	--	--	--	--
08 Area Sandvik Belt	086	48.2	0832-1635	2/15/79	--	--	--	--	--	--
Blanks (ug/sample)	028			2/11/79	--	--	--	--	--	--
	080			2/14/79	--	--	--	--	--	--

[a] Aromatic amines: A = Aniline; B = N,N-Dimethylaniline; C = o-Anisidine; D = p-Anisidine; E = o-Toluidine; F = 2,4-Dimethylaniline.

[b] Assuming a sample volume of 50 liters.

[c] "--" indicates not detected.

Table B-5. Plant A Personal Sampling Analytical Results (mg/m^3) for Aromatic Amines (February 10-18, 1979)

Personnel Sampled	Sample Number	Sample Volume (l)	Sampling Time	Date Collected	Aromatic Amines[a] (detection limit, mg/m^3)[b]					
					A (0.1)	B (0.1)	C (0.1)	D (0.1)	E (0.1)	F (0.1)
Laboratory Technician	074	48.6	0915-1720	2/14/79	--[c]	--	--	--	--	--
Laboratory Technician	075	47.7	0914-1721	2/14/79	--	--	--	--	--	--
Laboratory Technician	076	47.5	0925-1721	2/14/79	--	--	--	--	--	--
01 Area Operator	056	48.7	0834-1642	2/12/79	--	--	--	--	--	--
01 Area Technician/ Specialist	060	47.0	0832-1623	2/12/79	--	--	--	--	--	--
01 Area Mechanic	072	30.4	0855-1400	2/14/79	--	--	--	--	--	--
01 Area Operator	093	47.1	0844-1638	2/16/79	--	--	--	--	--	--
01 Area Operator	116	48.5	0836-1640	2/18/79	--	--	--	--	--	--
03 Area Foreman	018	48.7	0813-1621	2/10/79	--	--	--	--	--	0.1
03 Area Operator	019	47.2	0835-1630	2/10/79	--	--	--	--	--	0.2
03 Area Operator	045	54.5	1901-0404	2/11/79	--	--	--	--	--	--
03 Area Technician	057	47.4	0839-1636	2/15/79	--	--	--	--	--	0.1
03 Area Technician	105	50.0	0831-1650	2/17/79	--	--	--	--	--	0.1
04 Area Operator	061	42.1	0932-1630	2/12/79	--	--	--	--	--	--
04 Area Operator	085	47.6	0839-1634	2/15/79	0.1	0.1	--	--	--	0.1
04 Area Operator	092	48.3	0841-1645	2/16/79	--	--	--	--	--	--
08 Area Technician/ Specialist	059	46.7	0846-1632	2/12/79	--	--	--	--	--	--
08 Area Operator	091	48.4	0839-1644	2/16/79	--	--	--	--	--	--
Blanks (ug/sample)	028			2/11/79	--	--	--	--	--	--
	080			2/14/79	--	--	--	--	--	--

[a] Aromatic amines: A = Aniline; B = N,N-Dimethylaniline; C = o-Anisidine; D = p-Anisidine; E = o-Toluidine; F = 2,4-Dimethylaniline.

[b] Assuming a sample volume of 50 liters.

[c] "--" indicates not detected.

Table B-6. Plant A Area Sampling Analytical Results (ppm) for Benzene, Toluene, and Xylene (June 15-20, 1978)

Location Sampled	Sample Number	Sample Volume (ℓ)	Sampling Time	Date Collected	Compound (detection limit, ppm)[a]		
					Benzene (0.01)	Toluene (0.01)	Xylene (0.01)
Feeder Line to Slurry Mix Tank, Grade Level	006	29.0	0928-1404	6/15/78	--[b]	--	--
Feeder Line to Slurry Mix Tank, 1st Level	013	18.5	1410-1615	6/15/78	--	--	--
Filter	008	26.4	0943-1415	6/15/78	--	--	--
Filter	011	12.0	1420-1624	6/15/78	--	--	--
Solvent Bottoms Pump	017	17.1	0836-2328	6/16/78	--	--	--
Operator's Communication Booth	018	16.3	0836-2328	6/16/78	--	--	--
Operator's Communication Booth	023	21.4	1125-1500	6/16/78	--	--	--
Solvent Bottoms Pump	022	20.9	1130-1500	6/16/78	--	--	--
Downwind of Surge Reservoir	020	16.4	0855-2333	6/16/78	--	--	--
Downwind of Surge Reservoir	025	21.9	1140-1515	6/16/78	--	--	--
Blanks (µg/sample)	034			6/20/78	9	15	--
	035			6/20/78	9	16	--

[a] Assuming a sample volume of 25 liters.

[b] "--" indicates not detected.

Table B-7. Plant A Area Sampling Analytical Results (ppm) for Benzene, Toluene, and Xylene (February 11-15, 1979)

Location Sampled	Sample Number	Sample Volume (ℓ)	Sampling Time	Date Collected	Compound (detection limit, ppm)[a]		
					Benzene (0.01)	Toluene (0.01)	Xylene (0.01)
Slurry Mix Tank	042	55.1	1842-0355	2/11/79	0.02	0.03	0.03
Recycle Process Water Tank	083	47.9	0844-1642	2/15/79	0.04	0.09	0.06
04 Area Light Ends Column Reflux Pump	066	42.5	1918-0224	2/12/79	0.02	0.08	0.12
Sandvik Belt	117	47.3	0846-1638	2/11/79	--[b]	--	--
Blanks (µg/sample)	027			2/11/79	--	--	--
	081			2/14/79	--	--	--

[a] Assuming a sample volume of 50 liters.

[b] "--" indicates not detected.

Table B-8. Plant A Personal Sampling Analytical Results (ppm) for Benzene, Toluene, and Xylene (February 9-18, 1979)

Personnel Sampled	Sample Number	Sample Volume (l)	Sampling Time	Date Collected	Compound (detection limit, ppm)[a]		
					Benzene (0.02)	Toluene (0.01)	Xylene (0.02)
Laboratory Technician	071	48.0	0828-1628	2/13/79	--[b]	--	--
Laboratory Technician	070	48.9	0827-1630	2/13/79	--	--	--
Laboratory Technician	074	48.6	0915-1720	2/14/79	--	--	--
01 Unit Operator	043	53.4	0825-1532	2/11/79	0.02	0.06	0.04
01 Area Technician/Specialist	046	53.3	1909-0400	2/11/79	--	--	--
01 Unit Operator	062	41.3	1905-0200	2/12/79	--	0.02	0.04
03 Unit Operator	014	33.3	1248-1820	2/9/79	--	0.06	--
03 Unit Operator	064	43.9	1908-0226	2/12/79	--	0.01	--
03 Unit Operator	115	48.3	0839-1643	2/18/79	--	--	--
Blanks (ug/sample)	027			2/11/79	--	--	--
	081			2/14/79	--	--	--

[a] Assuming a sample volume of 50 liters.

[b] "--" indicates not detected.

PLANT B

Table B-9. Plant B Area Sampling Analytical Results ($\mu g/m^3$) for PNAs (May 14-24, 1979)..... B-13

Table B-10. Plant B Personal Sampling Analytical Results ($\mu g/m^3$) for PNAs (April 17-18, 1979; May 14-25, 1979)..... B-14

Table B-11. Plant B Area Sampling Analytical Results (mg/m^3) for Aromatic Amines (April 17, 1979; May 14-25, 1979)..... B-16

Table B-12. Plant B Personal Sampling Analytical Results (mg/m^3) for Aromatic Amines (April 17-18, 1979; May 13-25, 1979)..... B-17

Table B-13. Plant B Area and Personal Sampling Analytical Results (ppm) for Benzene, Toluene, and Xylene (April 17, 1979; May 14-23, 1979)..... B-

Table B-14. Plant B Area and Personal Sampling Analytical Results (mg/m^3) for Phenolic Compounds (April 18, 1979; May 14-25, 1979)..... B-

Table B-9. Plant B Area Sampling Analytical Results ($\mu g/m^3$) for PNAs (May 14-24, 1979)

Location Sampled:	Solvent Extraction (200 Area)		Solids Separation (300 Area)		Carbonization (800 Area)		Solvent Recovery (500 Area)		Fractionation (700 Area)		Hydrogenation (600 Area)		Blanks (µg/sample)	
Sample Number:	100	118	119	120	121	122	097	123	098	124	078	099	038	089
Sample Volume (ℓ):	2,187	2,257	2,499	2,487	2,310	2,539	2,812	2,320	2,070	2,382	2,790	2,685		
Sampling Time:	0826-2100	0900-2256	0903-2256	0907-2256	0910-2255	0915-2254	0813-2320	0927-2247	0816-2318	0914-2248	0755-2325	0823-2318		
Date Collected:	5/21/79	5/24/79	5/24/79	5/24/79	5/24/79	5/24/79	5/21/79	5/24/79	5/21/79	5/24/79	5/15/79	5/23/79	5/14	5/23
Compound (detection limit, $\mu g/m^3$)[a]														
Naphthalene (0.01)	8.0	16.2	14.4	10.7	14.2	12.8	22.9	11.1	19.6	7.4	11.5	18.8	--[b]	--
1-Methylnaphthalene (0.01)	10.3	21.2	27.0	0.02	13.2	10.0	--	14.0	31.5	9.0	28.7	0.02	--	--
2-Methylnaphthalene (0.01)	42.6	--	28.8	0.09	42.5	21.9	35.6	42.4	12.2	19.0	21.0	0.08	--	--
Quinoline (0.01)	0.4	1.4	0.6	2.4	1.3	0.2	3.5	0.5	1.4	0.7	0.2	2,4	--	--
Acenaphthalene (0.01)	0.3	0.05	0.3	1.0	0.1	0.05	1.0	0.1	0.2	0.06	0.1	0.9	--	--
Acenaphthene (0.01)	0.8	1.9	0.7	2.5	0.3	0.2	2.0	0.4	0.6	0.2	0.4	2.5	--	--
Fluorene (0.01)	0.5	1.2	0.4	1.6	0.2	0.1	1.0	0.2	0.4	0.3	0.2	1.7	--	--
Phenanthrene/Anthracene (0.01)	0.3	0.8	0.3	1.2	0.1	0.08	0.6	0.2	0.4	0.2	0.2	1.0	--	--
Acridine (0.01)	--	0.08	--	--	--	--	--	--	0.6	---	--	0.04	--	--
Carbazole (0.01)	--	0.03	0.02	--	--	--	0.01	--	--	0.2	--	0.2	--	--
Fluoranthene (0.01)	--	0.01	0.03	0.07	--	--	0.07	--	0.09	0.03	--	0.9	0.02	--
Pyrene (0.01)	0.1	0.3	0.3	0.7	0.07	0.01	0.5	0.04	0.6	0.2	0.8	0.3	0.02	--
Benzo(a)fluorene/ Benzo(b)fluorene (0.01)	0.02	0.04	0.04	0.2	0.03	--	0.02	--	0.2	0.03	--	--	0.002	--
Benz(a)anthracene/Chrysene/ Triphenylene (0.01)	--	--	--	0.02	0.02	--	--	--	0.05	--	0.04	0.06	--	--
Benzo(e)pyrene/ Benzo(a)pyrene (0.01)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Perylene (0.01)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,j)acridine (0.01)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)carbazole (0.01)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Indeno(1,2,3-cd)pyrene (0.01)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,h)anthracene (0.01)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene (0.01)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Anthanthrene (0.01)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coronene (0.06)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)pyrene (0.06)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dimethylbenz(a)anthracene (0.01)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL	63.3	43.3	72.9	20.5	72.0	45.4	67.2	68.9	67.9	37.4	63.1	28.9	0.04	0

[a] Assuming a sample volume of approximately 2,500 liters.

[b] "---" indicates not detected.

Table B-10. Plant B Personal Sampling Analytical Results ($\mu g/m^3$) for PNAs (April 17-18, 1979; May 14-25, 1979)

Personnel Sampled:	Operators											Shift Supervisors	
	200 Area			300/800 Area		500/700 Area			600/900 Area				
Sample Number:	050	096	112	105	111	074	094	131	016	097	133	095	106
Sample Volume (ℓ):	862	620	654	538	553	660	602	741	1,120	571	631	627	769
Sampling Time:	0744-1455	0802-1455	0828-1450	1541-2235	0820-1455	0735-1455	0804-1420	0717-1500	0735-1508	0803-1522	0724-1455	0756-1454	1534-2241
Date Collected:	5/14/79	5/23/79	5/24/79	5/23/79	5/24/79	5/15/79	5/23/79	5/25/79	4/18/79	5/23/79	5/25/79	5/23/79	5/23/79
Compound													
Naphthalene	0.05	0.03	0.05	0.02	0.04	0.02	0.08	0.05	--[a]	0.02	--	0.04	0.01
1-Methylnaphthalene	0.05	0.05	0.07	0.03	0.1	0.03	0.07	--	--	0.03	0.2	0.04	0.02
2-Methylnaphthalene	0.03	0.09	0.1	0.06	0.06	0.06	0.1	--	0.02	0.06	0.08	0.09	0.05
Quinoline	--	--	--	0.01	--	--	0.01	--	--	--	--	--	--
Acenaphthalene	--	--	--	--	--	--	--	--	--	--	--	--	--
Acenaphthene	--	--	--	--	--	--	--	--	--	--	--	--	--
Fluorene	--	--	--	--	--	--	--	--	--	--	--	--	--
Phenanthrene/Anthracene	--	--	--	--	--	--	--	--	--	--	--	--	--
Acridine	--	--	--	--	--	--	--	--	--	--	--	--	--
Carbazole	--	--	--	--	--	--	--	--	--	--	--	--	--
Fluoranthene	--	--	--	--	--	--	--	--	--	--	--	--	--
Pyrene	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(a)fluorene/ Benzo(b)fluorene	--	--	--	--	--	--	--	--	--	--	--	--	--
Benz(a)anthracene/ Chrysene/Triphenylene	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(e)pyrene/ Benzo(a)pyrene	--	--	--	--	--	--	--	--	--	--	--	--	--
Perylene	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,j)acridine	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)carbazole	--	--	--	--	--	--	--	--	--	--	--	--	--
Indeno(1,2,3-cd)pyrene	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,h)anthracene	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene	--	--	--	--	--	--	--	--	--	--	--	--	--
Anthanthrene	--	--	--	--	--	--	--	--	--	--	--	--	--
Coronene	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,l)pyrene	--	--	--	--	--	--	--	--	--	--	--	--	--
Dimethylbenz(a)anthracene	--	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL	0.1	0.2	0.2	0.1	0.2	0.1	0.3	0.05	0.02	0.1	0.3	0.2	0.08

[a] "--" indicates not detected.

(continued)

Table B-10 (concluded)

Personnel Sampled:	Maintenance Workers						Laboratory Workers						Blanks (µg/sample)		
	Millwrights				Pipefitters		Chemists			Technicians					
Sample Number:	005	012	020	023	002	010	008	052	116	009	019	051	039	086	094
Sample Volume (ℓ):	622	810	311	598	323	376	621	494	603	255	533	587			
Sampling Time:	-	0918-1603	0857-1530	0921-1535	0900-1335	0905-1521	0806-1500	0806-1535	0830-1541	0755-1500	0811-1501	0801-1500			
Date Collected:	4/17/79	4/17/79	4/18/79	4/18/79	4/17/79	4/17/79	4/17/79	5/14/79	5/24/79	4/18/79	5/14/79	5/23/79	5/14	5/23	5/23
Compound															
Naphthalene	0.01	0.04	0.1	0.03	--[a]	--	--	0.05	--	0.1	--	0.03	--	--	--
1-Methylnaphthalene	0.01	0.03	0.1	0.02	--	--	--	0.04	--	0.08	--	0.02	0.4	0.1	0.2
2-Methylnaphthalene	0.03	0.08	0.2	0.05	0.01	0.01	0.02	0.08	0.01	0.1	0.02	0.04	--	--	--
Quinoline	--	0.02	0.01	--	--	--	--	--	--	--	--	--	--	--	--
Acenaphthalene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acenaphthene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Fluorene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Phenanthrene/Anthracene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acridine	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Carbazole	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Fluoranthene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Pyrene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(a)fluorene/ Benzo(b)fluorene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benz(a)anthracene/ Chrysene/Triphenylene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(e)pyrene/ Benzo(a)pyrene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Perylene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,j)acridine	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)carbazole	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Indeno(1,2,3-cd)pyrene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,h)anthracene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Anthanthrene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coronene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)pyrene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dimethylbenz(a)anthracene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL	0.05	0.2	0.4	0.1	0.01	0.02	0.02	0.2	0.01	0.3	0.02	0.09	0.4	0.1	0.2

[a] "--" indicates not detected.

Table B-11. Plant B Area Sampling Analytical Results (mg/m^3) for Aromatic Amines (April 17, 1979; May 14-25, 1979)

Location Sampled	Sample Number	Sample Volume (l)	Sampling Time	Date Collected	Aromatic Amines[a] (detection limit, mg/m^3)[b]						
					A (0.2)	B (0.2)	C (0.2)	D (0.3)	E (0.2)	F (0.3)	G (0.3)
Solvent Extraction	135	43	0730-1500	5/25/79	--[c]	--	--	--	--	--	--
Solids Separation	054	92	0819-1603	5/14/79	--	--	--	--	--	--	--
	100	79	0830-1530	5/23/79	--	--	--	--	--	--	--
Carbonization	053	46	0821-1601	5/14/79	--	--	--	--	--	--	--
	099	41	0834-1530	5/23/79	--	--	--	--	--	--	--
Solvent Recovery	108	47	1600-2319	5/23/79	--	--	--	--	--	--	--
	117	60	0920-1545	5/24/79	--	--	--	--	--	--	--
Fractionation	055	44	0825-1604	5/14/79	--	--	--	--	--	--	--
Hydrogenation	014	45	0853-1620	4/17/79	--	--	--	--	--	--	--
	082	45	1538-2326	5/15/79	--	--	--	--	--	--	--
Tank Farm	015	44	0900-1626	4/17/79	--	--	--	--	--	--	--
Environmental Area	056	46	0829-1630	5/14/79	--	--	--	--	--	--	--
Blanks (mg/sample)	087-1			5/23/79	--	--	--	--	--	--	--
	144			5/25/79	--	--	--	--	--	--	--
	145			5/25/79	--	--	--	--	--	--	--
	146			5/25/79	--	--	--	--	--	--	--

[a]Aromatic amines: A = Aniline; B = N,N-Dimethylaniline; C = 2,4-Dimethylaniline; D = p-Nitroaniline; E = o-Toluidine; F = o-Anisidine; G = p-Anisidine.

[b]Assuming a sample of approximately 80 liters. [c]"--" indicates not detected.

Table B-12. Plant B Personal Sampling Analytical Results (mg/m^3) for Aromatic Amines (April 17-18, 1979; May 13-25, 1979)

Personnel Sampled	Sample Number	Sample Volume (l)	Sampling Time	Date Collected	Aromatic Amines[a] (detection limit, mg/m^3)[b]						
					A (0.2)	B (0.2)	C (0.2)	D (0.3)	E (0.2)	F (0.3)	G (0.3)
Operators											
200 Area	027	42	1622-2303	5/13/79	--[c]	--	0.6	--	--	--	--
	073	91	0733-1458	5/15/79	--	--	--	--	--	--	--
	134	44	9733-1455	5/25/79	--	--	--	--	--	--	--
300/800 Area	045	49	0742-1448	5/14/79	--	--	--	--	--	--	--
	046	89	0743-1502	5/14/79	--	--	--	--	--	--	--
	057	61	1528-2357	5/14/79	--	--	0.6	--	--	--	--
500/700 Area	103	84	1542-2248	5/23/79	--	--	--	--	--	--	--
	114	38	0817-1448	5/24/79	--	--	--	--	--	--	--
	138	75	1610-2258	5/25/79	--	--	--	--	--	--	--
600/900 Area	006	88	0740-1506	4/17/79	--	--	--	--	--	--	--
	044	82	0740-1530	5/14/79	--	--	--	--	--	--	--
	101	91	1523-2300	5/23/79	--	--	--	--	--	--	--
	109	57	1603-2318	5/23/79	--	--	--	--	--	--	--
1100/1200 Area	033	48	1620-2306	5/13/79	--	--	--	--	--	--	--
	034	40	1625-2315	5/13/79	--	--	--	--	--	--	--
	047	45	0750-1448	5/14/79	--	--	0.6	--	--	--	--
	104	41	1547-2252	5/23/79	--	--	--	--	--	--	--
Supervisors											
Operations	011	68	0925-1510	4/17/79	--	--	--	--	--	--	--
	048	43	0750-1555	5/14/79	--	--	0.4	--	--	--	--
Shift	061	84	1554-2359	5/14/79	--	--	0.3	--	--	--	--
Maintenance Workers											
Millwright	026	48	0937-1535	4/18/79	--	--	--	--	--	--	--
Insulators	021	40	0903-1530	4/18/79	--	--	--	--	--	--	--
	022	37	0910-1530	4/18/79	--	--	--	--	--	--	--
Pipefitters	024	75	0915-1543	4/18/79	--	--	--	--	--	--	--
	025	62	0916-1543	4/18/79	--	--	--	--	--	--	--
Laboratory Workers											
Chemists	075	82	0810-1550	5/15/79	--	--	--	--	--	--	--
	098	47	0847-1547	5/23/79	--	--	--	--	--	--	--
	136	42	0800-1543	5/25/79	--	--	--	--	--	--	--
Technicians	017	83	0800-1500	4/18/79	--	--	--	--	--	--	--
	018	80	0809-1501	4/18/79	--	--	--	--	--	--	--
	049	41	0804-1504	5/14/79	--	--	--	--	--	--	--
	062	46	1546-2300	5/14/79	--	--	--	--	--	--	--
Blanks (mg/sample)	087-1			5/23/79	--	--	--	--	--	--	--
	144			5/25/79	--	--	--	--	--	--	--
	145			5/25/79	--	--	--	--	--	--	--
	146			5/25/79	--	--	--	--	--	--	--

[a]Aromatic amines: A = Aniline; B = N,N-Dimethylaniline; C = 2,4-Dimethylaniline; D = p-Nitroaniline; E = o-Toluidine; F = o-Anisidine; G = p-Anisidine

[b]Assuming a sample volume of approximately 80 liters.

