

**INDUSTRIAL HYGIENE STUDY OF
COAL LIQUEFACTION PROCESSES**

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16. Abstract (Limit: 200 words) <p>Environmental and personal samples were analyzed for polynuclear aromatic (PNA) compounds including polycyclic aromatic hydrocarbons and aromatic amines, benzene (71432), toluene (108883), xylene (1330207), anilines, phenols, carbon-monoxide (630080), and hydrogen-sulfide (7783064) at five coal liquefaction (SIC-3312) pilot facilities. The industrial hygiene programs were reviewed. The most significant exposures were from PNA. The geometric mean of the area PNA concentrations ranged from 3.9 to 133.8 micrograms per cubic meter at the facilities. Most of the PNA were 2 and 3 ring compounds. Highest PNA exposures were connected with maintenance activities in the process areas. The concentrations of the other substances were rarely above the detection limits. Wipe samples showed the presence of PNA compounds containing up to 5 rings. Most occupational health programs included a preemployment physical, annual checkups, and a termination physical. Protective clothing was provided by all facilities; however, most facilities did not monitor clothing or personnel for residual contamination. The authors conclude that workers at all facilities are exposed to PNA. Recommendations include establishing a standardized medical monitoring protocol and developing methods for decontaminating protective clothing and equipment.</p>		
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A STUDY OF COAL LIQUEFACTION
AND GASIFICATION PLANTS:
AN INDUSTRIAL HYGIENE ASSESSMENT,
A CONTROL TECHNOLOGY ASSESSMENT,
AND THE DEVELOPMENT OF SAMPLING
AND ANALYTICAL TECHNIQUES

VOLUME I
INDUSTRIAL HYGIENE STUDY OF COAL
LIQUEFACTION PROCESSES



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liquefaction pilot plants. Air sampling was carried out for polynuclear aromatics (including polycyclic aromatic hydrocarbons, aromatic amines, and aza-arenes), simple aromatics (benzene, toluene, and xylene), anilines, phenolic compounds, and toxic gases (carbon monoxide and hydrogen sulfide). Sampling for polynuclear aromatic compounds (PNAs) was accomplished through the use of a silver-membrane filter followed by Chromosorb 102 sorbent; analysis for 36 individual PNA compounds was performed by gas chromatography and mass spectrometry.

Area and personal air sampling indicated that workers are exposed at low microgram per cubic meter concentrations to the light molecular weight, 2- and 3-ring PNA compounds. In some cases limited quantities of the 4- through 7-ring compounds were found. Highest exposures to PNAs are found to be associated with maintenance activities being carried out in the process area during plant operation.

Measurable amounts of phenolic compounds, anilines, and polycyclic aromatic amines were only occasionally found, and only at low levels. These levels may be misleading, however, due to the highly humid sampling conditions, and the demonstrated sensitivity of the sampling medium to water vapor.

Simple aromatic compounds (benzene, toluene, and xylene) were present only occasionally, and at low levels of personal exposure; all samples were well below current health standards.

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 be a health hazard.

Occurrence
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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 1970's 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.

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: Plant A, Plant B, and Plant C. Two other plants, Plant D, and Plant E, 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 determine the composition of product and byproduct streams, to identify process areas that may present high exposure potentials, to determine whether selected carcinogens are being concentrated in any process areas, to identify and evaluate controls which have been implemented to reduce worker exposures, and to review industrial hygiene and medical surveillance programs implemented at coal liquefaction plants.

No satisfactory method for sampling individual polynuclear aromatic compounds (PNAs) existed which was compatible with the requirements for personal sampling. Conventional collection devices using large packed columns of solid sorbent had been used in environmental studies, but these devices required powerful vacuum pumps with non-portable electric motors. A sampling device for PNAs was developed for this study which could be adapted to standard, battery-operated personal sampling pumps.

Walk-through surveys were conducted early in the project to determine the concentration ranges of chemical and physical agents identified in the literature as potential health hazards. Sampling done during the walkthrough surveys was also used to test the sampling apparatus and the analytical methods for PNAs. Sampling during the walkthrough surveys also included simple aromatics, phenolics, anilines, toxic gases, toxic metals, and physical agents.

Air samples were collected and analyzed for simple aromatics, phenolics, anilines, toxic gases, toxic metals, and polynuclear aromatic compounds (PNAs).

The scope of the study was modified to concentrate efforts on those chemical agents which appeared to present the most significant health hazards, or which were less well documented in the coal liquefaction industry.

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 uses of these products are 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, high ash and sulfur content, can be lowered 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.

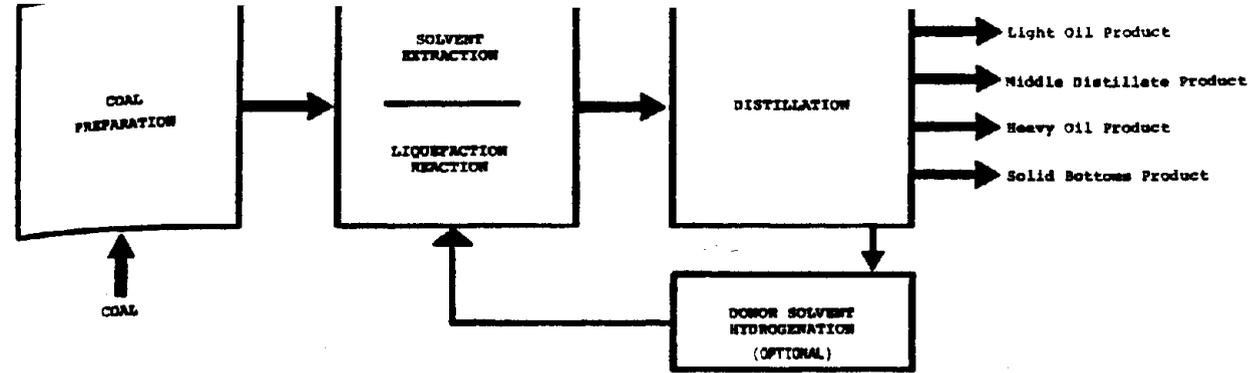


Figure 2-1. Simplified Coal Liquefaction Process Schematic

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 sub-bituminous 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

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; the 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 one 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

stream containing
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.

Catalytic Hydrogenation					
Catalytic Solvent Hydro-treatment	-	-	-	✓	-
Fractionation	✓	✓	✓	✓	✓
Carbonization	-	✓	-	-	-
Residue Separation	Vacuum stripper/ Flaker belt	Precipitation	Filtration/ Denshing	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 3000-3500 - hydrogenator	2500	2000+	up to 3000
Residence time	60 minutes	30 minutes - extractor	10 to 60 minutes	80 minutes	no information

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 (DEA 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.

The extrac-----
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 recycle 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 through 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.

Final Report
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 the hydrocracking the 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 from minus 8 to 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 in series. 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.

stripping. Fractionation
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 mixer/drier.

fractionation
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 (H₂) 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.

and are
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.

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. 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 tested 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.

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, exposures are expected to be more predictable after the establishment of detailed maintenance programs which outline the frequency of maintenance work and detail procedures for decontamination of equipment. Jobs with a high potential for exposure

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 in-plant exposure. In most plants, exposure to process materials and to solvents used in the analytical procedures occurs during sample preparation and analysis.

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 can be 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.

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 (primarily nitrogen and oxygen) is greater. The result is a considerable amount of material boiling over 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 that exhibit minimal direct carcinogenic activity have been shown to possess promoting and/or cocarcinogenic activity. It has been 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, Volume 2.

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/m³. 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.
- . H₂S 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.

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, and 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

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.

plants were in operation (Plants A, B, and C). 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, Pilot Plants D and E 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

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 were to be used as a guideline for the selection of species to be quantitated during the comprehensive surveys.

SELECTION OF PNA COMPOUNDS FOR SAMPLING AND ANALYSIS

Based on data obtained in the 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							B			
	Sample Type:	Location:	Coal Preparation	Mineral Separation	AIR Solvent Recovery	Product Solidification	Water Treatment	WIPE Solvent Recovery	BULK Process Solvent	Extraction	Solid Separation	AIR Solvent Recovery	Carb. Iz.
	Naphthalene	• ^a	•	•	•	•	•	•	•	•	•	•	•
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	•	•	•	•	•	•	•	•	•	•	•	•	•
Benzo (a) anthracene/Triphenylene/Chrysene	•	•	•	•	•	•	•	•	•	•	•	•	•
Benzoanthracene, 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	•	•	•	•	•	•	•	•	•	•	•	•	•
Benzo phenanthrene, monomethyls	•	•	•	•	•	•	•	•	•	•	•	•	•

^a "•" indicates compound detected.

^b "---" indicates compound not detected.

Table 3-3. Other Organic Compounds and Gases Screened in Walk-Through Surveys at Two Coa

Compound	Plant:		A								B					
	Sample Type:	Location:	AIR					WIPE	BULK	AIR						
			Coal Prep	Min-eral Sepa-ration	Sol-vent Re-covery	Product Solid-ification	Water Treat-ment	Sol-vent Re-covery	Pro-cess Sol-vent	Coal Dry-ing	Solvent Extrac-tion	Solid Sepa-ration	Sol-vent Re-covery	Carbon-ization	Stret-ford	Wa Tr
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 indenenes			--	--	--	--	--	--	--	--	--	--	--	--	--	--
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 ^d			•	--	--	--	--	--	--	--	--	--	--	--	--	--
Hydrogen sulfide ^d			--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sulfur dioxide ^d			--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ammonia ^d			--	--	--	--	--	--	--	--	--	--	--	--	--	--

^a• indicates compound detected.

^b-- indicates compound not detected.

^d indicates gases identified by detector tube.

Originally, 29⁷ 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. 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.

* Note that 1- and 2-naphthylamines are also PNAs; thus it is actually 36 PNAs that were measured in this study.

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	Benzo (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.

SAMPLES	PLANT A		PLANT B		PLANT C	PLANT D	PLANT E
	WT ^a	CS ^b	WT	CS	CS	CS	CS
AIR SAMPLES							
<u>Organics</u>							
PNA's	✓	✓	✓	✓	✓	✓	✓
Aromatic amines	✓	✓	✓	✓	✓	✓	✓
Phenolics	✓	-	✓	✓	✓	✓	✓
Benzene/Toluene/Xylene	✓	✓	✓	✓	✓	✓	✓
Hexane	✓	✓	✓	-	-	-	-
<u>Gases</u>							
Carbon monoxide (CO)	✓	✓	✓	-	-	-	✓
Hydrogen sulfide (H ₂ S)	✓	✓	✓	-	-	-	✓
Sulfur dioxide (SO ₂)	✓	✓	✓	-	-	-	-
Ammonia	-	-	✓	-	-	-	-
Metal carbonyls	-	-	-	-	-	-	✓ ^c
<u>Trace Metals</u>	-	✓ ^d	-	✓ ^d	-	-	✓ ^c
BULK SAMPLES							
<u>Organics</u>							
PNA's	✓	✓	✓	-	-	✓	-
<u>Trace Metals</u>	-	-	-	✓ ^d	-	-	-
WIPE SAMPLES							
<u>Organics</u>							
PNA's	-	✓	✓	-	-	✓	✓

^aWT = walk-through survey.

^bCS = comprehensive survey.

^cCobalt, molybdenum, nickel.

^dArsenic, beryllium, cadmium, copper, mercury, manganese, nickel, strontium, tellurium, magnesium.

A complete description of all procedures (including the validation testing) 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, 1983).

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.

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 Compounds (PNAs)

The general principle for collection of airborne PNAs and their aza-analogs 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.

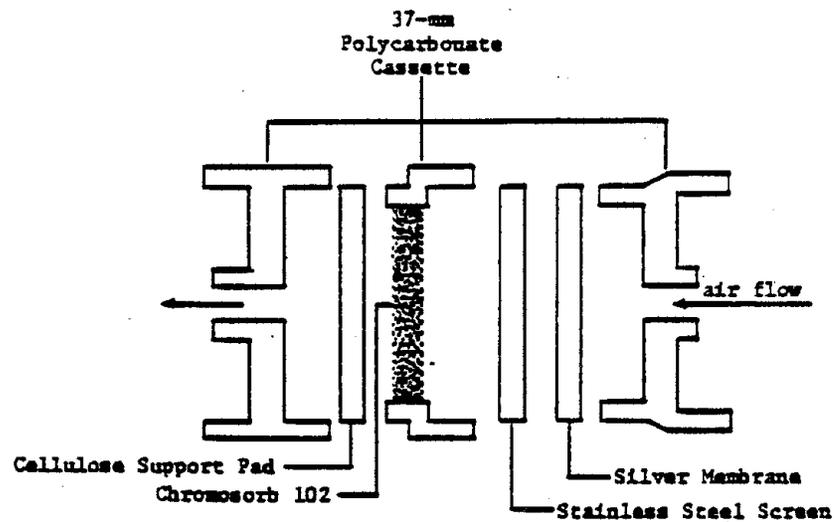


Figure 3-2. Area Monitoring Device for PNAs

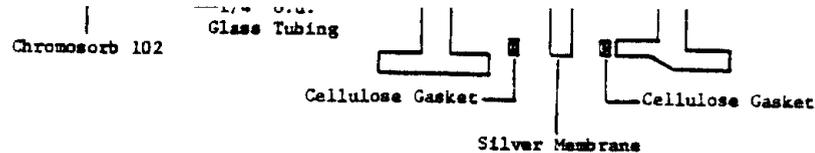


Figure 3-3. Personal Monitoring Device for PNAs

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-

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.

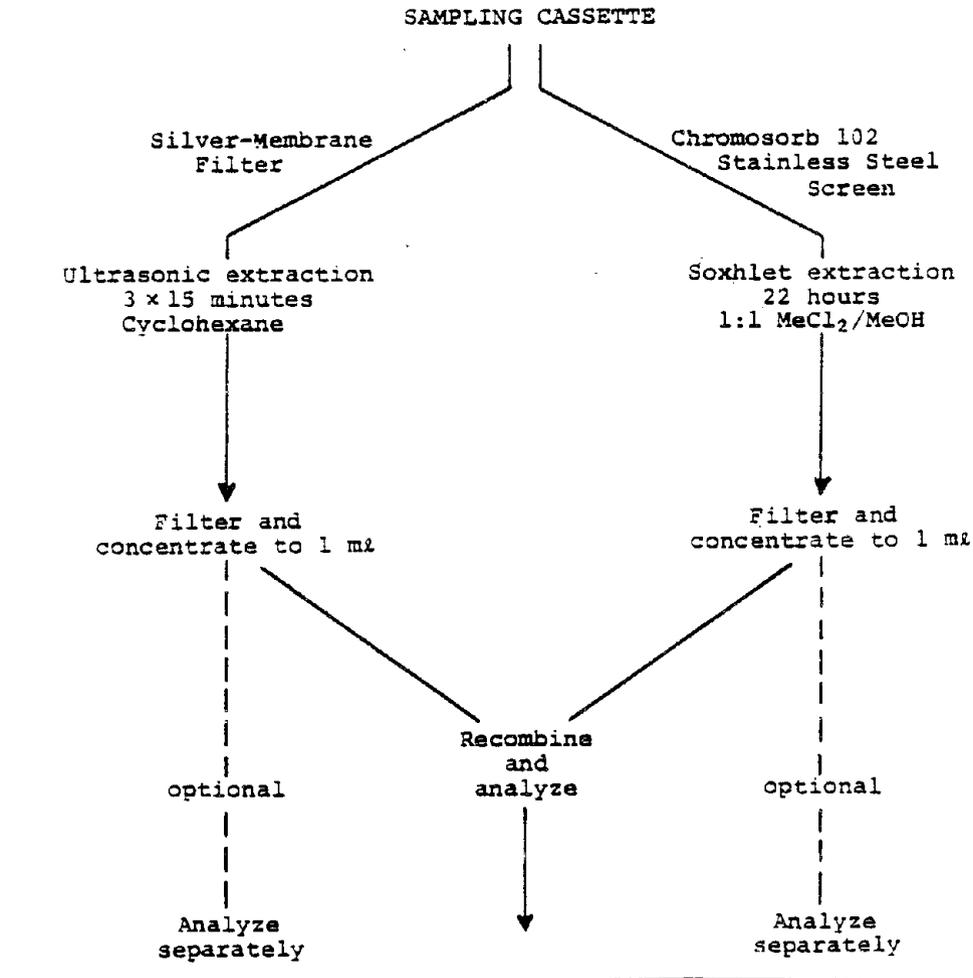


Figure 3-4. Sample Preparation Procedure

The 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 Bransonic 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, d₁₀-anthracene and d₁₂-chrysene. All GC analyses of the referenced PNA compounds produce symmetrical Gaussian peaks, with the exception of quino-
line 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:

- . 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- μ m 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

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

Anilines: 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.

Since the collection efficiency of the silica gel sampling medium has been shown to be adversely affected by relative humidities over 75%, and relative humidities were very high in all of the surveys, the measured levels of aromatic amines may be less than the levels present in the workplace.

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-xyleneol, and 2,4-xyleneol. Since silica gel is also the sampling medium for phenolic compounds,

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:

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

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

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

t.05 was chosen from the standard table.

<u>(n-1)</u>	<u>t.05</u>
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.

collected and analyzed for up to 36 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 grouped data are pooled, geometric means (GM) are listed along with the geometric standard deviation (GSD) and the 95% upper and lower confidence limits (UCL and LCL). When the grouped data consists of only 2 or 3 samples, the minimum and maximum values are shown, rather than the LCL and UCL.

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).

	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	43.3	63.3	98.5	1.2	0.4	0	0	0
	Distillation (Fractionation)	2	50.3	1.5	37.4	67.9	97.6	1.7	0.8	0	0	0
	Solvent Recovery	2	68.0	1.0	67.2	68.9	99.0	0.7	0.4	0	0	0
	Solids Separation	2	38.7	2.5	20.5	72.9	96.9	3.0	1.0	0	0	0
	Carbonization	2	57.2	1.4	45.4	72	99.7	0.2	0.1	0	0	0
	Hydrogenation	2	43.5	1.7	28.9	63.1	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	15.3	19.5	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	135.8	475	98.0	1.9	0.1	0	0	0
	Dissolving (Reactor Pump)	2	57.0	1.3	48.5	66.9	95.5	4.2	0.3	0	0	0
	Distillation											
	Atmospheric Fractionator											
	Light Gas/Oil Pump	3	554.5	1.4	382.	622	97.5	2.4	0.1	0	0	0
	Bottoms Pump	3	917.1	2.5	382	2412	95.5	3.6	0.9	0.1	0	0
	Vacuum Stripper											
	Light Gas/Oil Pump	3	403.5	44.1	5.1	3740	97.3	2.5	0.2	0.1	0	0
	Heavy Gas/Oil Pump	3	4.5	15.2	<0.1	31.4	83.0	15.3	1.7	0	0	0
	Residue Separation											
	Vacuum Bottoms Pump	3	169.5	1.9	114	357	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	42.7	75.1	82.5	15.8	1.7	0	0	0
	Control Room (Main)	3	36.8	2.0	23.3	82.6	97.3	2.7	0	0	0	0
	Control Room (CPU)	2	80.5	1.4	69.9	99.9	97.4	2.6	0	0	0	0
Oily Water Sump	2	180.6	14.4	27.4	1190	99.7	0.1	0.1	0	0	0	
Perimeter	3	0.7	2.9	<0.1	1.3	100	0	0	0	0	0	
Total In-Plant	34	133.8	7.9	65.8	271.8	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.

