VI. CONCLUSIONS AND RECOMMENDATIONS

NIOSH recognizes that there are many differences between a pilot plant and a commercial plant. First, commercial plants are designed for economical operation, whereas pilot plants are designed to obtain engineering data to optimize operating conditions. For example, commercial plants may reuse wastewater after treatment or process byproducts, such as char, mineral residue slurry, and sulfur, that are not used in pilot plants. Recycling of materials may result in higher concentrations of some toxic compounds in process streams. Second, because commercial plants operate longer between shutdowns than pilot plants, there may be significant differences in employee exposure to process materials. Third, the chemical composition of materials in commercial plants, the equipment configuration, and operating conditions may differ from those in pilot plants. New technology may be developed that could alter process equipment or the chemical composition of products or process streams. Such differences in chemical composition have been described for Fischer-Tropsch and Bergius oils [2]. Solvent de-ashing units are currently being investigated for solid-liquid separation [1]. Differences in equipment selection resulting from new technology or process improvements may affect the type of emission sources and extent of worker exposure.

Although the design of a commercial plant and the equipment used may be different than for a pilot plant, the engineering design considerations, which may affect the potential for worker exposure, and the recommended controls and work practices should be similar. Both commercial and pilot plant processes will operate in a high-temperature, high-pressure environment, and in most cases, a coal slurry will be used. Although the equipment may differ, the sources of exposure, such as leaks, spills, maintenance, handling, and accidents, will be similar. In addition, specific technology used to minimize or control worker exposure may be different for the two plant types. For example, commercial plants operate continuously and may use a closed system to handle solid wastes and to minimize inhalation hazards. This system may not be suitable for a pilot plant, which generally operates in a batch mode and where a portable local exhaust ventilation system could be provided when needed [1]. The systems differ, but both are designed to minimize worker exposure to hazardous materials.

Potential worker exposure to hazardous materials identified in pilot plants (see Appendix VI) warrants engineering controls and work practices as well as a comprehensive program of personal hygiene, medical surveillance, and training to minimize exposure in both pilot and commercial plants. If additional hazardous materials are identified in commercial plants, further precautions should be taken. If new process technology were to reduce potential hazards, a less vigorous control program might be warranted, but evidence of this is unavailable. When new data on these hazards become available, it will be appropriate to review and revise these recommendations.

Summary of Pilot Plant Hazards

An apparent excess incidence of cancerous and precancerous lesions was reported among workers in a West Virginia coal liquefaction plant that is no longer operating [4,53]. Although excess risk may have been overestimated because of design limitations, the excess observed to expected incidence would not be expected to be eliminated. Fifteen years after the initial study, a followup mortality study was conducted on the 50 plant workers who had cancerous and precancerous skin lesions. This followup study did not indicate an increased risk of systemic cancer. However, a better estimate of risk of systemic cancer mortality would have been derived if the entire original work force in the pilot plant had been followed up for more than 20 years.

Two other reports [1,75] demonstrated that the most common medical problems at pilot plants have been dermatitis, eye irritation, and thermal burns. From the available epidemiologic evidence, it is possible to identify several acute problems associated with occupational exposure to the coal liquefaction process. The full potential of cancer or other diseases of long latency possibly related to coal liquefaction, however, has not been established because of inadequate epidemiologic data.

There are numerous hazardous chemicals potentially in coal liquefaction plants for which health effects have been identified, dose-response relationships defined, and exposure limits established. Additional hazardous chemicals are present about which less is known. Furthermore, the combined effects of these chemicals in mixtures may differ from their independent effects.

Results of recent studies [14,15] using rats show that SRC-I and SRC-II process materials can cause adverse reproductive effects, including embryolethality, fetotoxicity, and fetal malformations. These effects are observed when materials are administered during both mid- and late gestation at dose levels high enough to cause >50% maternal lethality.

Long-term effects on nearly all major organ systems of the body have been attributed to constituent chemicals in various coal liquefaction process streams. Many of the aromatics and phenols irritate the skin or cause dermatitis. Silica dust and other components of the mineral residue may affect the respiratory system. Benzene, inorganic lead, and nitrogen oxides may affect the blood. Creosotes and coal tars affect the liver and kidneys, and toluene, xylene, hydrogen sulfide, and inorganic lead may affect the CNS.