[c]"--" indicates not detected.

Table B-13. Plant B Area and Personal Sampling Analytical Results (ppm) for Benzene, Toluene, and Xylene (April 17, 1979; May 14-23, 1979)

	Sample Number	Sample Volume (ℓ)	Sampling Time	Date Collected	Compound (detection limit, ppm)[a]		
					Benzene (0.04)	Toluene (0.02)	Xylene (0.01)
Location Sampled							
Hydrogenation	013	42	0852-1620	4/17/79	--[b]	0.06	--
Fractionation	084	47	1547-2327	5/15/79	--	0.03	--
Personnel Sampled							
Laboratory Technician	064	57	1550-2300	5/14/79	--	0.02	--
	076	85	0740-1448	5/15/79	--	0.08	--
	077	46	0742-1447	5/15/79	--	0.03	--
Blanks (mg/sample)	041			5/14/79	--	--	--
	088			5/23/79	--	--	--

[a]Assuming a sample volume of 40 liters. [b]"--" indicates not detected.

Table B-14. Plant B Area and Personal Sampling Analytical Results (mg/m^3) for Phenolic Compounds (April 18, 1979; May 14-25, 1979)

	Sample Number	Sample Volume (ℓ)	Sampling Time	Date Collected	Phenolic Compounds[a] (detection limit, mg/m^3)[b]								
					A	B	C	D	E	F	G	H	I
Location Sampled													
Carbonization	099	41	0834-1530	5/23/79	--[c]	--	--	--	--	--	--	--	--
Environmental Area	056	46	0829-1630	5/14/79	--	--	--	--	--	--	--	--	--
Laboratory	062	46	1546-2300	5/14/79	--	--	--	--	--	--	--	--	--
Personnel Sampled													
Operators:													
600/900 Area	109	57	1603-2318	5/23/79	--	--	--	--	--	--	--	--	--
1100/1200 Area	034	40	1625-2315	5/13/79	--	--	--	--	--	--	--	--	--
Maintenance:													
Millwright	026	48	0937-1535	4/18/79	--	--	--	--	--	--	--	--	--
Blanks (mg/sample)	040			5/14/79	--	--	--	--	--	--	--	--	--
	087			5/23/79	--	--	--	--	--	--	--	--	--
	145			5/25/79	--	--	--	--	--	--	--	--	--

[a]Phenolic compounds: A = Phenol; B = o-Ethylphenol; C = p-Ethylphenol; D = o-Cresol; E = m-Cresol; F = p-Cresol; G = 2,3-Xylenol; H = 2,5-Xylenol; I = 3,5-Xylenol.
[b]Assuming a sample volume of 45 liters. [c]"--" indicates not detected.

PLANT C

Table B-15. Plant C Area Sampling Analytical Results ($\mu g/m^3$) for PNAs (November 12-17, 1979)..... B-20

Table B-16. Plant C Personal Sampling Analytical Results ($\mu g/m^3$) for PNAs (November 12-17, 1979)..... B-21

Table B-17. Plant C Personal and Area Sampling Analytical Results (mg/m^3) for Aromatic Amines (November 12-17, 1979)..... B-22

Table B-18. Plant C Personal and Area Sampling Analytical Results (ppm) for Benzene, Toluene, and Xylene (November 12-17, 1979)..... B-23

Table B-19. Plant C Area Sampling Analytical Results (mg/m^3) for Phenolics (November 12-17, 1979)..... B-24

Table B-15. Plant C Area Sampling Analytical Results ($\mu g/m^3$) for PNAs (November 12-17, 1979)

Sample Location:	CIRCULATION PUMP P143	SLURICE PUMP P178	FEED PUMP P111	WASH SOLVENT PUMP P169	FILTER SCRUBBER PUMP P125	REFLUX PUMP P139	LIQUID COAL PUMP P119	LET-DOWN VALVE 415	SLURRY FEED PUMP P103	FILTER F103	FRACTIONATING COLUMN T105	FLUSH SOLVENT PUMP P203	PRODUCT COOLER K125	BLANKS[a]	
Sample Number:	017	021	022	035	036	037	044	048	057	058	059	069	108	024	049
Sample Volume (ℓ):	1,253	1,737	1,488	1,030	1,488	1,308	1,140	1,325	1,248	1,507	1,205	1,408	1,154		
Sample Time:	1446-2230	1456-2233	1501-2232	0654-1506	0650-1505	0654-1507	1450-2245	1503-2240	0645-1504	0700-1506	0708-1510	1431-2231	0655-1456		
COMPOUND															
Naphthalene	2.4	3.8	2.7	1.6	0.9	9.02	4.5	--[b]	--	--	1.2	6.8	3.0	--	0.03
Quinoline	0.05	0.02	0.1	--	0.02	0.1	0.1	--	--	--	--	0.05	0.2	--	--
2-Methylnaphthalene	6.6	2.9	4.08	1.0	1.3	7.6	7.6	--	--	--	1.0	5.6	4.2	--	--
1-Methylnaphthalene	1.4	0.4	0.8	0.2	0.2	1.09	1.1	--	--	--	0.2	1.1	0.8	--	--
Acenaphthalene	0.06	--	0.02	--	--	--	0.03	--	--	--	--	0.03	0.03	--	--
Acenaphthene	0.9	0.1	0.5	0.06	0.06	0.3	1.4	--	0.02	--	0.08	0.5	0.7	--	--
Fluorene	0.5	0.2	0.3	0.06	0.04	0.2	0.9	--	0.06	--	0.04	0.3	0.06	--	--
Phenanthrene/Anthracene	1.4	0.5	1.1	0.3	0.1	0.8	1.6	--	0.5	0.2	0.2	0.8	3.5	0.05	0.01
Acridine	--	--	0.01	--	0.01	--	0.02	--	--	--	--	--	0.05	--	--
Carbazole	--	--	0.02	--	--	0.03	0.03	--	--	--	--	--	0.1	--	--
Fluoranthene	0.2	0.06	0.2	0.05	0.03	0.2	0.2	--	0.06	0.06	--	0.09	1.03	--	--
Pyrene	0.08	0.04	0.1	0.05	0.01	0.2	0.08	--	0.04	0.05	--	0.05	0.5	--	--
Benzo(a)fluorene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(b)fluorene	--	--	--	--	--	--	--	--	--	--	--	--	0.2	--	--
Benz(a)anthracene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Chrysene/Triphenylene	--	--	--	--	--	--	--	--	--	--	--	--	0.1	--	--
Dimethylbenz(a)anthracene	--	--	--	--	--	--	--	--	--	--	--	--	0.03	--	--
Benzo(e)pyrene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(a)pyrene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Perylene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,j)acridine	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)carbazole	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Indeno(1,2,3-cd)pyrene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenzanthracene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Anthanthrene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coronene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenzpyrene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL	13.6	8.02	9.9	3.3	2.7	19.5	17.6	--	0.7	0.3	2.7	15.3	15.3	0.05	0.04

[a] Blanks measured in µg/sample.

[b] "--" indicates compound was not detected.

Table B-16. Plant C Personal Sampling Analytical Results (μg/m³) for PNAs (November 12-17, 1979)

Sample Location:	OPERATOR				MAINTENANCE							LABORATORY TECHNICIAN			BLANKS[a]	
	C	C	D	D	Pipe-fitter	Insu-lator	Insu-lator	Oiler	Instru-	Mill-wright	Mill-wright	Chemist	Chemist	Chemist		
Sample Number:	038	053	014	054	006	007	008	012	002	011	001	041	068	076	025	050
Sample Volume (ℓ):	828	720	610	539	611	614	620	792	744	554	683	720	599	802		
Sample Time:	1435-2215	0635-1405	1431-2220	0646-1415	0720-1510	0721-1513	0723-1520	0729-1515	0700-1516	0728-1510	0700-1508	1440-2210	1436-2217	0631-1423		
COMPOUND																
Naphthalene	9.5	--[b]	2.6	2.2	4.8	9.5	2.9	1.8	2.5	11.5	1.4	0.8	19.4	3.3	--	--
Quinoline	0.05	--	0.04	0.04	0.1	0.2	0.09	0.01	0.09	0.3	0.07	0.04	0.2	0.2	--	--
2-Methylnaphthalene	9.3	--	3.3	5.2	12.09	13.1	5.6	1.9	5.9	11.2	3.9	1.8	17.2	4.3	--	--
1-Methylnaphthalene	1.4	--	0.8	0.9	1.9	3.0	1.06	0.4	1.0	2.1	0.7	0.3	3.4	1.0	--	--
Acenaphthalene	0.01	--	--	--	0.01	0.01	--	--	0.05	0.03	--	--	0.1	--	--	--
Acenaphthene	0.4	--	0.3	0.5	0.8	1.1	0.4	0.1	0.4	0.7	0.3	0.1	1.0	0.3	--	--
Fluorene	0.2	--	0.2	0.2	0.4	0.7	0.2	0.09	0.5	0.5	0.2	0.9	0.8	0.2	--	--
Phenanthrene/Anthracene	0.5	0.05	0.8	0.8	1.2	1.4	0.7	0.3	0.6	1.0	1.0	0.4	1.4	0.6	--	--
Acridine	--	--	--	--	--	--	--	--	--	0.01	--	--	0.03	--	--	--
Carbazole	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Fluoranthene	0.02	--	0.1	0.06	0.1	0.08	0.05	0.07	0.07	0.07	0.09	0.05	0.06	0.04	--	--
Pyrene	0.01	--	0.09	0.02	0.09	0.09	0.04	0.04	0.04	0.06	0.06	0.05	0.06	0.02	--	--
Benzo(a)fluorene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(b)fluorene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benz(a)anthracene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Chrysene/Triphenylene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dimethylbenz(a)anthracene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(e)pyrene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(a)pyrene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Perylene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,j)acridine	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)carbazole	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Indeno(1,2,3-cd)pyrene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenzanthracene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Anthanthrene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coronene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenzpyrene	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL	21.4	0.05	8.2	9.9	21.5	29.2	11.04	4.7	11.2	27.5	7.7	4.4	43.6	10.0	--	--

[a] Blanks measured in μg/sample.

[b] "--" indicates compound not detected.

Table B-17. Plant C Personal and Area Sampling Analytical Results (mg/m^3) for Aromatic Amines (November 12-17, 1979)

	PERSONAL SAMPLES											
Sample Location:	OPERATOR			MAINTENANCE					LABORATORY			
	C	D	D	Pipe-fitter	Instru-ment	Instru-ment	Instru-ment	Mill-wright	Analyst	Tech-nician	Chemist	Chemist
Sample Number:	045	074	096	009	033	034	079	080	001	002	003	005
Sample Volume (ℓ):	47	48	41	48	44	43	48	50	43	39	48	48
Sample Time:	0625-1410	0700-1457	0657-1412	0721-1514	0702-1456	0700-1457	0705-1500	0658-1507	0710-1414	0715-1415	0720-1515	0723-1513
COMPOUND												
Aniline (0.2) [a]	--[b]	--	--	--	--	--	--	--	--	--	--	--
N,N-Dimethylaniline (0.2)	--	--	--	--	--	--	--	--	0.3	0.4	--	--
2,4-Dimethylaniline (0.2)	--	--	--	--	--	--	--	--	--	--	--	--
p-Nitroaniline (0.3)	--	--	--	--	--	--	--	--	--	--	--	--
o-Toluidine (0.2)	--	--	--	--	--	--	--	--	--	--	--	--
o-Anisidine (0.3)	--	--	--	--	--	--	--	--	--	--	--	--
p-Anisidine (0.3)	--	0.8	--	--	--	--	--	--	--	--	--	--
1-Naphthylamine (0.4)	--	--	--	--	--	--	--	--	--	--	--	--

	AREA SAMPLES													
Sample Location:	BLEND TANK P102	FEED PUMP P111	SLUICE PUMP P178	WASH SOLVENT PUMP P169	FLUSH SOLVENT PUMP P203	REFLUX PUMP P139	CIRCU-LATION PUMP P143	LET-DOWN VALVE 415	FILTER SCRUBBER PUMP P125	FILTER F103	FRACTION-ATING COLUMN T105	BLANKS (mg/sample)		
Sample Number:	104	060	101	019	018	062	102	061	106	098	103	023	040	094
Sample Volume (ℓ):	49	49	50	47	107	53	48	49	50	49	125			
Sample Time:	0701-1504	0708-1511	0658-1503	0250-1032	0243-1030	0645-1505	0631-1433	0700-1308	0640-1443	0650-1455	0625-1425			
COMPOUND														
Aniline (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
N,N-Dimethylaniline (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2,4-Dimethylaniline (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
p-Nitroaniline (0.3)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
o-Toluidine (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
o-Anisidine (0.3)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
p-Anisidine (0.3)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1-Naphthylamine (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--

[a] Number in parenthesis indicates detection limit in mg/m^3 and assumes a sample volume of about 45 liters.

[b] "--" indicates compound was not detected.

Table B-18. Plant C Personal and Area Sampling Analytical Results (ppm) for Benzene, Toluene, and Xylene (November 12-17, 1979)

	PERSONAL SAMPLES												
Sample Location:	OPERATOR				MAINTENANCE			LABORATORY			BLANKS (mg/sample)		
	C	C	D	D	Mill wright	Mill-wright	Instru-ment	Chemist	Chemist	Chemist			
Sample Number:	029	066	032	040	063	064	031	055	056	092	026	052	091
Sample Volume (ℓ):	46	109	43	47	49	49	47	45	46	108			
Sample Time:	0636-1415	1423-2215	0640-1350	1425-2215	0703-1503	0704-1514	0705-1454	0650-1416	0642-1418	1425-2215			
COMPOUND													
Benzene (0.01)[a]	--[b]	--	--	--	--	--	--	--	--	--	0.004	0.004	0.004
Toluene (0.01)[a]	--	--	--	--	--	--	--	--	--	--	0.002	0.002	0.002
Xylene (0.01)[a]	--	--	--	--	--	--	--	--	--	--	0.002	0.002	0.002

	AREA SAMPLES										
Sample Location:	CIRCU-LATING PUMP P143	FEED PUMP P111	BLEND TANK V101	SLUICE PUMP P178	VACUUM PUMP T102	SOLVENT PUMP P203	LETDOWN VALVE 415	FILTER F103	SCRUBBER PUMP P125	FRACTION-ATING PUMP P151	SOLVENT PUMP P169
Sample Number:	045	046	097	071	078	043	028	030	099	100	105
Sample Volume (ℓ):	47	47	48	47	47	49	46	46	48	110	44
Sample Time:	1453-2245	1456-2245	0635-1435	1442-2234	0641-1435	1446-2245	0643-1425	0646-1422	0640-1443	0628-1427	0643-1445
COMPOUND											
Benzene (0.01)[a]	--[b]	--	--	--	--	--	--	--	--	--	--
Toluene (0.01)[a]	--	--	--	--	--	--	--	--	--	--	--
Xylene (0.01)[a]	--	--	--	--	--	--	--	--	--	--	--

[a] Detection limit in ppm.

[b] "--" indicates compound was not detected.

Table B-19. Plant C Area Sampling Analytical Results (mg/m^3) for Phenolics (November 12-14, 1979)

Sample Location:	CAUSTIC PUMP P106	HOT WELL	BLANKS (mg/sample)	
Sample Number:	020	070	027	051
Sample Volume (ℓ):	48	48		
Sample Time:	1452-2234	1434-2232		
COMPOUND				
Phenol (0.3)[a]	--[b]	--	--	--
o-Cresol (0.3)	--	--	--	--
m-Cresol (0.3)	--	--	--	--
p-Cresol (0.3)	--	--	--	--
o-Ethylphenol (0.7)	--	--	--	--
p-Ethylphenol (0.7)	--	--	--	--
2,3-Xylenol (0.7)	--	--	--	--
2,4-Xylenol (0.7)	--	--	--	--

[a] Number in parenthesis indicates detection limit in mg/m^3.

[b] "--" indicates compound was not detected.

PLANT D

Table B-20. Plant D Area Sampling Analytical Results ($\mu g/m^3$) for PNAs (May 18-23, 1981)..... B-26

Table B-21. Plant D Personal Sampling Analytical Results ($\mu g/m^3$) for PNAs (May 18-23, 1981)..... B-29

Table B-22. Plant D Blanks Sampling Analytical Results (μg/sample) for PNAs (May 18-23, 1981)..... B-31

Table B-23. Plant D Wipe Sampling Analytical Results for PNAs (May 23, 1981)..... B-32

Table B-24. Plant D Bulk Sampling Analytical Results for PNAs (May 23, 1981)..... B-33

Table B-25. Plant D Area Sampling Analytical Results (mg/m^3) for Aromatic Amines (May 18-23, 1981)..... B-34

Table B-26. Plant D Personal Sampling Analytical Results (mg/m^3) for Aromatic Amines (May 18-23, 1981)..... B-35

Table B-27. Plant D Area Sampling Analytical Results (ppm) for Benzene, Toluene, and Xylene (May 18-23, 1981)..... B-36

Table B-28. Plant D Personal Sampling Analytical Results (ppm) for Benzene, Toluene, and Xylene (May 18-23, 1981)..... B-37

Table B-29. Plant D Area and Personal Sampling Analytical Results (mg/m^3) for Phenolic Compounds (May 19-23, 1981)..... B-38

Table B-20. Plant D Area Sampling Analytical Results ($\mu g/m^3$) for PNAs (May 18-23, 1981)

Location Sampled:	Main Control House Site 1			CPU Control Room Site 2		High-Pressure Slurry Feed Pump P-102 Site 3			Reactor Separator Pump P-106 Site 4		Atmospheric Fractionator Light Gas/Oil Pump P-202 Site 5		
Sample Number:	4-027	4-104	4-182	4-004	4-200	4-060*	4-090*	4-149*	4-021	4-144*	4-005	4-105	4-181*
Sample Volume (l):	1,218	1,098	1,310	1,327	1,157	1,247	1,391	1,229	1,157	1,253	1,248	1,098	1,246
Sampling Time:	0811-1652	0730-1700	0846-1752	1628-0141	2043-0445	2117-0548	0840-1810	2034-0518	0905-1659	0941-1823	1634-0204	1950-0528	0905-1744
Date Collected:	5/19/81	5/20/81	5/22/81	5/18/81	5/22/81	5/19/81	5/20/81	5/21/81	5/19/81	5/21/81	5/18/81	5/20/81	5/22/81
Compound (detection limit, $\mu g/m^3$)[a]													
Naphthalene (0.2)	7.9	8.7	21.7	18.3	21.1	59.4	267.9	223.1	31.3	18.8	137.4	387.5	306.9
1-Methylnaphthalene (0.2)	2.5	2.9	11.8	6.7	14.3	13.1	48.6	54.5	4.4	4.2	46.3	66.3	59.4
2-Methylnaphthalene (0.2)	9.6	9.2	39.9	35.7	51.6	50.5	172.2	162.4	25.6	17.0	152.4	243.3	201.4
Quinoline (0.2)	--[b]	--	--	--	--	--	--	--	--	--	--	--	--
Acenaphthalene (0.2)	--	--	--	--	0.5	0.6	2.5	1.6	--	0.3	--	1.4	2.6
Acenaphthene (0.2)	1.3	1.6	2.7	2.3	4.1	3.0	10.4	8.8	1.6	1.5	15.3	7.9	17.4
Fluorene (0.2)	2.0	1.9	4.6	--	5.9	6.0	18.6	12.5	2.2	3.3	11.9	4.2	14.4
Phenanthrene/Anthracene (0.2)	--	1.1	1.9	1.9	2.4	3.0	6.0	10.7	1.8	3.1	14.7	6.3	15.0
Acridine (0.2)	--	0.6	--	--	--	--	1.1	--	--	--	0.7	--	0.7
Carbazole (0.2)	--	--	--	--	--	--	--	0.2	--	--	--	--	--
Fluoranthene (0.2)	--	--	--	--	--	--	0.2	0.4	--	--	0.9	--	0.8
Pyrene (0.2)	--	--	--	--	--	0.2	0.5	0.5	--	0.3	1.4	--	1.1
Benzo(a)fluorene/ Benzo(b)fluorene (0.2)	--	--	--	--	--	--	--	--	--	--	1.2	--	0.7
Benz(a)anthracene/Chrysene/ Triphenylene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(j)fluoranthene/ Benzo(b)fluoranthene/ Benzo(k)fluoranthene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(e)pyrene/ Benzo(a)pyrene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--
Perylene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,j)acridine (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)carbazole (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--
Indeno(1,2,3-cd)pyrene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,h)anthracene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--
Coronene (0.5)	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)pyrene (0.8)	--	--	--	--	--	--	--	--	--	--	--	--	--
Dimethylbenz(a)anthracene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--
3-Methylcholanthrene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--
6,13-Dimethylbenz(a,h)-anthracene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL	23.3	26.0	82.6	64.9	99.9	135.8	528.0	474.7	66.9	48.5	382.2	716.9	622.4

[a] Assuming a sample volume of 1,200 liters.

[b] "--" indicates not detected.

*Methyltetralins, which co-elute with naphthalene, detected in sample.