^h for n=2 or 3 minimum and maximum value shown (not LCL and UCL)

Residue Separation											
Flaker Belt (empty)	3	11.6	1.4	8.0	15.2	95.6	1.4	3.1	0	0	0
Waste Oil Recovery	3	36.8	4.4	0.7	88.4	97.3	1.1	1.4	0.2	0	0
Control Room	3	6.1	19.5	<0.1	39.9	99.7	0	0.3	0	0	0
Seal Oil Pump	3	26.4	1.5	16.9	40.2	92.2	4.2	3.7	0	0	0
Perimeter	3	1.2	6.7	0.3	10.8	100	0	0	0	0	0
Total In-Plant	27	34.8	4.1	19.7	61.2	96.9	1.4	1.7	0	0	0

^aNumber of samples collected. ^bGeometric mean of concentrations. ^cGeometric standard deviation.

^dLower 95% confidence limit of geometric mean. ^eUpper 95% confidence limit of geometric mean.

^f< indicates value below detection limit.

^j for n=2 or 3 minimum and maximum value shown (not LCL and UCL)

	Product Solidificat'n	3	70.5	3.9	17.7	266	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	3	4.2	4.9	<0.2 ^d	211.1	79.7	19.5	0.8	0	0	0
B	OPERATORS											
	Extraction	3	0.2	1	0.1	0.2	100	0	0	0	0	0
	Fractionation/ Solvent Recovery	3	<0.2	2.5	0.05	0.3	100	0	0	0	0	0
	Solids Separation/ Carbonization	3	<0.2	1.5	0.1	0.2	100	0	0	0	0	0
	Hydrogenation/ Utilities	3	<0.2	3.9	0.2	0.3	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	0.01	0.02	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	0.01	0.2	100	0	0	0	0	0
	Technician	3	<0.2	3.9	0.02	0.3	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	1.0	72.6	0.05	21.4	97.3	2.7	0.05	0	0	0
	"D"	2	9.0	1.1	8.2	9.9	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	11.0	29.2	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	7.7	27.5	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	3.2	4.4	43.6	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.

^h for n=2 or 3 minimum and maximum value shown (not LCL and UCL)

	Solvent Hydrogenation	3	299.7	4.4	76.4	1453	99.2	0.8	0	0	0	0
	Offsite & Utilities	2	88.3	1.6	62.3	125	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	8.0	25	87.6	12.4	0	0	0	0
	Millwright	3	188.3	5.5	60.5	1323	98.9	1.1	0.03	0	0	0
	Pipefitter	4	51.1	1.2	17.2	70.1	98.2	1.8	0	0	0	0
	Insulator	2	24.5	1.9	15.7	38.3	96.3	3.7	0	0	0	0
	Electrician	2	34.3	1.5	25.7	45.8	92.6	6.6	0.8	0	0	0
	Instrument Technician	3	41.5	2.1	17.4	67.6	98.6	1.4	0	0	0	0
	Laborer	3	19.0	1.4	13.6	27.2	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 (dis-solving)	3	8.0	20.6	<0.2	171	99.1	0.3	0.5	0	0	0
	Fractionation	3	29.1	1.5	18.8	44.6	97.4	2.1	0	0	0	0
	Solids Separation	1	9.6	N/A ^e	N/A	N/A	100	0	0	0	0	0
	Wastewater Treatment	2	47.5	3.4	20.1	112.3	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	12.8	10.6	0.7	244.2	100	0	0	0	0	0
	Machinist	3	1.8	11.5	<0.2	30.8	100	0	0	0	0	0
	Insulator	2	121.3	2.8	59.3	248	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.

^f N/A = not applicable.

^g "<" indicates value below detection limit.

^j for n=2 or 3 minimum and maximum value shown (not LCL and UCL)

level of the analytical method.

	Process solvent	•	•	•	•	•	□
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"□" indicates sample not analyzed for this group of PNAs.

B	Solids Separation	2	--	--	"	"	--	"
	Solvent Recovery	2	--	--	"	"	--	"
	Carbonization	1	--	--	"	"	--	"
	Waste Treatment	1	--	--	"	"	--	"
	Stratford Unit	2	--	--	"	"	--	"
C	Slurry Blend	1	--	--	--	--	--	"
	Reactor	1	--	--	--	--	--	"
	Solids Separation	6	--	--	--	--	--	"
	Distillation	1	--	--	--	--	--	"
	Seal Oil Pump	1	--	--	--	--	--	"
Product Solidification	1	--	--	--	--	--	"	
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	--	--	--	--	--	--	

^aNumber of samples collected.

^bIncludes o- and p-anisidine.

^cIncludes 1- and 2-naphthylamine.

^d"--" indicates compound not detected.

^e"n" indicates sample not analyzed for this compound.

B	Residue Separation	1	--	--	--	--	--	--
	Coal Preparation	1	--	--	--	--	--	--
	Solids Separation	11	--	--	--	--	--	--
	Solvent Extraction	13	--	--	--	--	--	--
	Solvent Recovery	6	--	--	--	0.1	--	--
	Carbonization	7	--	--	--	--	--	--
	Fractionation	2	--	0.03	--	--	--	--
	Hydrogenation	2	--	0.06	--	--	--	--
	Stratford Unit	2	"	"	"	--	--	--
C	Slurry Blend	2	--	--	--	"	"	"
	Reactor	1	--	--	--	"	"	"
	Solids Separation	6	--	--	--	"	"	"
	Distillation	1	--	--	--	"	"	"
	Seal Oil Pump	1	--	--	--	"	"	"
	Caustic Pump	1	"	"	"	--	--	--
	Hot Well	1	"	"	"	--	--	--
	D	Control Rooms	5	0.19	0.11	--	"	"
Slurry Feed	4	0.04	--	0.02	--	--	--	
Reactor	2	--	--	--	"	"	"	
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	"	"	"	
Flush Oil Pump	3	0.04	0.08	0.52	"	"	"	
Oily Water Sump	2	0.32	0.54	0.85	"	"	"	
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	--	--	--	--	--	--

^aNumber of samples collected. ^bIncludes o- and p-ethylphenol. ^cIncludes o-, m-, and p-cresol.

^dIncludes 2,3- and 3,5-xyleneol. ^e"n" indicates sample not analyzed for this compound.

^f"--" indicates compound not detected.

B	Laboratory Technician	3	--	0.08	--	"	"	"
C	Unit Operator	4	--	--	--	"	"	"
	Laboratory Technician	3	--	--	--	"	"	"
	Maintenance Personnel	3	--	--	--	"	"	"
D	Unit Operator	15	0.13	0.05	0.18	--	--	--
	Maintenance Personnel	16	0.34	0.10	0.05	--	--	--
E	Unit Operator	5	"	"	"	--	--	--
	Maintenance Personnel	5	"	"	"	--	--	--

^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-xyleneol. ^e "—" indicates sample not analyzed for this compound.
^f "—" indicates compound not detected.

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.

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

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	✓	-	-	✓	-

- . 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, safety shoes, long sleeves, and hardhats. Earmuffs are usually available as well.

Protection of workers from inhalation of potentially dangerous gases and air-borne 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 most of the plants for cleaning nonlaunderable articles, such as gloves and rubber items. One plant required nonlaunderable items to be disposed of when soiled, or at the end of the work day. Worker contact with heavily soiled articles of this nature was noted frequently.

before and after showering, or changing after showering, 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.

the skin by a nurse (Plants A, B and C); charting of skin lesions (Plants A, D, 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: ^a	184	88 ^b	121	200-250	150 ^b
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	hemocult	-	-	ongoing exposure histories	-
Epidemiological Program	✓			✓	

^aNot all tests given to all personnel.

^bProcess workers only.

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/ FNAs	-	Benzene solubles	Benzene solubles	Benzene solubles
Gases	✓	CO, H ₂ S	-	✓	-
Benzene, Toluene, Xylene	✓	-	✓	✓	-
Phenolics	✓	-	✓	✓	-
Noise	✓	✓	✓	✓	-

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

Fluoranthene	none detected to 7.7
Pyrene	none detected to 129
Benz(a)anthracene	none detected to 8.8
Chrysene	none detected to 14
Coronene	none detected to 0.21
Benzo(e)anthracene	none detected to 0.87
Dibenz(a,h)anthracene	none detected
Acenaphthene	none detected to 0.57
Fluorene	none detected to 6.2
Phenanthrene	none detected to 9.5
Benzo(b)fluoranthene	none detected to 165
1,2,4,5-Dibenzopyrene	none detected to 2.8
Benzo(g,h,i)perylene	none detected to 0.08

Overall, samples collected from the product solidification area showed higher concentrations of these compounds than samples collected elsewhere. Personal air sampling analyses have failed to detect these PNA compounds because of the small volume of air collected.

- . Phenol and phenolic compounds have not been found in any airborne samples in concentrations above 0.01 ppm.
- . Carbon monoxide concentrations in the coal receiving and preparation building have reached levels as high as 700 ppm at the coal feeder chute.
- . Noise surveys have revealed noise levels in excess of 90 dBA in the following areas: coal preparation, slurry preheating, solvent recovery and recompression, product solidification, bio-unit, boiler house, hydrogen generation, and Dowtherm unit. However, personal monitoring with noise dosimeters has not indicated any noise exposures above 100 percent of the OSHA permissible levels.

- . during upset conditions,
- . during activities that circumvent the closed system,
- . during equipment maintenance, 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

a vessel) or in emergency situations involving major process leaks.

Maintenance workers have duties which routinely involve contact with process stream constituents. These workers often 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 pre-maintenance 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.

being repaired; it 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 blinds and plugs whenever feasible when working on equipment and vessels. Blinds 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.

- . 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 visible tar deposition of all facilities visited.

disposal, and the use of steam cleaning, an effective procedure observed for 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. In plant A a jackhammer was used 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

sign-out system
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.

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 selected 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 plant.

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:

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

Operator (Personal Samples)	Number of Samples Collected	13	12	4	17	9
	Geometric Mean ($\mu\text{g}/\text{m}^3$)	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 ($\mu\text{g}/\text{m}^3$)	17.6	<0.2	<0.2	52.7	4.8
	Upper 95% Confidence Limit ($\mu\text{g}/\text{m}^3$)	73.0	0.2	257.8	178.2	72.7
Maintenance (Personal Samples)	Number of Samples Collected	2	6	7	20	15
	Geometric Mean ($\mu\text{g}/\text{m}^3$)	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 ($\mu\text{g}/\text{m}^3$)	8.1	<0.2	7.2	23.8	3.6
	Upper 95% Confidence Limit ($\mu\text{g}/\text{m}^3$)	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 ($\mu\text{g}/\text{m}^3$)	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 ($\mu\text{g}/\text{m}^3$)	<0.2	<0.2	0.7	N/A	N/A
	Upper 95% Confidence Limit ($\mu\text{g}/\text{m}^3$)	211.1	0.2	222.4	N/A	N/A

^a<" indicates value below detection limit.

^bN/A = not applicable.

	and Dissolving	4	47.0	1.8	43.3	121.9
	Solids Separation	6	52.6	1.5	35.3	78.3
	Fractionation	6	52.6	1.5	35.3	78.3
C	Coal Preparation, Slurrying, and Dissolving	2	0.3	4.0	0.13	0.7
	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	1.3	372
	Fractionation	11	24.5	1.9	16.0	37.6
	Control Room	3	6.2	19.5	<0.1	39.9
	Perimeter	3	1.2	6.7	0.3	10.8

^aNumber of samples collected.

^bGeometric mean of concentrations.

^cGeometric standard deviation.

^dLower 95% confidence limit of geometric mean.

^eUpper 95% confidence limit of geometric mean.

^fN/A = not applicable.

^g< indicates value below detection limit.

^h for n=2 or 3, minimum and maximum values shown (not LCL and UCL)

$$\frac{S_1}{n_1} + \frac{S_2}{n_2}$$

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

Plant A

A comparison of all area samples collected at Plant A (GM = 21.4 ug/m³; 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/m³) is five times the area mean, and the operator mean (GM = 35.8 ug/m³), 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 are a source of additional exposure. The operator levels are not as high as those of maintenance because operators did not actively participate in most repair activities.

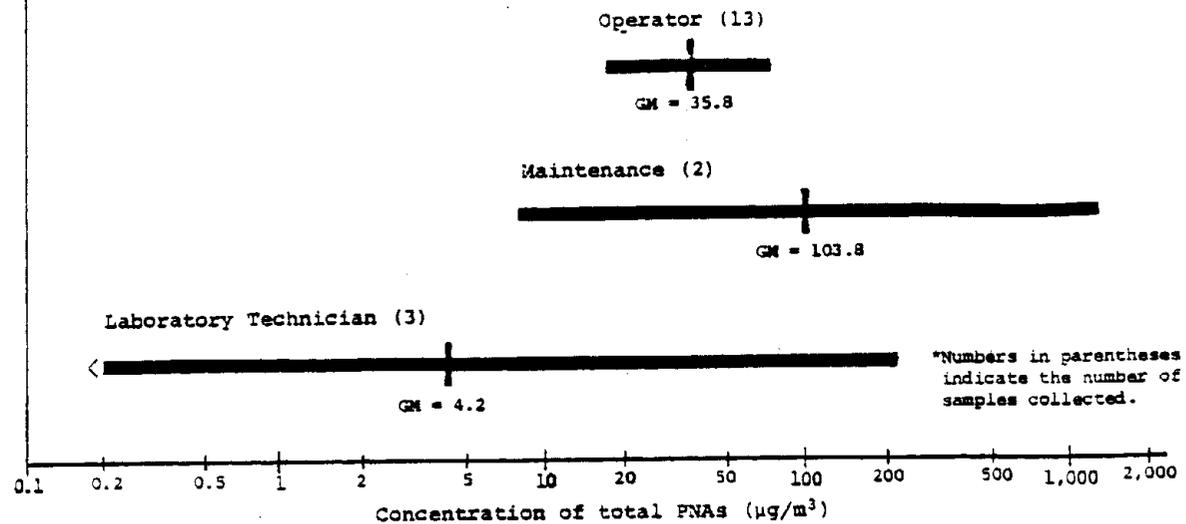


Figure 5-1. Plant A Geometric Mean PNA Concentrations and 95% Confidence Limits for Combined Area, Operator, Maintenance, and Laboratory Technician Samples

The laboratory technicians have a geometric mean exposure of $4.2 \mu\text{g}/\text{m}^3$ which is 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 is nine times that

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 ($GM = 31.3 \text{ ug/m}^3$) and the fractionation ($GM = 23.2 \text{ ug/m}^3$) 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.

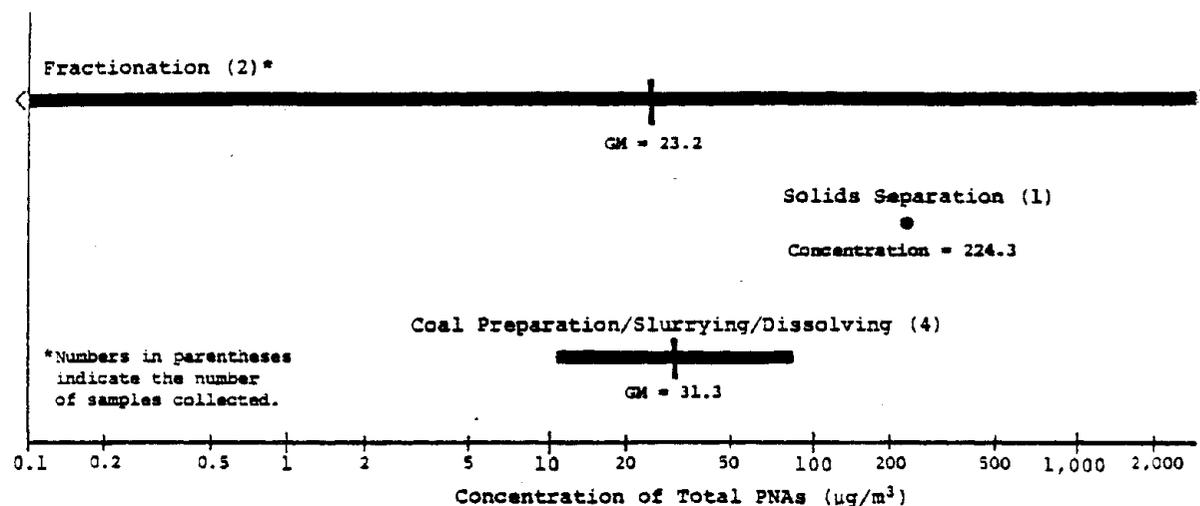


Figure 5-2. Plant A Geometric Mean PNA Concentrations and 95% Confidence Limits for Major Unit Operations

within this area.

Plant B

A significant difference ($P < 0.01$) was observed between the combined area samples ($GM = 50.6 \text{ ug/m}^3$) and the three worker groups ($GM = 0.2 \text{ ug/m}^3$ 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.

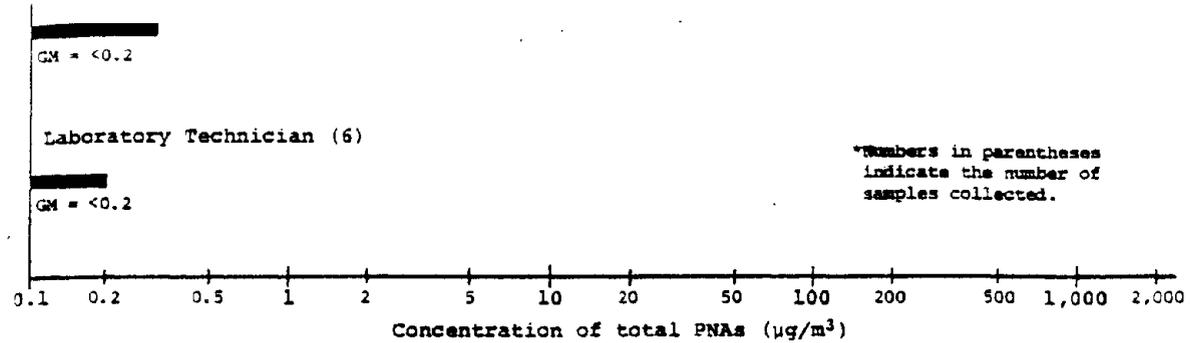


Figure 5-3. Plant B Geometric Mean PNA Concentrations and 95% Confidence Limits for Combined Area, Operator, Maintenance, and Laboratory Technician Samples

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.