Operating conditions in coal liquefaction plants (such as high temperature and pressure, and erosion/corrosion associated with slurry handling) increase the potential for leaks in process equipment. These conditions also increase the potential for acute, possibly fatal exposures to carbon monoxide, hydrogen sulfide, and hydrocarbon emissions. Furthermore, there is the potential for explosions when combustible material is released from processes operating at temperatures above the autoignition temperature of the materials being contained.

Because of the new technology involved, it is not possible to accurately predict the operational longevity of individual equipment components used in a plant. Often, frequent maintenance is required for some components, involving disassembling normally closed system components and, in some cases, requiring worker entry into confined spaces.

Control of Pilot Plant Hazards

Because sufficient data are not available to support exposure limits for all coal liquefaction materials, recommendations are made for worker protection through the combined implementation of engineering controls, work practices, medical surveillance, exposure monitoring, education and training, and use of personal protective equipment. In many cases, it is not possible to specify a single course of action that is correct for every situation. The information presented in this document is intended to assist those persons responsible for evaluating hazards and recommending controls in coal liquefaction pilot plants. By applying these recommendations to individual situations, it may be possible to reduce or eliminate potential workplace hazards.

(a) Medical Surveillance

Workers in coal liquefaction plants may be exposed to a wide variety of chemicals that can produce adverse health effects in many organs of the body. Medical surveillance is therefore necessary to assess the ability of employees to perform their work and to monitor them for any changes or adverse effects of exposure. Particular attention should be paid to the skin, oral cavity, respiratory system, and CNS. Effects on the skin may range from discoloration to cancer [17]. In addition to local effects on the respiratory tract mucosa [60,61], there is the potential for disabling lung impairment from cancer [17,18].

NIOSH recommends that a medical surveillance program be instituted for all potentially exposed employees in coal liquefaction plants and that it include preplacement and interim medical histories supplemented with preplacement and periodic examinations emphasizing the lungs, the upper respiratory tract, and the skin. Workers frequently exposed to coal-derived materials should be examined at least annually to permit early detection of adverse effects. In addition, a complete physical examination following the protocol of periodic examinations should be performed when employment is terminated.

Pulmonary function tests (FVC and FEV_1) should be performed annually. Chest X-ray films should also be made annually to aid in detecting any existing or developing adverse effects on the lungs. Annual audiometric examinations should be given to all employees who work in areas where noise levels exceed 85 dBA for an 8-hour daily exposure. The skin of employees who are occupationally exposed to coal-derived liquids should be thoroughly examined periodically for any actinic and other effects or the presence of benign or premalignant lesions. Employees with suspected lesions should be referred to a dermatologist for evaluation.

Other specific tests that should be included in the medical examination are routine urinalysis, CBC, and tests to screen liver function. Additional tests, such as sputum cytology, urine cytology, and ECG, may be performed if deemed necessary by the responsible physician.

Information about specific occupational health hazards and plant conditions should be provided to the physician who performs, or is responsible for, the medical surveillance program. This information should include an estimate of the employee's actual and potential exposure to the physical and chemical agents generated, including any available workplace sampling results, a description of any protective devices or equipment the employee is required to use, and the toxic properties of coal liquefaction materials.

Employees or prospective employees with medical conditions that may be directly or indirectly aggravated by work in a coal liquefaction plant should be counseled by the examining physician regarding the increased risk of health impairment associated with such employment.

Emergency first-aid services should be established under the direction of the responsible physician to provide care to any worker poisoned by materials such as hydrogen sulfide, carbon monoxide, and liquid phenols. Medical services and equipment should be available for emergencies such as severe burns and asphyxiation.

Pertinent medical records should be maintained for all employees for at least 30 years after the last occupational exposure in a coal liquefaction plant.

(b) Engineering Controls

In coal liquefaction plants, coal liquids are contained in equipment that is not open to the atmosphere. Standards, codes, and regulations for maintaining the integrity of that equipment are currently being applied. The use of engineering controls to minimize the release of contaminants into the workplace environment will lessen dependence on respirators for protection. In addition, lower contaminant concentration levels resulting from the application of engineering controls will reduce the instances where respirators are required, make possible the use of less confining, easier-to-use respirators when they are required, and provide added protection for workers whose respirators are not properly fitted or conscientiously worn.