(continued)

Table B-20 (continued)

Location Sampled:	Atmospheric Fractionator Bottoms Pump P-204 Site 6			Vacuum Stripper Light Gas/Oil Pump P-207 Site 7			Vacuum Stripper Heavy Gas/Oil Pump P-208 Site 8			Vacuum Stripper Bottoms Pump P-210 *** Site 9		
Sample Number:	4-062*	4-141	4-198	4-025	4-100*	4-138*	4-063	4-104	4-225	4-080	4-199	4-226
Sample Volume (l):	1,252	1,262	1,174	1,108	1,090	1,270	1,249	1,267	1,010	1,405	1,135	1,164
Sampling Time:	2110-0541	0914-1820	2101-0510	0848-1655	1950-0520	0928-1017	2101-0533	0859-1747	0726-1436	0825-1801	2114-0507	0740-1545
Date Collected:	5/19/81	5/21/81	5/22/81	5/19/81	5/20/81	5/21/81	5/19/81	5/22/81	5/23/81	5/20/81	5/22/81	5/23/81
Compound (detection limit, $\mu g/m^3$)[a]												
Naphthalene (0.2)	351.4	830.7	79.0	2.0	1,261.1	1,822.9	--[b]	10.0	2.4	25.9	32.1	15.9
1-Methylnaphthalene (0.2)	162.5	619.6	47.5	0.5	406.7	368.0	--	4.3	2.1	10.2	38.8	8.5
2-Methylnaphthalene (0.2)	249.7	819.7	104.4	1.4	1,771.0	1,115.6	--	8.1	4.2	24.0	90.6	23.7
Quinoline (0.2)	--	--	--	--	--	--	--	--	--	--	--	--
Acenaphthalene (0.2)	8.8	18.6	1.6	--	0.5	5.9	--	0.1	--	0.8	2.5	1.2
Acenaphthene (0.2)	25.8	24.4	24.8	--	61.8	54.6	--	1.8	0.9	12.7	20.4	12.6
Fluorene (0.2)	21.9	38.1	21.0	0.3	77.5	43.0	--	2.4	1.6	13.7	33.9	10.8
Phenanthrene/Anthracene (0.2)	15.6	31.6	41.1	0.9	123.0	28.1	--	1.9	2.7	20.3	116.3	11.0
Acridine (0.2)	--	0.6	4.3	--	9.1	2.7	--	--	--	1.1	4.5	0.8
Carbazole (0.2)	--	0.6	0.9	--	--	--	--	--	--	0.4	2.0	0.5
Fluoranthene (0.2)	0.8	2.5	13.1	--	11.7	1.3	--	0.2	0.2	1.5	4.5	1.4
Pyrene (0.2)	1.5	4.9	22.5	--	14.3	1.8	--	0.4	0.4	2.8	6.7	2.2
Benzo(a)fluorene/ Benzo(b)fluorene (0.2)	--	0.8	17.7	--	1.0	0.7	--	--	--	1.0	4.6	1.9
Benz(a)anthracene/Chrysene/ Triphenylene (0.2)	--	--	2.5	--	--	--	--	--	--	--	0.2	--
Benzo(j)fluoranthene/ Benzo(b)fluoranthene/ Benzo(k)fluoranthene (0.2)	--	--	0.3	--	--	--	--	--	--	--	--	--
Benzo(e)pyrene/ Benzo(a)pyrene (0.2)	--	--	0.5	--	--	--	--	--	--	--	--	--
Perylene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,j)acridine (0.2)	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)carbazole (0.2)	--	--	--	--	0.5	--	--	--	--	--	--	--
Indeno(1,2,3-cd)pyrene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,h)anthracene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--
Coronene (0.3)	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)pyrene (0.8)	--	--	--	--	--	--	--	--	--	--	--	--
Dimethylbenz(a)anthracene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--
3-Methylcholanthrene (0.2)	--	--	0.4	--	--	--	--	--	--	--	--	--
6,13-Dimethylbenz(a,h)-anthracene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL	830.0	2,412.1**	381.6	5.1	3,738.2	3,444.6	--	31.4	14.5	114.4	357.1	119.3

[a] Assuming a sample volume of 1,200 liters.

[b] "--" indicates not detected.

*Methyltetralins, which co-elute with naphthalene, detected in sample.

**This sample was taken during a plant emergency; a stream from elsewhere in the plant was diverted through this pump. Therefore, it would not be considered representative.

***Not representative of a commercial plant.

(continued)

Table B-20 (concluded)

Location Sampled:	Solvent Fractionator Side Stream Pumps P-306, P-307 Site 10		Solvent Fractionator Bottoms Pump P-308 Site 11			High-Pressure Flush Oil Pump P-113 Site 12		Oily Water Sump Site 13		Upwind Perimeter		
Sample Number:	4-026	4-150*	4-008*	4-107	4-197	4-135	4-224	4-061	4-148*	4-093	4-151	4-185
Sample Volume (ℓ):	1,166	1,272	1,376	1,100	1,200	1,308	1,198	1,247	1,253	1,364	1,184	1,226
Sampling Time:	0858-1656	2025-0515	1646-0210	1935-0506	2054-0514	0919-1815	0721-1540	2123-0554	2041-0523	0905-1824	2051-0528	0909-1740
Date Collected:	5/19/81	5/21/81	5/18/81	5/20/81	5/22/81	5/21/81	5/23/81	5/19/81	5/21/81	5/20/81	5/21/81	5/22/81
Compound (detection limit, $\mu g/m^3$)[a]												
Naphthalene (0.2)	14.1	1,638.0	553.8	24.1	2.3	22.0	13.7	10.4	791.1	--[b]	1.1	0.9
1-Methylnaphthalene (0.2)	12.3	246.7	32.4	4.7	1.4	5.5	5.3	2.6	88.6	--	--	--
2-Methylnaphthalene (0.2)	24.4	1,099.6	211.7	11.9	6.7	14.7	15.6	12.0	291.1	--	0.2	0.3
Quinoline (0.2)	--	--	--	--	--	--	--	--	--	--	--	--
Acenaphthalene (0.2)	1.2	0.7	1.5	--	--	0.8	0.4	--	1.3	--	--	--
Acenaphthene (0.2)	2.3	4.0	1.9	1.5	0.8	4.9	1.2	1.1	7.4	--	--	--
Fluorene (0.2)	8.7	6.2	8.7	2.2	2.3	10.4	2.7	1.0	6.7	--	--	--
Phenanthrene/Anthracene (0.2)	8.0	3.3	9.3	2.2	2.4	12.8	2.8	0.3	3.4	--	--	--
Acridine (0.2)	1.8	--	0.5	--	--	0.6	--	--	--	--	--	--
Carbazole (0.2)	--	--	--	--	--	0.3	0.3	--	--	--	--	--
Fluoranthene (0.2)	0.4	--	1.0	--	--	1.1	0.3	--	--	--	--	--
Pyrene (0.2)	0.3	0.2	2.1	0.4	0.2	1.6	0.4	--	0.4	--	--	--
Benzo(a)fluorene/ Benzo(b)fluorene (0.2)	--	--	1.0	--	--	0.4	--	--	--	--	--	--
Benz(a)anthracene/Chrysene/ Triphenylene (0.2)	--	0.3	--	--	--	--	--	--	--	--	--	--
Benzo(j)fluoranthene/ Benzo(b)fluoranthene/ Benzo(k)fluoranthene (0.2)	--	--	0.7	--	--	--	--	--	--	--	--	--
Benzo(e)pyrene/ Benzo(a)pyrene (0.2)	--	--	0.3	--	--	--	--	--	--	--	--	--
Perylene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,j)acridine (0.2)	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)carbazole (0.2)	--	--	--	--	--	--	--	--	--	--	--	--
Indeno(1,2,3-cd)pyrene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,h)anthracene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--
Coronene (0.8)	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)pyrene (0.8)	--	--	--	--	--	--	--	--	--	--	--	--
Dimethylbenz(a)anthracene (0.2)	--	--	0.9	--	--	--	--	--	--	--	--	--
3-Methylcholanthrene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--
6,11-Dimethyldibenz(a,h)-anthracene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL	71.5	2,999.0	825.8	47.0	16.1	75.1	42.7	27.4	1,190.0	--	1.3	1.2

[a] Assuming a sample volume of 1,200 liters.

[b] "--" indicates not detected.

*Methyltetralins, which co-elute with naphthalene, detected in sample.

Table B-21. Plant D Personal Sampling Analytical Results (μg/m³) for PNAs (May 18-23, 1981)

Personnel Sampled:	Process Technicians (Operators)																
	Liquefaction-Distillation Unit									Solvent Hydrogenation Unit			Coal Preparation Unit			Offsite & Utilities	
	#1			#2			#3										
Sample Number:	4-116	4-171	4-210	4-101[a]	4-117	4-211[a]	4-011	4-049	4-133[a]	4-059[a]	4-134	4-219	4-118	4-170	4-218	4-048	4-132
Sample Volume (ℓ):	776	759	588	714	660	630	732	723	771	676	784	560	736	732	313	616	731
Sampling Time:	2137-0614	0855-0521	0945-1645	0948-1749	2016-0530	0940-1640	2011-0418	1033-1835	0925-1759	1004-0515	0925-1808	0719-1351	2201-0612	2101-0528	0722-1300	1132-1836	0925-1807
Date (1981) Collected:	5/20	5/22	5/22	5/20	5/20	5/22	5/18	5/19	5/21	5/19	5/21	5/23	5/20	5/22	5/23	5/19	5/21
Compound (detection limit, μg/m³)[a]																	
Naphthalene (0.4)	15.4	29.1	15.2	163.0	20.2	136.2	10.9	1.6	45.2	895.1	116.6	23.3	17.9	8.9	31.2	15.4	74.6
1-Methylnaphthalene (0.4)	3.6	25.8	7.3	63.6	4.9	53.4	5.0	1.2	13.0	121.6	33.0	11.8	5.0	2.6	10.3	13.1	9.9
2-Methylnaphthalene (0.4)	12.8	71.4	31.8	188.4	15.9	251.4	25.6	3.9	42.3	408.1	71.0	27.6	16.9	13.5	48.8	25.4	28.8
Quinoline (0.4)	--[b]	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acenaphthalene (0.4)	--	0.5	--	2.6	--	0.5	0.4	--	1.6	0.8	1.0	0.5	--	--	--	--	--
Acenaphthene (0.4)	1.6	2.9	2.6	18.6	1.6	10.8	2.7	0.5	6.4	11.6	5.9	4.1	1.7	1.1	3.6	2.5	3.4
Fluorene (0.4)	2.2	4.4	2.4	20.0	2.0	9.5	5.9	0.8	8.0	11.2	9.2	4.6	1.8	1.6	4.5	3.0	5.8
Phenanthrene/Anthracene (0.4)	1.0	3.4	2.5	10.2	2.0	6.9	3.4	--	3.1	4.2	5.9	4.5	0.9	1.8	4.6	2.9	2.6
Acridine (0.4)	--	--	--	3.0	--	--	--	--	--	0.4	--	--	0.6	--	--	--	--
Carbazole (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Fluoranthene (0.4)	--	--	--	0.5	--	--	--	--	--	--	--	--	--	--	--	--	--
Pyrene (0.4)	--	--	--	0.8	--	0.5	--	--	--	--	0.6	--	--	--	--	--	--
Benzo(a)fluorene/ Benzo(b)fluorene (0.4)	--	--	--	0.6	--	--	--	--	--	--	--	--	--	--	--	--	--
Benz(a)anthracene/Chrysene/ Triphenylene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(j)fluoranthene/ Benzo(b)fluoranthene/ Benzo(k)fluoranthene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(e)pyrene/ Benzo(a)pyrene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Perylene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,j)acridine (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)carbazole (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Indeno(1,2,3-cd)pyrene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,h)anthracene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coronene (1.6)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)pyrene (1.6)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dimethylbenz(a)anthracene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3-Methylcholanthrene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
6,13-Dimethyldibenz(a,h)-anthracene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL	36.6	137.5	61.8	471.3	46.6	469.2	53.9	10.0	119.6	1,451.0	242.6	76.4	44.8	29.5	101.0	62.3	125.1

[a] Assuming a sample volume of 700 liters.

[b] "---" indicates not detected.

*Methyltetralins, which co-elute with naphthalene, detected in sample.

(continued)

Table 21 (concluded)

Personnel Sampled:	Maintenance Personnel																		
	Welders			Millwrights			Pipefitters				Insulators		Electricians		Instrument Technicians			Laborers		
Sample Number:	4-016	4-127	4-164	4-015	4-096	4-125	4-001	4-077	4-162	4-147	4-021	4-078	4-024	4-163	4-022	4-076	4-126	4-073	4-192	4-165
Sample Volume (ℓ):	726	684	729	548	645	619	720	754	627	619	659	759	612	738	726	708	722	642	451	753
Sampling Time:	0745-1549	0731-1507	0743-1549	0005-0610	1545-2255	0734-1540	1545-2346	0825-1648	1155-1853	1622-2344	0729-1527	0818-1644	0732-1547	0720-1532	0750-1554	0001-1646	1538-2339	1210-0918	1605-2343	0723-1545
Date (1981) Collected:	5/19	5/21	5/22	5/19	5/20	5/21	5/18	5/21	5/21	5/21	5/19	5/20	5/19	5/22	5/19	5/20	5/21	5/20	5/22	5/22
Compound (detection limit, $\mu g/m^3$)[a]																				
Naphthalene (0.4)	5.4	9.0	2.5	11.3	37.1	693.0	18.6	23.7	15.6	23.7	4.1	11.3	1.1	11.6	18.0	28.9	6.8	8.1	3.1	7.3
1-Methylnaphthalene (0.4)	3.0	2.2	1.6	4.6	7.9	138.4	6.8	4.1	3.8	4.5	2.8	7.2	13.3	5.8	16.1	8.1	2.7	3.2	1.8	1.8
2-Methylnaphthalene (0.4)	6.0	5.5	3.2	29.3	28.5	448.1	34.2	18.7	20.3	14.1	5.5	16.7	5.0	20.9	21.2	26.1	6.8	11.3	5.9	7.9
Quinoline (0.4)	--[b]	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acenaphthalene (0.4)	--	--	--	1.0	0.4	1.0	--	--	--	--	--	--	--	0.6	--	--	--	--	--	--
Acenaphthene (0.4)	2.0	0.8	--	3.5	2.6	22.3	3.1	1.2	1.6	1.4	0.8	1.0	1.9	1.4	1.9	1.4	0.5	1.8	0.7	0.5
Fluorene (0.4)	2.7	1.2	0.7	5.8	3.3	12.2	3.9	1.4	1.7	1.4	1.4	1.2	2.6	2.0	2.3	2.3	0.6	1.9	1.5	0.6
Phenanthrene/Anthracene (0.4)	5.2	0.6	--	5.0	2.0	6.9	1.6	--	1.0	1.1	1.1	0.9	1.8	2.0	1.3	0.8	--	0.9	0.6	0.5
Acridine (0.4)	0.7	--	--	--	1.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Carbazole (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	0.9	--	--	--	--	--	--
Fluoranthene (0.4)	--	--	--	--	--	0.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Pyrene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	0.6	--	--	--	--	--	--
Benzo(a)fluorene/ Benzo(b)fluorene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benz(a)anthracene/Chrysene/ Triphenylene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(j)fluoranthene/ Benzo(b)fluoranthene/ Benzo(k)fluoranthene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(e)pyrene/ Benzo(a)pyrene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Perylene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,j)acridine (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)carbazole (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Indeno(1,2,3-cd)pyrene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,h)anthracene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coronene (1.6)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)pyrene (1.6)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dimethylbenz(a)anthracene (0.4)	--	--	--	--	--	0.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3-Methylcholanthrene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
6,13-Dimethyldibenz(a,h)-anthracene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL	25.0	19.3	8.0	60.5	83.4	1,322.8	68.2	49.1	44.0	46.2	15.7	38.3	25.7	45.8	60.8	67.6	17.4	27.2	13.6	18.6

[a] Assuming a sample volume of 700 liters.

[b] "--" indicates not detected.

*Methyltetralins, which co-elute with naphthalene, detected in sample.

Table B-22. Plant D Blanks Sampling Analytical Results (µg/sample) for PNAs (May 18-23, 1981)

Type of Blank:	Area Sample Blanks					Personal Sample Blanks				
Sample Number:	4-039	4-042	4-084	4-186	4-235	4-029	4-043	4-083	4-187	4-236
Date Collected:	5/18/81	5/19/81	5/20/81	5/22/81	5/23/81	5/18/81	5/19/81	5/20/81	5/22/81	5/23/81
Compound										
Napnthalene	5.01	0.34	1.50	0.64	0.23	0.63	0.23	0.25	0.04	0.43
1-Methylnaphthalene	1.40	0.12	0.27	0.07	0.02	0.41	0.10	0.08	0.02	0.06
2-Methylnaphthalene	3.36	0.20	0.73	0.23	0.07	0.41	0.09	0.12	--[a]	0.10
Quinoline	--	--	--	--	--	--	--	--	--	--
Acenaphthalene	--	--	0.01	--	--	--	--	0.03	--	0.01
Acenaphthene	0.13	0.05	0.03	0.01	--	0.11	--	0.01	--	--
Fluorene	0.16	0.17	0.05	0.04	--	0.13	0.13	0.01	--	0.01
Phenanthrene/Anthracene	0.66	1.10	0.07	--	--	0.64	--	--	--	--
Acridine	--	--	0.08	--	0.07	--	--	0.14	--	--
Carbazole	--	--	--	--	--	--	--	0.10	--	--
Fluoranthene	0.02	0.02	0.01	--	--	0.02	--	0.02	--	--
Pyrene	0.01	0.01	0.03	0.01	0.01	0.01	--	0.02	--	--
Benzo(a)fluorene/ Benzo(b)fluorene	--	--	0.06	--	--	--	--	0.02	--	--
Benz(a)anthracene/ Chrysene/Triphenylene	0.01	--	0.04	--	--	--	--	0.03	--	--
Benzo(j)fluoranthene/ Benzo(b)fluoranthene/ Benzo(k)fluoranthene	--	--	--	--	--	--	--	--	--	--
Benzo(e)pyrene/ Benzo(a)pyrene	--	--	--	--	--	--	--	--	--	--
Perylene	--	--	--	--	--	--	--	--	--	--
Dibenz(a,j)acridine	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)carbazole	--	--	--	--	--	--	--	--	--	--
Indeno(1,2,3-cd)pyrene	--	--	--	--	--	--	--	--	--	--
Dibenz(a,h)anthracene	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene	--	--	--	--	--	--	--	--	--	--
Coronene	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)pyrene	--	--	--	--	--	--	--	--	--	--
Dimethylbenz(a)anthracene	--	--	--	--	--	--	--	--	--	--
3-Methylcholanthrene	--	--	--	--	--	--	--	--	--	--
6,13-Dimethyldibenz(a,h)-anthracene	--	--	--	--	--	--	--	0.04	--	--
TOTAL	10.76	2.01	2.88	1.00	0.40	2.36	0.55	0.83	0.06	0.61

[a] "--" indicates not detected.

Table B-23. Plant D Wipe Sampling Analytical Results for PNAs (May 23, 1981)

Location Sampled:	Wrench Handle	Control House Door Handle	Control House Lunch Table	Instrument Cover F-226T	Valve Handle P-204B	North Flaker Staircase Ground Level	Bench and Lockers/Dirty Change Room
Sample Number:	4-244	4-245	4-250	4-254	4-256	4-258	4-264
Compound							
Naphthalene	•[a]	•	•	•	•	--[b]	•
1-Methylnaphthalene	•	•	•	•	•	--	--
2-Methylnaphthalene	•	•	•	•	•	--	--
Quinoline	--	--	--	•	•	--	--
Acenaphthalene	--	--	--	•	--	--	--
Acenaphthene	•	•	•	•	•	•	--
Fluorene	•	•	•	•	•	•	--
Phenanthrene/Anthracene	•	•	•	•	•	•	•
Acridine	--	•	--	•	•	•	--
Carbazole	--	•	--	•	•	•	--
Fluoranthene	•	•	•	•	•	•	•
Pyrene	•	•	•	•	•	•	•
Benzo(a)fluorene/ Benzo(b)fluorene	•	•	•	•	•	•	•
Benz(a)anthracene/ Chrysene/Triphenylene	•	•	•	•	•	•	•
Benzo(j)fluoranthene/ Benzo(b)fluoranthene/ Benzo(k)fluoranthene	•	•	--	•	•	•	•
Benzo(e)pyrene/ Benzo(a)pyrene	•	•	--	•	•	•	•
Perylene	--	•	--	•	•	•	--
Dibenz(a,j)acridine	--	--	--	--	--	--	--
Dibenz(a,i)carbazole	--	--	--	--	--	--	--
Indeno(1,2,3-cd)pyrene	--	--	--	•	•	•	--
Dibenz(a,h)anthracene	--	--	--	--	--	--	--
Benzo(g,h,i)perylene	--	--	--	•	•	•	--
Coronene	--	--	--	--	--	--	--
Dibenz(a,i)pyrene	--	--	--	--	--	--	--
Dimethylbenz(a)anthracene	--	--	--	•	--	--	--
3-Methylcholanthrene	--	--	--	•	--	--	--
6,13-Dimethyldibenz(a,j)-anthracene	--	--	--	--	--	--	--

[a] "•" indicates compound detected.

[b] "--" indicates compound not detected.