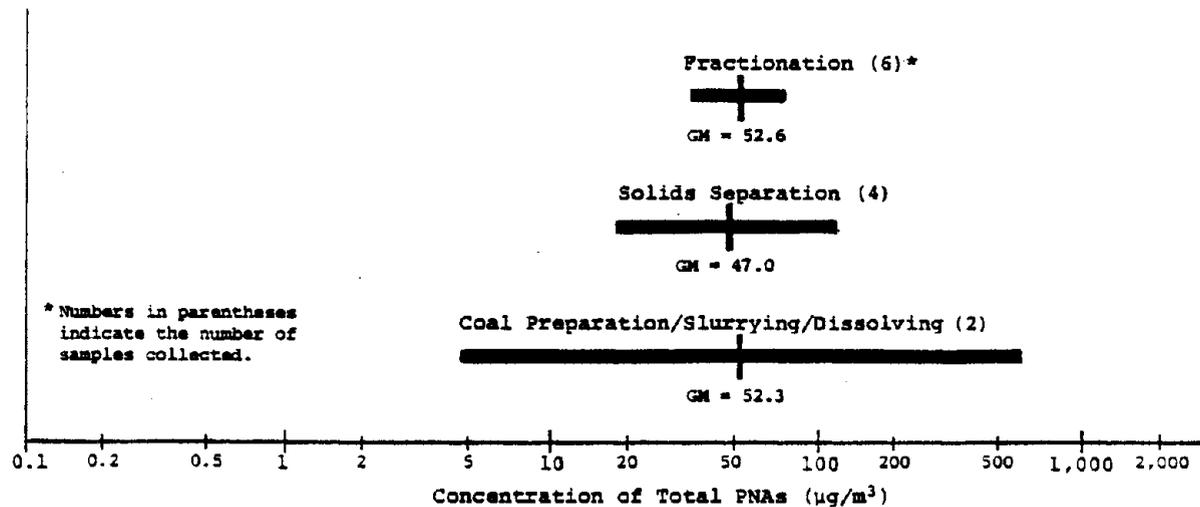


Figure 5-4. Plant B Geometric Mean PNA Concentrations and 95% Confidence Limits for Major Unit Operations

perform minor repair activities (e.g., fixing a leaking valve), it appears that such activities did not add significantly to the operators' overall exposure.

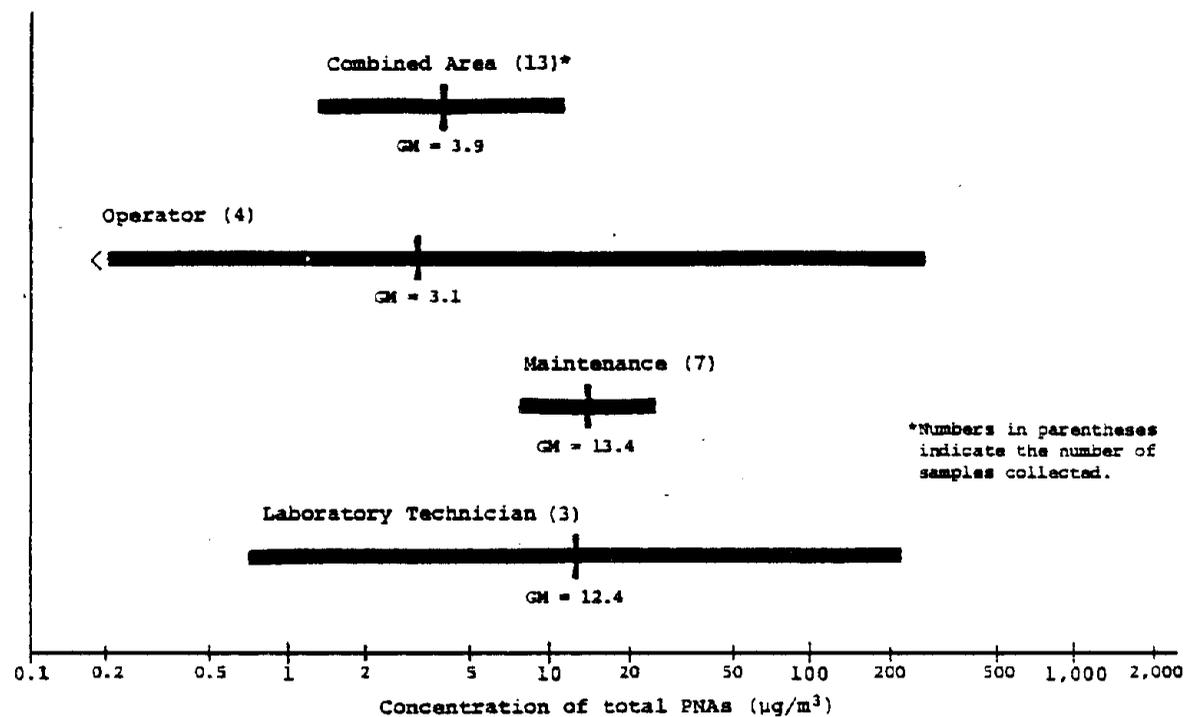


Figure 5-5. Plant C Geometric Mean PNA Concentrations and 95% Confidence Limits for Combined Area, Operator, Maintenance, and Laboratory Technician Samples

No significant difference ($P > 0.05$) existed between the means of the maintenance group ($GM = 13.4 \text{ ug/m}^3$) and the laboratory technician group ($GM = 12.4 \text{ ug/m}^3$), 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

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 $\mu\text{g}/\text{m}^3$) with that of the solids separation area and the coal dissolving area being significantly lower.

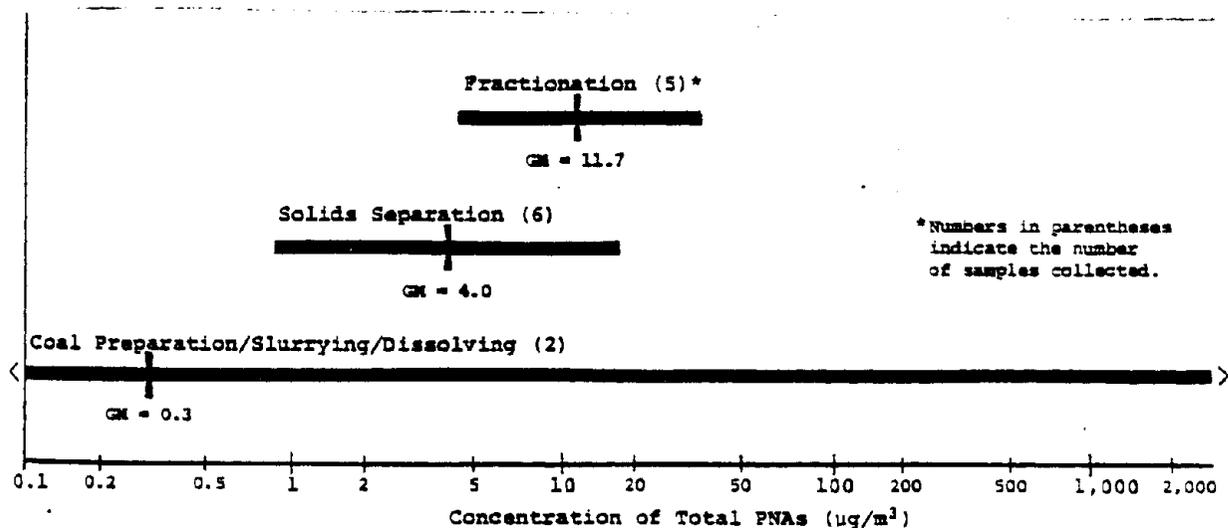


Figure 5-6. Plant C Geometric Mean PNA Concentrations and 95% Confidence Limits for Major Unit Operation Samples

38.8 $\mu\text{g}/\text{m}^3$).

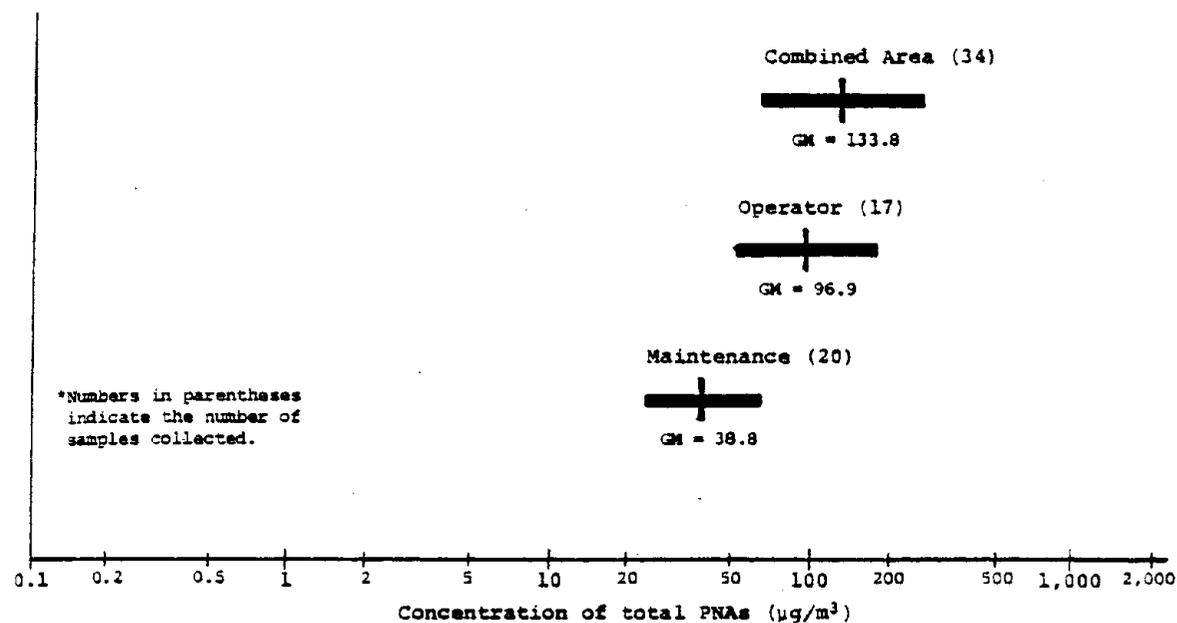


Figure 5-7. Plant D Geometric Mean PNA Concentrations and 95% Confidence Limits for Combined Area, Operator, and Maintenance Samples

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

A, D, ---
This difference may be 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 ($GM = 0.7 \text{ ug/m}^3$) (Table 5-2; Figure 5-8). The PNA level for the control room ($GM = 50.4 \text{ ug/m}^3$) was 71 times, and the levels of the dis- solver/coal preparation ($GM = 161.2 \text{ ug/m}^3$) and the fractionation ($GM = 155.7 \text{ ug/m}^3$) 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.

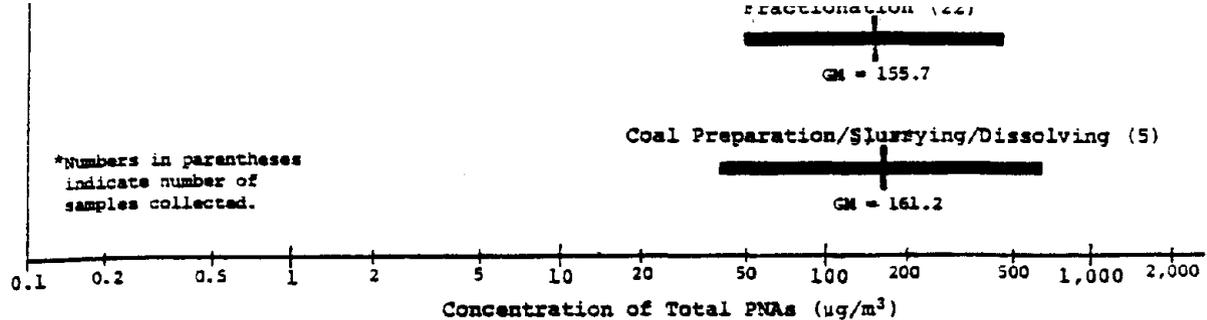


Figure 5-8. Plant D Geometric Mean PNA Concentrations and 95% Confidence Limits for Major Unit Operations, Control Room, and Perimeter Samples

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 ($GM = 34.8 \text{ ug/m}^3$) was three times the mean measured on maintenance workers ($GM = 12.6 \text{ ug/m}^3$) and two times that of the operators ($GM = 18.7 \text{ ug/m}^3$). 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.

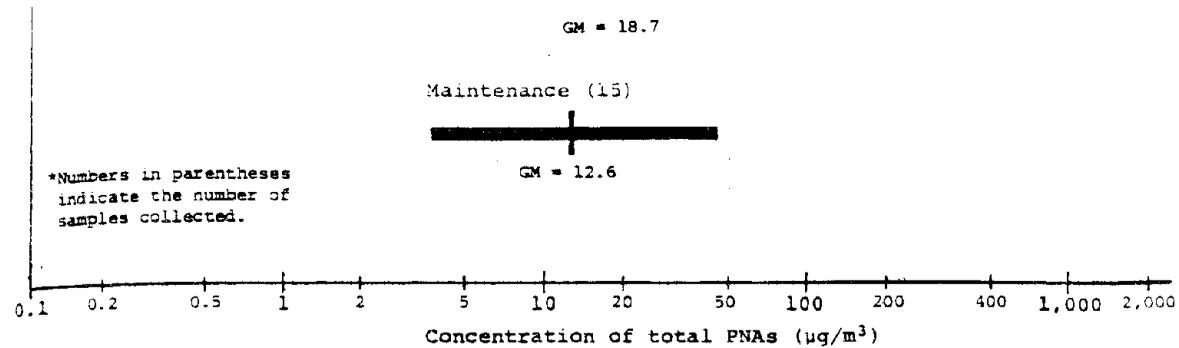


Figure 5-9. Plant E Geometric Mean PNA Concentrations and 95% Confidence Limits for Combined Area, Operator, and Maintenance Samples

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 no 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 shops which are outside of the process area.

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 ($GM = 1.2 \text{ ug/m}^3$) (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 ($GM = 6.2 \text{ ug/m}^3$); the fractionation section was 400 percent higher ($GM = 24.5 \text{ ug/m}^3$); the dissolver/coal preparation area ($GM = 69.2 \text{ ug/m}^3$) was 400 percent higher than the fractionation area; and the solids separation section posted the highest level ($GM = 135.4 \text{ ug/m}^3$) 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.

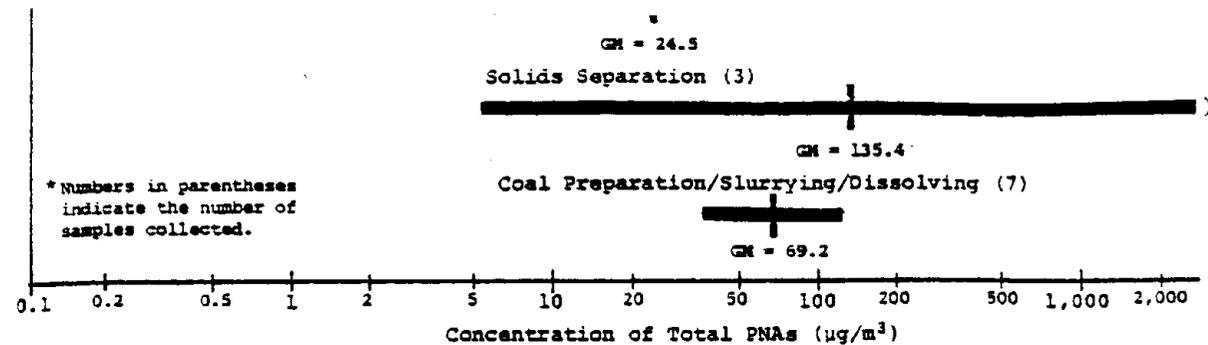


Figure 5-10. Plant E Geometric Mean PNA Concentrations and 95% Confidence Limits for Major Unit Operation, Perimeter, and Control Room Samples

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.

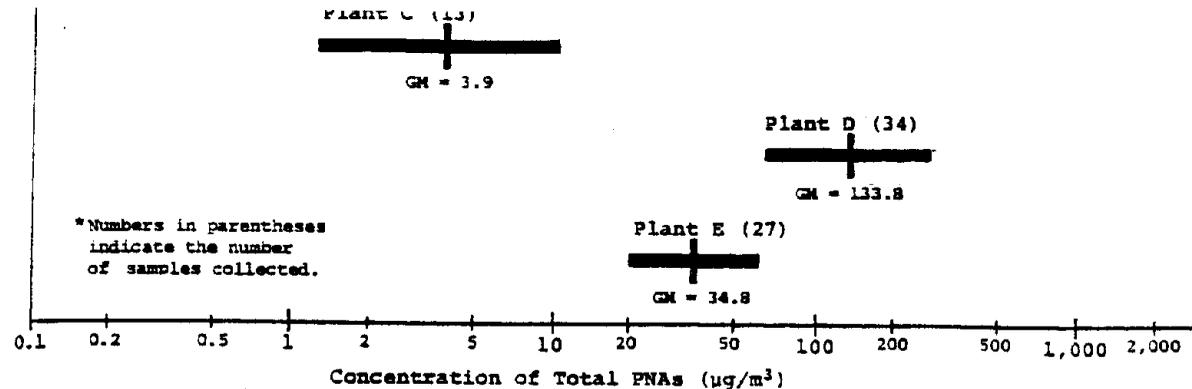


Figure 5-11. Geometric Mean PNA Concentrations with 95% Confidence Limits for (combined) Area Samples from Five Liquefaction Facilities

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 necessarily lead to a corresponding increase in the ambient PNA levels. This result suggests that extrapolation of PNA levels from these pilot plants to larger facilities may not be justified.

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.