Principles of engineering control of workplace hazards in coal liquefaction plants can be applied to both pilot and commercial plants, and to all types of liquefaction processes. Recognizing that engineering design for both demonstration and commercial coal liquefaction plants is only currently being developed, emphasis should be placed on design to prevent employee exposure, ie, to ensure integrity of process containment, limit the need for worker exposure during maintenance, and provide for maximum equipment reliability. These design considerations include minimizing the effects of erosion, corrosion, instrument failure, and seal and valve failure, and providing for equipment separation, redundancy, and fail-safe design. Additional techniques for limiting worker exposure, such as designing process sampling equipment to minimize the release of process material, are also appropriate. A system safety program that will identify control strategies and the risks of accidental release of process materials is needed for evaluating plant design and operating procedures.

The primary objectives of engineering controls are to minimize the potential for worker exposure to hazardous materials and to reduce the exposure level to within acceptable limits. Many of the engineering design considerations discussed throughout this assessment are addressed in existing standards, codes, and regulations such as the ASME Boiler and Pressure Vessel Code and the NFPA standards. These provide the engineering design specifications necessary for ensuring the integrity and reliability of equipment used to handle hazardous materials, the degree of redundancy and fail-safe design, and the safety of plant layout and operation. Although these regulations address design considerations that may affect worker safety and health, several engineering design considerations are not specifically addressed. These include the need for a system safety program, equipment maintainability, improved sampling systems, and reducing the likelihood of coal slurry coking or solidifying.

Because coal liquefaction plants are large and involve many unit operations and unit processes, a mechanism is needed to ensure that engineering designs are reviewed and supported by the appropriate safety and health professionals. This review would provide for early recognition and resolution of safety and health problems. A formal system safety program should be formulated and instituted for this review and analysis of design, identification of hazards and potential accidents, and specification of safety controls and procedures. Review and analysis should be conducted during both initial plant design and process design modifications using methods such as fault-tree analysis, failure-mode evaluation, or other safety analysis techniques. Process operating modes such as startup, normal production, shutdown, emergency, and maintenance should be considered in the hazards review process. At a minimum, the system safety program should include:

(1) A schedule stating when reviews and analyses are required.

(2) Assignment of employee responsibilities to ensure that these reviews are performed.

(3) Methods of analyses that should be used.

(4) Documentation and safety certification requirements.

(5) Documented review procedures for ensuring that knowledgeable health and safety personnel, as well as the engineering, maintenance, or management staff review designs and design changes.

Coal liquefaction plants should be designed to ensure that systems, unit operations, and unit processes handling hazardous and coal-derived materials can be maintained or repaired with minimal employee exposure. Prior to removal or maintenance activities, such equipment should, at a minimum, be:

(1) Isolated from the process stream.

(2) Flushed and purged, where practicable, to remove residual materials.

The flush, purge, and residual process materials should be contained, treated, and disposed of properly if they are not recycled. Gas purges should be disposed of by incineration in a flare system or by other effective methods. Areas into which flammable materials are collected should have adequate ventilation to reduce the flammable vapor concentration to less than its lower explosive limit. When employees must enter these areas, adequate ventilation should be provided to reduce the toxic vapor concentration to whatever NIOSH recommends as the lower exposure limit.

During process stream sampling, the potential for worker exposure to the material being sampled can be significant. Sampling techniques observed during plant visits have ranged from employees holding a small can and directing the material into it using a nozzle, to closed-loop systems using a sampling bomb. Reducing employee exposure during sampling is essential. Where practicable, process stream sampling systems should use a closed-loop system designed to remove flammable or toxic material from the sampling lines by flushing and purging before removing the sampling bomb. Discharges from the flushing and purging of sampling lines should be collected and disposed of properly.

The chemical and physical characteristics of the coal slurry handled in coal liquefaction plants may necessitate frequent maintenance, increasing the possibility of worker exposure to potentially hazardous materials. If heated improperly, the coal slurry can coke and plug lines and equipment. In addition, the pour point of the coal slurry is high, and lines and equipment will become plugged if the temperature of the slurry falls below this point.

Instrumentation and controls should be provided to maintain proper heating of the coal slurry, thus minimizing its coking potential. When coking does occur, local ventilation and/or respirators should be provided to limit worker exposure to hazardous materials during decoking activities. The potential for solidification of the coal slurry in lines and equipment during startup, routine and emergency operations, and shutdown should be minimized by heat-tracing equipment and lines to maintain temperatures greater than the pour point of the material.