Table B-24. Plant D Bulk Sampling Analytical Results for PNAs (May 23, 1981)

Material Sampled:	Solvent Hydrogenation Naphtha	Solvent Fractionator Bottoms
Sample Number:	4-259	4-260
Date Collected:	5/23/81	5/23/81
Compound		
Naphthalene	●[a]	●
1-Methylnaphthalene	--[b]	●
2-Methylnaphthalene	--	●
Quinoline	--	--
Acenaphthalene	--	●
Acenaphthene	--	●
Fluorene	●	●
Phenanthrene/Anthracene	●	●
Acridine	--	●
Carbazole	--	●
Fluoranthene	●	●
Pyrene	●	●
Benzo(a)fluorene/Benzo(b)fluorene	--	●
Benz(a)anthracene/Chrysene/ Triphenylene	--	●
Benzo(j)fluoranthene/Benzo(b)-fluoranthene/Benzo(k)fluoranthene	--	●
Benzo(e)pyrene/Benzo(a)pyrene	--	●
Perylene	--	●
Dibenz(a,j)acridine	--	●
Dibenz(a,i)carbazole	--	●
Indeno(1,2,3-cd)pyrene	--	●,
Dibenz(a,h)anthracene	--	●
Benzo(g,h,i)perylene	--	●
Coronene	--	●
Dibenz(a,i)pyrene	--	●
Dimethylbenz(a)anthracene	--	●
3-Methylcholanthrene	--	●
6,13-Dimethyldibenz(a,h)anthracene	--	●

[a] "●" indicates compound detected.

[b] "--" indicates compound not detected.

Table B-25. Plant D Area Sampling Analytical Results (mg/m^3) for Aromatic Amines (May 18-23, 1981)

Location Sampled	Sample Number	Sample Volume (l)	Sampling Time	Date Collected	Aromatic Amine[a] (detection limit, mg/m^3)[b]								
					A (0.1)	B (0.1)	C (0.1)	D (0.1)	E (0.1)	F (0.1)	G (0.1)	H (0.1)	I (0.1)
Main Control House Site 1	4-029	100	0831-1652	5/19/81	--[c]	--	--	--	--	--	--	--	--
	4-108	90	1910-0500	5/20/81	--	--	--	--	--	--	--	--	--
	4-177	109	0850-1753	5/22/81	--	--	--	--	--	--	--	--	--
CPU Control Room Site 2	4-002	111	1625-0140	5/18/81	--	--	--	--	--	--	--	--	--
	4-207	96	2046-0445	5/22/81	--	--	--	--	--	--	--	--	--
High-Pressure Slurry Feed Pumps, P-102, Site 3	4-066	102	2117-0548	5/19/81	--	--	--	--	--	--	--	--	--
	4-092	113	0846-1811	5/20/81	--	--	--	--	--	--	--	--	--
Reactor Separator Pump, P-106, Site 4	4-036	95	0905-1659	5/19/81	--	--	--	--	--	--	--	--	--
	4-146	104	0943-1824	5/21/81	--	--	--	--	--	--	--	--	--
Atmospheric Fractionator Light Gas/Oil Pump, P-202, Site 5	4-007	111	1650-0205	5/18/81	--	--	--	--	--	--	--	--	--
	4-175	104	0905-1744	5/22/81	--	--	--	--	--	--	--	--	--
Atmos. Frac. Bottoms Pump, P-204, Site 6	4-143	105	0936-1821	5/21/81	0.4	--	0.1	--	--	--	--	--	--
	4-203	97	2103-0510	5/22/81	--	--	--	--	--	--	--	--	--
Vacuum Stripper Light Gas/Oil Pump, P-207, Site 7	4-033	98	0847-1635	5/19/81	--	--	--	--	--	--	--	--	--
	4-113	89	1954-0521	5/20/81	--	--	--	--	--	--	--	--	--
	4-139	106	0929-1818	5/21/81	0.4	0.1	--	0.3	--	0.6	--	--	--
Vacuum Stripper Heavy Gas/Oil Pump, P-208, Site 8	4-050	102	2101-0533	5/19/81	--	--	--	--	--	--	--	--	--
	4-179	106	0900-1748	5/22/81	--	--	--	--	--	--	--	--	--
Vacuum Stripper Bottoms Pump, P-210, Site 9	4-037	115	0830-1805	5/20/81	--	--	--	--	--	--	--	--	--
	4-201	95	2114-0507	5/22/81	--	--	--	--	--	--	--	--	--
	4-232	97	0740-1545	5/23/81	--	--	--	--	--	--	--	--	--
Solvent Fractionator Side Stream Pumps, P-306,P-307, Site 10	4-032	96	0855-1656	5/19/81	--	--	--	--	--	--	--	--	--
	4-159	106	2023-0515	5/21/81	--	--	--	--	--	--	--	--	--
	4-231	98	0734-1545	5/23/81	--	--	--	--	--	--	--	--	--
Solvent Fractionator Bottoms Pump, P-308, Site 11	4-010	112	1650-0210	5/18/81	0.3	--	--	--	--	--	--	--	--
	4-110	90	1937-0507	5/20/81	--	--	--	--	--	--	--	--	--
	4-205	100	2053-0514	5/22/81	--	--	--	--	--	--	--	--	--
High-Pressure Flush Oil Pump, P-113, Site 12	4-157	98	1644-0053	5/21/81	--	--	--	--	--	--	--	--	--
	4-233	100	0721-1540	5/23/81	--	--	--	--	--	--	--	--	--
Oily Water Sump, Site 13	4-068	102	2123-0554	5/19/81	--	--	--	--	--	--	--	--	--
	4-156	104	2043-0524	5/21/81	--	--	--	--	--	--	--	--	--
Upwind Perimeter	4-161	104	2050-0529	5/21/81	--	--	--	--	--	--	--	--	--
	4-181	102	0909-1739	5/22/81	--	--	--	--	--	--	--	--	--
Blanks	4-086			5/20/81	--	--	--	--	--	--	--	--	--
	4-191			5/22/81	--	--	--	--	--	--	--	--	--
	4-238			5/23/81	--	--	--	--	--	--	--	--	--
	4-241			5/23/81	--	--	--	--	--	--	--	--	--

[a] Aromatic Amines: A = aniline; B = N,N-dimethylaniline; C = o-toluidine; D = 2,4-dimethylaniline; E = o-anisidine; F = p-anisidine; G = 1-naphthylamine; H = 2-naphthylamine; I = p-nitroaniline.

[b] Assuming a sample volume of 100 liters.

[c] "--" indicates compound not detected.

[d] "--" indicates samples not analyzed for these compounds.

Table B-26. Plant D Personal Sampling Analytical Results (mg/m^3) for Aromatic Amines (May 18-23, 1981)

Personnel Sampled	Sample Number	Sample Volume (ℓ)	Sampling Time	Date Collected	Aromatic Amine[a] (detection limit, mg/m^3)[b]								
					A (0.1)	B (0.1)	C (0.1)	D (0.1)	E (0.1)	F (0.1)	G (0.1)	H (0.1)	I (0.7)
Process Technicians													
Liquefaction/ Distillation Unit #1	4-014	105	2009-0430	5/18/81	--[c]	--	--	--	--	--	¤[d]	¤	¤
	4-046	89	1113-1837	5/19/81	--	--	--	--	--	--	--	--	--
Liquefaction/ Distillation Unit #2	4-047	99	1028-1842	5/19/81	--	--	--	--	--	--	--	--	--
	4-222	96	0746-1541	5/23/81	--	--	--	--	--	--	¤	¤	¤
Liquefaction/ Distillation Unit #3	4-069	30	2203-0613	5/19/81	--	--	--	--	--	--	¤	¤	¤
	4-098	99	2107-0525	5/20/81	--	--	--	--	--	--	¤	¤	¤
	4-220	90	0735-1535	5/23/81	--	--	--	--	--	--	--	--	--
Solvent Hydrogenation Unit	4-119	26	2147-0602	5/20/81	--	--	--	--	--	--	¤	¤	¤
	4-172	84	2058-0510	5/22/81	--	--	--	--	--	--	--	--	--
Offsite & Utilities	4-054	89	2153-0605	5/19/81	--	--	--	--	--	--	--	--	--
	4-097	97	2100-0532	5/20/81	--	--	--	--	--	--	¤	¤	¤
Maintenance Workers													
Welders	4-019	85	0742-1547	5/19/81	--	--	--	--	--	--	¤	¤	¤
	4-079	167	0759-1543	5/20/81	--	--	--	--	--	--	¤	¤	¤
Millwrights	4-124	76	0012-0728	5/21/81	--	--	--	--	--	--	¤	¤	¤
	4-131	88	1530-2302	5/21/81	--	--	--	--	--	--	--	--	--
	4-195	20	2104-0537	5/22/81	--	--	--	--	--	--	--	--	--
Pipefitters	4-055	97	1538-2341	5/19/81	--	--	--	--	--	--	--	--	--
	4-102	79	1602-2344	5/20/81	--	--	--	--	--	--	¤	¤	¤
	4-169	74	0753-1538	5/22/81	--	--	--	--	--	--	--	--	--
Instrument Technicians	4-075	83	0007-0710	5/20/81	--	--	--	--	--	--	--	--	--
	4-196	89	1605-2335	5/22/81	--	--	--	--	--	--	--	--	--
Laborers	4-017	72	0010-0706	5/19/81	--	--	--	--	--	--	¤	¤	¤
	4-056	97	1540-2345	5/19/81	--	--	--	--	--	--	¤	--	--
Blanks	4-037			5/19/81	--	--	--	--	--	--	¤	¤	¤
	4-188			5/22/81	--	--	--	--	--	--	--	--	--
	4-239			5/23/81	--	--	--	--	--	--	¤	¤	¤

[a] Aromatic Amines: A = aniline; B = N,N-dimethylaniline; C = o-toluidine; D = 2,4-dimethylaniline; E = o-anisidine; F = p-anisidine; G = 1-naphthylamine; H = 2-naphthylamine; I = p-nitroaniline.

[b] Assuming a sample volume of 100 liters.

[c] "--" indicates compound not detected.

[d] "¤" indicates samples not analyzed for these compounds.

Table B-27. Plant D Area Sampling Analytical Results (ppm) for Benzene, Toluene, and Xylene (May 18-23, 1981)

Location Sampled	Sample Number	Sample Volume (ℓ)	Sampling Time	Date Collected	Compound (detection limit, ppm)[a]		
					Benzene (0.01)	Toluene (0.02)	Xylene (0.02)
Main Control House, Site 1	4-030	100	0832-1652	5/19/81	--[b]	--	--
	4-109	90	1930-0500	5/20/81	--	0.11	--
	4-176	109	0900-1748	5/22/81	0.19	--	--
CPU Control Room, Site 2	4-003	111	1626-0140	5/18/81	0.02	--	0.31
	4-208	96	2045-0445	5/22/81	--	--	--
High-Pressure Slurry Feed Pump, P-102, Site 3	4-065	102	2117-0548	5/19/81	--	--	--
	4-091	113	0846-1811	5/20/81	--	--	0.02
	4-154	105	2034-0520	5/21/81	0.04	--	--
Reactor Separator Pump, P-106, Site 4	4-035	95	0905-1655	5/19/81	--	--	--
	4-145	104	0942-1823	5/21/81	--	--	--
Atmospheric Fractionator Light Gas/Oil Pump, P-202, Site 5	4-006	114	1636-0204	5/18/81	--	--	--
	4-114	90	1958-0527	5/20/81	0.03	0.06	0.21
	4-178	104	0905-1744	5/22/81	--	--	--
Atmospheric Fractionator Bottoms Pump, P-204, Site 6	4-052	103	2101-0533	5/19/81	--	--	0.02
	4-142	105	0935-1820	5/21/81	--	--	--
	4-204	97	2103-0510	5/22/81	--	--	--
Vacuum Stripper Light Gas/Oil Pump, P-207, Site 7	4-031	100	0834-1655	5/19/81	--	0.02	0.02
	4-112	90	1952-0521	5/20/81	0.12	0.14	0.26
	4-140	105	0929-1818	5/21/81	0.13	--	--
Vacuum Stripper Heavy Gas/Oil Pump, P-208, Site 8	4-051	102	2101-0533	5/19/81	--	--	--
	4-174	106	0900-1748	5/22/81	--	--	--
	4-228	99	0726-1542	5/23/81	--	0.02	0.06
Vacuum Stripper Bottoms Pump, P-210, Site 9	4-089	114	0832-1803	5/20/81	--	--	--
	4-202	95	2114-0507	5/22/81	--	--	--
Solvent Fractionator Side Stream Pumps, P-306, P-307, Site 10	4-034	96	0855-1656	5/19/81	--	--	--
	4-155	106	2025-0515	5/21/81	--	--	--
	4-227	98	0734-1545	5/23/81	--	0.03	0.17
Solvent Fractionator Bottoms Pump, P-308, Site 11	4-009	113	1647-0210	5/18/81	--	--	--
	4-111	90	1937-0504	5/20/81	0.04	0.04	0.06
	4-206	100	2053-0514	5/22/81	--	0.03	0.11
High-Pressure Flush Oil Pump, P-113, Site 12	4-136	85	0919-1641	5/21/81	0.04	0.08	0.52
	4-158	98	1644-0052	5/21/81	--	--	--
	4-229	100	0721-1540	5/23/81	--	--	--
Oily Water Sump, Site 13	4-067	102	2123-0554	5/19/81	--	--	--
	4-153	104	2045-0524	5/21/81	0.32	0.54	0.85
Upwind Perimeter	4-094	112	0908-1826	5/20/81	--	--	--
	4-152	103	2051-0529	5/21/81	--	--	0.02
	4-180	102	0909-1739	5/22/81	--	--	--
Blanks	4-038			5/18/81	--	--	--
	4-085			5/20/81	--	--	--
	4-189			5/22/81	--	--	--
	4-237			5/23/81	--	--	--

[a] Assuming a sample volume of 90 liters.

[b] "--" indicates not detected.

Table B-28. Plant D Personal Sampling Analytical Results (ppm) for Benzene, Toluene, and Xylene (May 18-23, 1981)

Personnel Sampled	Sample Number	Sample Volume (ℓ)	Sampling Time	Date Collected	Compound (detection limit, ppm)[a]		
					Benzene (0.01)	Toluene (0.02)	Xylene (0.02)
Process Technicians, Liquefaction-Distillation Unit #1	4-013	82	2009-0430	5/18/81	0.04	0.03	0.18
	4-044	52	1113-1837	5/19/81	--[b]	--	--
	4-216	46	0714-1534	5/23/81	0.14	--	0.02
Process Technicians, Liquefaction-Distillation Unit #2	4-045	25	1028-1842	5/19/81	--	0.02	--
	4-071	95	2200-0612	5/19/81	--	--	--
	4-215	101	0716-1541	5/23/81	--	0.02	--
Process Technicians, Liquefaction-Distillation Unit #3	4-070	113	2203-0613	5/19/81	0.02	--	0.02
	4-100	111	0907-1725	5/20/81	0.13	--	--
	4-217	95	0735-1535	5/23/81	--	--	--
Process Technicians, Solvent Hydrogenation Unit	4-120	15	2147-0601	5/20/81	--	--	--
	4-173	66	0858-1710	5/22/81	--	--	--
	4-212	80	2151-0445	5/22/81	0.03	0.05	--
Process Technicians, Offsite & Utilities	4-053	98	2152-0605	5/19/81	--	--	--
	4-099	103	0900-1732	5/20/81	0.13	--	--
	4-209	47	2150-0450	5/22/81	--	0.05	0.04
Maintenance Personnel, Welders	4-020	90	0743-1547	5/19/81	0.02	--	--
	4-057	76	1538-2341	5/19/81	0.34	--	--
	4-080	88	0759-1543	5/20/81	0.03	--	--
	4-082	96	0800-1540	5/20/81	--	--	--
Maintenance Personnel, Millwrights	4-123	84	0012-0727	5/21/81	0.07	0.10	0.05
	4-128	86	1530-2305	5/21/81	--	--	--
	4-194	82	1557-2338	5/22/81	0.05	0.02	--
Maintenance Personnel, Pipefitters	4-103	95	1602-2344	5/20/81	--	0.02	--
	4-122	67	0015-0720	5/21/81	--	--	--
	4-167	40	1952-0338	5/22/81	--	--	--
Maintenance Personnel, Instrument Technicians	4-074	89	0006-0710	5/20/81	--	--	--
	4-166	38	0735-1529	5/22/81	--	--	--
	4-193	97	1605-2335	5/22/81	--	--	--
Maintenance Personnel, Laborers	4-016	65	0010-0706	5/19/81	--	--	--
	4-058	83	1540-2145	5/19/81	--	--	--
	4-129	91	1547-2320	5/21/81	--	--	--
Blanks	4-038			5/18/81	--	--	--
	4-040			5/19/81	--	--	--
	4-085			5/20/81	--	--	--
	4-190			5/22/81	--	--	--
	4-240			5/23/81	--	--	--
	4-242			5/23/81	--	--	--

[a] Assuming a sample volume of 90 liters.

[b] "--" indicates not detected.

Table B-29. Plant D Area and Personal Sampling Analytical Results (mg/m^3) for Phenolic Compounds (May 19-23, 1981)

	Sample Number	Sample Volume (ℓ)	Sampling Time	Date Collected	Compound (detection limit, mg/m^3)[a]						
					Phenol (0.02)	o-Cresol (0.02)	m-Cresol/ p-Cresol (0.02)	o-Ethyl-phenol (0.02)	2,3-Xylenol (0.02)	p-Ethyl-phenol (4.0)	3,5-Xylenol (4.0)
Location Sampled											
Site #3	4-160	105	2034-0520	5/21/81	--[b]	--	--	--	--	--	--
Site #5	4-115	90	1957-0527	5/20/81	--	--	--	--	--	--	--
Site #6	4-064	103	2110-0543	5/19/81	--	--	--	--	--	--	--
Site #8	4-234	99	0725-1542	5/23/81	--	--	--	--	--	--	--
Upwind Perimeter	4-095	111	0912-1826	5/20/81	--	--	--	--	--	--	--
Blank	4-041			5/19/81	--	--	--	--	--	--	--
Personnel Sampled											
Process Technician[a] LDU #1	4-221	97	0714-1534	5/23/81	--	--	--	--	--	--	--
Process Technician LDU #2	4-072	55	2201-0612	5/19/81	--	--	--	--	--	--	--
Process Technician SHU	4-214	69	0950-1645	5/22/81	--	--	--	--	--	--	--
Process Technician OSU	4-213	79	0950-1650	5/22/81	--	--	--	--	--	--	--
Maintenance Worker/ Welder	4-081	82	0800-1540	5/20/81	--	--	--	--	--	--	--
Maintenance Worker/ Pipefitter	4-121	85	0015-0720	5/21/81	--	--	--	--	--	--	--
Maintenance Worker/ Instrument Tech.	4-168	79	0735-1529	5/22/81	--	--	--	--	--	--	--
Maintenance Worker/ Laborer	4-130	118	1547-2318	5/21/81	--	--	--	--	--	--	--
Blank	4-239			5/23/81	--	--	--	--	--	--	--

[a] Assuming a sample volume of 100 liters. [b] "--" indicates compound not detected.

[a] Process technician location key: LDU = liquefaction/distillation unit; SHU = solvent hydrogenation unit; OSU = offsite & utilities.

PLANT E

Table B-30. Plant E Area Sampling Analytical Results ($\mu g/m^3$) for PNAs (August 10-14, 1981)..... B-40

Table B-31. Plant E Personal Sampling Analytical Results ($\mu g/m^3$) for PNAs (August 10-14, 1981)..... B-42

Table B-32. Plant E Wipe Sampling Analytical Results for PNAs (August 14, 1981)..... B-44

Table B-33. Plant E Area Sampling Analytical Results ($\mu g/m^3$) for Aromatic Amines (August 10-14, 1981)..... B-45

Table B-34. Plant E Personal Sampling Analytical Results ($\mu g/m^3$) for Aromatic Amines (August 10-14, 1981)..... B-46

Table B-35. Plant E Area Sampling Analytical Results (ppm) for Benzene, Toluene, and Xylene (August 10-14, 1981)..... B-47

Table B-36. Plant E Area and Personal Sampling Analytical Results (mg/m^3) for Phenolic Compounds (August 10-14, 1981)..... B-48

Table B-37. Plant E Area Sampling Analytical Results for Metals (μg) and Metal Carbonyls ($\mu g/\ell$) (August 10-14, 1981).... B-49

Table B-30. Plant E Area Sampling Analytical Results (μg/m³) for PNAs (August 10-14, 1981,

Location Sampled:	Slurry Preparation			Reactor				Hydroclone			Vacuum Tower			Flaker Belt (empty)		
Plant Status[a]:	R	N	N	R	R	N	N	N	N	R	N	N	N	N	N	N
Sample Number:	015	148	203	046	027	124	125	126	144	109	022	147	207	021	171	202
Sample Volume (ℓ):	1,250	1,130	1,020	880	1,250	1,160	1,140	1,200	1,150	720	1,130	1,150	1,090	1,120	1,160	1,120
Sampling Time:	2306-0835	1527-2416	0740-1503	0844-1450	2309-0838	1122-1926	1523-2317	1115-1937	1513-2315	0935-1438	1418-2208	1504-2305	0712-1445	1424-2211	1456-2300	0700-1445
Date (1981) Collected:	8/11	8/13	8/14	8/11	8/11	8/13	8/13	8/13	8/13	8/12	8/10	8/13	8/14	8/10	8/13	8/14
Compound (detection limit, μg/m³)[b]																
Naphthalene (0.2)	14.2	10.8	24.6	0.7	14.6	16.1	7.4	3.1	28.1	81.9	7.7	2.2	2.6	2.2	2.1	3.4
1-Methylnaphthalene (0.2)	5.7	13.3	34.4	2.0	9.9	16.4	10.9	3.5	31.8	59.7	3.4	3.4	4.9	2.6	1.4	2.6
2-Methylnaphthalene (0.2)	17.6	44.3	116.3	12.5	39.7	89.3	34.7	9.4	105.8	204.1	22.3	9.7	14.5	7.4	4.5	6.5
Quinoline (0.2)	--[a]	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acenaphthalene (0.2)	--	0.8	2.0	1.8	0.4	1.3	0.6	0.9	0.5	3.8	1.6	0.8	0.7	0.2	--	--
Acenaphthene (0.2)	0.4	1.9	4.8	3.6	2.0	--	--	1.7	14.7	8.7	3.4	--	--	0.5	--	0.3
Fluorene (0.2)	--	1.5	4.6	9.3	1.0	3.6	1.4	3.2	15.4	10.7	5.4	2.8	3.6	0.7	--	--
Phenanthrene/Anthracene (0.2)	--	--	--	--	--	--	--	1.4	7.4	1.6	--	--	--	--	--	--
Acridine (0.2)	--	--	--	0.4	--	--	--	--	--	--	--	--	--	--	--	--
Carbazole (0.2)	--	--	--	--	--	--	--	0.3	0.3	--	--	--	0.6	--	--	--
Fluoranthene (0.2)	--	--	--	--	--	--	--	0.8	6.3	--	--	--	0.5	--	--	--
Pyrene (0.2)	--	0.3	0.4	0.7	--	0.3	0.2	4.7	2.1	1.5	0.8	0.6	5.3	1.1	--	--
Benzo(a)fluorene/ Benzo(b)fluorene (0.2)	--	--	--	--	--	--	--	2.1	0.6	--	--	0.3	1.5	0.5	--	--
Benz(a)anthracene/Chrysene/ Triphenylene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(j)fluoranthene/ Benzo(b)fluoranthene/ Benzo(k)fluoranthene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(e)pyrene/ Benzo(a)pyrene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Perylene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,j)acridine (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)carbazole (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Indeno(1,2,3-cd)pyrene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,h)anthracene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coronene (0.8)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,l)pyrene (0.8)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dimethylbenz(a)anthracene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3-Methylcholanthrene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
6,11-dimethyldibenz(a,h)-anthracene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL	37.9	72.9	187.1	31.0	67.6	127.0	55.2	31.3	213.0	372.0	44.6	19.8	34.2	15.2	8.0	12.8

[a] Plant status: N = normal operating conditions; R = recirculating oil.