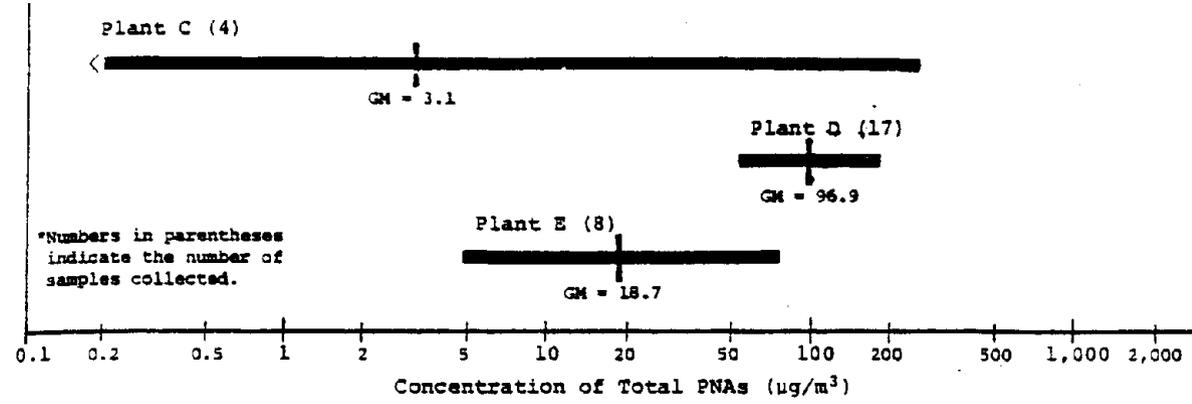


Figure 5-12. Geometric Mean PNA Concentrations and 95% Confidence Limits for Operators at Five Liquefaction Plants

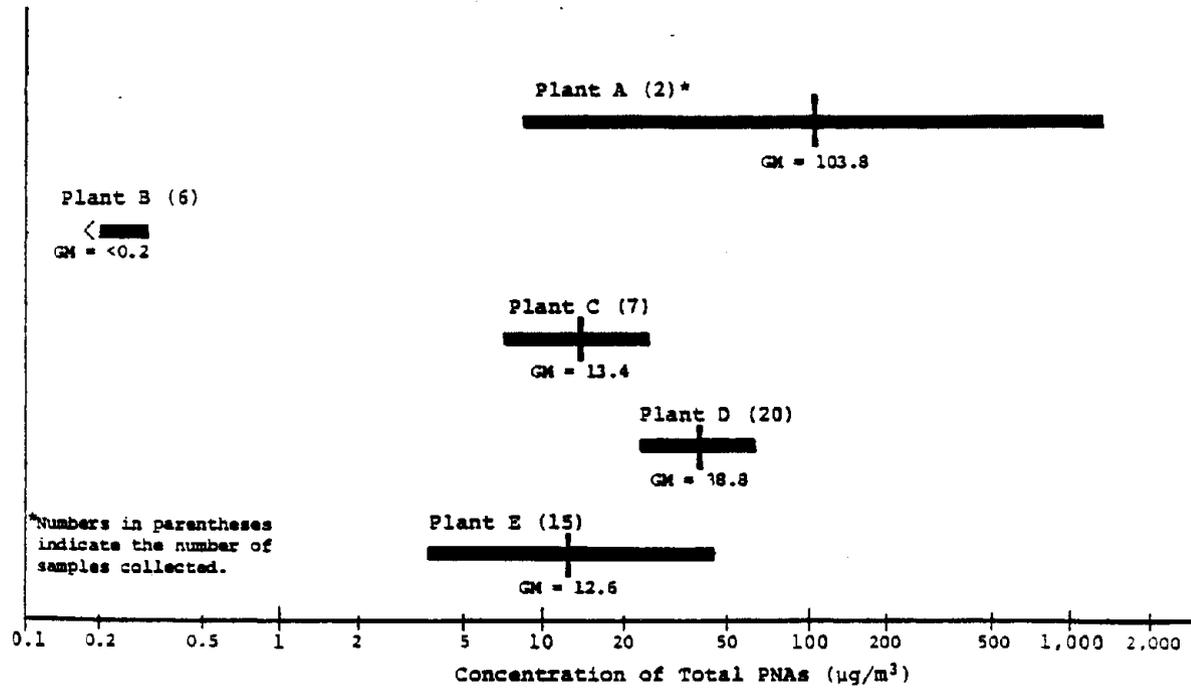


Figure 5-13. Geometric Mean PNA Concentrations with 95% Confidence Limits for Maintenance Workers at Five Liquefaction Plants

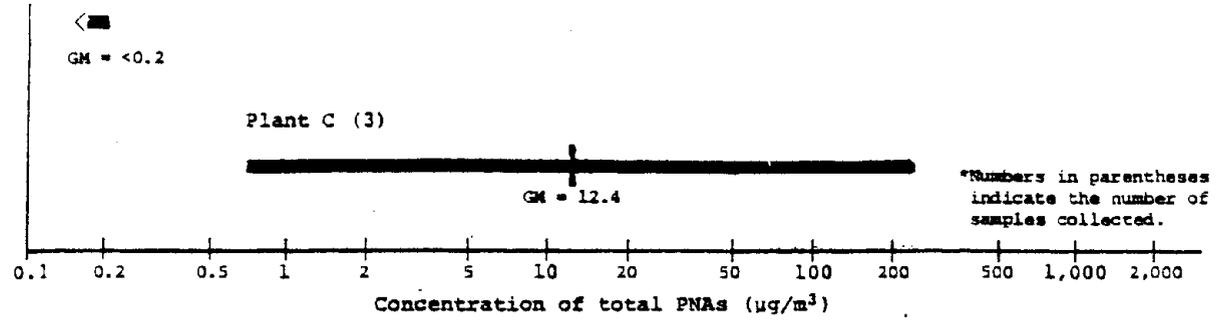


Figure 5-14. Geometric Mean PNA Concentrations with 95% Confidence Limits for Laboratory Technicians at Three Liquefaction Plants

C	5	^a (3.1)	^a (12.6)	^a (12.4)
D	1	1 (96.9)	2 (38.8)	d
E	2	3 (18.7)	3 ^a (13.4)	d

^aGeometric mean concentration ($\mu\text{g}/\text{m}^3$) given in parentheses.

^bLimit of detection of analytical procedure.

^cNo significant difference between Plants C and E ($P > 0.05$).

^dNo 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)

^aGeometric mean concentration ($\mu\text{g}/\text{m}^3$) given in parentheses.

^bNo sampling conducted at these plants for laboratory technician group.

^cLimit of detection of analytical procedure.

^dNo significant difference between Plants C and E ($P > 0.05$).

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 carcinogens phenanthrene and 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 these five coal liquefaction plants is equivalent to the exposure ranges found in the nine petroleum refineries.

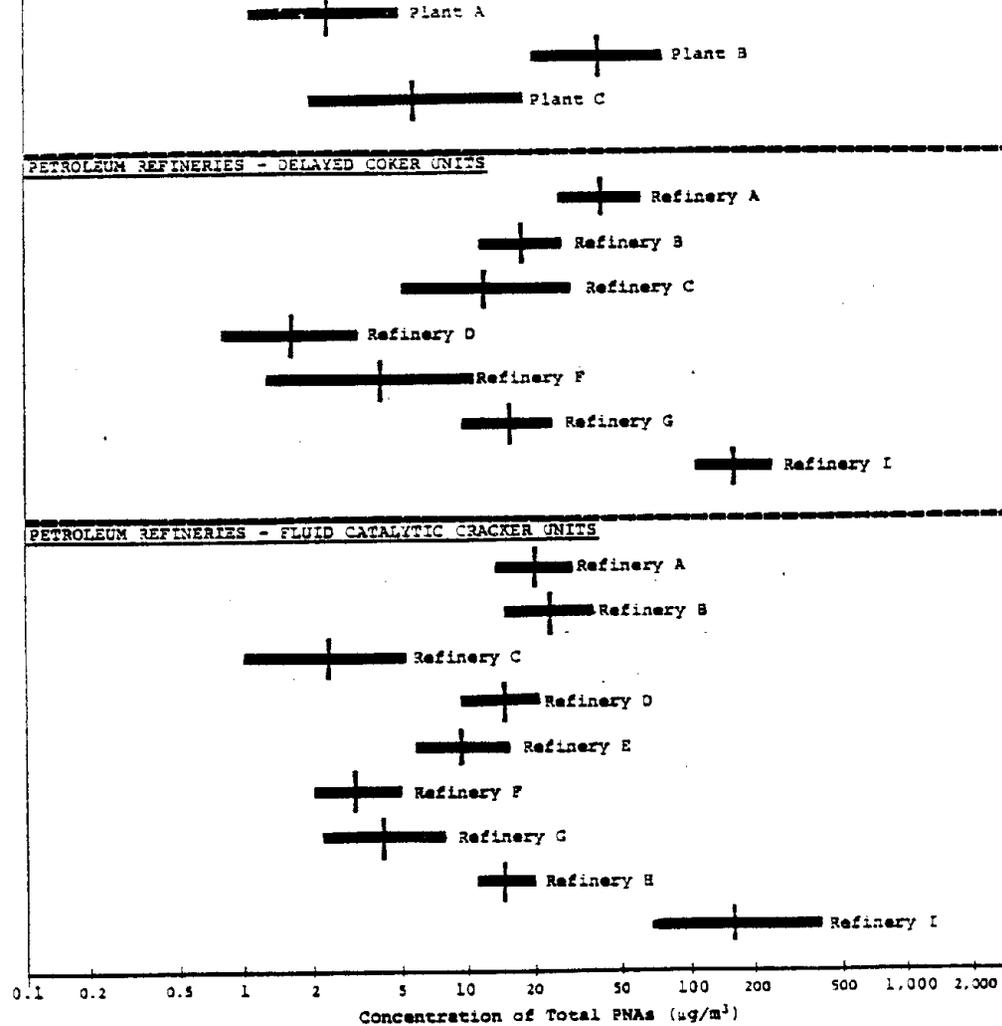


Figure 5-15. Geometric Mean PNA Concentrations with 95% Confidence Limits for Personal Samples Collected at Coal Liquefaction and Coal Gasification Plants, and Petroleum Refineries

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 seem to indicate that employee exposure to simple aromatic amines was not a frequent occurrence in the five plants; however, the sampling and analytical methods used were questionable. High humidity and/or rain was present at all of the plants surveyed; the silica gel sampling medium has been demonstrated to be unreliable under these conditions. Thus, these data cannot be used as evidence that polynuclear aromatic amines (PAAs) are not present in the plant environments. PAA's are, however, known to be present in the process streams.

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 had not been validated by NIOSH, and the methods used in this study (P&CAM 168 and 264) for the simple aromatic amines are not necessarily applicable to PAAs.

OTHER ORGANICS

Over 200 area and personal samples were collected and analyzed for benzene, toluene, xylene, phenols, cresols, and xylenols. All of the samples had concentrations less than 1 ppm (Tables 4-6 and 4-7). Benzene was found in 35 of 208, toluene in 35, xylene in 25 of the 298 samples collected. Phenols were found in only one of the 298 samples. Cresols and xylenols were not detected in any of the personal or area samples.

The low airborne levels of these compounds found seem to indicate that they may not be a significant health concern in these plants; however, the

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 specific to 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 in most pilot plants:

- . most plants did not attempt to identify optimal materials for protective clothing manufacture,
- . most plants lacked guidelines for discarding nonlaunderable, contaminated clothing including shoes, boots, gloves, slickers, etc.,
- . most plants lack the provision for clothing change before meals, and
- . most plants lack a program for routinely determining the effectiveness of the personal hygiene program by checking for residual contamination of personnel before meals and 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

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 FEV₁ 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 the disease 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.

ogist (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 at this time.

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.

5-27



analytical methods used. The PNA 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 pilot facility processed 80,000 tons of coal during a 10,600 hour run. 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 under the conditions sampled.

Plant size, design, unit process, and operating conditions could not always be 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 concentrations. Routine plant operator activities usually 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 potentially significant source of chronic PNA and coal tar product 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

groups of chemicals rarely showed measureable concentrations. There are, however, some questions about the effectiveness of the sampling and analytical methods at the conditions encountered during the surveys, especially for the aromatic amines and the phenolic compounds.

The medical surveillance programs established by the plants reflect their management's awareness of the occupational hazards associated with the facilities. Although no standard medical surveillance program or battery of tests has been widely accepted for these types of facilities, the corporate medical officers have generally developed programs in accordance with many of the NIOSH guidelines for similar industries.

- o 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.

- o Standardized sampling methods should be developed for assessing workplace dermal exposure to PNAs; this should be correlated with health effects information, if possible.

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

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

- o Improved, possibly less complex sampling and analytical methods for PNAs, or a PNA indexing system for selection of "proxy" PNAs for assessment of total PNA exposures need to be developed. The method should be able to utilize analytical instrumentation other than mass spectrometry because of its high cost and inherent variability.

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

- o Improved sampling media and methods are needed for airborne phenolics and aromatic amines.

- o Further research, leading to a standardized medical monitoring protocol, needs to be done.

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PROCESS DESCRIPTION

The Plant A process 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. Carbon dioxide is available for use in the coal storage bin to prevent conditions which could lead to a fire. The coal slurry is fed through the Wilson-Snyder reciprocating pump to be pressurized to approximately 1,500-2,000 psig. 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 is cooled to about 288°C (550°F), and the pressure is reduced 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.

A-3

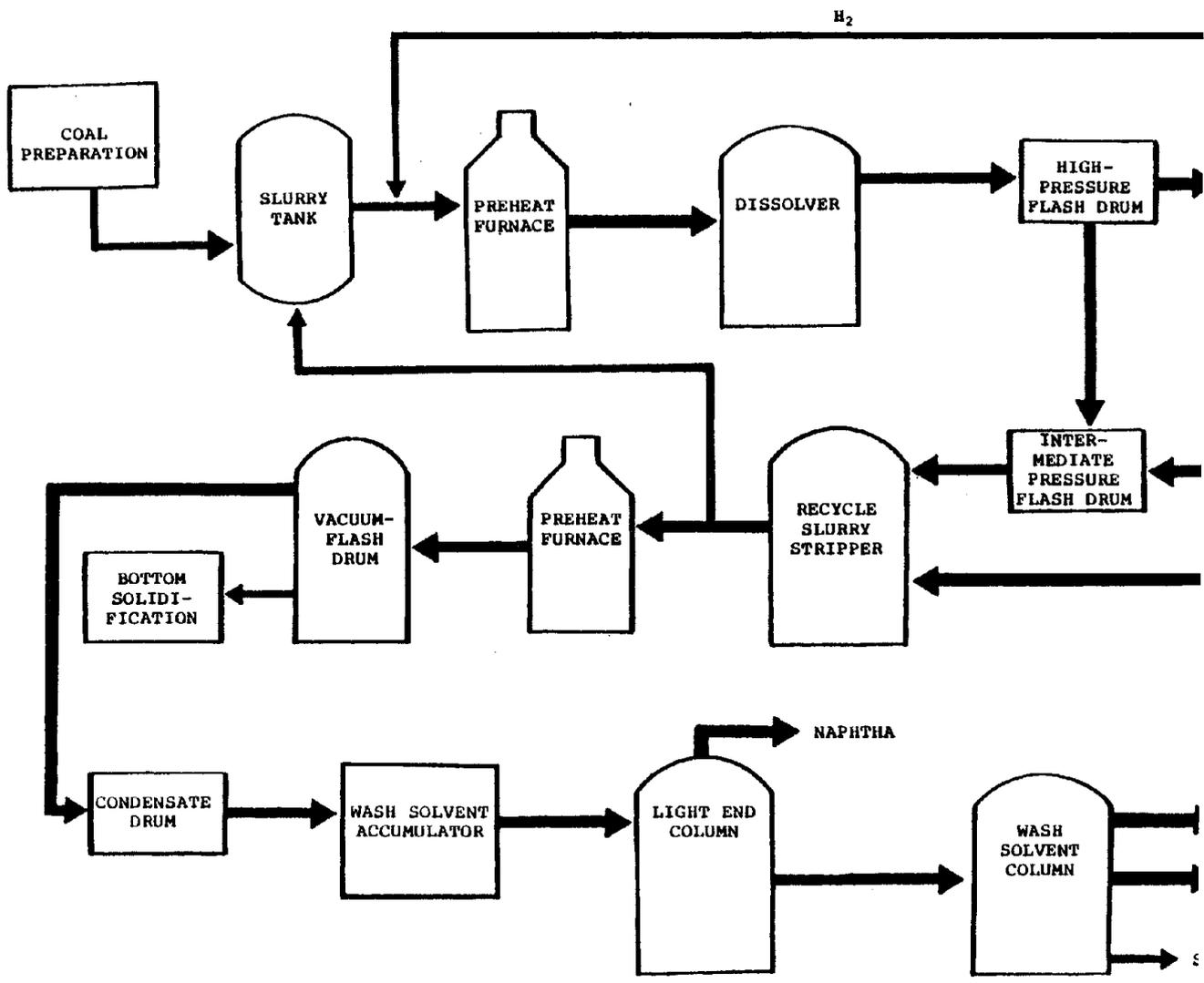


Figure A-1. Plant A Process Schematic II Mode

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 this process 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 storage 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.

Process (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 ($\text{FeS} + \text{H}_2\text{S}$). FeS_2 is known to have catalytic properties and apparently helps to catalyze the hydrogenation reaction.

FACILITY DESCRIPTION

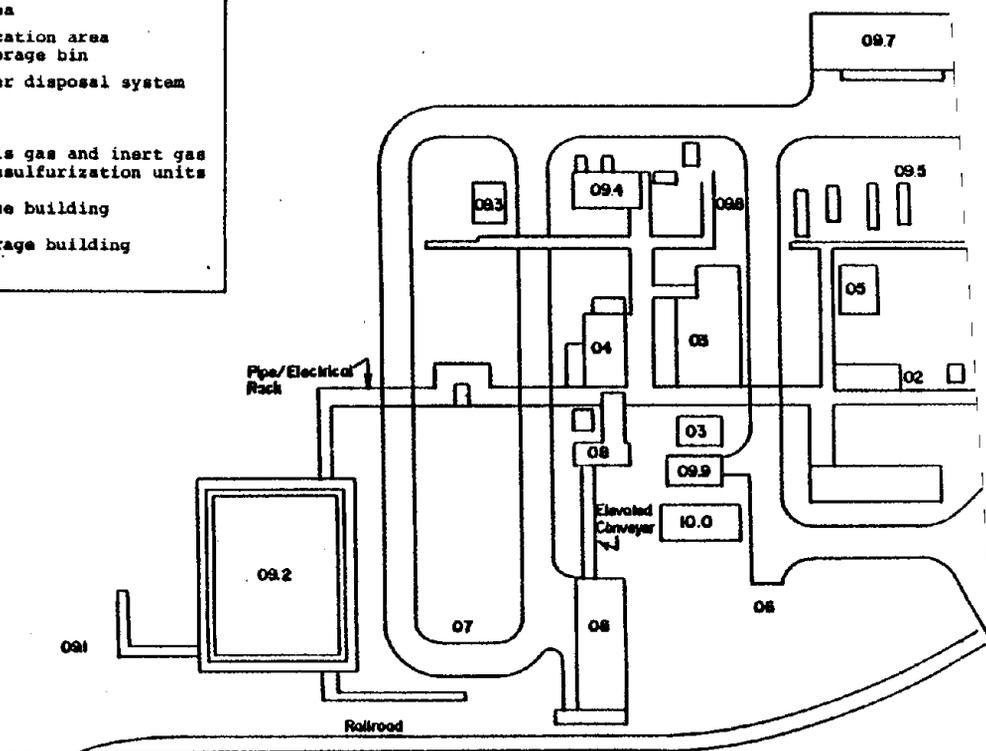
pilot Plant A is laid out as a rectangle with a panhandle (Figure A-2). A railroad track is located along most of the southern boundary of the plant. The railroad is used both to bring in coal and remove the final product.

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



A-6

Figure A-2. Plant A Plant Layout

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 an effluent 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 effluent coming from the biotreatment unit has no odor.