Where practicable, equipment used to handle fluids that contain solids should be flushed and purged during shutdown to minimize the potential for coal slurry solidification or settling of solids.

When lines become plugged, one method for removing the plug is hydroblasting. During hydroblasting activities, adequate ventilation or respiratory protection should be provided. Water that is contaminated by process materials should be collected, treated, and recycled, or disposed of.

These design considerations and controls are necessary to protect worker safety and health by minimizing exposures to potentially hazardous materials. During the design and operation of coal liquefaction plants, every effort should be made to use engineering controls as much as possible. When available engineering controls are not sufficient or practical, work practices and personal protective equipment should be used as a supplementary protective measure.

(c) Work Practices

The major objective in the use of work practices is to provide additional protection to the worker when engineering controls are not adequate or feasible. Workplace safety programs have been developed in coal liquefaction pilot plants to address risks of fire, explosion, and toxic chemical exposure. These programs are patterned after similar ones in the petroleum refining and chemical industries. Most coal liquefaction pilot plants have written policies and procedures for various work practices, eg, procedures for breaking into pipelines, lockout of electrical equipment, tag-out of valves, fire and rescue brigades, safe work permits, vessel entry permits, wearing safety glasses and hardhats, housekeeping, and other operational safety practices [1]. Personnel responsible for the development of safety programs for coal liquefaction plants can draw upon general industry standards, voluntary guidelines of similar industries, equipment manufacturers' recommendations, operating experience, and common sense to develop similar programs tailored to their own operations. Appendix VIII contains some of the codes and standards applicable to both the development of safety programs for, and the design of, coal liquefaction plants.

It is common practice in industry to develop detailed operating procedures for each phase of operation, including startup, normal operation, routine maintenance, normal shutdown, emergency shutdown, and shutdown for extended periods. In developing these procedures, consideration should be given to provisions for safe storage of process materials, and for decontamination of equipment requiring maintenance.

Emergency fire and medical services are recommended. At a minimum, these services should be capable of handling minor emergencies and controlling serious ones until additional help can arrive. Prior to operation, local fire and medical service personnel should be made aware of the various hazardous chemicals used and any special emergency procedures necessary. This step will help to ensure that, when summoned, these local services know the hazards and required actions. In addition, emergency medical services are needed at the plant at all times to provide treatment necessary in life or death situations such as asphyxiation.

The potential for occupational exposure to hazardous materials increases during maintenance operations. For this reason, provisions should be made for preventing inadvertent entry of inert or toxic materials into the work area before work begins in or on any tank, line, or equipment. Where practicable, process equipment and connecting lines handling toxic gases, vapors, or liquids should be flushed, steamed, or otherwise purged before being opened. Flushed liquids should be safely disposed of by diverting them to sealed drains, storage vessels, or other appropriate collecting devices. Toxic gases should be incinerated, flared, recycled, or otherwise disposed of in a safe manner.

Tanks, process equipment, and lines should be cleaned, maintained, and repaired only by properly trained employees under responsible supervision. When practical, such work should be performed from outside the tank or equipment.

To avoid skin contamination, the accumulation of hazardous materials on work surfaces, equipment, and structures should be minimized, and spills and leaks of hazardous materials should be cleaned up as soon as possible. Employees engaged in cleanup operations should wear suitable respiratory protective equipment and protective clothing. Employees should also be aware of the possible permeation risk of some protective equipment and protective clothing, and should take care to change such equipment or clothing whenever skin contact with hazardous materials occurs. Cleanup operations should be performed and directly supervised by employees instructed and trained in procedures for safe decontamination or disposal of equipment, materials, and waste. All other persons should be excluded from the area of the spill or leak until cleanup is complete and safe conditions have been restored.

A set of procedures covering fire, explosion, asphyxiation, and any other foreseeable emergencies that might arise in coal liquefaction plants should be formulated. All potentially affected employees should be thoroughly instructed in the implementation of these procedures and reinstructed at least annually.