[b] Assuming a sample volume of 1,000 liters.

[c] "--" indicates not detected.

(continued)

Table B-30 (concluded)

Location Sampled:	Fractionator		Waste Oil Recovery			Control Room			Seal Oil Pump			Perimeter			Blanks (µg/sample)	
Plant Status[a]:	N	N	R	N	N	R	R	N	R	N	N	R	N	N		
Sample Number:	128	145	016	146	208	045	017	172	056	127	204	105	114	206	073	177
Sample Volume (ℓ):	1,090	1,150	1,390	1,130	1,070	1,060	1,080	1,120	1,140	1,180	970	1,080	1,150	1,150		
Sampling Time:	1105-1919	1508-2308	2317-0855	1541-2331	0720-1445	0831-1554	2301-0828	1530-2310	1436-2230	1111-1923	0735-1455	0720-1448	1147-1947	0717-1515		
Date (1981) Collected:	8/13	8/13	8/11	8/13	8/14	8/11	8/11	8/13	8/11	8/13	8/14	8/12	8/13	8/14	8/11	8/14
Compound (detection limit, µg/m³)[b]																
Naphthalene (0.2)	21.9	6.6	13.7	1.9	14.1	--[c]	6.0	5.9	1.0	1.8	5.2	5.1	--	0.6	0.1	1.6
1-Methylnaphthalene (0.2)	12.7	4.2	13.3	1.2	9.2	--	4.4	8.3	0.9	4.6	3.8	--	--	--	--	0.6
2-Methylnaphthalene (0.2)	36.9	12.0	52.0	3.1	49.1	--	16.0	24.7	9.6	15.5	14.7	5.7	0.3	--	--	1.1
Quinoline (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acenaphthalene (0.2)	1.9	1.0	1.2	--	2.9	--	0.4	0.3	1.2	1.7	0.5	--	--	--	--	0.1
Acenaphthene (0.2)	--	--	3.9	0.3	--	--	1.1	0.7	--	5.1	--	--	--	--	--	0.2
Fluorene (0.2)	4.7	3.3	3.2	--	5.2	--	1.2	--	3.1	6.6	2.4	--	--	--	0.1	0.5
Phenanthrene/Anthracene (0.2)	--	--	--	--	0.3	--	--	--	--	1.2	--	--	--	--	0.3	6.1
Acridine (0.2)	--	--	--	--	0.3	--	--	--	0.3	0.5	--	--	--	--	--	--
Carbazole (0.2)	--	--	--	--	0.5	--	--	--	--	0.3	--	--	--	--	--	--
Fluoranthene (0.2)	--	--	--	--	--	--	--	--	--	0.3	--	--	--	--	--	0.2
Pyrene (0.2)	--	0.8	0.6	0.2	1.7	--	--	--	0.5	2.0	0.6	--	--	--	0.1	0.1
Benzo(a)fluorene/ Benzo(b)fluorene (0.2)	--	0.3	0.2	--	0.7	--	--	--	0.3	0.6	--	--	--	--	--	--
Benz(a)anthracene/Chrysene/ Triphenylene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.1
Benzo(j)fluoranthene/ Benzo(b)fluoranthene/ Benzo(k)fluoranthene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(e)pyrene/ Benzo(a)pyrene (0.2)	--	--	0.3	--	--	--	--	--	--	--	--	--	--	--	--	--
Perylene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,j)acridine (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)carbazole (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Indeno(1,2,3-cd)pyrene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,h)anthracene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coronene (0.8)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)pyrene (0.8)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dimethylbenz(a)anthracene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3-Methylcholanthrene (0.2)	--	--	--	--	--	--	0.2	--	--	--	--	--	--	--	--	--
6,13-Dimethyldibenz(a,h)-anthracene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL	78.1	28.2	88.4	6.7	84.0	0	29.3	39.9	16.9	40.2	27.2	10.8	0.3	0.6	0.6	10.6

[a] Plant status: N = normal operating conditions; R = recirculating oil.

[b] Assuming a sample volume of 1,000 liters.

[c] "--" indicates not detected.

Table B-31. Plant E Personal Sampling Analytical Results ($\mu g/m^3$) for PNAs (August 10-14, 1981)

Personnel Sampled:	Operators								
	#3	#3	#3	#5	#5	#5	#8	#11	#11
Plant Status[a]:	R	N	N	R	R	N	N	R	R
Sample Number:	039	121	149	060	110	211	020	038	031
Sample Volume (ℓ):	468	593	729	752	686	705	677	546	670
Sampling Time:	0918-1430	1135-1810	1838-0244	1904-0245	0653-1430	1900-0250	1509-2240	0730-1430	2323-0650
Date (1981) Collected:	8/11	8/13	8/13	8/11	8/12	8/14	8/10	8/11	8/12
Compound (detection limit, $\mu g/m^3$)[b]									
Naphthalene (0.4)	--[c]	31.7	2.9	7.8	4.3	11.6	0.8	4.9	20.1
1-Methylnaphthalene (0.4)	--	37.6	1.4	4.5	3.0	6.8	3.7	4.2	18.4
2-Methylnaphthalene (0.4)	--	89.8	3.0	11.8	9.1	21.9	5.1	10.5	64.6
Quinoline (0.4)	--	--	--	--	--	--	--	--	--
Acenaphthalene (0.4)	--	2.0	--	0.7	0.5	0.6	--	--	1.3
Acenaphthene (0.4)	--	4.7	0.3	1.7	0.8	--	--	0.5	3.5
Fluorene (0.4)	--	3.8	--	2.3	1.1	1.8	--	--	4.4
Phenanthrene/Anthracene (0.4)	--	--	--	--	--	1.9	--	--	--
Acridine (0.4)	--	--	--	--	--	--	--	--	--
Carbazole (0.4)	--	0.6	--	--	--	--	--	--	--
Fluoranthene (0.4)	--	--	--	--	--	--	--	--	--
Pyrene (0.4)	--	0.9	--	0.5	--	--	--	--	--
Benzo(a)fluorene/ Benzo(b)fluorene (0.4)	--	--	--	--	--	--	--	--	--
Benz(a)anthracene/Chrysene/ Triphenylene (0.4)	--	--	--	--	--	--	--	--	--
Benzo(j)fluoranthene/ Benzo(b)fluoranthene/ Benzo(k)fluoranthene (0.4)	--	--	--	--	--	--	--	--	--
Benzo(e)pyrene/ Benzo(a)pyrene (0.4)	--	--	--	--	--	--	--	--	--
Perylene (0.4)	--	--	--	--	--	--	--	--	--
Dibenz(a,j)acridine (0.4)	--	--	--	--	--	--	--	--	--
Dibenz(a,i)carbazole (0.4)	--	--	--	--	--	--	--	--	--
Indeno(1,2,3-cd)pyrene (0.4)	--	--	--	--	--	--	--	--	--
Dibenz(a,h)anthracene (0.4)	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene (0.4)	--	--	--	--	--	--	--	--	--
Coronene (1.6)	--	--	--	--	--	--	--	--	--
Dibenz(a,i)pyrene (1.6)	--	--	--	--	--	--	--	--	--
Dimethylbenz(a)anthracene (0.4)	--	--	--	--	--	--	--	--	--
3-Methylcholanthrene (0.4)	--	--	--	--	--	--	--	--	--
6,13-Dimethyldibenz(a,h)-anthracene (0.4)	--	--	--	--	--	--	--	--	--
TOTAL	0	171.1	7.6	29.3	18.8	44.6	9.6	20.1	112.3

(continued)

[a] Plant status: N = normal operating conditions; R = recirculating oil.

[b] Assuming a sample volume of 625 liters.

[c] "--" indicates not detected.

Table B-31 (concluded)

Personnel Sampled:	Maintenance Personnel															Blanks (µg/sample)	
	Pipefitters/Welders					Machinists			Insulators		Laborers						
Plant Status[a]:	N	N	R	R	N	R	R	N	N	N	R	R	R	N	N		
Sample Number:	018	019	037	030	123	059	035	150	122	209	036	061	111	156	210	072	220
Sample Volume (ℓ):	654	652	518	645	483	638	571	683	480	744	486	609	636	693	567		
Sampling Time:	1604-2320	1603-2320	0864-1430	2347-0657	1008-1530	0755-1500	0831-1520	1545-2320	1010-1530	0750-1535	0006-1330	1604-2250	0803-1557	1540-2322	0744-1500		
Date (1981) Collected:	8/10	8/10	8/11	8/12	8/13	8/11	8/11	8/13	8/13	8/14	8/11	8/11	8/12	8/13	8/14	8/11	8/14
Compound (detection limit, µg/m³)[b]																	
Naphthalene (0.4)	3.7	1.2	--[c]	35.0	21.0	--	--	6.3	43.2	10.9	9.2	5.7	4.7	--	16.7	1.8	1.4
1-Methylnaphthalene (0.4)	2.7	1.3	--	24.9	15.6	--	--	7.2	50.6	9.6	13.1	6.3	--	--	13.5	0.3	0.6
2-Methylnaphthalene (0.4)	4.7	2.9	--	87.3	38.0	--	0.5	16.6	134.4	36.4	34.0	13.2	12.2	--	39.3	0.5	1.6
Quinoline (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acenaphthalene (0.4)	--	--	--	0.9	1.2	--	--	--	2.6	0.5	0.8	0.4	0.5	--	1.0	--	0.1
Acenaphthene (0.4)	--	--	--	2.5	3.0	--	--	0.7	7.2	1.2	--	1.2	1.2	--	2.3	--	0.1
Fluorene (0.4)	0.7	0.4	--	2.3	2.4	--	--	--	6.2	0.7	2.3	1.2	1.1	--	2.6	--	0.4
Phenanthrene/Anthracene (0.4)	--	--	--	--	--	--	--	--	0.5	--	--	--	--	--	2.4	--	3.3
Acridine (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Carbazole (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Fluoranthene (0.4)	--	--	--	--	--	--	--	--	0.5	--	--	--	--	--	--	--	0.1
Pyrene (0.4)	--	--	--	--	--	--	--	--	2.2	--	--	--	--	--	0.5	--	0.1
Benzo(a)fluorene/ Benzo(b)fluorene (0.4)	--	--	--	--	--	--	--	--	0.8	--	--	--	--	--	--	--	--
Benz(a)anthracene/Chrysene/ Triphenylene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(j)fluoranthene/ Benzo(b)fluoranthene/ Benzo(k)fluoranthene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(e)pyrene/ Benzo(a)pyrene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Perylene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,j)acridine (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)carbazole (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Indeno(1,2,3-cd)pyrene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,h)anthracene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coronene (1.6)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dibenz(a,i)pyrene (1.6)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dimethylbenz(a)anthracene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3-Methylcholanthrene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
6,12-Dimethyldibenz(a,h)-anthracene (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL	11.8	5.8	0	152.9	81.2	0	0.5	30.8	248.2	59.1	59.4	28.0	19.7	0	70.1	2.6	7.7

[a] Plant status: N = normal operating conditions; R = recirculating oil.

[b] Assuming a sample volume of 625 liters.

[c] "--" indicates not detected.

Table B-32. Plant E Wipe Sampling Analytical Results for PNAs (August 14, 1981)

Type of Sample:	Wipe Samples		
Location Sampled:	Control Room	Slurry Pump	Seal Oil Pump
Sample Number:	229	230	234
Date Collected:	8/14/81	8/14/81	8/14/81
Compound			
Naphthalene	•[a]	•	•
1-Methylnaphthalene	--[b]	•	•
2-Methylnaphthalene	--	•	•
Quinoline	--	--	--
Acenaphthalene	--	•	•
Acenaphthene	--	•	•
Fluorene	--	•	•
Phenanthrene/Anthracene	•	•	•
Acridine	--	•	•
Carbazole	--	•	•
Fluoranthene	--	•	•
Pyrene	•	•	•
Benzo(a)fluorene/ Benzo(b)fluorene	•	•	•
Benz(a)anthracene/ Chrysene/Triphenylene	--	•	•
Benzo(j)fluoranthene/ Benzo(b)fluoranthene/ Benzo(k)fluoranthene	--	•	•
Benzo(e)pyrene/ Benzo(a)pyrene	--	•	•
Perylene	--	•	•
Dibenz(a,j)acridine	--	•	•
Dibenz(a,i)carbazole	--	•	--
Indeno(1,2,3-cd)pyrene	--	•	•
Dibenz(a,h)anthracene	--	--	--
Benzo(g,h,i)perylene	--	•	•
Coronene	--	--	•
Dibenz(a,i)pyrene	--	•	--
Dimethylbenz(a)anthracene	--	--	--
3-Methylcholanthrene	--	•	•
6,13-Dimethyldibenz(a,h)-anthracene	--	--	--

[a] "•" indicates compound detected. [b] "--" indicates compound not detected.

Table B-33. Plant E Area Sampling Analytical Results ($\mu g/m^3$) for Aromatic Amines (August 10-14, 1981)

Location Sampled	Sample Number	Sample Volume (L)	Sampling Time	Date Collected	Aromatic Amines[a] (detection limit, $\mu g/m^3$)[b]							
					A (23)	B (34)	C (46)	D (19)	E (21)	F (29)	G (25)	H (26)
Slurry Preparation	004	96	1405-2205	8/10/81	--[c]	--	--	--	--	--	--	--
	094	85	0728-1433	8/12/81	--	--	--	--	--	--	--	--
	165	94	1527-2316	8/13/81	--	--	--	--	--	--	--	--
	194	91	0740-1503	8/14/81	--	--	--	--	--	--	--	--
Reactor	002	95	1409-2206	8/10/81	--	--	--	--	--	--	--	--
	163	106	1524-2250	8/13/81	--	--	--	--	--	--	--	--
	135	96	1123-1926	8/13/81	--	--	--	--	--	--	--	--
Hydroclone	062	82	1251-2227	8/11/81	--	--	--	--	--	--	--	--
	162	104	1515-2315	8/13/81	--	--	--	--	--	--	--	--
	136	100	2315-0737	8/13/81	--	--	--	--	--	--	--	--
	186	88	0730-1450	8/14/81	--	--	--	--	--	--	--	--
Vacuum Tower	006	95	1417-2208	8/10/81	--	--	--	--	--	--	--	--
	097	91	0715-1442	8/12/81	--	--	--	--	--	--	--	--
	164	96	1505-2305	8/13/81	--	--	--	--	--	--	--	--
	185	89	0712-1445	8/14/81	--	--	--	--	--	--	--	--
Flaker Belt	050	75	0850-1437	8/11/81	--	--	--	--	--	--	--	--
	028	114	2314-0846	8/11/81	--	--	--	--	--	--	--	--
	168	102	1456-2300	8/13/81	--	--	--	--	--	--	--	--
	192	93	0700-1445	8/14/81	--	--	--	--	--	--	--	--
Fractionator	065	105	1430-2229	8/11/81	--	--	--	--	--	--	--	--
	081	86	0720-1428	8/12/81	--	--	--	--	--	--	--	--
	096	86	0720-1428	8/12/81	--	--	--	--	--	--	--	--
	167	96	1508-2308	8/13/81	--	--	--	--	--	--	--	--
	191	89	0720-1445	8/14/81	--	--	--	--	--	--	--	--
Waste Oil Recovery	053	68	0900-1442	8/11/81	--	--	--	--	--	--	--	--
	137	99	1100-1916	8/13/81	--	--	--	--	--	--	--	--
	129	94	1543-2331	8/13/81	--	--	--	--	--	--	--	--
	195	33	0750-1140	8/14/81	--	--	--	--	--	--	--	--
Control Room	130	97	1132-1935	8/13/81	--	--	--	--	--	--	--	--
	134	93	1532-2319	8/13/81	--	--	--	--	--	--	--	--
	183	96	0708-1500	8/14/81	--	--	--	--	--	--	--	--
Seal Oil Pump	052	74	0915-1437	8/11/81	--	--	--	--	--	--	--	--
	082	87	2323-0637	8/11/81	--	--	--	--	--	--	--	--
	188	88	0735-1455	8/14/81	--	--	--	--	--	--	--	--
Perimeter	107	90	0720-1448	8/12/81	--	--	--	--	--	--	--	--
	131	96	1145-1947	8/13/81	--	--	--	--	--	--	--	--
	181	96	0718-1515	8/14/81	--	--	--	--	--	--	--	--
Blanks (ug/sample)	078			8/11/81	--	--	--	--	--	--	--	--
	179			8/13/81	--	--	--	--	--	--	--	--

[a] Aromatic amines: A = Aniline; B = N,N-Dimethylaniline; C = 2,4-Dimethylaniline; D = o-Toluidine; E = o-Anisidine; F = p-Anisidine; G = 1-Naphthylamine; H = 2-Naphthylamine.

[b] Assuming a sample volume of 90 liters.

[c] "--" indicates not detected.

Table B-34. Plant E Personal Sampling Analytical Results ($\mu g/m^3$) for Aromatic Amines (August 10-14, 1981)

Personnel Sampled	Sample Number	Sample Volume (L)	Sampling Time	Date Collected	Compound (detection limit, $\mu g/m^3$)[a]							
					Aniline (30)	N,N-Dimethyl-aniline (39)	2,4-Dimethyl-aniline (51)	o-Toluidine (23)	o-Anisidine (24)	p-Anisidine (33)	1-Naphthyl-amine (29)	2-Naphthyl-amine (10)
Operators												
#3 Operator	025	96	0711-	8/10/81	--[b]	--	--	--	--	--	--	--
	117	40	1135-1530	8/13/81	--	--	--	--	--	--	--	--
#5 Operator	119	75	0955-	8/13/81	--	--	--	--	--	--	--	--
	155	93	0645-1446	8/13/81	--	--	--	--	--	--	--	--
	215	89	0700-1450	8/14/81	--	--	--	--	--	--	--	--
#8 Operator	040	21	0740-1440	8/11/81	--	--	--	--	--	--	--	--
	032	90	2330-0650	8/11/81	--	--	--	--	--	--	--	--
#10 Operator	104	97	0655-1430	8/12/81	--	--	--	--	--	--	--	--
#11 Operator	026	96	1506-2241	8/10/81	--	--	--	--	--	--	--	--
	089	94	2315-	8/11/81	--	--	--	--	--	--	--	--
	091	87		8/11/81	--	--	--	--	--	--	--	--
Maintenance Personnel												
Pipefitter	044	69	0845-1430	8/11/81	--	--	--	--	--	--	--	--
	101	51	0900-1335	8/12/81	--	--	--	--	--	--	--	--
	120	60	1008-1528	8/13/81	--	--	--	--	--	--	--	--
	158	79	1540-2317	8/13/81	--	--	--	--	--	--	--	--
	201	89	0755-1515	8/14/81	--	--	--	--	--	--	--	--
Machinist	154	150	1545-2320	8/13/81	--	--	--	--	--	--	--	--
	214	89	0755-1520	8/14/81	--	--	--	--	--	--	--	--
Instrument/ Electrician	066	81	1601-2250	8/11/81	--	--	--	--	--	--	--	--
	090	93	1135-	8/11/81	--	--	--	--	--	--	--	--
Insulator	118	54	1010-1530	8/13/81	--	--	--	--	--	--	--	--
Laborer	042	73	0806-1330	8/11/81	--	--	--	--	--	--	--	--
	041	77	1603-2250	8/11/81	--	--	--	--	--	--	--	--
	159	102	1540-2323	8/13/81	--	--	--	--	--	--	--	--
	213	51	0745-1402	8/14/81	--	--	--	--	--	--	--	--
Blanks (µg/sample)	074			8/11/81	--	--	--	--	--	--	--	--
	223			8/14/81	--	--	--	--	--	--	--	--

[a] Assuming a sample volume of 80 liters.

[b] "--" indicates not detected.