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

6-V

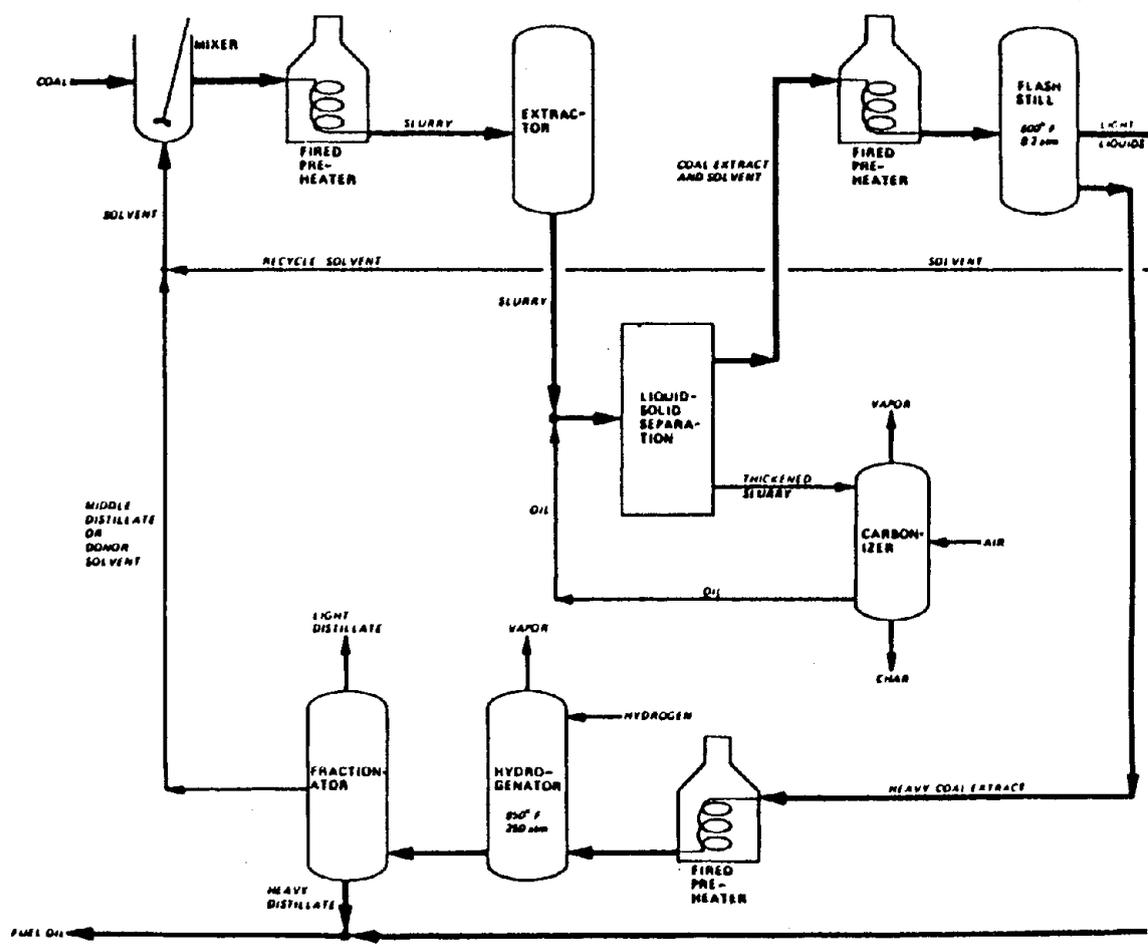


Figure A-3. Plant B Process Schematic

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 knock-out 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

and then flashed across a pressure control valve into a flash still at minus 5 inches of water pressure (14.5 psia). 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 liquid 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.

of the ...
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.

FACILITY DESCRIPTION

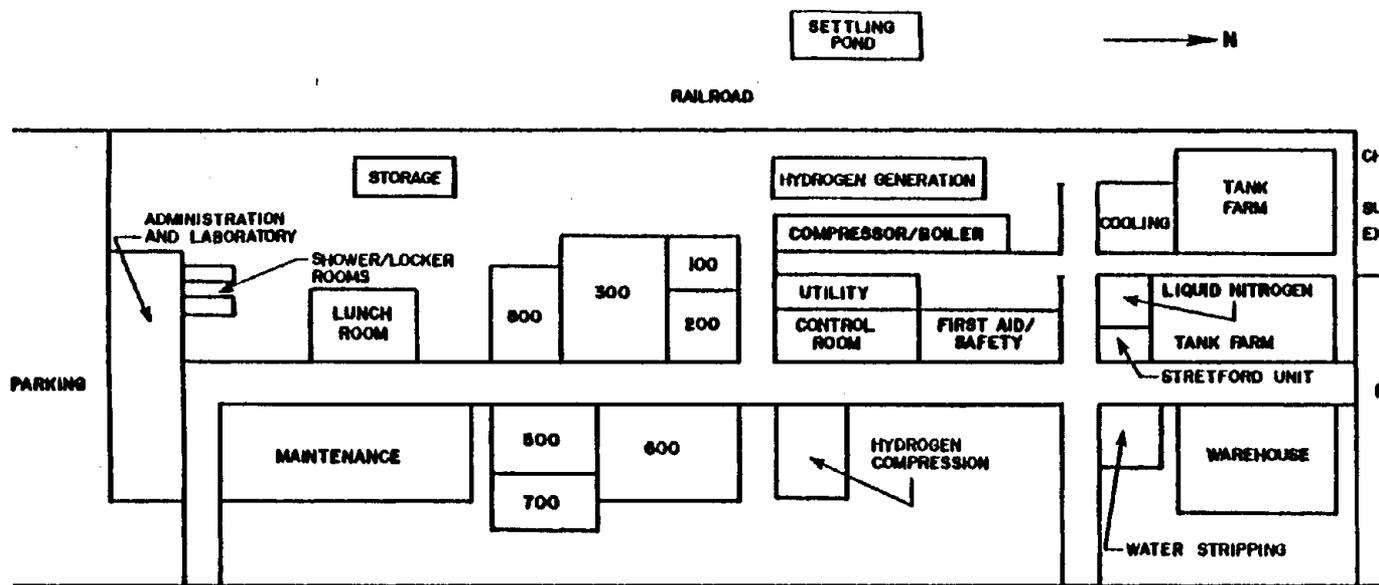
The Plant B Test Facility has a north-south, east-west orientation, with the Administration Building at the south end of the plant and the holding ponds for char, solvent refined coal, and sulfur at the north end. The plant itself is divided roughly in half by a service road.

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

location
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.

A-14



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

Pilot Plant C 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.

A-16

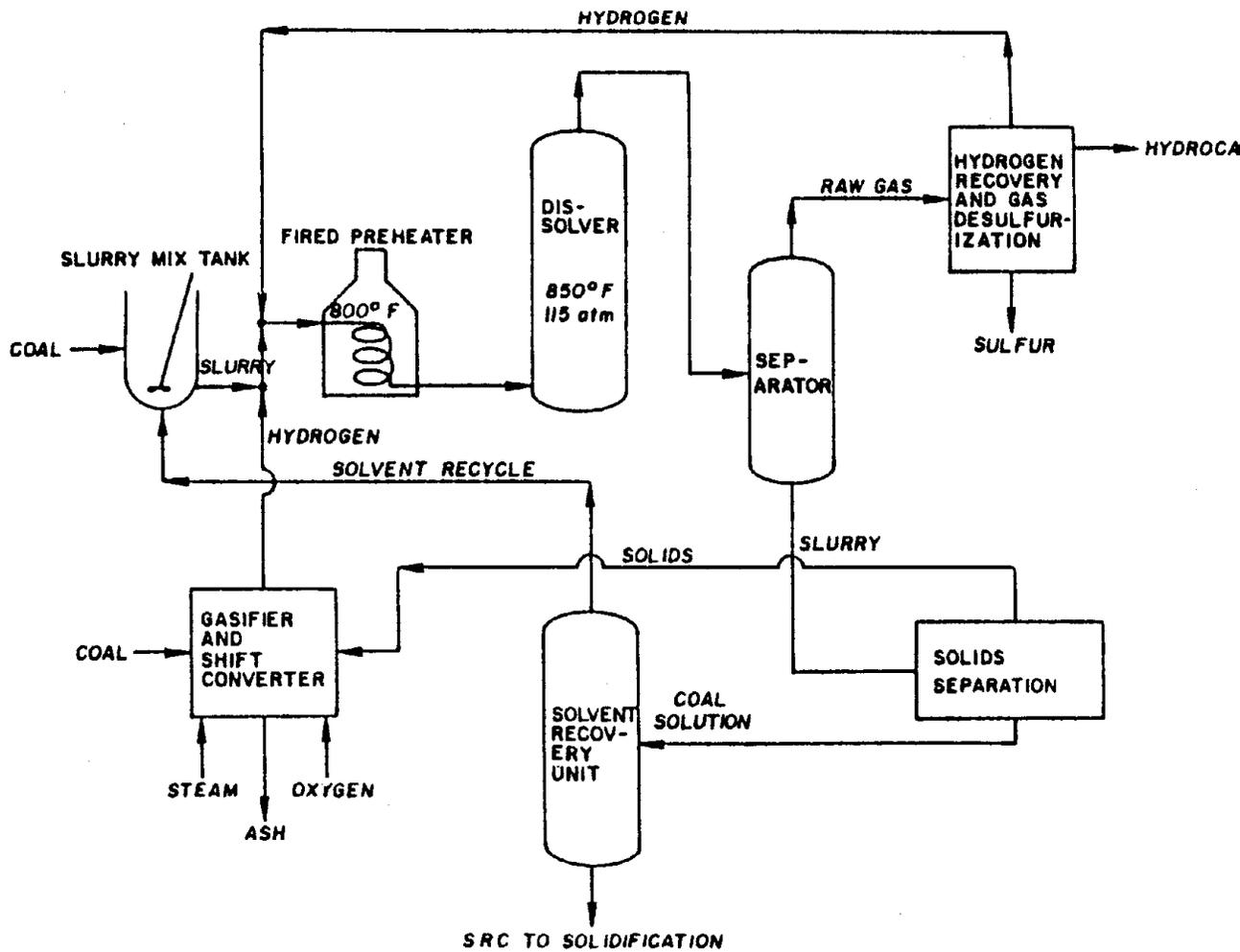


Figure A-5. Plant C Process Schematic

Filtered product from the vacuum column. Recirculated liquid product is mixed with material from the vacuum preheater surge drum. The vacuum column overhead pressure is maintained at 28 to 30 inches of Hg. vacuum. The material in the column is separated 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 Plant C, 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 Plant C 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.

P108 A/B	Water Circulating Pump	T104	Light Solvent Recovery Column
P110 A/B	Reclaim Tank Pumps	T105	Fractionating Column
P111 A/B	Filter Feed Pumps	V101 A/B	Slurry Blend Tanks
P116 A/B	Preheater Surge Drum Pumps	V103	High-Pressure Separator
P119 A/B	Liquid Coal Pumps	V104	High-Pressure Vent Separator
P125 A/B	Filter Scrubber Pumps	V105	Solvent Decanter
P139 A/B	Reflux Pumps	V106	Recycle Hydrogen Water Scrubber
P142 A/B/C	Preheat Tank Pumps	V110	Flash Tank
P143	Wash Tank Circulating Pump	V111	Reclaim Tank
P169 A/B	Wash Solvent Pumps	V120	Vacuum Preheater Surge Drum
P178	Sluice Pump	V123	Process Solvent Storage Tank
P203	Flush Solvent Pump	V124 A	Light Oil Product Tank
P205 A/B	Dowtherm Circulating Pumps	V124 B	Wash Solvent Storage Tank
P206	Dowtherm Surge Pump	V129	Caustic Tank
B102	Slurry Preheater	V131	Recovered Solvent Tank
B103	Distillation Column Preheater	V140	Precoat Makeup Tank
B203	Dowtherm Heater	V141	Wash Tank
C102	Hydrogen Recycle Compressor	V144	High-Pressure Blowdown Tank
C104	Fresh Hydrogen Compressor	V147	Precoat Tank
E102	Dissolver Product Cooler	V164	Feed Tank for T104
E103	High-Pressure Cooler	V170	T104 Overhead Holding Tank
E107	Flash Condenser	V178	Wash Solvent Storage Tank
E122	Solvent Draw Cooler	V206	Dowtherm
F103	Pressure Leaf Filter		
K111	Vacuum Jet		
K125	Product Cooler		

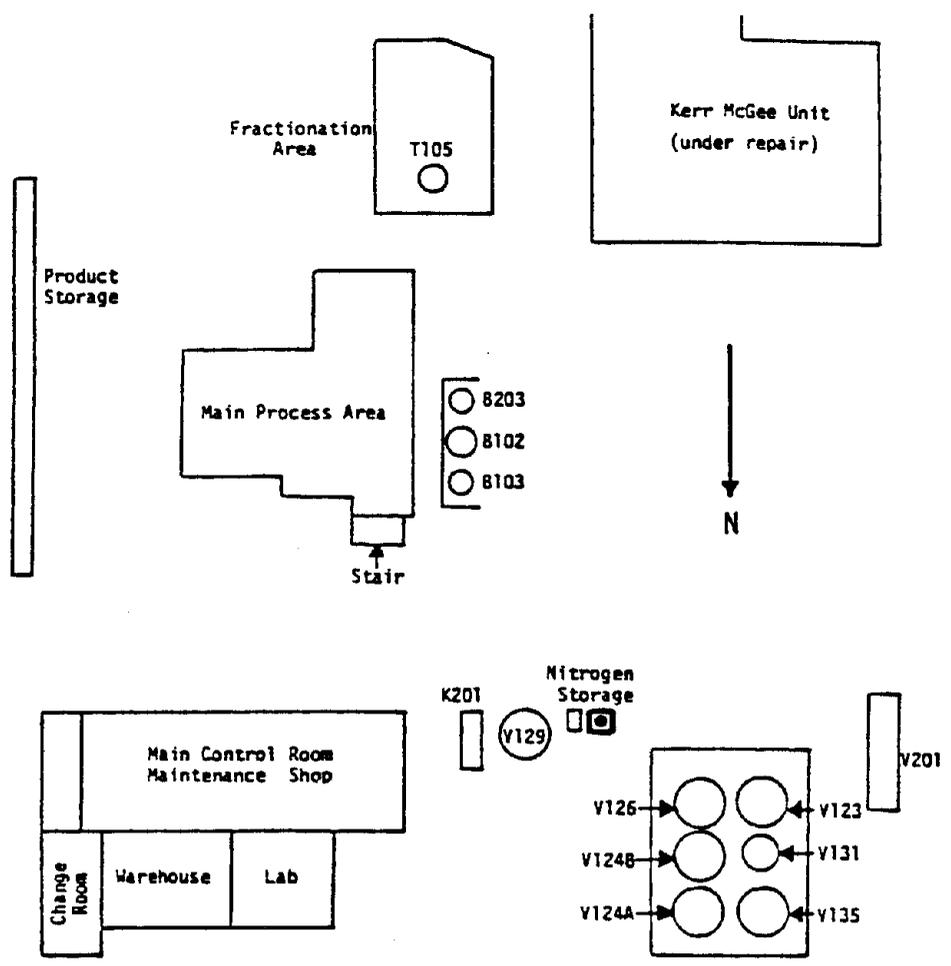


Figure A-6. Plant C Layout

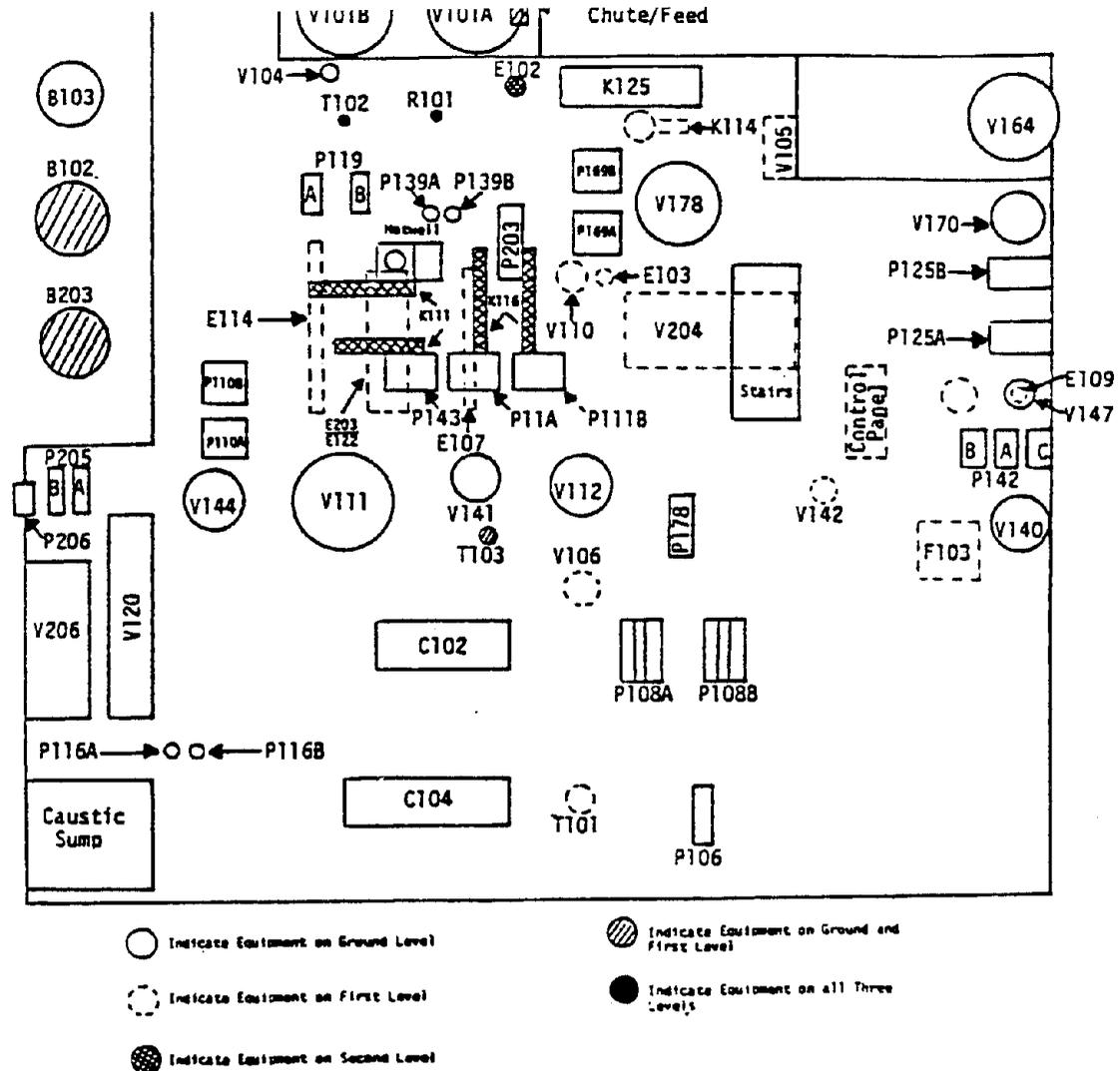


Figure A-7. Plant C Layout of Main Process Area

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.