These procedures should include emergency medical care provisions and prearranged plans for transportation of injured employees. Where outside emergency services are used, prearranged plans should be developed and provided to all essential parties. Outside emergency services personnel should be informed orally and in writing of the potential hazards associated with coal liquefaction plants. Fire and emergency rescue drills should be conducted at least semiannually to ensure that employees and all outside emergency services personnel are familiar with the plant layout and the emergency plans and procedures. Necessary emergency equipment, including appropriate respirators and other personal protective equipment, should be stored in readily accessible locations.

Access to process areas should be restricted to prevent inadvertent entry of unauthorized persons who are unfamiliar with the hazards, precautions, and emergency procedures associated with the process. When these persons are permitted to enter a restricted area, they should be informed of the potential hazards and of the necessary actions to take in an emergency.

(d) Informing Employees of Hazards

At the beginning of employment, all employees should be informed of the known occupational exposure hazards associated with coal liquefaction plants. The following information could be included as part of a training program:

(1) Identification of toxic raw materials and coal liquefaction products and byproducts.

(2) Toxic effects, including the possible increased risk of developing cancer.

(3) Signs and symptoms of overexposure to hydrogen sulfide, carbon monoxide, other toxic gases, and aerosols.

(4) Fire and explosion hazards.

(5) Oxygen deficiency hazards.

(6) Emergency first-aid treatment for overexposure.

(7) Plant layout and emergency evacuation procedures.

(8) The use, limits of use, storage, and maintenance of all personal protective clothing and equipment that may be used.

(9) Hazards that may arise during materials handling, process sampling, housekeeping, waste disposal, and maintenance.

(10) The reasons for and the practice of personal hygiene.

(11) A description of the general nature of environmental and medical surveillance procedures and the advantages to the employee in cooperating with such procedures.

Training should be repeated periodically as part of a continuing education program to ensure that all employees have current knowledge of job hazards, signs and symptoms of overexposure, proper maintenance and emergency procedures, proper use of protective clothing and equipment, and the advantages of good personal hygiene. Retraining should be conducted at least annually or whenever necessitated by changes in equipment, processes, materials, or employee work assignments.

Because employees of vendors who service coal liquefaction pilot plants may also come into contact with contaminated materials, similar information should be provided to them. This can be accomplished more readily if operators of coal liquefaction plants obtain written acknowledgements from contractors receiving waste products, contaminated clothing, or equipment that these employers will inform their employees of the potential hazards that might arise from occupational exposure to coal liquefaction materials.

Another means of informing employees of hazards is to post warning signs and labels. All warning signs should be printed both in English and in the predominant language of non-English-reading employees. Employees reading languages other than those used on labels and posted signs should receive information regarding hazardous areas and should be informed of the instructions printed on labels and signs. All labels and signs should be readily visible at all times.

It is recommended that the following sign be posted at or near systems handling or containing coal-derived liquids:

DANGER
CANCER-SUSPECT AGENTS

AUTHORIZED PERSONNEL ONLY
WORK SURFACES MAY BE CONTAMINATED
PROTECTIVE CLOTHING REQUIRED
NO SMOKING, EATING, OR DRINKING

In all areas in which there is a potential for exposure to toxic gases such as hydrogen sulfide and carbon monoxide, signs should be posted at or near all entrances. At a minimum, these signs should contain the following information:

CAUTION
TOXIC GASES MAY BE PRESENT
AUTHORIZED PERSONNEL ONLY

When respiratory protection is required, the following statement should be posted or added to the warning signs:

RESPIRATOR REQUIRED

The locations of first-aid supplies and emergency equipment, including respirators, and the locations of emergency showers and eyewash basins should be clearly marked.

Based on the potential for serious exposure or injury, the employer should determine additional areas that should be posted or items that should be labeled with appropriate warnings.

(e) Sanitation and Personal Hygiene

Good personal hygiene practices are needed to ensure prompt removal of any coal liquefaction materials that may be absorbed through the skin. These practices include frequent washing of exposed skin surfaces, daily showers, and self-observation and reporting of any lesions that develop. To encourage good personal hygiene practices, adequate facilities for washing and showering should be provided in readily accessible locations.