Table B-35. Plant E Area Sampling Analytical Results (ppm) for Benzene, Toluene, and Xylene (August 10-14, 1981)

Location Sampled	Sample Number	Sample Volume (ℓ)	Sampling Time	Date Collected	Compound (detection limit, ppm)[a]		
					Benzene (0.01)	Toluene (0.01)	Xylene (0.01)
Slurry Preparation	010	116	2306-0836	8/11/81	0.01	0.01	0.01
Reactor	047	73	0844-1450	8/11/81	--[b]	--	--
	011	106	2309-0830	8/11/81	0.03	0.01	0.01
	139	96	2322-0723	8/13/81	0.02	0.01	--
Hydroclone	085	88	2305-0626	8/11/81	--	--	--
	084	85	0725-1430	8/12/81	--	0.01	--
	151	96	1515-2315	8/13/81	--	--	--
	200	100	0730-1450	8/14/81	--	--	--
Vacuum Tower	008	95	1417-2208	8/10/81	0.01	0.01	0.01
	069	98	1441-2230	8/11/81	0.01	--	--
	083	90	0715-1443	8/12/81	--	--	--
	152	88	1505-2305	8/13/81	--	--	--
Flaker Belt (empty)	003	93	1424-2211	8/10/81	--	--	--
	153	95	1456-2300	8/13/81	--	--	--
	197	105	0700-1445	8/14/81	0.01	0.01	--
Fractionator	068	93	1431-2224	8/11/81	--	--	--
	138	99	1105-1919	8/13/81	--	--	--
	198	56	0720-1445	8/14/81	0.06	0.02	0.01
Waste Oil Recovery	009	116	2317-0856	8/11/81	--	--	--
	048	68	0900-1442	8/11/81	--	--	--
	140	99	1100-1916	8/13/81	--	0.02	--
Control Room	012	97	2301-0850	8/11/81	0.02	0.01	--
	049	89	0831-1554	8/11/81	--	--	--
	116	96	1135-1935	8/12/81	--	--	--
Seal Oil Pump	070	97	1436-2230	8/11/81	--	--	--
Perimeter	108	90	0720-1448	8/12/81	--	--	--
	143	96	1145-1947	8/13/81	--	--	--
	219	125	0715-1515	8/14/81	0.03	--	--
Blanks (µg/sample)	076			8/11/81	0.003	--	--
	178			8/13/81	--	--	--
	222			8/14/81	--	--	--

[a] Assuming a sample volume of 100 liters.

[b] "--" indicates not detected.

Table B-36. Plant E Area and Personal Sampling Analytical Results (mg/m^3) for Phenolic Compounds (August 10-14, 1981)

	Sample Number	Sample Volume (ℓ)	Sampling Time	Date Collected	Compound (average detection limit, mg/m³) Phenol (0.1)	Cresols (0.1)	o-Ethyl-phenol (0.1)	p-Ethyl-phenol (0.1)	2,3-Xylenol (0.1)	3,5-Xylenol (0.1)
Location Sampled										
Slurry Preparation	005	96	1405-2205	8/10/81	--[a]	--	--	--	--	--
	098	88	0728-1433	8/12/81	--	--	--	--	--	--
	196	89	0740-1503	8/14/81	--	--	--	--	--	--
Reactor	001	95	1409-2406	8/10/81	--	--	--	--	--	--
	133	96	1123-1926	8/13/81	--	--	--	--	--	--
Hydroclone	064	105	1426-2227	8/11/81	--	--	--	--	--	--
	161	96	1515-2315	8/13/81	--	--	--	--	--	--
	190	88	0730-1450	8/14/81	--	--	--	--	--	--
Vacuum Tower	007	95	1417-2208	8/10/81	--	--	--	--	--	--
	095	90	0715-1443	8/12/81	--	--	--	--	--	--
	169	105	1505-2305	8/13/81	--	--	--	--	--	--
	187	91	0712-1445	8/14/81	--	--	--	--	--	--
Flaker Belt (empty)	051		0850-1435	8/11/81	--	--	--	--	--	--
	029	114	2314-0846	8/11/81	--	--	--	--	--	--
	193	96	0700-1445	8/14/81	--	--	--	--	--	--
Fractionator	063	126	1436-2229	8/11/81	--	--	--	--	--	--
	079	86	2331-0639	8/11/81	--	--	--	--	--	--
	132	190	1105-1919	8/13/81	--	--	--	--	--	--
	170	98	1508-2308	8/13/81	--	--	--	--	--	--
	189	89	0720-1445	8/14/81	--	--	--	--	--	--
Waste Oil Recovery	166	94	1541-2331	8/13/81	--	--	--	--	--	--
	199	22	0755-1508	8/14/81	--	--	--	--	--	--
Seal Oil Pump	080	87	2323-0637	8/11/81	--	--	--	--	--	--
Control Room	160	107	1532-2319	8/13/81	--	--	--	--	--	--
	184	96	0708-1500	8/14/81	--	--	--	--	--	--
Perimeter	106	90	0720-1448	8/12/81	--	--	--	--	--	--
	141	96	1145-1947	8/13/81	--	--	--	--	--	--
	182	96	0717-1515	8/14/81	--	--	--	--	--	--
Blanks (mg/sample)	075			8/11/81	--	--	--	--	--	--
	180			8/13/81	--	--	--	--	--	--
	224			8/14/81	--	--	--	--	--	--
Personnel Sampled										
Operators										
#3 Operator	024	104	0711-1412	8/10/81	--	--	--	--	--	--
#8 Operator	043	101	0740-1440	8/11/81	--	--	--	--	--	--
#8 Operator	033	74	2330-0650	8/11/81	--	--	--	--	--	--
#10 Operator	102	51	0655-1430	8/12/81	--	--	--	--	--	--
#11 Operator	023	100	1506-2242	8/10/81	--	--	--	--	--	--
Maintenance Personnel										
Instrument/Electrician	067	85	1602-2250	8/11/81	--	--	--	--	--	--
	034	89	2350-0655	8/11/81	--	--	--	--	--	--
Laborer	092	92	2330-0705	8/11/81	--	--	--	--	--	--
	093	77	2330-0705	8/11/81	--	--	--	--	--	--
	103	77	0803-1507	8/12/81	--	--	--	--	--	--
Blanks (mg/sample)	075			8/11/81	--	--	--	--	--	--
	180			8/13/81	--	--	--	--	--	--
	224			8/14/81	--	--	--	--	--	--

[a] "--" indicates not detected.

Table B-37. Plant E Area Sampling Analytical Results for Metals (µg) and Metal Carbonyls (µg/ℓ) (August 10-14, 1981)

Location Sampled	Sample Number	Sample Volume (ℓ)	Sampling Time	Date Collected	Metals (detection limit, µg)			Metal Carbonyls (detection limit, µg/ℓ)[a]		
					Cobalt (0.04)	Molybdenum (0.15)	Nickel (0.20)	Cobalt (4)	Molybdenum (25)	Nickel (20)
Reactor	014	713	1411-2206	8/10/81	--[b]	--	--	--	--	--
	142	725	1123-1926	8/13/81	--	--	--	--	--	--
	173	661	1523-2315	8/13/81	--	--	--	--	--	--
	217	690	0735-1500	8/14/81	--	--	--	u[c]	u	u
	237	668	0735-1500	8/14/81	u	u	u	--	--	--
Hydroclone	071	720	1426-2227	8/11/81	--	--	--	--	--	--
	086	638	0725-1430	8/12/81	--	--	--	--	--	--
Vacuum Tower	013	702	1420-2208	8/10/81	--	--	--	--	--	--
Flaker Belt	055	521	0848-1435	8/11/81	--	--	--	--	--	--
	174	728	1422-2300	8/13/81	--	--	--	--	--	--
	216	705	0700-1445	8/14/81	--	--	--	u	u	u
	212	698	0700-1445	8/14/81	u	u	u	--	--	--
Blanks	077			8/11/81	--	--	--	u	u	u
	176			8/13/81	--	--	--	u	u	u
	225			8/14/81	u	u	u	--	--	--
	226			8/14/81	u	u	u	--	--	--

[a] Assuming a sample volume of 600 liters.

[b] "--" indicates not detected.

[c] "u" indicates sample not analyzed for compound.

APPENDIX C

HEALTH EFFECTS OF COAL-DERIVED MATERIALS

EPIDEMIOLOGICAL STUDIES

Epidemiological studies of workers throughout the world have long established an association between exposure to the combustion or distillation products of coal and an increased incidence of cancer at many sites throughout the body.

One epidemiologic study of workers in a coal conversion plant can be found in the literature (Sexton, 1960). This study is based on 5 years of medical surveillance of 359 workers employed in a direct coal hydrogenation plant in Institute, WV. Fifty workers were described as having skin abnormalities, and 10 of these lesions were originally diagnosed as skin cancer. The conclusion by the author stated that "an increased incidence of skin cancer was found in workers exposed nine months or more to contact with coal hydrogenation chemicals."

In a subsequent review of the data, a consulting pathologist confirmed only 5 of the 10 cases of skin cancer, and statistical analysis of this new incidence does not support the initial conclusion. Follow-up studies on these 50 workers have not as yet revealed an increase in systemic cancers or in cancer mortalities in that work force. However, the age of the workers, the long latency period of systemic tumors, and the small number of workers studied (the group of 309 workers without skin lesions were not followed) preclude conclusions concerning long-term health effects. The follow-up studies were limited primarily to maintenance personnel expected to have high contact but low inhalational exposure to coal process liquids.

In addition, the relevance of these studies to today's coal conversion processes is questionable. Process and control technology, as well as work procedures and hygiene practices, result in significantly reduced worker exposure levels in present-day plants.

Epidemiological studies of other workers exposed to soot and carbon black, as well as to coal tar and pitch, over a long period of time have established an association between exposure to these related materials and an increased incidence of cancer.

Soot was first noted as a cause of skin cancer by Pott (1775) and later by Butlin (1892a) in chimney sweeps. Supporting evidence was provided by Schamberg (1910) who noted the reduction of scrotal cancer after the institution of control measures. Positive correlations between increased systemic cancer and exposure to carbon black and oil in the rubber industry were reported by Henry (1946). Polynuclear aromatic hydrocarbons (PNAs) which are carcinogenic to mice have subsequently been identified in carbon black and processed rubber tire extracts (Falk and Steiner, 1952).

Skin cancer among coal tar and pitch workers was first described by Butlin (1892b). Since that time, studies by Henry (1946, 1947) and by Bogovski (1960) have enumerated over 3,000 cases of occupational skin cancer attributed to tar and pitch. Subsequent chemical analysis of coal tar has identified numerous PNAs including benz(a)anthracene, benz(a)pyrene, dibenz-(a,h)pyrene, dibenz(a,i)pyrene, benzo(b)fluoranthene, and dibenz(a,h)-anthracene (IARC, 1973).

Exposure to coal tar products as they are produced in the coking industry and in the coal gas industry provides the closest industrial analogy to coal conversion. The common use of coal, similar temperatures and the reducing atmosphere used in its processing provide the basis for this comparison. The latter factor of temperature is of significance because the production of carcinogenic materials and the incidence of lung cancer in occupational workers appear to increase with coal processing temperatures up to about 815°C (1,500°F) (U.S. DOE, 1980).

While the chemical content of these materials can be argued to be similar, the potential exposures are not. Coking is carried out in batches with poor containment of materials. Fugitive emissions are much higher than those expected from the continuous, enclosed coal liquefaction processes. In addition, concurrent exposures to other chemicals will be different in the two industries. For example, coking involves significant exposure to sulfur dioxide which is reported to have synergistic effects on carcinogenicity.

Nonetheless, a knowledge of the health hazards of these related industries can be expected to provide a base for chemical and medical monitoring and future risk assessment of coal conversion technologies.

Doll et al. (1972) reported the results of a 12-year prospective mortality study of over 11,000 gas industry workers in Great Britain having exposure to coal tar products. Significantly higher rates of death from lung cancer were found for the high-exposure coal-carbonizing workers than for men in general; this was not true for other workers in the plant. Subsequent longer term cumulative studies indicated an increased risk of death from bladder cancer as well as possible scrotal cancer in these high-exposure workers.

Similarly, Kuroda and Kawahata (1936) reported excesses of lung cancer among Japanese coal gas workers, and Kennaway and Kennaway (1947) found a threefold increase in lung cancer mortalities in coke oven-charger workers.

Redmond et al. (1976) reported on an epidemiologic study of cancer in steelworkers including coke plant workers. They found that coke oven workers with 5 or more years of exposure had a higher risk of cancer of the lung and kidney than did the workers in the plant who were not coke oven workers.

Reid and Buck (1956) conducted an epidemiologic study to determine the cancer mortality of coke plant workers in Great Britain. Their results also showed higher-than-expected numbers of deaths from respiratory and other cancer in coke oven workers but not for other workers in the plant.

The NIOSH (1977a) criteria document on coal tar products contains a recommendation for a permissible exposure limit (PEL) of 0.1 mg/m^3 of coal tar measured as the cyclohexane-extractable fraction of total particulate matter. This recommendation takes into consideration both the carcinogenicity of this material and the lowest concentation that can be reliably detected by environmental monitoring. The federal OSHA standard is 0.2 mg/m^3 of coal tar pitch volatiles defined as "the fused polycyclic hydrocarbons which volatilize from the distillation residues of coal, petroleum, wood, and other organic matter" (OSHA, 1978).

TOXICOLOGICAL TESTING OF COAL CONVERSION MATERIALS

Coal conversion materials have been estimated to contain over 10,000 different chemical substances, often of unknown biological activity. The first toxicological testing of these materials was undertaken by Hueper (1956a, 1956b) on oils produced in Bruceton, PA, by the original German Bergius process and in Louisiana, MO, by the old Fischer-Tropsch process. Carcinogenicity of the higher boiling fractions when applied to animals (skin painting and injection) was thus established. In addition, greater carcinogenic potential was seen for materials produced by the Bergius process than by the Fischer-Tropsch process.

Battelle's Pacific-Northwest Laboratory (PNL), under the aegis of the Department of Energy (DOE), is currently implementing a comprehensive testing program of SRC-I and SRC-II liquefaction materials. Dupont has published limited and preliminary toxicological data on SRC-II and EDS materials. Oak Ridge National Laboratory (ORNL) is currently evaluating H-Coal materials. Preliminary results from all of these toxi- cological programs are discussed below and summarized in Table C-1.

Acute and Subchronic Toxicity

Acute toxicities of the three SRC-II coal liquefaction products (light, middle, and heavy distillate), SRC-I process solvent, and SRC-I light oil have been determined from oral feeding studies in female rats. SRC-II materials were found to have toxicities which were similar to those of many compounds in commercial use (benzoic acid, phosphoric acid, and sodium tartrate) but which exceeded that of crude petroleum. SRC-I wash solvent was at least five times more toxic than any of the other process streams in this study. All materials or their effects were shown to be cumulative (Mahlum, 1981).

In cultures of Vero (African green monkey kidney) cells, SRC-II heavy distillate and SRC-I process solvent were significantly more toxic than either middle or light distillate or than Prudhoe Bay or Wilmington petroleum crudes (Battelle PNL, 1979).

Table C-1. Toxicological Testing Results for Coal Conversion Materials

Tests	SRC-II (Fort Lewis)							SRC-I (Fort Lewis)		SRC-I (Wilsonville)		H-Coal (PDU)		EDS (Baytown)	Low-Btu Gasifier "Dirty Gas"	Crude Petroleums	
	Raw Naphtha (Light Distillate)	Middle Distillate	Heavy Distillate	Recycle Process H_2O	Wastewater Plant Influent	Wastewater Plant Effluent	Vacuum Bottoms	Light Oil	Process Solvent	Solid Product	Process Solvent	Blended Distillate[a]	Severely Hydrotreated Blended Distillate[a]	Heavy Gas/Oil Product		Prudhoe Bay	Wilmington
Acute Toxicity																	
In vivo LD_{50} (g/kg)	2.1	3	3.8					3.0			2.8						
In vitro VERO[a]	-	-	+						+								
CHO[b]				+	+	-										-	-
RAM[c]							+										
Subchronic Toxicity																	
5-day (g/kg)	1	1.2	1.5					2.4			1.0						
14- or 28-day (g/kg)																	
Mutagenicity/ Carcinogenicity																	
Point Mutation Ames	-	-	+	+	-	-	+	-	+	+	+	+	-	+	+	+	+
Chromosomal SHE[d]			+						+								
Skin Painting	-		+											+			
Reproduction																	
Decreased Fertility	-	-	+														
Reproductive Success	+	+	+														
Perinatal and Postnatal Survival	+	+	+														
Fetal Abnormalities	-	-	+														

[a] Monkey Kidney Cell Cytotoxicity. [b] Chinese Hamster Ovary Cytotoxicity. [c] Rabbit Alveolar Microphage Cytotoxicity.

[d] Syrian Hamster Embryo Transformation. [e] A blend of 2.9 medium distillate and 1 part heavy distillate.

Mutagenicity/Carcinogenicity

High-boiling point materials (230°C; 450°F) from all four of the major coal liquefaction processes having potential for commercialization (SRC-I, SRC-II, H-Coal, and EDS) have displayed significant mutagenic activity in the Ames microbial system. In general, higher boiling point materials exhibit greater mutagenicity. This activity exceeds that of petroleum crudes, and resides primarily in the basic fractions as contrasted with petroleum crudes where the major mutagenic activity is found in the neutral fractions and is attributed to PNAs.

In the cases of SRC-I, SRC-II, and H-Coal materials, this mutagenicity has been found to be associated mostly with primary aromatic amines. Further, in the cases of SRC-I and SRC-II materials, these primary aromatic amines were found to be mostly 3- and 4-ring compounds including aminonaphthalenes, aminoanthracenes, aminophenanthrenes, aminopyrenes, and aminochrysenes (Battelle PNL, 1979). The mutagenic/carcinogenic role of PNAs in coal liquids (found in the neutral fractions and in both greater quantities and variety than in petroleum fractions) in unclear. Elucidation awaits further advances in subfractionation and characterization techniques.

In the case of SRC-II materials specifically, the light-oil fraction was found to be negative in the Ames assay, while the heavy-distillate product was positive and the heavier vacuum bottoms even more strongly positive. Inconsistant results for middle-distillate oil -- found inactive by Pelroy (1981) but active by Calkins et al. (1979) -- can possibly be attributed to the variability of the chemical composition of different test samples. No temperature ranges for definition of these distillate fractions were included.

Skin painting studies in mice have been carried out using SRC-II heavy and light distillates (Mahlum, 1981). Heavy distillate was found to cause malignant skin tumors following dermal application. Increasing concentrations of this material both increased the incidence of these tumors and decreased the latency period for tumor development. Light distillate did not exhibit tumorigenic properties in mice similarly treated.

Hydrotreatment of SRC-II distillate materials has been shown to alter both the chemical composition and the mutagenicity of these materials. A distillate blend of SRC-II product containing 3 parts middle distillate and 1 part heavy distillate was found to contain primarily 2- and 3-ringed aromatic and heteroatomic species together with high concentrations of phenolic and polynuclear aromatic components. Hydrotreatment resulted in predominately hydroaromatic species of lower overall molecular weight, along with reduced concentrations of heteroatomic species. Most nitrogen- and sulfur-containing compounds underwent transformation. Oxygen content was reduced, resulting in lowered phenolic concentrations and the elimination of the furans (Battelle PNL, 1980).

The mutagenic response, as measured by the Ames assay, was considerably reduced for this hydrotreated material. Hydrotreatment severe enough to remove 67 percent of the nitrogen and 82 percent of the oxygen produced mutagenic rates comparable to those of the controls (Battelle PNL, 1980).

A second, less expensive approach to reducing the genotoxic potential of high-boiling coal liquids, that of distilling off the heavy fractions, correlated with positive results in the Ames mutagenicity assay, is currently being investigated by Battelle Laboratories (Pelroy and Wilson, 1981). Uncertainties concerning analytical methods and masking of genetic effects of individual fractions require further study.

Of SRC-I materials, SRC solid product and SRC process solvent have both been found to be mutagenic in the Ames assay. Unlike SRC-II materials, however, part of this activity was found to be located in fractions identified with phenolic compounds (Pelroy, 1981).

SRC-I materials exhibiting a positive effect in the microbial test also caused mammalian cell transformation. For most materials, the presence of S9 was necessary to effect the transformation; however, a small amount of activity was observed with SRC-I process solvent without S9, indicating the presence of direct-acting agents (Mahlum, 1981).

Toxicity testing of H-Coal materials has shown that the neutral and basic fractions of blended H-Coal distillates from the Trenton, NJ, PDU exhibit significant mutagenic activity eliminated by high-severity hydrotreatment (Cowser, 1980). Mammalian toxicity and skin carcinogenesis assays with these materials are under way. Process materials from the H-Coal pilot plant are being added as they become available. However, no test results for specific streams produced under standard operating conditions are yet available.

An Exxon Donor Solvent (EDS) product sample (heavy gas/oil) was tested for mutagenic and tumorigenic activity by Calkins et al. (1979). The heavy gas/oil was found to be strongly mutagenic in the Ames assay and a potent tumorigenic agent in a mouse skin painting assay. In the latter study, 18 of 30 mice developed skin tumors.

Reproductive Effects/Teratogenicity

Reproductive effects/teratogenicity studies in rats using SRC-II light, middle, and heavy distillate (by gavage) showed some increased prenatal mortality by all three materials, and an increase in the incidence of malformations by heavy distillate when administrered on the 12th through 16th day of gestation (Battelle PNL, 1979). The increased frequency of prenatal mortality occurred occasionally in the absence of signs of maternal toxicity, but the increase in malformations nearly always was accompanied by a decrease in maternal weight gain during pregnancy.

Likewise, SRC-I light oil and wash solvent were not significantly fetotoxic or teratogenic at doses below those causing maternal toxicity; thus, the fetus may be no more sensitive to these exposures than are adult females. However SRC-I process solvent consistently induced fetal mortality and major malformations at levels below those producing signs of fetal toxicity (Battelle PNL, 1979).

POLYNUCLEAR AROMATIC HYDROCARBONS

Polynuclear aromatic hydrocarbons (PNAs) are produced when organic materials are subjected to high temperatures. Hundreds of different compounds result which can be absorbed following skin contact, inhalation, and ingestion.