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 equipment and the major process steps involved in the system. A process schematic of the Plant D facility is presented in Figure A-8. For discussion 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 to minus 30 mesh and dried to

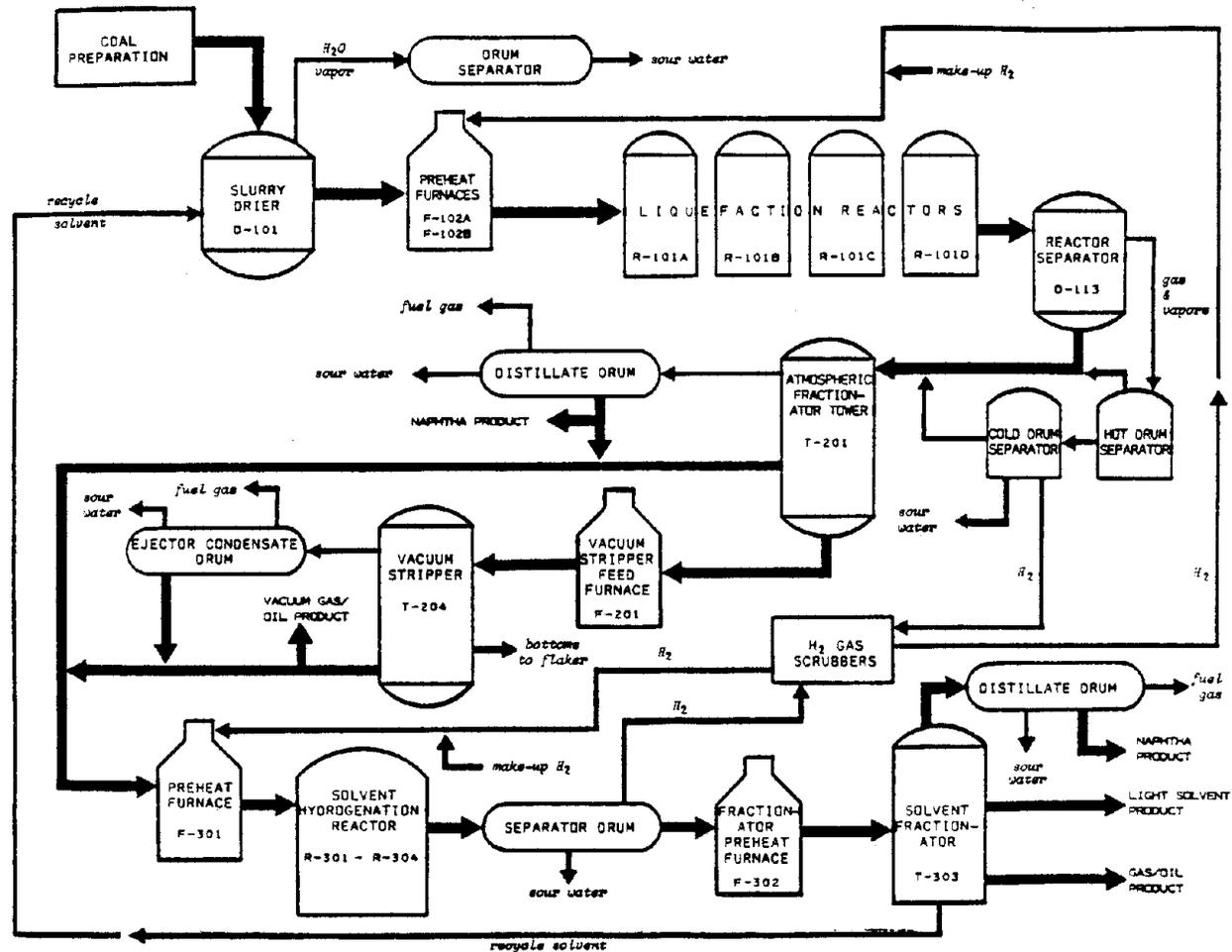


Figure A-8. Plant D Process Schematic

proofing for the coal preparation processes. For dust suppression, concrete 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 drum (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 drum 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).

donor solvent and molecular hydrogen. The operating parameters of the pilot plant are:

<u>Coal feed rate:</u>	160 to 200 tons/day (dry coal)
<u>Reactor temperature:</u>	441 to 451°C (825 to 844°F)
<u>Design temperature range:</u>	427 to 460°C (800 to 860°F)
<u>Reactor pressure:</u>	2,000 to 2,200 psig
<u>Design pressure range:</u>	1,900 to 2,600 psig
<u>Reactor residence time:</u>	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

Distillation occurs first 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.

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

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) recycle, fuel gas recovery and use, and sour water disengaging. Certain of these processes are linked to a nearby refinery.

Hydrogen is initially piped to Plant D from the refinery and is introduced at both the liquefaction and the hydrogenation reactors. Hydrogen not consumed in reactions is recovered from the separator drums after the process stream leaves the reactors. The impure gas is scrubbed with water and diethanolamine (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.

finely ... 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; this is not produced on site at the plant D pilot facility, however.

FACILITY DESCRIPTION

The Plant D Coal Liquefaction Pilot Plant 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.

	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

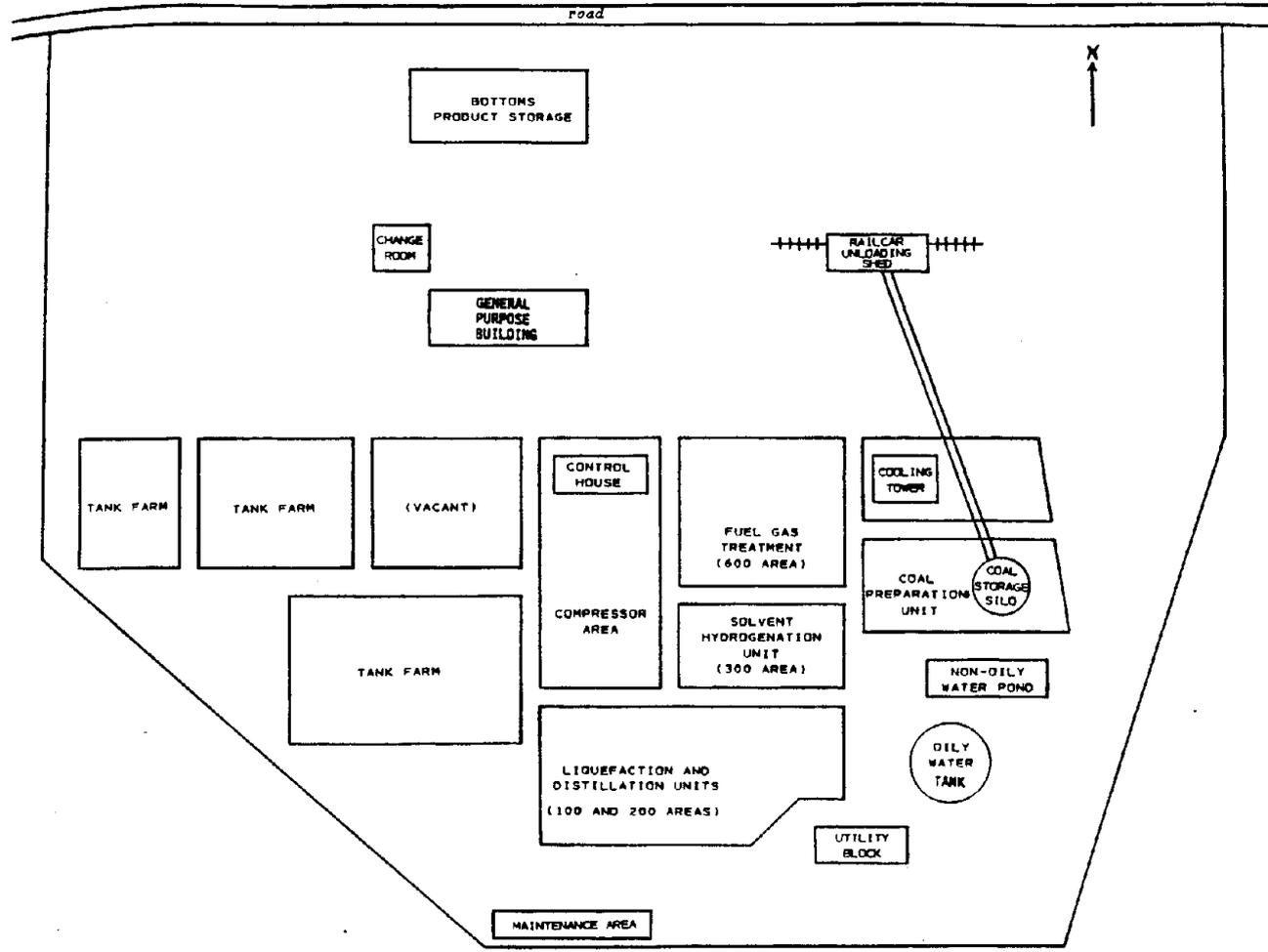


Figure A-9. Plant D Plant Layout

A-31

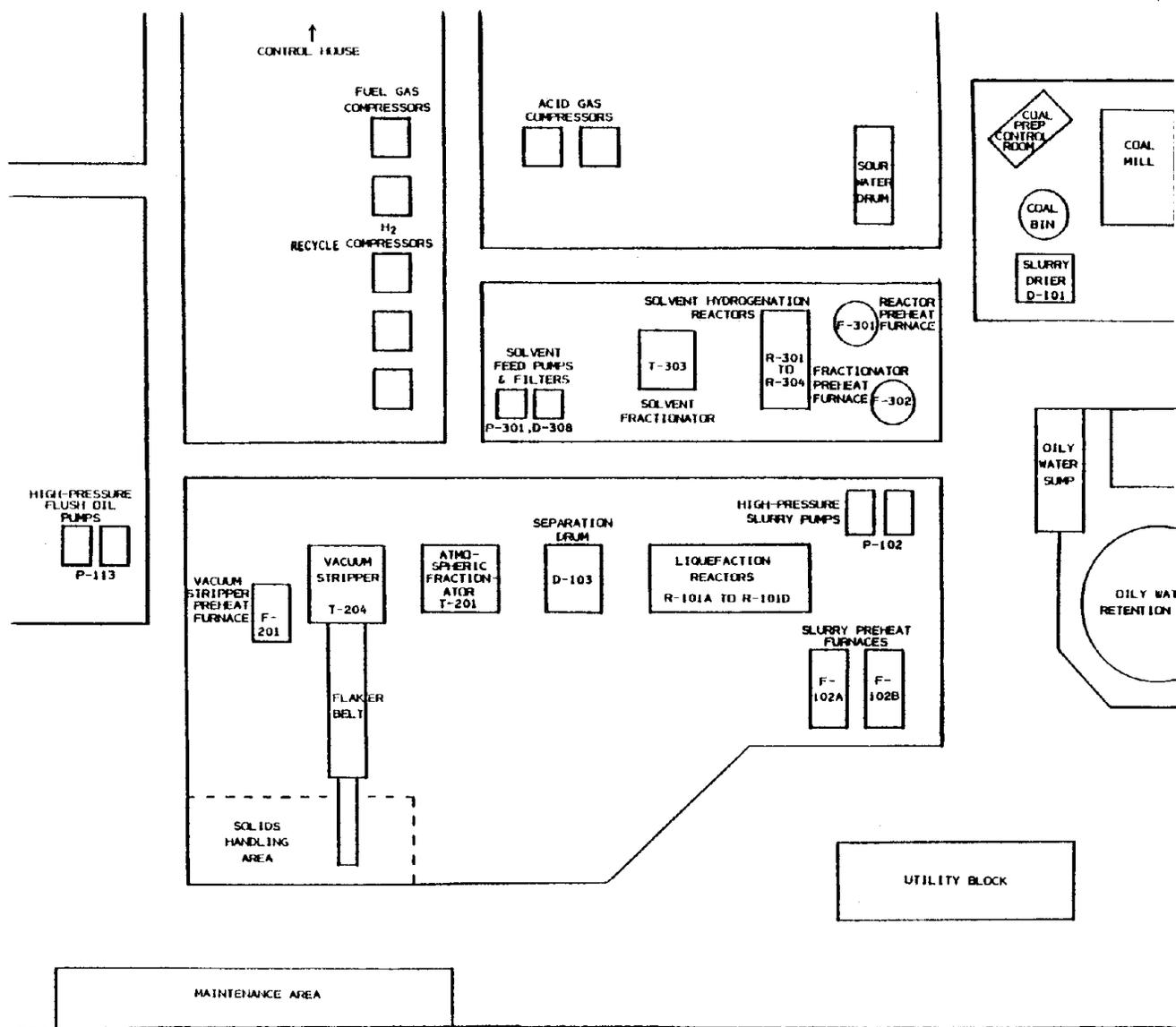


Figure A-10. Plant D Process Area Layout

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.

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 hydro-liquefaction 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 Plant E 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

A-34

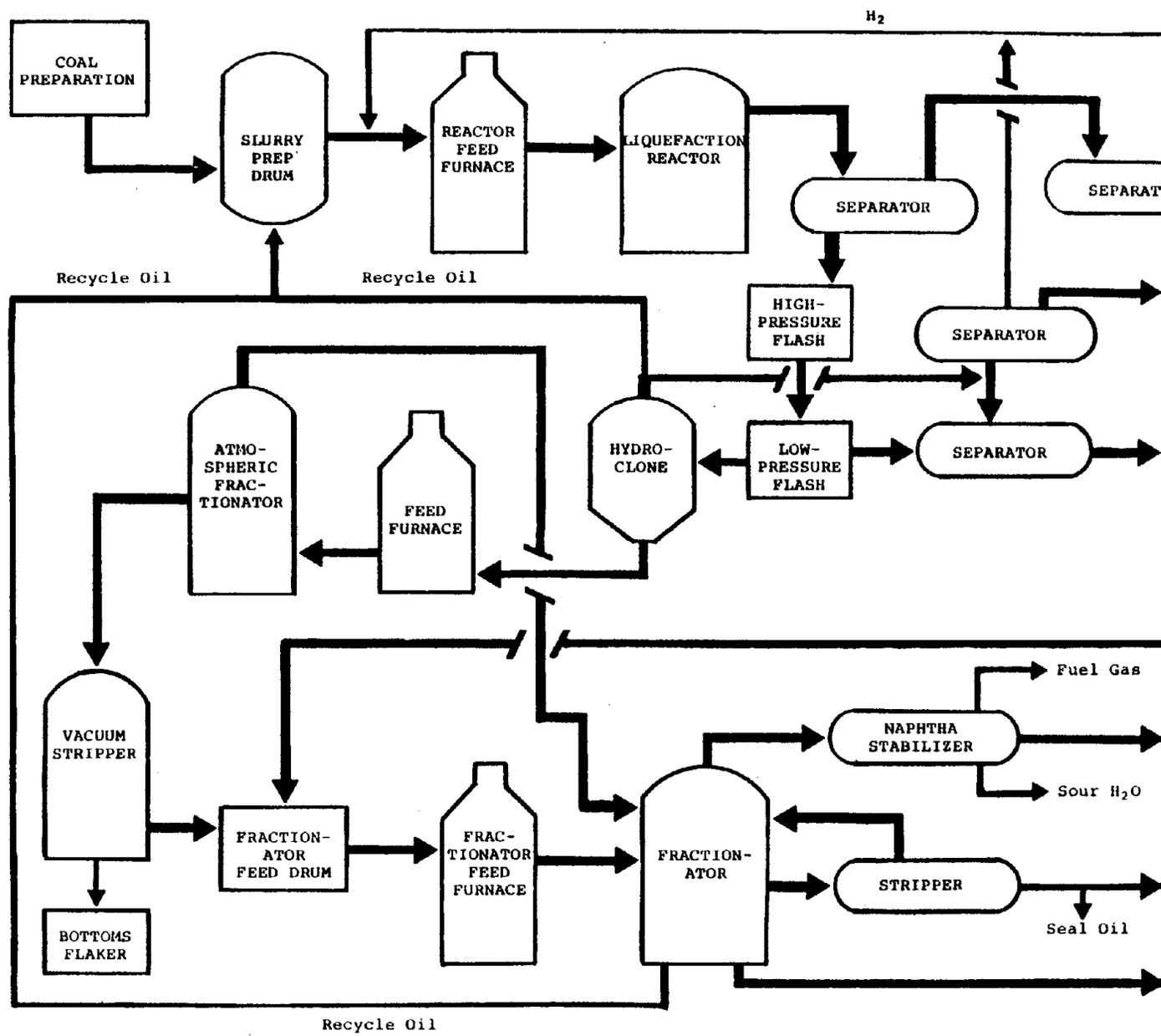


Figure A-11. Plant E Process Schematic (syncrude mode)
Source: Ashland Synthetic Fuels, Inc.

900-ton storage bins. This coal is removed with a weigh reeder 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 recovered 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.

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 into 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.

separation. Bottoms from the vacuum stripper, consisting of residue, unreacted coal, and mineral material, is delivered to the flaker solidification process. Here, a fully enclosed and ventilated 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

actor 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, naphtha, 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 is sited alongside a river just north of an 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 river 2 miles upstream from its juncture with the another 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.

the plant, 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 slabs. 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, dominated by the Raymond bowl mill, is housed in a semi-enclosed, 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 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

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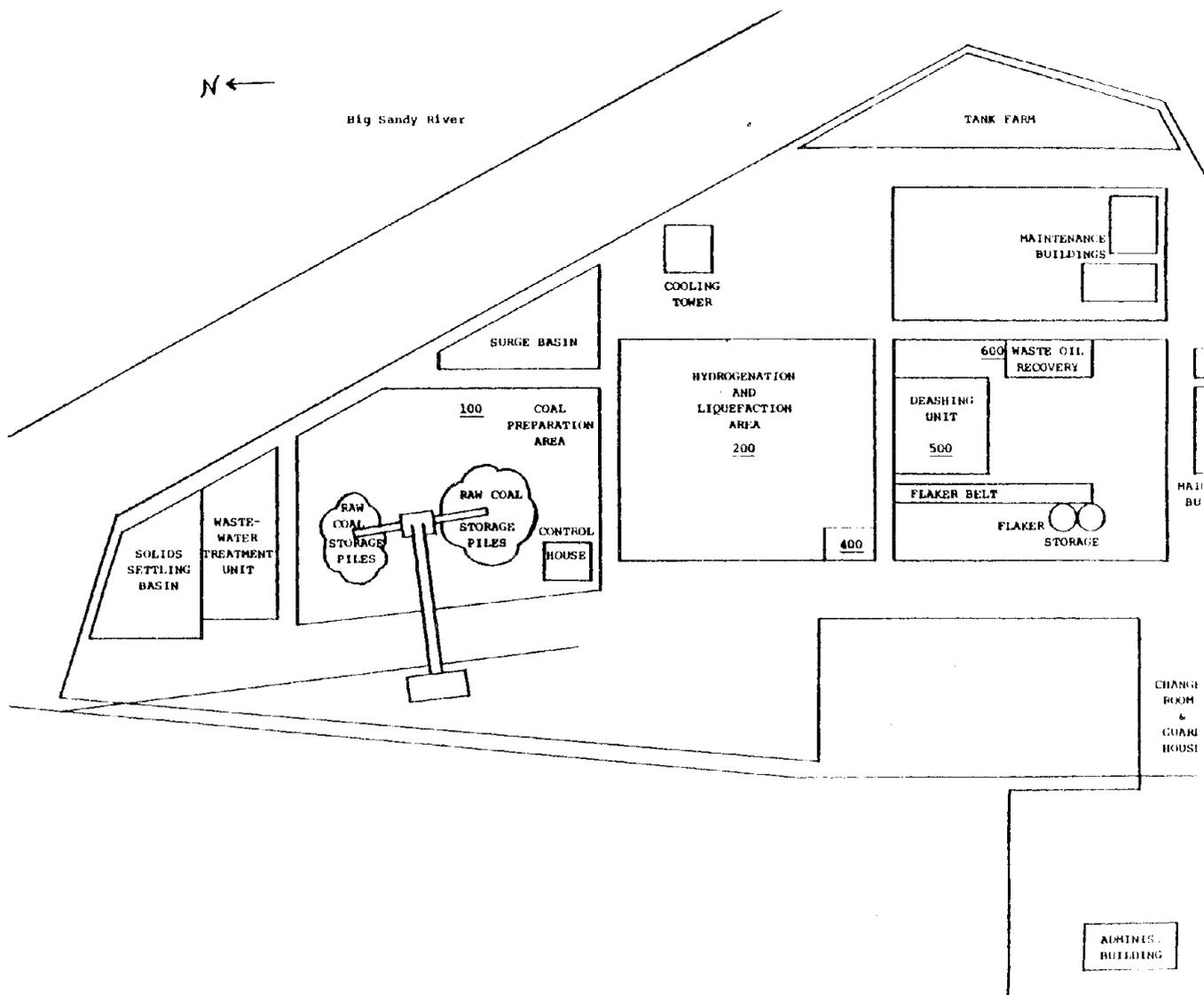