Change rooms should be provided that are equipped with storage facilities for street clothes and separate storage facilities for work garments, protective clothing, work boots, hardhats, and other safety equipment. Employees working in process areas should be encouraged to shower and shampoo at the end of each workshift. A separate change area for removal and disposal of contaminated clothing, with an exit to showers, should be provided. The exit from the shower area should open into a clean change area. Employers should instruct employees working in process areas to wear clean work clothing daily and to remove all protective clothing at the completion of the workshift. Closed, labeled containers should be provided for contaminated clothing that is to be drycleaned, laundered, or discarded.

Lunchroom facilities should have a positive-pressure filtered air supply and should be readily accessible to employees working in process areas. Employees should be instructed to remove contaminated hardhats, boots, gloves, and other protective equipment before entering lunchrooms, and handwashing facilities should be provided near lunchroom entrances.

The employer should discourage the following activities in process areas: carrying, consuming, or dispensing food and beverages; using tobacco products and chewing gum; and applying cosmetics. This does not apply to lunchrooms or clean change rooms.

Washroom facilities, eyewash fountains, and emergency showers should be readily accessible from all areas where hazardous materials may contact the skin or eyes. Employees should be encouraged to wash their hands before eating, drinking, smoking, or using toilet facilities, and as necessary during the workshift to remove contamination. Employers should instruct employees not to use organic solvents such as carbon tetrachloride, benzene, or gasoline for removing contamination from the skin, because these chemicals may enhance dermal absorption of hazardous materials and are themselves hazardous. Instead, the use of waterless hand cleansers should be encouraged.

If gross contamination of work clothing occurs during the workshift, the employee should wash the affected areas and change into clean work clothing at the earliest safe opportunity. The employee should then contact his immediate supervisor, who should document the incident and provide the data for inclusion in the medical and exposure records.

Techniques using UV radiation to check for skin contamination have been tested [1]. However, the correlation between contamination and fluorescence is imperfect, and there are also possible synergistic effects of using UV radiation with some of the chemicals. For these reasons, the use of UV radiation for checking skin contamination should only be allowed under medical supervision.

(f) Personal Protective Equipment and Clothing

Employers should provide clean work clothing, respiratory protection, hearing protection, workshoes or shoe coverings, and gloves, subject to limitations described in Chapter V. Respirators may be necessary to prevent workers from inhaling or ingesting coal-derived materials. However, because respirators are not effective in all cases--for reasons including improper fit, inadequate maintenance, and worker avoidance--they should be used only when other methods of control are inadequate. Selection of the proper respirator for specific operations depends on the type of contaminant, its concentration, and the location of work operations. Selection of respirators and other protective equipment can be controlled through the use of safe work permits.

Protective clothing should be selected for effectiveness in providing protection from the hazards associated with the specific work area or operation involved. The employer should ensure that protective clothing is inspected and maintained to preserve its effectiveness.

(g) Monitoring and Recordkeeping Requirements

Performance criteria should be established to help employers evaluate the progress made toward achieving their worker protection objectives. Sampling and analysis for air contaminants provide a reasonable means for control performance assessment. Records of disruptions in plant operation by process area, including the frequency and severity of leaks, provide an excellent means for comparing performance with objectives and for directing future efforts to problem areas. A comparison of these records with data from periodic personal monitoring for specific toxicants affords additional performance evaluation.

Where appropriate, industrial hygiene monitoring should be used to determine whether employee exposure to chemical and physical hazards is within the limits set by OSHA or those recommended by NIOSH and to indicate where corrective measures are needed if such exposure exceeds those limits. To determine compliance with recommended PEL's, NIOSH recommends the use of the sampling and analytical methods contained in the NIOSH Manual of Analytical Methods [147-149].

Because of the numerous chemicals involved in coal liquefaction processes, it is impractical to routinely monitor for every substance to which exposure might occur. Therefore, an exposure monitoring program based on the results of an initial survey of potential exposures is recommended. The cyclohexane-soluble fraction (cyclohexane extractable) of the sampled airborne particulate, which has been recommended in criteria documents [17,18,76] as an indicator of the quantity of PAH compounds present, should be used. Additional compounds for which worker exposure may exceed established limits should be selected for inclusion in the monitoring program based on results of the initial survey. Exposure monitoring should be repeated quarterly, and the number of employees selected should be large enough to allow estimation of the exposure of all employees assigned to work in process areas.