The content of PNAs in coal-derived crude oil has been estimated to be 5 to 20 percent compared to 1 percent in petroleum crudes (Zedeck, 1980). Analysis of coal liquefaction process streams and the industrial hygiene air and bulk sampling carried out in the present study have confirmed the presence of vapor and particulate PNAs at coal conversion plants. However, emissions from plants have not been completely characterized, many processes and resulting material streams are being changed as the technology matures, and improved control technologies are expected.

The most important concern regarding the effects of this exposure (dermal, oral, and/or inhalation) is the potential risk of cancer and/or inheritable chromosomal damage in persons chronically exposed to low levels of these chemicals over long periods of time.

The chemical family of PNAs has been found to contain many potent mutagens and carcinogens that act in minute amounts almost universally at the site of application. That is to say, tumors appear in the tissue directly exposed to the carcinogen, usually in the skin or lung. The property of carcinogenicity appears to depend on metabolic activation of these chemicals by the microsomal mixed-function oxidase system to biologically active diolepoxide derivatives. It also appears to be stereospecific. Slight changes in molecular structure can result in significant changes in carcinogenic activity. Only PNAs with three or more rings have been found to be strong mutagens and carcinogens, and alkylation often produces an increase in this mutagenicity. Nonetheless, despite recent advances in the understanding of some structure-activity relationships of these chemicals, it is not possible to predict mutagenic activity based on molecular structure.

Interactions among carcinogens, cocarcinogens, and promotors must also be considered when exposure to complex mixtures of chemicals occurs. Co-carcinogens increase the overall carcinogenic process caused by a carcinogen when exposure to the cocarcinogen occurs simultaneously with exposure to the carcinogen. Kuschner (1981) demonstrated that cancer incidence in rats exposed to benz(a)pyrene (a carcinogen) increased directly with simultaneous exposure to sulfur dioxide (a cocarcinogen). The aliphatic hydrocarbon dodecane was found by Smith et al. (1951) to have cocarcinogenic properties. Bingham and Falk (1969) demonstrated a 1,000-fold increase in the potency of low concentrations of benz(a)pyrene by the simultaneous application of dodecane. The authors suggest that certain long-chain hydrocarbons may play the decisive role in determining the carcinogenic potency of a mixture; the importance of the concentration of the initiator (carcinogen) may be minimal. Finally, certain sulfur compounds, aldehydes, and phenolics have all been shown to stimulate the effects of PNAs and other carcinogens in mouse skin (Slaga et al., 1978).

Equally complex and imperfectly understood is the role of promotors in cancer production. These chemicals increase the tumorigenic response to a chemical carciongen when they are applied after the carcinogen, but do not have carcinogenic properties when applied alone. For example, Van Duuren et al. (1978) have shown that the application of a PNA can be followed by months and, in fact, 1 year later by a promoting stimulus such as the application of phorbol esters from croton oil and still result in the production of skin tumors.

To further complicate the picture, other interactions occur between chemicals as they undergo transformation by chemical and physical processes in the environment, and alteration during uptake and transport by the human body. This often leads to health effects totally unpredictable on the basis of a simple knowledge of effects of exposure to individual PNA compounds in animals. Thus, while information concerning effects of individual chemicals fills many gaps in the understanding of general PNA toxicity, it has severe limitations when applied to analysis of the risk involved from exposure to complex mixtures.

Toxicity

Very limited acute or chronic toxicity information, other than that concerning carcinogenicity, is available for PNAs. In general, these chemicals are primary irritants which on repeated or prolonged contact with the skin cause photosensitaization and dermatitis, and upon contact with lung tissue cause pulmonary edema, pneumonitis, and hemorrhage (Boulos, 1978).

A review by Philips et al. (1973) pinpoints the hematopoietic system, gonads, and intestinal epithelium as being especially susceptible to PNA injury. The cells of all these tissues are rapidly dividing, and it is easy to speculate that injury to the DNA replicative phase of the cell accounts for this toxicity, as well as for the carcinogenic potential associated with many of these chemicals.

Naphthalene is the most abundant constituent of coal tar. Inhalation of naphthalene causes headache, confusion, nausea, and perspiration. Severe exposure has been reported to cause severe hemolysis, vomiting, hematuria, and optic neuritis (Boulos, 1978). The OSHA standard for exposure to naphthalene of 10 ppm is intended to minimize the risk of adverse ocular effects.

Carcinogenicity

The Environmental Protection Agency has compiled a list of 124 PNAs identified in the environment which summarizes the toxicity/carcinogenicity data available for them. Those PNAs ranked by EPA and also included in the present industrial hygiene study as well as several related compounds are listed in Table C-2 (adapted from Kingsbury and White, 1979). Also shown in the table are information summaries of the experimental animal testing data for each compound.

Thirty-one PNAs, including many of those measured in this industrial hygiene study, have been rated by the National Academy of Science (NAS). This information based on an evaluation by the International Agency for Research on Cancer (IARC) is presented in Table C-3. Other carcinogenicity rankings for PNAs are available as well. However, quantification and ordering in the

Table C-2. Carcinogenicity Data for Selected PNAs

Compound	Information Summary	Compound	Information Summary
Anthracene	Lowest effective dose for tumorigenic response in mice is 3300 mg/kg.	Fluoranthene	LD_{50} (oral, rat): 2000 mg/kg.
Phenanthrene	Lowest dose for tumorigenic response in mice is 71 mg/kg.	Benzo(k)fluoranthene	Lowest effective dose for tumorigenic response in mice is 72 mg/kg.
Benz(a)anthracene	Lowest effective dose for tumorigenic response in mice is 2 mg/kg.	Benzo(j)fluoranthene	Lowest effective dose for tumorigenic response in mice is 288 mg/kg.
7,12-Dimethylbenz(a)-anthracene	Tumors in 7 species reported. Lowest effective dose is 21 ug/kg.	1,2:5,6-Dibenzo-fluorene	Lowest effective dose for tumorigenic response in mice is 590 mg/kg.
3-Methylcholanthrene	Tumors in 8 species reported. Lowest effective dose is 0.312 mg/kg.	Benzo(b)fluoranthene	Lowest effective dose for tumorigenic response in mice is 40 mg/kg.
Benzo(c)phenanthrene and alkyl derivatives	Lowest effective dose for tumorigenic response in mice is 10 mg/kg.	Indeno(1,2,3-cd)-pyrene	Lowest effective dose for tumorigenic response in mice is 72 mg/kg.
Chrysene	Lowest effective dose for tumorigenic response in mice is 99 mg/kg.	Phenanthridine	Based on acridine. LD_{50} (oral, rat): 2000 mg/kg.
Triphenylene	...	Benzo(f)quinoline	Based on acridine. LD_{50} (oral, rat): 2000 mg/kg.
Pyrene	Lowest effective dose reported for tumorigenic response in mice is 10 g/kg.	Benzo(h)quinoline	Based on acridine: LD_{50} (oral, rat): 2000 mg/kg.
Benzo(g)chrysene	Lowest effective dose reported for tumorigenic response in mice is 720 mg/kg.	Benz(a)acridine	...
Dibenz(a,c)anthracene	Lowest effective dose reported for tumorigenic response in mice is 440 mg/kg.	Benz(c)acridine	Lowest effective dose for tumorigenic response in mice is 468 mg/kg.
Dibenz(a,h)anthracene	Tumors in 5 species are reported. Lowest effective dose is 0.006 mg/kg.	Dibenz(a,j)acridine	Lowest effective dose for tumorigenic response in mice is 11 mg/kg.
Benzo(a)pyrene	Tumors in 6 species are reported. Lowest effective dose is 2 ug/kg.	Dibenz(a,h)acridine	Lowest effective dose for tumorigenic response in mice is 10 mg/kg.
Benzo(e)pyrene	Tumors in 2 species are reported. Lowest effective dose is 140 mg/kg.	Dibenz(c,h)acridine	Lowest effective dose for tumorigenic response in mice is 1020 mg/kg.
Perylene	...	Carbazole	Lowest lethal dose (oral, rat): 500 mg/kg.
Picene	Lowest effective dose for tumorigenic response in mice is 111 mg/kg.	Benzo(c)carbazole	Lowest effective dose for tumorigenic response in mice is 840 mg/kg.
Dibenzo(a,h)pyrene	Lowest effective dose for tumorigenic response in mice is 165 mg/kg.	Dibenzo(a,i)carbazole	Lowest effective dose for tumorigenic response in mice is 510 mg/kg.
Dibenzo(a,i)pyrene	Tumors in 2 species reported. Lowest effective dose is 2 mg/kg.	Dibenzo(c,g)carbazole	Tumors in 4 species reported. Lowest effective dose is 8 mg/kg.
Dibenzo(a,l)pyrene	Lowest effective dose for tumorigenic response in mice is 48 mg/kg.	Dibenzo(a,g)carbazole	Lowest effective dose for tumorigenic response in mice is 270 mg/kg.
Benzo(ghi)perylene	...	Benzo(b)thiophene	Lowest lethal dose (intraperitoneal, mouse): 512 mg/kg
Coronene	...		
2,3-Benzofluorene	...		

Adapted from: Kingsbury and White (1979)

Table C-3. National Academy of Science Ratings for Selected PNAs

Compound	Indications of Carcinogenicity[a]	
	Ratings Suggested by NAS[b]	Comments
Benzo(a)pyrene	+++	Produced tumors in all 9 animal species reported tested. Latent periods shorter than for other polycyclics with possible exception of dibenz(a,h)anthracene.
Dibenz(a,h)anthracene	+++	Tumors produced in 6 animal species. Both local and systemic carcinogenic effects observed. Effective at low doses. Single dose effective in newborn mice.
7,12-Dimethylbenz(a)-anthracene	++++	Not addressed
3-Methylcholanthrene	+++	Not addressed
Dibenz(a,i)pyrene	+++	Rapid appearance of local sarcoma observed from subcutaneous injection in mice and hamsters. Skin painting on mice was also effective but less active than benzo-(a)pyrene.
Benz(a)anthracene	+	Carcinogenic in mice by several routes. Effective oral dose similar to methylcholanthrene but without gastro-intestinal tract tumors.
Dibenzo(c,g)carbazole	+++	Carcinogenic in rat, mouse, hamster, and possibly dog. Both local and systemic effects observed. Appears to be stronger respiratory tract carcinogen than benzo(a)-pyrene in hamster.
Benzo(c)phenanthrene (and $-CH_3$ derivatives)	+++	Not addressed
Dibenzo(a,h)acridine	++	Skin tumors and lung tumors in mice observed following skin painting or subcutaneous administration. Not tested adequately by other routes or in other species.
Dibenzo(a,j)acridine	++	Skin tumors in mice followed topical application. Subcutaneous administrations at highest dosage produced local sarcomas and lung tumors. Not tested in other species.
Benzo(b)fluoranthene	++	Produced skin tumors in mice following repeated skin painting but only at levels 10 times higher than effective benzo(a)pyrene levels. Not tested by other routes.
Dibenzo(a,l)pyrene	+	Subcutaneous administration in mice resulted in sarcomas in all animals. Not treated by other routes or in other species.
Phenanthrene	-	Not addressed
Benzo(k)fluoranthene	-	Not addressed
Indeno(1,2,3-cd)pyrene	+	A complete carcinogen and initiation of skin carcino-genesis in mice, but of lower potency than benzo(a)-pyrene. Local sarcomas followed subcutaneous injection in mice. Not treated by other routes as in other species.
Methylchrysenes	Not Listed	Not addressed
Chrysene	±	Skin tumors in mice followed repeated painting at high concentrations only. High dose, subcutaneous injections produced low incidence of tumors after long induction time.
Picene	Not Listed	Not addressed
Benzo(e)pyrene	-	Data from skin painting experiments in mice evoked weaker response than benzo(a)pyrene or dibenz(a,h)-anthracene. Not tested by other routes.
Dibenzo(a,h)pyrene	+++	Carcinogenic effects demonstrated following repeated skin painting in mice and injections in mice and rats. Not tested by other routes or in other species.

(continued)

Table C-3 (concluded)

Compound	Indications of Carcinogenicity[a]	
	Ratings Suggested by NAS[b]	Comments
Dibenzo(a,g)carbazole	±	Not addressed
Benzo(j)fluoranthene	↔	A high incidence of skin carcinomas results from repeated skin painting in mice. Not tested in other species or by other routes.
Cholanthrene	↔	Not addressed
Dibenz(a,c)anthracene	+	Not addressed
Benzo(c)acridine	Not listed	Skin tumors in mice followed topical application. Bladder tumors in rats followed paraffin wax pellet implantation. Not tested by other routes or in other species.
Benzo(a)carbazole	±	Not addressed
Dibenz(a,i)carbazole	±	Not addressed
Dibenz(c,h)acridine	±	Not addressed
Dibenz(a,g)fluorene	+	Not addressed
Dibenz(a,j)anthracene	+	Not addressed
Dibenz(a,c)fluorene	±	Not addressed

[a] Indications of Carcinogenicity, refer to the Public Health Service Survey.

[b] Carcinogenicity code given by NAS:

- not carcinogenic
± uncertain or weakly carcinogenic
+ carcinogenic
↔, ↔↔, ↔↔↔ strongly carcinogenic

Adapted from: Kingsbury and White (1979)

field of carcinogenicity is difficult due to the necessity of weighing diverse factors such as percentage and species of animals at risk with tumor, mutiplicity of developing tumors, time of tumor occurrence, and routes of exposure utilized by the investigators.

No federal health standards exist for individual PNAs, although 13 of these compounds* are listed in the EPA Consent Degree List and are considered as a group to be potential carcinogens. A threshold limit value (TLV)/time-weighted average (TWA) of 0.2 mg/m^3 for total particulate PNAs determined as cyclohexane-solubles has been recommended by the American Conference of

*Benz(a)anthracene, benzo(a)pyrene, 3,4-benzofluoranthene, benzo(k)fluoranthene, chrysene, acenaphthalene, anthracene, benzo(g,h,i)perylene, fluorene, phenanthrene, dibenz(a,h)anthracene, indeno(1,2,3-cd)pyrene, and pyrene.

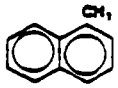
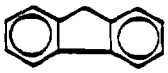
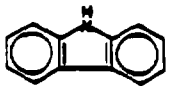
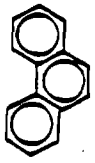
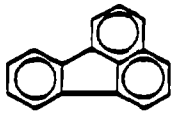
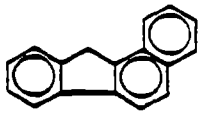
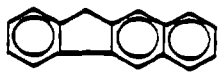
Governmental Industrial Hygienists (ACGIH, 1981). This TLV recognizes the carcinogenic potential of PNAs collectively and is an attempt to minimize concentrations of the higher weight PNAs that are suspected carcinogens.

The 34 individual species of PNAs that were measured in the present industrial hygiene study are pictured in Table C-4; molecular weights, boiling points, and the number of aromatic rings are included when available. Tumorigenic citations of either "CAR" or "NEO" are listed in the Registry of Toxic Effects of Chemical Substances (NIOSH, 1980) for 17 of these chemicals (footnoted in Table C-4), and several others including the prevalent naphthalene are rated as equivocal tumorigenic agents on the basis of at least one experimental study in the literature. A special occupational hazard review for chrysene has been published by NIOSH (1978b).

The PNAs contain some species which are also highly teratogenic. Not all of these PNAs are alike in their teratogenic properties, and the teratogenic effects are even less well understood than the carcinogenic effects. For example, benzo(a)pyrene is not an effective teratogen, whereas 7,12-dimethylbenzanthracene produces a high incidence of defects in exposed animals (Weisburger and Williams, 1980). The evidence for inheritable chromosomal damage is limited and inconclusive.

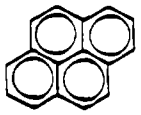
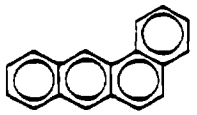
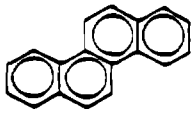
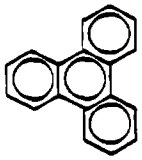
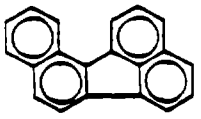
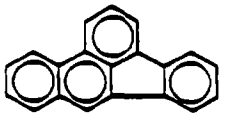
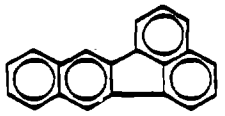
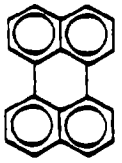
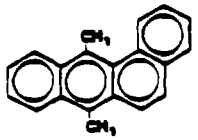
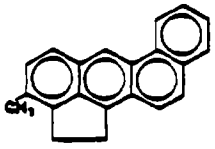
Virtually no toxicological data are available for the oxygen or sulfur heterocyclic PNAs, and there is no evidence to suggest that they are carcinogenic. On the other hand, nine nitrogen heterocyclic PNAs have demonstrated carcinogenic activity, whereas data are lacking on many others (Kingsbury and White, 1979). Five nitrogen heterocyclics were measured in the present industrial hygiene study. Three of them (quinoline, dibenz-(a,j)acridine, and dibenz(a,i)carbazole) are suspected of having carcinogenic properties; information on the other two (acridine and carbazole) has not demonstrated this carcinogenicity.

Table C-4. Polynuclear Aromatic Hydrocarbons

Compound	Structure	Molecular Weight	Boiling Point (°C)	Number of Aromatic Rings
Naphthalene		128.19	218	2
Quinoline*		129.16	238.05	2
1-Methylnaphthalene		142.2	244.64	2
2-Methylnaphthalene		142.2	241.05	2
Acenaphthalene		152.21	265-275	2
Acenaphthene		154.21	279	2
Fluorene		166.23	293-295	2
Carbazole		167.21	355	3
Phenanthrene*		178.22	340	3
Anthracene*				
Acridine		179.22	345-346	3
Fluoranthene		202.24	375	3
Benzo(a)fluorene		216.29	413	3
Benzo(b)fluorene				

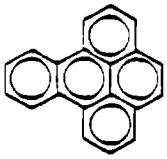
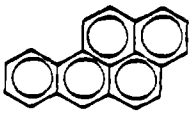
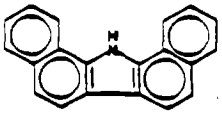
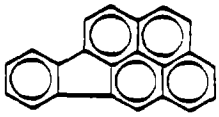
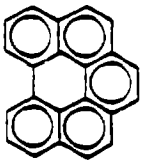
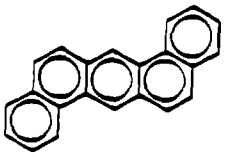
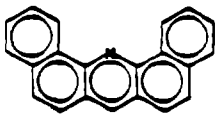
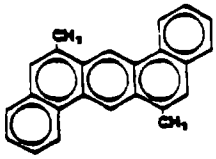
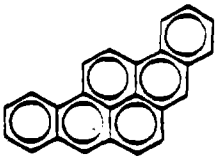
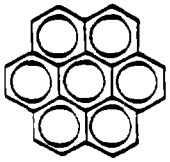
*Associated with tumorigenic citations of either "NEO" or "CAR" in the 1979 Registry of Toxic Effects of Chemical Substances (NIOSH, 1980).

Table C-4 (continued)

Compound	Structure	Molecular Weight	Boiling Point (°C)	Number of Aromatic Rings
Pyrene		202.24	393	4
Benz(a)anthracene*		228.28	435	4
Chrysene*				
Triphenylene				
Benzo(j)fluoranthene*		252.32	480	4
Benzo(b)fluoranthene*				
Benzo(k)fluoranthene				
Perylene		252.32	350-400	4
Dimethylbenz(a)anthracene* (7,12- is pictured)		256.35	--	4
3-Methylcholanthrene*		268.34	--	4

*Associated with tumorigenic citations of either "NEO" or "CAR" in the 1979 Registry of Toxic Effects of Chemical Substances (NIOSH, 1980).

Table C-4 (concluded)

Compound	Structure	Molecular Weight	Boiling Point (°C)	Number of Aromatic Rings
Benzo(e)pyrene		252.32	310-312	5
Benzo(a)pyrene*				
Dibenz(a,i)carbazole*		267	--	5
Indeno(1,2,3-cd)pyrene*		276.22	--	5
Benzo(g,h,i)perylene*		276.22	273	5
Dibenz(a,h)anthracene*		278.33	262	5
Dibenz(a,j)acridine*		280.32	--	5
6,13-Dimethyldibenz(a,h)-anthracene*		306.35	--	5
Dibenzo(a,i)pyrene*		302.28	--	6
Coronene*		300.34	525	7

*Associated with tumorigenic citations of either "NEO" or "CAR" in the 1979 Registry of Toxic Effects of Chemical Substances (NIOSH, 1980).

AROMATIC AMINES

Aromatic amines have been detected in high-boiling point (370°C; 700°F) coal liquids. They have been shown by chemical fractionation and analytical methods to be largely responsible for the high level of mutagenicity associated with these materials in the Ames test. The most mutagenically active boiling-point cuts appear to contain the highest concentration of 4- and 5-ring polynuclear aromatic amines as well as the highest concentration of total polynuclear aromatic amines (Pelroy and Wilson, 1981).

The major health concern regarding occupational exposure to aromatic amines is the potential risk of cancer, especially of the urinary tract. Absorption of these chemicals occurs readily through both the lungs and the skin, and can result in the appearance of tumors following a latency period of from 4 to 40 years. In addition, exposure to many of the aromatic amines results in methemoglobinemia which, in very large, acute exposures, can be fatal.