Figure A-12. Plant E Plant Layout

A-41

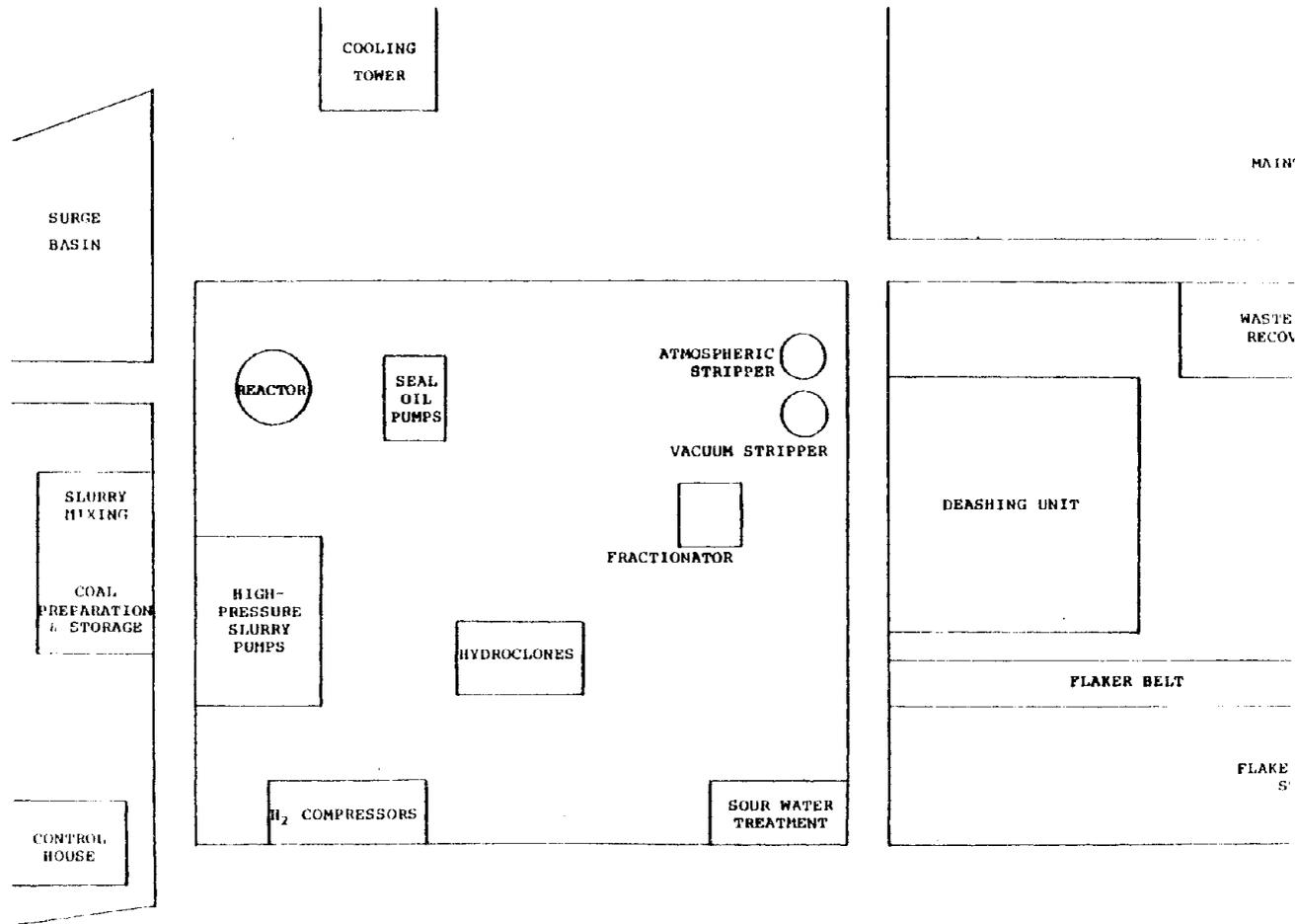


Figure A-13. Plant E Detailed Layout of Hydrogenation/Liquefaction Area (not to scale)

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

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

Location Sampled:	Slurrying			Dissolving	Mineral Separation	Fractionation	Solidification	Gas Recycle
	Between Crusher & Pumps	Between Crusher & High-Pressure Pumps	Slurry Mix Tank	High-Pressure Flash Drum	Slurry Pump	Wash Solvent Bottoms Pump	Sandvik Belt	At Refractor
Sample Number:	006	007	010	040	041	025	026	066
Sample Volume (l):	3,312	3,146	3,395	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	1847-023
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
Compound (detection limit, $\mu\text{g}/\text{m}^3$) ^a								
Naphthalene (0.01)	5.7	0.3	5.2	5.3	8.9	10.6	0.8	-- ^b
1-Methylnaphthalene (0.01)	1.0	0.7	0.6	0.3	1.1	6.7	0.2	0.02
2-Methylnaphthalene (0.01)	8.1	0.2	4.6	2.0	34.9	10.5	0.6	--
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
Phenanthrene/Anthracene (0.01)	13.7	9.6	26.6	3.03	43.3	16.1	1.8	0.4
Acridine (0.01)	1.8	--	--	--	--	--	--	--
Carbazole (0.01)	3.8	0.2	4.6	0.2	28.9	0.2	0.04	0.02
Fluoranthene (0.01)	1.7	0.5	2.7	0.2	23.0	0.6	0.07	0.02
Pyrene (0.01)	1.5	0.2	1.6	0.2	24.9	0.7	0.1	0.02
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

^a Assuming a sample volume of 4,000 liters.

^b "--" indicates not detected.

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

Personnel Sampled	Laboratory Technicians			Oil Area Personnel					
	Wulder	Operator	Tech-nician	Tech-nician	Mechanic	Operator	Operator		
Sample Number:	053	054	055	003	011	012	020	073	103
Sample Volume (l):	304	251	450	220	352	245	243	182	275
Sampling Time:	0828-1655	0831-1653	0830-1650	0955-1335	1235-1825	1234-1824	0821-1625	0856-1400	0833-1314
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	7.5
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	--
Benzo(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	10.6

--" indicates not detected.

(continued)

Table B-2 (concluded)

Personnel Sampled:	03 Area Personnel			04 Area Personnel			06 Area Personnel		
	Operator	Operator	Operator	Operator	Operator	Operator	Operator	Operator	Operator
Sample Number:	033	088	090	016	021	035	013	022	014
Sample Volume (l):	439	242	418	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
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	0.4
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
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	--
Benz(a)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

^a-- indicates not detected.

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 ($\mu\text{g}/\text{sample}$)	036			6/20/78	--	--	--	0.09
	037			6/20/78	--	--	--	0.07

² Aromatic amines: A = Aniline; B = N,N-Dimethylaniline; C = o-Anisidine;
D = p-Anisidine.

³ Assuming a sample volume of 25 liters.

⁴ "--" indicates not detected.

Slurry Mix Tank	097	47.3	0857-1651	2/16/79	--	--	--	--	--	--
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	--	--	--	--	--	--

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

⁵ Assuming a sample volume of 50 liters.

^c "--" indicates not detected.

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. ^a "--" indicates not detected.

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 (ug/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.

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 (ug/sample)	027			2/11/79	--	--	--
	081			2/14/79	--	--	--

^a Assuming a sample volume of 50 liters.

^b "--" indicates not detected.

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.

Table B-9.	Plant B Area Sampling Analytical Results ($\mu\text{g}/\text{m}^3$) for PNAs (May 14-24, 1979).....	B-13
Table B-10.	Plant B Personal Sampling Analytical Results ($\mu\text{g}/\text{m}^3$) for PNAs (April 17-18, 1979; May 14-25, 1979).....	B-14
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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 ($\mu\text{g}/\text{m}^3$) for PNAs (May 14-2

Location Sampled:	Solvent Extraction (200 Area)		Solids Separation (300 Area)		Carbonization (800 Area)		Solvent Recovery (500 Area)		Fractionation (700 Area)		Hydro (600)	
	Sample Number:	100	118	119	120	121	122	097	123	098	124	07B
Sample Volume (L):	2,187	2,257	2,499	2,487	2,310	2,539	2,812	2,320	2,870	2,382	2,790	
Sampling Time:	0826-2100	0900-2256	0901-2256	0907-2256	0910-2255	0915-2254	0813-2320	0927-2247	0816-2318	0934-2248	0755-2325	
Date Collected:	5/23/79	5/24/79	5/24/79	5/24/79	5/24/79	5/24/79	5/23/79	5/24/79	5/23/79	5/24/79	5/15/79	
Compound (detection limit, $\mu\text{g}/\text{m}^3$) ^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	
1-Methylnaphthalene (0.01)	10.3	21.2	27.0	0.02	13.2	10.0	--	14.0	31.5	9.0	28.7	
2-Methylnaphthalene (0.01)	42.6	--	28.8	0.09	42.5	21.9	35.6	42.4	12.2	19.0	21.0	
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	
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	
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	
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	
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	
Acridine (0.01)	--	0.08	--	--	--	--	--	--	0.6	--	--	
Carbazole (0.01)	--	0.03	0.02	--	--	--	0.01	--	--	0.2	--	
Fluoranthene (0.01)	--	0.01	0.03	0.07	--	--	0.07	--	0.09	0.03	--	
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	
Benzo(a)fluorene/ Benzo(b)fluorene (0.01)	0.02	0.04	0.04	0.2	0.03	--	0.02	--	0.2	0.03	--	
Benz(a)anthracene/Chrysene/ Triphenylene (0.01)	--	--	--	0.02	0.02	--	--	--	0.05	--	0.04	
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	

^a Assuming a sample volume of approximately 2,500 liters.

^b "--" indicates not detected.

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

Personnel Sampled:	Operators										
	200 Area			300/800 Area		500/700 Area			600/900 Area		
Sample Number:	050	096	112	105	113	074	094	131	016	097	133
Sample Volume (ft):	862	620	654	538	553	660	602	741	1,120	571	611
Sampling Time:	0744-1455	0802-1455	0828-1450	1541-2235	0820-1455	0735-1455	0804-1420	0717-1500	0735-1508	0803-1522	0724-1455
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
Compound											
Naphthalene	0.05	0.03	0.05	0.02	0.04	0.02	0.08	0.05	-- ^a	0.02	--
1-Methylnaphthalene	0.05	0.05	0.07	0.03	0.1	0.03	0.07	--	--	0.01	0.2
2-Methylnaphthalene	0.03	0.09	0.1	0.06	0.06	0.06	0.1	--	0.02	0.06	0.08
Quinoline	--	--	--	0.01	--	--	0.01	--	--	--	--
Acenaphthalene	--	--	--	--	--	--	--	--	--	--	--
Acenaphthene	--	--	--	--	--	--	--	--	--	--	--
Fluorene	--	--	--	--	--	--	--	--	--	--	--
Phenanthrene/Anthracene	--	--	--	--	--	--	--	--	--	--	--
Acridine	--	--	--	--	--	--	--	--	--	--	--
Carbazole	--	--	--	--	--	--	--	--	--	--	--
Fluoranthene	--	--	--	--	--	--	--	--	--	--	--
Pyrene	--	--	--	--	--	--	--	--	--	--	--
Benzo(a)fluorene/ Benzo(b)fluorene	--	--	--	--	--	--	--	--	--	--	--
Benzo(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	0.1	0.2	0.2	0.1	0.2	0.1	0.3	0.05	0.02	0.1	0.1

^a--" indicates not detected.

Table B-10 (concluded)

Personnel Sampled:	Maintenance Workers						Laboratory Workers					
	Millwrights				Pipefitters		Chemists			Technician		
	Sample Number:	005	012	020	023	002	010	008	052	116	009	019
	Sample Volume (l):	622	810	313	598	323	376	621	494	603	255	533
Sampling Time:	-	0918- 1603	0857- 1530	0921- 1535	0900- 1335	0905- 1521	0806- 1500	0806- 1535	0830- 1541	0755- 1500	0811- 1501	
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	
Compound												
Naphthalene	0.01	0.04	0.1	0.03	-- ^a	--	--	0.05	--	0.1	--	
1-Methylnaphthalene	0.01	0.03	0.1	0.02	--	--	--	0.04	--	0.08	--	
2-Methylnaphthalene	0.03	0.08	0.2	0.05	0.01	0.01	0.02	0.08	0.01	0.1	0.02	
Quinoline	--	0.02	0.01	--	--	--	--	--	--	--	--	
Acenaphthalene	--	--	--	--	--	--	--	--	--	--	--	
Acenaphthene	--	--	--	--	--	--	--	--	--	--	--	
Fluorene	--	--	--	--	--	--	--	--	--	--	--	
Phenanthrene/Anthracene	--	--	--	--	--	--	--	--	--	--	--	
Acridine	--	--	--	--	--	--	--	--	--	--	--	
Carbazole	--	--	--	--	--	--	--	--	--	--	--	
Fluoranthene	--	--	--	--	--	--	--	--	--	--	--	
Pyrene	--	--	--	--	--	--	--	--	--	--	--	
Benzo (a) fluorene/ Benzo (b) fluorene	--	--	--	--	--	--	--	--	--	--	--	
Benzo (a) anthracene/ Chrysene/Triphenylene	--	--	--	--	--	--	--	--	--	--	--	
Benzo (a) 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	

^a--" indicates not detected.

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	--	--	--	--	--	--	--

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

^bAssuming a sample of approximately 80 liters.

^c"--" indicates not detected.

300/800 Area	134	44	9733-1455	5/25/79	--	--	--	--	--	--	--
	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	--	--	--	--	--	--	--

^aAromatic amines: A = Aniline; B = N,N-Dimethylaniline; C = 2,4-Dimethylaniline;
D = p-Nitroaniline; E = o-Toluidine; F = o-Anisidine; G = p-Anisidine

^bAssuming a sample volume of approximately 80 liters.

^c"--" indicates not detected.

Fractionation	084	47	1547-2327	5/15/79	--	0.08	--
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	--	--	--

^aAssuming a sample volume of 40 liters.

^b--" indicates not detected.

Table B-14. Plant B Area and Personal Sampling Analytical Results (mg/m³) for Phenolic Compounds (April 18, 1979; May 14-25, 1979)

Location Sampled	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	
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	--	--	--	--	--	--	--	--	--	--

^aPhenolic 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.

^bAssuming a sample volume of 45 liters.

^c--" indicates not detected.

Table B-15.	Plant C Area Sampling Analytical Results ($\mu\text{g}/\text{m}^3$) for PNAs (November 12-17, 1979).....	B-20
Table B-16.	Plant C Personal Sampling Analytical Results ($\mu\text{g}/\text{m}^3$) 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 ($\mu\text{g}/\text{m}^3$) 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
Sample Number:	017	021	022	035	036	037	044	048	057	058	059	069
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	1,488
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
COMPOUND												
Naphthalene	2.4	3.8	2.7	1.6	0.9	9.02	4.5	-- ^b	--	--	1.2	6.8
Quinoline	0.05	0.02	0.1	--	0.02	0.1	0.1	--	--	--	--	0.05
2-Methylnaphthalene	6.6	2.9	4.08	1.0	1.3	7.6	7.6	--	--	--	1.0	5.6
1-Methylnaphthalene	1.4	0.4	0.8	0.2	0.2	1.09	1.1	--	--	--	0.2	1.1
Acenaphthalene	0.06	--	0.02	--	--	--	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
Fluorene	0.5	0.2	0.3	0.06	0.04	0.2	0.9	--	0.06	--	0.04	0.3
Phenanthrene/Anthracene	1.4	0.5	1.1	0.3	0.1	0.8	1.6	--	0.5	0.2	0.2	0.8
Acridine	--	--	0.01	--	0.01	--	0.02	--	--	--	--	--
Carbazole	--	--	0.02	--	--	0.03	0.03	--	--	--	--	--
Fluoranthene	0.2	0.06	0.2	0.05	0.03	0.2	0.2	--	0.06	0.06	--	0.09
Pyrene	0.08	0.04	0.1	0.05	0.01	0.2	0.08	--	0.04	0.05	--	0.05
Benzo(a)fluorene	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(b)fluorene	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(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	13.6	8.02	9.9	3.3	2.7	19.5	17.6	--	0.7	0.3	2.7	15.3

^a Blanks measured in $\mu\text{g}/\text{sample}$.

^b "--" indicates compound was not detected.

Table B-16. Plant C Personal Sampling Analytical Results ($\mu\text{g}/\text{m}^3$) for 1 (November 12-17, 1979)

Sample Location:	OPERATOR				MAINTENANCE								LABORATORY	
	C	C	D	D	Pipe-fitter	Insulator	Insulator	Oiler	Instru-	Mill-wright	Mill-wright	Chemist	Chem	
Sample Number:	038	053	014	054	006	007	008	012	082	011	081	041	08	
Sample Volume (l):	828	720	610	539	611	614	620	792	744	554	683	720	59	
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	14	
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	
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-Methylnaphthalene	9.3	--	3.3	5.2	12.09	13.1	5.6	1.9	5.9	11.2	3.9	1.8	17	
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	
Acenaphthalene	0.01	--	--	--	0.01	0.01	--	--	0.05	0.03	--	--	0	
Acenaphthene	0.4	--	0.3	0.5	0.8	1.1	0.4	0.1	0.4	0.7	0.3	0.1	1	
Fluorene	0.2	--	0.2	0.2	0.4	0.7	0.2	0.09	0.5	0.5	0.2	0.9	0	
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	
Acridine	--	--	--	--	--	--	--	--	--	0.01	--	--	0	
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	
Pyrene	0.01	--	0.09	0.02	0.09	0.09	0.04	0.04	0.04	0.06	0.06	0.05	0	
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	4	

^a Blanks measured in $\mu\text{g}/\text{sample}$.

^b "--" indicates compound not detected.

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) ^a	--	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	CIRCULATION PUMP P143	LET-DOWN VALVE 415	FILTER SCRUBBER PUMP P125	FILTER F103	FRACTIONATING 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/m³ and assumes a sample volume of about 45 liters.

^b "--" indicates compound was not detected.

Sample Number:	029	066	032	040	063	064	031	055	056	092	026	052	091
Sample Volume (L):	46	109	43	47	49	46	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			
<u>COMPOUND</u>													
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	43	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
<u>COMPOUND</u>											
Benzene (0.01) ^a	-- ^b	--	--	--	--	--	--	--	--	--	--
Toluene (0.01) ^a	--	--	--	--	--	--	--	--	--	--	--
Xylene (0.01) ^a	--	--	--	--	--	--	--	--	--	--	--

^a Detection limit in ppm.
^b "--" indicates compound was not detected.