The combination of data from exposure records, work histories, and medical histories, including histories of personal habits such as smoking and diet, will provide a means of evaluating the effectiveness of engineering controls and work practices, and of identifying causative agents for effects that may be revealed during medical monitoring. The ability to detect potential occupational health problems early is particularly critical in a developing technology such as coal liquefaction. Such identification is needed because exposures to numerous aromatic hydrocarbons, aliphatic hydrocarbons, sulfur compounds, toxic trace elements, and coal dusts result in an occupational environment for which anticipation of all potential health effects is difficult.

It is important that medical records and pertinent supporting documents be established and maintained for all employees, and that copies be included of any environmental exposure records applicable to the employee. To ensure that these records will be available for future reference and correlation, they should be maintained for the duration of employment plus 30 years. Copies of these medical records should be made available to the employee, former employee, or to his or her designated representative. In addition, the designated representatives of the Secretary of Health and Human Services and of the Secretary of Labor may have access to the records or copies of them.

VII. RESEARCH NEEDS

Information obtained from coal liquefaction pilot plants can be used to qualitatively assess the hazards in commercial plants in the future. Differences in operating conditions between pilot and commercial plants, however, do not currently allow these risks to be quantified. Once commercial plants begin operating, data can be collected for quantification. Studies currently being conducted by NIOSH are listed in Appendix IX. Additional research topics, divided into near- and far-term needs, are discussed here. Most of the research necessary can be based on pilot plant operations (near-term studies) and then carried over into commercial operations. However, certain research will not be possible until commercial plants are in operation (far-term studies). Research should not only be directed at recognition and evaluation of the risks but at future quantification and control of them.

Near-Term Studies

Additional research needed to identify and assess the toxicity of materials in coal liquefaction plants can be based on the materials in pilot plants. Included in this research should be industrial hygiene studies, animal toxicity studies, personal hygiene studies, prospective epidemiology studies of pilot plant workers, and studies on the carcinogenic, mutagenic, teratogenic, and reproductive effects of these coal liquefaction materials.

Near-term industrial hygiene studies are necessary because the risks cannot be assessed unless the hazards can be detected and measured. To account for changes that occur, these studies should be expanded concurrently with development of the technology. Detailed chemical analyses of all liquid and gaseous process streams, as well as surface contaminants, should be conducted to provide additional information on potential hazards. These analyses will be complicated by the fact that process stream composition will vary over a wide range depending on the reactivity and type of coal, rate of heating, liquefaction temperature, catalysts, pressure, and contact time [2]. Therefore, as many combinations of coal types and operating conditions as possible should be studied in order to characterize these changes. Studies should also be conducted to determine the extent to which PAH compounds and aromatic amines are absorbed on the surface of mineral residues and to determine whether PAH's or aromatic amines are lost through evaporation during aerosol sample collection. Studies to correlate fluorescence of surface contamination with biologically active constituents may lead to useful methods for measuring surface contamination. Instruments that measure PAH's and aromatic amines in real time are desirable.

The significance of both PAH's and aromatic amines as inhalation hazards should be determined. Existing sampling and analytical methods for determining PAH concentrations in the workplace air, based on the cyclohexane-soluble material in particulate samples, require refinement to improve accuracy, sensitivity, and precision. The current sampling method does not capture vapor-phase organic compounds, and some loss of the more volatile compounds from the airborne particulate may occur during sampling. Mutagenicity tests with various fractions of coal liquefaction materials containing 3- and 4-ring primary aromatic amines are important mutagens [150]. Further chemical analyses of these fractions should be done to identify the specific compounds present. As individual aromatic amines are identified, sampling and analytical methods need to be developed to measure them. Studies are also needed to determine how long samples remain stable prior to analysis. If necessary, handling methods that prevent sample deterioration and loss should be developed.

Animal studies to determine the toxicities of distillation fractions are required in order to investigate the potential effects of long-term exposure to coal liquids, vapors, and aerosols, particularly at low concentrations, and effects of the distillation fractions of the liquids on various physiologic systems. As the individual components of these fractions are determined, animal toxicity studies should be done for them as well. Previous studies [5-8] have only used dermal and im routes of administration. Well-planned inhalation studies in several animal species are needed to determine the exposure effects of aerosols and volatiles from synthetic coal liquids. Comparative animal studies using products from different processes could provide information that would help to further identify chemical constituents contributing to the toxic effects.