Many aromatic amines, derivatives, and analogs have been found positive in the Ames Salmonella bioassay for mutagenicity and/or to be carcinogenic for animals undergoing toxicity testing. Unlike the carcinogenic PNAs, these compounds do not usually cause cancer at the point of application, but rather at distant locations in the body. An exception is 2-anthramine which, in addition to causing a varity of tumors in areas distant from the site of exposure, causes skin cancer in rats subjected to dermal applications. The specific target site seems to depend on the animal species tested and on the specific structure of the aryl group. In man, the urinary bladder appears to be the most common target (Weisburger and Williams, 1980).

The property of carcinogenicity appears to require metabolic activation. Studies have established that, with few exceptions, a key activation reaction, N-hydroxylation (a liver mixed-function oxidase-dependent metabolic reaction) is a prerequisite for tumor production. Animals lacking this metabolic pathway often exhibit negative aromatic amine carcinogenic assays. Further, the sensitivity of a particular tissue to carcinogenicity induced by aromatics amines appears to depend at least partially on the ability of the target organ to convert the carcinogen or an intermediate metabolite to

its active form. Thus, it is generally believed that aromatic amine-induced cancer of the urinary bladder is most likely due to the release of active carcinogens such as arylhydroxylamine derivatives from their transport conjugates at this site (Clayson and Gardner, 1976).

Certain structure-activity relationships have been elucidated for the aromatic amines. For example, the monocyclic arylamines including aniline show weak or no carcinogenic potential in animal tests, whereas a number of substituted anilines are positive. In general, arylamines when substituted by an electron donating methyl or halogen in the ortho position appear to be more powerful carcinogens than the unsubstituted compound. Although these relationships are important in the selection of suspected chemicals for testing and/or monitoring, it is not yet possible to predict carcinogenic activity on the basis of molecular structure.

OSHA (1978) recognizes 17 chemicals as causing cancer in humans; nine of these are aromatic nitro and amino compounds.* Of the nine aromatic amines measured in this industrial hygiene study of coal conversion facilities, two (1-naphthylamine and 2-naphthylamine) are on this OSHA list. Two others (o-toluidine and o-anisidine) are suspected carcinogens, having induced cancers in animals but only at high doses and without the establishment of dose-dependent relationships. On the other hand, aniline -- long thought to be the agent responsible for human bladder cancer in the dye industry -- has been found to have only very weak carcinogenic properties in animals. Other aromatic amines including benzidine, the naphthylamines, 4-aminodiphenyl, 4-nitrodiphenyl, and 4,4-diaminodiphenyl are not generally believed to be the carcinogenic agents in the dye industry (Beard and Noe, 1981).

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*2-Acetylaminofluorene, 4-aminodiphenyl, benzidine (and salts), 3,3-dichlorobenzidine (and salts), 4-dimethylaminoazobenzene, 1-naphthylamine, 2-naphthylamine, 4-nitrobiphenyl, and 4,4-methylenebis-(chloroaniline).

The monocyclic arylamines -- aniline, o-toluidine, o-anisidine -- have all been found to be carcinogenic in animals, but only after continuous intake of high doses. Aniline studies failed to produce the characteristic bladder tumors, but unexpectedly resulted in subcutaneous carcinoma (NCI, 1978). These chemicals, when substituted in the ortho position by an electron donating methyl or halogen, appear to be more powerful carcinogens than the unsubstituted compounds (Weisburger and Williams, 1980). In addition, hemorrhagic cystitis has been observed in workers handling toluidines and chlortoluidines in other industries; however, a relationship to urinary tract cancer has not been established (Hamilton and Hardy, 1974).

2-Naphthylamine is one of the most potent industrial carcinogens ever encountered (Clayson and Gardner, 1976). Occupational exposure to commercial-grade 2-naphthylamine has shown a strong association with bladder cancer. In a report by Case et al. (1954), 26 deaths occurred among exposed workers where 0.3 were expected. Other studies found incidences of bladder tumors in exposed workers of up to 94 percent.

In addition, 2-naphthylamine was the first aromatic amine conclusively established as an experimental carcinogen. Subsequent testing has shown positive tumorigenic results from exposure in dogs, monkeys, mice, and hamsters (the latter response occurring only after high doses); results in rats and rabbits have been negative. Good correlation between tumor production and the appearance of N-oxidative products in the urine lends support to the belief that an active metabolite is the carcinogenic agent (Clayson and Gardner, 1976).

1-Naphthylamine remains unproven as a carcinogenic agent. Occupational exposure to it in a number of industries has been correlated with bladder cancer (Parkes, 1976); however, the possibility of simultaneous exposure to 2-naphthylamine cannot be ruled out. In animals, no carcinogenic effect has been found after testing in dogs or hamsters. However, its metabolite N-(1-naphthyl)-hydroxylamine causes cancer in animals when administered intraperitoneally.

Federal standards for exposure to seven of the aromatic amines measured in the industrial hydiene of coal conversion facilities are as follows:

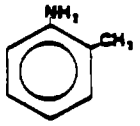
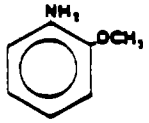
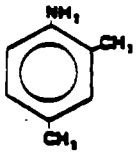
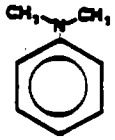
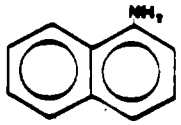
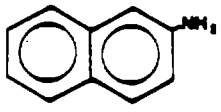
. aniline	5 ppm	19 mg/m^3
. N,N-dimethylaniline	5 ppm	25 mg/m^3
. o-toluidine	5 ppm	22 mg/m^3
. 2,4-dimethylaniline	5 ppm	25 mg/m^3
. o-anisidine		0.5 mg/m^3
. p-anisidine		0.5 mg/m^3
. p-nitroaniline	1 ppm	6 mg/m^3

Because there is no known threshold dose below which a carcinogen will not induce cancer, 1-naphthylamine and 2-naphthylamine have no exposure limits; all contact is to be avoided.

The most important toxic effect following exposure to many aromatic amines including aniline, N,N-dimethylaniline, p-nitroaniline, and the toluidines, other than the development of cancer, is the development of methemoglobinemia. Methemoglobin, a chemical oxidative product of hemoglobin, cannot combine reversibly with oxygen, and at blood levels approaching 60 percent produces symptoms of hypoxia (Beard and Noe, 1981).

Table C-5 shows the molecular structure, molecular weight, and when available, the vapor pressure of the nine aromatic amines measured in this study.

Table C-5. Aromatic Amines

Aromatic Amine	Structure	Molecular Weight	Boiling Point (°C)	Vapor Pressure (mm Hg)
Aniline		93.13	184.13	0.6
o-Toluidine		107.16	200.23	<1
o-Anisidine		123.16	224	<0.1
p-Anisidine		123.16	243	<0.1
p-Nitroaniline		138.13	284	<<1
2,4-Dimethylaniline		119.18	--	--
N,N-Dimethylaniline		121.18	194.15	<1
1-Naphthylamine		143.19	300.8	--
2-Naphthylamine		143.19	306.1	--

THE SIMPLE AROMATICS (BENZENE, TOLUENE, XYLENE)

Light and middle coal liquefaction distillates have been found to contain concentrations of the monocyclic (simple) aromatics ranging from 0.1 to 1.0 percent by volume (Pittsburg and Midway Coal Mining Co., 1980).

Due to high volatility and low skin absorption, the major exposure to these hydrocarbons is from vapor inhalation. The major acute toxic effect is narcosis. In addition, chronic exposure to benzene produces damage to the blood and the blood-forming organs. However, this myelotoxicity has not been demonstrated for either toluene or xylene.

Benzene

The major effect of acute inhalation of benzene is central nervous system (CNS) depression with death resulting from respiratory failure and circulatory collapse. For man, an exposure of 20,000 ppm is usually fatal within 5 to 10 minutes, and 7,500 ppm inhaled for 30 to 60 minutes produces toxic effects (Flury, 1928). The NIOSH (1978c) IDLH (immediately dangerous to life or health) level is 2,000 ppm.

Other toxic effects from severe, acute exposure to benzene include CNS symptoms of convulsions, paralysis, and unconsciousness. Milder exposure produces reversible euphoria, giddiness, headache, nausea, and unsteadiness (NIOSH, 1974). Postmortem findings in fatal cases include petechial hemorrhages of the brain, pleura, pericardium, urinary tract, mucous membranes, and skin (Gerarde, 1960). Breathlessness, nervous irritability, and unsteady gait have been found to persist for up to 3 weeks following an acute exposure (Gerarde, 1960).

Strong evidence linking chronic benzene exposure with damage to the blood-forming tissue and to chromosomal aberrations has long been recognized. On the basis primarily of depression of such blood parameters as erythrocyte count, hemoglobin, hematocrit, mean corpuscular red cell volume, platelet counts, and leukocyte counts in persons exposed to benzene, NIOSH (1974)

recommended a TWA exposure for workers of not greater than 10 ppm, with a ceiling of 25 ppm. This is in agreement with the existing Federal standard.

In addition, more recent clinical and epidemiological evidence has implicated benzene in the causation of leukemia. Presumptive case histories of benzene-induced leukemia reported by NIOSH (1974) include those of: Mallory et al. (1939), 2 such cases; Vigliani and Saita (1964), 6 cases; Forni and Moreo (1967), 1 case; Forni and Moreo (1969), 1 case; and Tareeff et al. (1963), 16 cases in the U.S.S.R. Vigliani and Saita (1964), comparing the incidence of acute leukemia in Milan in 1959-1961 with that in 1962-1963, found a 20-fold increase in leukemia in the latter period which coincided with a sharp increase in benzene poisonings. Cavignaux (1962) demonstrated a high incidence of leukemia among cases of benzene poisoning in France.

These reports are substantiated by a Japanese case-control study (Ishimaru et al., 1971) in which leukemia patients were paired with controls. The authors concluded that occupations involving exposure to benzene occurred more than twice as frequently among leukemia victims than among controls. On the other hand, Thorpe (1974), studying 28,000 petroleum workers exposed to low levels of benzene, found the incidence of leukemia to be no higher for these petroleum workers than for the general population.

The early symptoms of chronic benzene poisoning are vague, consisting of headache, fatigue, and anorexia; and early blood examination usually shows only slight abnormalities in hematological parameters. As the disease progresses, however, bone marrow changes including aplasia or hyperplasia, and peripheral blood changes including anemia, leukopenia, and thromocytopenia develop.

Acute dermal contact with liquid benzene may cause local erythema and blistering of the skin. Repeated or prolonged contact may result in drying, scaling, or dermatitis. However, no evidence exists for systemic injury following dermal contact.

Toluene and Xylene

The primary health effect associated with occupational exposure to both toluene and xylene is CNS depression following acute inhalation of vapors. Reports comparing the relative acute toxicities of benzene, toluene, and xylene are conflicting, possibly because of the different toxicities associated with various isomers. However, these toxicities all appear to be of the same order of magnitude (NIOSH, 1975).

Distinct symptoms from an exposure to toluene appear at about 200 ppm; they include headache, lassitude, anorexia, fatigue, and skin paresthesias. As concentration and/or length of exposure is increased, more severe symptoms appear, including muscular weakness, incoordination, mental confusion, and loss of consciousness (NIOSH, 1973).

Exposure to both toluene and xylene vapors produces local effects as well; they are irritating to the eyes, noise, and throat. In a subjective study by Nelson et al. (1943), reported in NIOSH (1975), a majority of test subjects felt that they could work in an atmosphere of 200 ppm for toluene, but only of 100 ppm for xylene.

Current scientific evidence indicates that, unlike benzene, neither toluene nor xylene cause injury to the blood-forming tissues of the body (NIOSH, 1973). In addition, other effects from chronic exposure to low concentrations of toluene and xylene have not been documented.

The OSHA (1978) standard for toluene is 200 ppm as an 8-hour TWA, with an acceptable ceiling concentration of 300 ppm; maximum peaks of 500 ppm are allowed for 10 minutes. However, NIOSH (1973) recommends a TWA of 100 ppm and a ceiling of 200 ppm. The OSHA standard for xylene is 100 ppm, which is in agreement with the NIOSH recommendation.

PHENOLIC COMPOUNDS

Phenolic compounds are formed from coal during conditions of high temperature and high pressure. Production of phenolic compounds is highly variable

depending upon process conditions and quench system operations. In the liquefaction process, phenolics can comprise up to 25 percent of the light-oil fractions and are present in concentrations of up to 10,000 mg/L in untreated wastewater (Herbes et al., 1976).

Industrial exposure to phenolic compounds is chiefly from dermal contact resulting in both local injury and systemic toxicity following absorption. However, at high process temperature, inhalation of vapors and particulate phenolics with rapid absorption is also possible.

In general, these compounds are highly irritating to the skin, mucous membranes, and eyes. Systemic effects usually involve the central nervous or cardiovascular systems, or both; this may be accompanied by renal and hepatic damage. Of the phenolics measured* in this liquefaction study, phenol is by far the most prevalent and the one that has been studied most. Therefore, the health effects from exposure to phenol are discussed in the most detail here; information concerning the cresols and the xylenols is also discussed when their toxicological manifestations differ from those of phenol.

Phenol

Phenol is a general cell toxin that coagulates protein and produces tissue necrosis (Liao and Oehme, 1980). Its potent corrosive properties cause local damage to exposed tissue. Dermal contact initially produces painless whitening of the exposed area; continuing exposure results in severe burns and necrosis. Skin contact by humans with solutions, emulsions, or pure preparations containing from 80 to 100 percent phenol for a little as 5 to 20 minutes has resulted in death. Eye contact may cause severe damage and blindness (NIOSH, 1976).

The systemic action of a large, acute exposure following absorption appears to be on the CNS resulting in collapse and unconsciousness. Death may occur

*Phenol, o-cresol, m-cresol, p-cresol, o-ethylphenol, p-ethylphenol, 2,3-xylenol, and 2,4-xylenol.

from respiratory arrest or from direct cardiac paralysis (Sollmann, 1957; Deichmann and Keplinger, 1981). The "immediately dangerous to life or health" (IDLH) concentration has been set by NIOSH (1978c) at 100 ppm. Absorption from the lungs following smaller acute or chronic inhalation exposure and from the skin following acute or chronic contact with solid, liquid, or vaporized phenol is rapid and results in systemic damage to the nervous system, heart, respiratory system, liver, and kidneys (Whitthaus, 1911; Piotrowski, 1971). In some exposures, hemolysis leading to hemoglobinurea and jaundice have been reported. NIOSH (1976) further states that "phenol in excess of normal physiologic capacities adversely affects nearly all organs."

The significant health hazard from chronic exposure to low levels of phenol, especially in industrial environments, may be its tumor-promoting activity which has been demonstrated in several strains of mice. However, no information is available concerning chronic human exposure to phenol from inhalation or skin contact; nor are epidemiological studies of occupational exposure to phenol by inhalation found in the literature.

However, animals clinically exposed to phenol vapor have exhibited myocardial, pulmonary, vascular, hepatic, and renal damage (Deichmann et al., 1944). In addition, phenol appears to have tumor-promoting activity in many strains of mice when repeatedly applied to the shaved skin after initiation with known carcinogens (Boutwell and Bosch, 1959; Van Duuren et al., 1971; Van Duuren and Goldschmidt, 1976). It was not found to be carcinogenic when applied alone to the skin of standard strains of mice.

A threshold limit value of 20 mg/m^3 (5 ppm) determined as a TWA, or of 60 mg/m^3 as a ceiling concentration for 15 minutes has been recommended by NIOSH (1976) and is in agreement with the OSHA standard.

Cresol

Cresol presents an occupational hazard from both dermal contact and vapor/aerosol inhalation. Due to the similarities between the reported health effects of exposure to cresol and phenol, these two chemicals have usually been considered analogous with regard to toxicological manifestations. Both

chemicals are readily absorbed, cause skin and eye burns, and produce systemic damage to the nervous system, heart, liver, and kidneys.

However, NIOSH (1978a) cites a French study of 34 resin workers exposed to cresol, formaldehyde, and ammonia (Corcos, 1939) and a Russian animal study (Uzhdavini et al., 1974) as evidence for setting a more stringent limit on exposure levels of cresol. They conclude that, while dermal exposure to phenol and cresol products similar effects, inhalation of cresol results in more severe upper airway irritation. In addition, NIOSH reports that repeated or prolonged skin exposure to low concentrations of cresol may cause skin rash and discoloration -- a sensitization reaction not seen in phenol exposure.

A threshold limit value of 2.3 ppm determined as a time-weighted average is recommended by NIOSH (1978a). The OSHA standard is 5 ppm (22 mg/m^3).

Xylenol

Inhalation and dermal contact with xylenol result in absorption, rapid metabolism, and excretion of the urine (NIOSH, 1978a). Much of the information on the toxic effects of exposure to xylenol comes from Russian studies in animals.

Acute exposures to xylenol cause moderate toxic effects, but less than exposure to phenol or to the monomethylphenols (cresols) (Uzhdavini et al., 1974). Signs of acute toxicity include irritation of the skin and mucous membranes, blood vessel dilation, and neuropathy, all of which vary with dose and route of exposure.

In chronic toxicity studies using mice, xylenol inhalation produced slight growth retardation (Uzhdavini et al., 1979). A study with rats given oral doses of xylenol resulted in decreased liver, kidney, and heart weights, and dystrophy of liver cells (Maazik, 1968).

Xylenol disolved in benzene promoted papillomas and carcinomas when skin-painted on mice after one subcarcinogenic dose of the initiator DMBA

(Boutwell and Bosch, 1959). Some of the results indicated that xylenol might also be a carcinogen; however, the mice used (Sutter) are highly susceptible to carcinomas. No information was found on xylenol's possible carcinogenicity for humans, but contact is generally avoided at levels far below those used in the animal studies.

No exposure guidelines are available for xylenol.

TOXIC GASES AND VAPORS

Coal liquefaction processes which involve the reaction of coal constituents under high temperatures and high pressures present a potential for leakage of toxic gases and vapors into the industrial environment. Although these gases and vapors are normally confined in vessels and pipelines, release can occur from leaking valves, seals, flanges, and vents, as well as during a process upset or vessel rupture.

The toxic gas that is expected to be present in all coal liquefaction processes at concentrations that can be dangerous is hydrogen sulfide. In addition, lower levels of other toxic gases and vapors including hydrogen cyanide (HCN), carbon disulfide (CS_2), carbonyl sulfide (COS), and various metal carbonyls may be present.

A large, acute exposure to hydrogen sulfide can cause respiratory failure and death within a few minutes. Other CNS symptoms of an acute, sublethal dose include weakness, dizziness, headaches, nervousness, and convulsions. Recovery is usually complete, although residual polyneuritis from resulting CNS damage has been reported (Hamilton and Hardy, 1974). The mechanism of actions appears to be inhibition of the cytochrome oxidase system necessary for cellular respiration (Doull et al., 1980), and toxic action on the carotid body (Hamilton and Hardy, 1974) leading to central respiratory paralysis. Hypoxia resulting from the inability of cells to utilize oxygen can cause damage to other organs as well.

Hydrogen sulfide is also a potent local irritant. Eye exposure results in conjunctivitis, keratitis, and palpebral edema, although corneal ulceration

is rare. Photophobia and lacrimation have also been reported. However, no reports of lasting eye damage were found in the literature (NIOSH, 1977b). Respiratory tract irritation produces rhinitis, pharyngitis, bronchitis, pneumonia, and hemorrhagic pulmonary edema.

Effects of chronic exposure to low concentrations of hydrogen sulfide have not been documented. Cough, disturbed sleep, fatigue, headache, nausea, vomiting, and diarrhea have all been reported at a wide range of concentrations.

NIOSH recommends a ceiling concentration for hydrogen sulfide no greater than 10 ppm; the OSHA standard is a ceiling value of 20 ppm with a maximum peak of 50 ppm for a maximum duration of 10 minutes one time only.

Table C-6 summarizes the major toxicological effects and target organs for the groups of chemicals studied in the five coal liquefaction plants.

Table C-6. Major Toxicological Effects of Chemicals Sampled at Five Coal Liquefaction Plants

Chemical	Major Organs at Risk	Indicator of Exposure
PNAs	Skin (cancer) Lung (cancer	
Aromatic Amines	Lung (cancer) Urinary Tract (cancer)	
Naphthalene	Blood (methemoglobinemia, hemolysis)	
Aniline	CNS Liver	
Benzene	CNS (depressant) Blood-forming elements (depression, cancer)	Urinary phenols.
Toluene	CNS (depressant) Skin (sensitization)	Urinary hippuric acid
Xylene	CNS (depressant)	Urinary hippuric acid
Phenolics	CNS (depressant) Cardiovascular System Respiratory System Liver Kidney "all organs" (NIOSH, 1977) (cancer promotor)	Urinary or serum phenol
Cresol	Skin (sensitization)	
Hydrogen Sulfide (H_2S)	CNS (depressant, respiratory arrest)	

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15. Supplementary Notes

16. Abstract (Limit: 200 words) An industrial hygiene assessment was conducted at five coal liquefaction facilities to determine employee exposures to suspected hazardous chemicals. Air sampling was performed to determine levels of polynuclear aromatics (PNAs), the simple aromatics, aromatic amines, and several toxic gases. The results of both area and personal air sampling showed that workers were exposed to numerous PNAs usually at low microgram per cubic meter concentrations. The light molecular weight 2 to 3 ring PNAs were found in the highest concentration with very small or no quantities of the 4 through 7 ring compounds detected. Highest exposures to PNAs were associated with maintenance activities being carried out in the process area during facility operation. The results of air sampling for aromatic amines, phenolic compounds and the simple aromatic compounds showed that these chemicals were present only at very low levels and that airborne exposures to these compounds may not be a major health hazard during normal operations. However, skin absorption would remain a concern. Nonquantitative wipe sampling for PNAs revealed the presence of up to 5 ring PNA compounds on most surfaces sampled, indicating that dermal exposure to higher ring PNAs may present a potential health hazard.

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18. Availability Statement	19. Security Class (This Report)	21. No. of Pages 232
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