	P106	--	(mg/sample)	
Sample Number:	020	070	027	051
Sample Volume (L):	48	48		
Sample Time:	1452- 2234	1434- 2232		
<u>COMPOUND</u>				
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/m³.

^b "--" indicates compound was not detected.

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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 Light Duty
Sample Number:	4-027	4-104	4-182	4-004	4-200	4-060*	4-090*	4-149*	4-021	4-144*	4-005
Sample Volume (L):	1,218	1,098	1,310	1,327	1,157	1,247	1,391	1,229	1,157	1,253	1,340
Sampling Time:	0833-1652	0730-1700	0846-1752	1628-0141	2043-0445	2117-0548	0840-1810	2034-0518	0905-1659	0941-1823	1633-0204
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
Compound (detection limit, $\mu\text{g}/\text{m}^3$) ^a											
Naphthalene (0.2)	7.9	8.7	21.7	18.3	21.1	59.4	267.9	221.1	31.3	18.8	137.4
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
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
Quinoline (0.2)	-- ^b	--	--	--	--	--	--	--	--	--	--
Acenaphthalene (0.2)	--	--	--	--	0.5	0.6	2.5	1.6	--	0.3	--
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
Fluorene (0.2)	2.0	1.9	4.6	--	5.9	6.0	18.6	12.5	2.2	3.3	11.9
Phenanthrene/Anthracene (0.2)	--	1.1	1.9	1.9	2.4	3.0	6.0	10.7	1.8	3.1	14.7
Acridine (0.2)	--	0.6	--	--	--	--	1.1	--	--	--	0.7
Carbazole (0.2)	--	--	--	--	--	--	--	0.2	--	--	--
Fluoranthene (0.2)	--	--	--	--	--	--	0.2	0.4	--	--	0.9
Pyrene (0.2)	--	--	--	--	--	0.2	0.5	0.5	--	0.3	1.4
Benzo(a)fluorene/ Benzo(b)fluorene (0.2)	--	--	--	--	--	--	--	--	--	--	1.2
Benzo(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,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

^a Assuming a sample volume of 1,200 liters. ^b "--" indicates not detected.

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

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		
	Sample Number:	4-062*	4-141*	4-198	4-025	4-106*	4-138*	4-061	4-184
Sample Volume (l):	1,252	1,262	1,174	1,188	1,098	1,270	1,249	1,267	1,010
Sampling Time:	2110-0541	0934-1820	2101-0510	0848-1655	1950-0520	0928-1817	2101-0533	0859-1747	0726-1416
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
Compound (detection limit, $\mu\text{g}/\text{m}^3$) ^a									
Naphthalene (0.2)	351.4	830.7	79.0	2.0	1,261.1	1,822.9	-- ^b	10.0	2.4
1-Methylnaphthalene (0.2)	162.5	639.6	47.5	0.5	406.7	368.0	--	4.3	2.1
2-Methylnaphthalene (0.2)	249.7	819.7	104.4	1.4	1,771.0	1,115.6	--	8.1	4.2
Quinoline (0.2)	--	--	--	--	--	--	--	--	--
Acenaphthalene (0.2)	8.8	18.6	1.6	--	0.5	5.9	--	0.3	--
Acenaphthene (0.2)	25.8	24.4	24.8	--	61.8	54.6	--	1.8	0.9
Fluorene (0.2)	21.9	38.1	21.0	0.3	77.5	43.0	--	2.4	1.6
Phenanthrene/Anthracene (0.2)	15.6	31.6	41.1	0.9	123.0	28.1	--	3.9	2.7
Acridine (0.2)	--	0.6	4.3	--	9.1	2.7	--	--	--
Carbazole (0.2)	--	0.6	0.9	--	--	--	--	--	--
Fluoranthene (0.2)	0.8	2.5	13.1	--	11.7	1.3	--	0.2	0.2
Pyrene (0.2)	1.5	4.9	22.5	--	14.3	1.8	--	0.4	0.4
Benzo(a)fluorene/ Benzo(b)fluorene (0.2)	--	0.8	17.7	--	1.0	0.7	--	--	--
Benz(a)anthracene/Chrysene/ Triphenylene (0.2)	--	--	2.5	--	--	--	--	--	--
Benzo(j)fluoranthene/ Benzo(b)fluoranthene/ Benzo(k)fluoranthene (0.2)	--	--	0.3	--	--	--	--	--	--
Benzo(a)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 (0.8)	--	--	--	--	--	--	--	--	--
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	838.0	2,412.1	381.6	5.1	3,738.2	3,444.6	--	31.4	14.5

^a Assuming a sample volume of 1,200 liters.

^b "--" indicates not detected.

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

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		Upstream
Sample Number:	4-026	4-150*	4-008*	4-107	4-197	4-135	4-224	4-061	4-140*	4-093
Sample Volume (l):	1,166	1,272	1,376	1,100	1,200	1,308	1,198	1,247	1,251	1,364
Sampling Time:	0858-1656	2025-0515	1646-0210	1935-0506	2054-0514	0919-1815	0721-1540	2123-0554	2041-0523	0905-1824
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
Compound (detection limit, $\mu\text{g}/\text{m}^3$) ^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-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	--
Quinolins (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	--
Acridins (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	--	--	--	--
Benzo(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)acridins (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)	--	--	--	--	--	--	--	--	--	--
6,13-Dimethyldibenz(a,h)- anthracene (0.2)	--	--	--	--	--	--	--	--	--	--
TOTAL	73.5	2,999.0	825.8	47.0	16.1	75.1	42.7	27.4	1,190.0	--

^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 ($\mu\text{g}/\text{m}^3$) for PNAs (May

Personnel Sampled:	Process Technicians (Operators)													
	Liquefaction-Distillation Unit									Solvent Hydrogenation Unit			Coal Pr	
	#1	4-210	4-101*	#2	4-211*	4-011	4-049	4-133*	4-059*	4-134	4-219	4-118	U	
Sample Number:	4-116	4-171	4-210	4-101*	4-117	4-211*	4-011	4-049	4-133*	4-059*	4-134	4-219	4-118	U
Sample Volume (L):	776	759	588	714	660	630	732	723	771	676	784	560	736	U
Sampling Time:	2137-0614	0855-0521	0945-1645	0948-1749	2016-0530	0940-1640	2011-0418	1033-1835	0925-1759	1004-0535	0925-1808	0719-1351	2201-0612	U
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	U
Compound (detection limit, $\mu\text{g}/\text{m}^3$) ^d														
Naphthalene (0.4)	15.4	29.1	15.2	163.0	20.2	136.2	10.9	3.6	45.2	895.1	116.6	23.3	17.9	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	1
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	1
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	
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	
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	
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	--	--	--	--	--	--	--	--	--	
Benzo(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	1,453.0	242.6	76.4	44.8	2

^a Assuming a sample volume of 700 liters.

^b "--" indicates not detected.

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

Table B-21 (concluded)

Personnel Sampled:	Maintenance Personnel														
	Welders			Millwrights			Pipefitters			Insulators		Elec- tricians		Inst Techn	
Sample Number:	4-018*	4-127*	4-164	4-015	4-096	4-125*	4-001	4-077	4-162*	4-147	4-023	4-078	4-024	4-161	4-022
Sample Volume (l):	726	684	729	548	645	639	720	754	627	639	659	759	612	711	726
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
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
Compound (detection limit, µg/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
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
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
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
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
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
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,l)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,l)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

^a Assuming a sample volume of 700 liters.

^b "--" indicates not detected.

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

Naphthalene	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	--	--	--	--	--	--	--	--	--	--
6,11-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,

Location Sampled:	Wrench Handle	Control House Door Handle	Control House Lunch Table	Instrument Cover P-226T	Valve Handle P-204B	North Flank Staircase Ground Lev
Sample Number:	4-244	4-245	4-250	4-254	4-256	4-258
Compound						
Naphthalene	• ^a	•	•	•	•	-- ^b
1-Methylnaphthalene	•	•	•	•	•	--
2-Methylnaphthalene	•	•	•	•	•	--
Quinoline	--	--	--	•	•	--
Acenaphthalene	--	--	--	•	--	--
Acenaphthene	•	•	•	•	•	•
Fluorene	•	•	•	•	•	•
Phenanthrene/Anthracene	•	•	•	•	•	•
Acridine	--	•	--	•	•	•
Carbazole	--	•	--	•	•	•
Fluoranthene	•	•	•	•	•	•
Pyrene	•	•	•	•	•	•
Benzo(a)fluorene/ Benzo(b)fluorene	•	•	•	•	•	•
Benzo(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,l)pyrene	--	--	--	--	--	--
Dimethylbenz(a)anthracene	--	--	--	•	--	--
3-Methylcholanthrene	--	--	--	•	--	--
6,11-Dimethyldibenz(a,j)- anthracene	--	--	--	--	--	--

^a "•" indicates compound detected.

^b "--" indicates compound not detected.

Compound			
Naphthalene	•	•	•
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, h) anthracene	--	•	•

"•" indicates compound detected.

"--" indicates compound not detected.

CPU Control Room Site 2	4-002	111	1625-0140	5/19/81	--	--	--	--	--	--	--	--	--
	4-207	96	2046-0445	5/22/81	--	--	--	--	--	--	±	±	±
High-Pressure Slurry Feed Pumps, P-102, Site 3	4-066	100	2117-0548	5/19/81	--	--	--	--	--	--	--	--	--
	4-092	113	0846-1311	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 Frac- tionator 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	0847-1655	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	4-087	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-106, P-107, 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-108, 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.

Distillation Unit #3	4-222	98	0748-1541	5/23/81	--	--	--	--	--	--	□	□	□
	4-069	30	2203-0613	5/19/81	--	--	--	--	--	--	□	□	□
	4-098	99	2107-0525	5/20/81	--	--	--	--	--	--	□	□	□
Solvent Hydrogenation Unit	4-220	90	0735-1535	5/23/81	--	--	--	--	--	--	--	--	--
	4-119	26	2147-0602	5/20/81	--	--	--	--	--	--	□	□	□
Offsite & Utilities	4-172	84	2058-0510	5/22/81	--	--	--	--	--	--	--	--	--
	4-054	89	2153-0605	5/19/81	--	--	--	--	--	--	--	--	--
Maintenance Workers	4-097	97	2100-0532	5/20/81	--	--	--	--	--	--	□	□	□
	Welders												
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 "u" indicates samples not analyzed for these compounds.

CPU CONTROL ROOM, Site 2	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	111	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 Fraction- ator 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 Fraction- ator 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.

	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	1540-2345	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/m³) for Pheno (May 19-23, 1981)

Location Sampled	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-Ethylphenol (0.02)	2,3-Xylenol (0.02)
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 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.

^c Process technician location key: LDU - liquefaction/distillation unit; SHU = solvent hydrogenation unit; OSU - offsite

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

Location Sampled:	Slurry Preparation			Reactor				Hydroclone			Vacuum Tower			
	R	N	N	R	R	N	N	N	N	R	N	N	N	N
Plant Status ^a :	R	N	N	R	R	N	N	N	N	R	N	N	N	N
Sample Number:	015	148	203	046	027	124	125	126	144	109	022	147	207	021
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
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
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
Compound (detection limit, $\mu\text{g}/\text{m}^3$) ^b														
Naphthalene (0.2)	14.2	10.8	24.6	0.7	14.6	16.1	7.4	3.3	28.1	81.9	7.7	2.2	2.6	2.2
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
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
Quinoline (0.2)	-- ^c	--	--	--	--	--	--	--	--	--	--	--	--	--
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
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,i)pyrene (0.8)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dimethylbenz(a)anthracene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3-Methylcholanthrene (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
6,13-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

^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-30 (concluded)

Location Sampled:	Fractionator		Waste Oil Recovery			Control Room			Seal Oil Pump			Perimeter	
Plant Status ^a :	N	N	R	N	N	R	R	N	R	N	N	K	N
Sample Number:	128	145	016	146	200	045	017	172	056	127	204	105	114
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
Sampling Time:	1105- 1919	1508- 2308	2317- 0855	1541- 2331	0720- 1445	0811- 1554	2301- 0828	1530- 2318	1436- 2230	1111- 1923	0735- 1455	0720- 1448	1147- 1947
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
Compound (detection limit, µg/m ³) ^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	--
1-Methylnaphthalene (0.2)	12.7	4.2	13.3	1.2	9.2	--	4.4	8.3	0.9	4.6	3.8	--	--
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
Quinoline (0.2)	--	--	--	--	--	--	--	--	--	--	--	--	--
Acenaphthalene (0.2)	1.9	1.0	1.2	--	2.9	--	0.4	0.3	1.2	1.7	0.5	--	--
Acenaphthene (0.2)	--	--	3.9	0.3	--	--	1.1	0.7	--	5.1	--	--	--
Fluorene (0.2)	4.7	3.3	3.2	--	5.2	--	1.2	--	3.1	6.6	2.4	--	--
Phenanthrene/Anthracene (0.2)	--	--	--	--	0.3	--	--	--	--	1.2	--	--	--
Acridine (0.2)	--	--	--	--	0.3	--	--	--	0.3	0.5	--	--	--
Carbazole (0.2)	--	--	--	--	0.5	--	--	--	--	0.3	--	--	--
Fluoranthene (0.2)	--	--	--	--	--	--	--	--	--	0.3	--	--	--
Pyrene (0.2)	--	0.8	0.6	0.2	1.7	--	--	--	0.5	2.0	0.6	--	--
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)	--	--	--	--	--	--	--	--	--	--	--	--	--
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

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

^b Assuming a sample volume of 1,000 liters.

^c "--" indicates not detected.

Compound (detection limit, $\mu\text{g}/\text{m}^3$) ^b	Sampling Time:									
	0918-1430	1135-1810	1838-0244	1904-0245	0653-1430	1900-0250	1509-2240	0710-1430	2323-0650	
Date (1981) Collected:	8/11	8/13	8/13	8/11	8/12	8/14	8/10	8/11	8/12	
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)	--	--	--	--	--	--	--	--	--	
Benzo(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	

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

^b Assuming a sample volume of 625 liters.

^c "--" indicates not detected.

(continued)

Table B-31 (concluded)

Personnel Sampled:	Maintenance Personnel													
	Pipefitters/Welders				Machinists				Insulators				Laborers	
Plant Status ^d :	N	N	R	R	N	R	R	N	N	N	R	R	R	R
Sample Number:	018	019	037	030	123	059	035	150	122	209	036	061	111	156
Sample Volume (L):	654	652	518	645	483	638	571	683	480	744	486	609	616	691
Sampling Time:	1604-	1603-	0864-	2347	1008-	0755-	0831-	1545-	1010-	0750-	0806-	1604-	0803-	1540
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
Compound (detection limit, $\mu\text{g}/\text{m}^3$) ^b														
Naphthalene (0.4)	3.7	1.2	-- ^a	35.0	21.0	--	--	6.3	43.2	10.9	9.2	5.7	4.7	--
1-Methylnaphthalene (0.4)	2.7	1.3	--	24.9	15.6	--	--	7.2	50.6	9.6	13.1	6.1	--	--
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	--
Quinoline (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Acenaphthalene (0.4)	--	--	--	0.9	1.2	--	--	--	2.6	0.5	0.8	0.4	0.5	--
Acenaphthene (0.4)	--	--	--	2.5	3.0	--	--	0.7	7.2	1.2	--	1.2	1.2	--
Fluorene (0.4)	0.7	0.4	--	2.3	2.4	--	--	--	6.2	0.7	2.3	1.2	1.1	--
Phenanthrene/Anthracene (0.4)	--	--	--	--	--	--	--	--	0.5	--	--	--	--	--
Acridine (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Carbazole (0.4)	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Fluoranthene (0.4)	--	--	--	--	--	--	--	--	0.5	--	--	--	--	--
Pyrene (0.4)	--	--	--	--	--	--	--	--	2.2	--	--	--	--	--
Benzo(a)fluorene/ Benzo(b)fluorene (0.4)	--	--	--	--	--	--	--	--	0.8	--	--	--	--	--
Benzo(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,l)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	11.8	5.8	0	152.9	81.2	0	0.5	30.8	248.2	59.3	59.4	28.0	19.7	0

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

^b Assuming a sample volume of 625 liters.

^c "--" indicates not detected.

Compound			
Naphthalene	• ^a	•	•
1-Methylnaphthalene	-- ^b	•	•
2-Methylnaphthalene	--	•	•
Quinoline	--	--	--
Acenaphthalene	--	•	•
Acenaphthene	--	•	•
Fluorene	--	•	•
Phenanthrene/Anthracene	•	•	•
Acridine	--	•	•
Carbazole	--	•	•
Fluoranthene	--	•	•
Pyrene	•	•	•
Benzo(a)fluorene/ Benzo(b)fluorene	•	•	•
Benzo(a)anthracene/ Chrysene/Triphenylene	--	•	•
Benzo(j)fluoranthene/ Benzo(b)fluoranthene/ Benzo(k)fluoranthene	--	•	•
Benzo(a)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.

	194	91	0740-1303	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	--	--	--	--	--	--	--	--
Hydroclones	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 (μ g/sample)	078			8/11/81	--	--	--	--	--	--	--	--
	179			8/13/81	--	--	--	--	--	--	--	--

^c 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 ($\mu\text{g}/\text{m}^3$) for Aromatic (August 10-14, 1981)

Personnel Sampled	Sample Number	Sample Volume (L)	Sampling Time	Date Collected	Compound (detection limit, $\mu\text{g}/\text{m}^3$) ^a						Hal
					Aniline (30)	N,N-Dimethyl-aniline (39)	2,4-Dimethyl-aniline (53)	o-Toluidine (23)	o-Anisidine (24)	p-Anisidine (33)	
Operators											
#3 Operator	025	96	0711-	8/10/81	-- ^b	--	--	--	--	--	
	117	48	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	83	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 ($\mu\text{g}/\text{sample}$)	074			8/11/81	--	--	--	--	--	--	
	223			8/14/81	--	--	--	--	--	--	

^a Assuming a sample volume of 80 liters.

^b "--" indicates not detected.

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.

Reactor	001	95	1409-2406	8/10/81	--	--	--	--	--	--
	133	96	1123-1926	8/13/81	--	--	--	--	--	--
Hydroclone	064	105	1428-2227	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	--	--	--	--	--	--
#9 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	--	--	--	--	--	--

"--" indicates not detected.

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

Location Sampled	Sample Number	Sample Volume (l)	Sampling Time	Date Collected	Metals (detection limit, μg)			Metal Carbon (detection limit, μg)	
					Cobalt (0.04)	Molybdenum (0.15)	Nickel (0.20)	Cobalt (4)	Molybdenum (4)
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	--	--	--	" ^a	--
	237	668	0735-1500	8/14/81	"	"	"	--	--
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	--	--	--	"	--
	212	698	0700-1445	8/14/81	"	"	"	--	--
Blanks	077			8/11/81	--	--	--	"	--
	176			8/13/81	--	--	--	"	--
	225			8/14/81	"	"	"	--	--
	226			8/14/81	"	"	"	--	--

^a Assuming a sample volume of 600 liters.

^b "--" indicates not detected.

^c "a" indicates sample not analyzed.