Toxicologic investigations [5-9,51] of carcinogenic effects in animals have illustrated that liquefaction products can induce cancerous lesions in some animal species, although not all materials produced similar results in all of the species tested. Additional tests of mutagenic, carcinogenic, teratogenic, and reproductive effects should be performed to augment available information on various process streams and products from different coal liquefaction processes. Less is known about the toxicity of products from pyrolysis and solvent extraction processes than about products from catalytic and noncatalytic hydrogenation and indirect liquefaction processes. Another area that requires further investigation is the potential for co-carcinogenesis and inhibition or promotion of carcinogenic effects by various constituents of coal liquefaction materials. Tests for teratogenic and reproductive effects have only been performed for one type of coal liquefaction process, ie, noncatalytic hydrogenation. Additional tests should be performed for coal liquefaction materials from other processes, particularly those selected for commercial development.

Microbial studies [40,42,44,45,50,150] have indicated mutagenic potential in various coal liquefaction products and their distillation fractions. However, these effects have not been replicated in cell cultures of human leukocytes [43]. The potential mutagenic effects should be systematically investigated in greater detail both in human cell cultures and in animals. Additional studies with mutagenic test systems would be useful for identifying the active constituents in fractions from different process streams.

While much research can be done to learn more about the hazards of exposure to process materials, research should also be carried out to improve the safety of work with materials already known or suspected to be toxic. Some contamination of workers' skin and clothing will occur regardless of the engineering controls implemented and work practices used. Therefore, personal hygiene studies should be conducted to determine the best cleaning methods for skin areas, including wounds and burns, and to develop ways to determine that cleansing has been effectively accomplished. UV radiation has been used to detect skin contamination [1]; however, further investigations are needed on the synergistic effects of UV radiation and coal liquefaction materials, particularly at wavelengths above 360 nm. The application of image enhancement devices to allow the use of low UV radiation intensities should be considered. Alternative methods for measuring or detecting skin contamination should also be considered.

Methods are also needed to test and evaluate the effectiveness of personal protective clothing against coal liquefaction materials. Decontamination procedures need to be developed for items such as safety glasses and footwear. In addition, the adequacy of laundering procedures should be evaluated.

The development of a simple noninvasive method for biologic monitoring of significant exposure to coal liquefaction products would be useful, because it is difficult to determine the extent of exposure from skin contamination. A urine test that would signal such an exposure is desirable.

Many pilot plant workers will be involved in commercial plant operation in the future. If these workers are included in future epidemiologic studies of commercial plant workers, it will be important to know their previous history of exposure in pilot plants. Therefore, prospective epidemiologic studies of these workers should begin now. In addition, it would be desirable to conduct a followup study of all employees of the Institute, West Virginia, plant, including 309 workers who were not followed up in Palmer's study [53]. It is possible that workers other than those who developed lesions were exposed to process materials. A followup study may reveal the occurrence of adverse health effects in these workers.

Solid waste generated during coal liquefaction processes includes ash, spent catalysts, and sludge. Trace levels of contaminants, eg, heavy metals, that are present in raw materials will be concentrated in this waste. Therefore, studies should be done to characterize solid waste composition and to assess worker exposure to hazardous waste components.

Far-Term Studies

Unless epidemiologic studies are undertaken independently outside the United States, there will be no opportunity to gather meaningful epidemiologic data on commercial plants until they are operating in this country. Once these commercial operations begin, detailed, long-term prospective epidemiologic studies of worker populations should be conducted to assess the effects of occupational exposure to coal liquefaction materials and to quantify the risks associated with these effects. Because the purpose of these epidemiologic studies is to correlate the health effects with exposure, they must include, at a minimum, detailed industrial hygiene surveys and comprehensive medical and work histories.

Detailed industrial hygiene surveys, including measurements of materials such as PAH's, aromatic amines, total particulates, trace metals, and volatile hydrocarbons, are necessary on a continuous or frequent basis so that worker exposure can be characterized over time. In addition, these surveys will identify any problems associated with the engineering controls or work practices. Comprehensive work and medical histories, including smoking or other tobacco use, and eating and drinking habits, are important for detecting confounding variables that may affect the potential risk to workers. Morbidity and mortality data from worker populations in coal liquefaction plants should be compared with those of properly selected control populations; eg, persons exposed to coal conversion products should be compared with those working in crude petroleum refinery plants.