III. HAZARDS TO HEALTH AND SAFETY FROM EXPOSURES IN COAL GASIFICATION PLANTS

Potential Exposures

(a) High-BTU Coal Gasification

After the mid 1980's, the development of the second generation coal gasification processes (such as HYGAS, Bi-Gas, CO2 Acceptor, etc) should be sufficiently advanced for one or more of these processes to be commercialized and eventually replace the Lurgi gasifier in the United States. Until then, commercial high-BTU coal gasification plants built in the United states will follow the Lurgi design with minor modifications to suit local conditions [3-6]. Some of the statistics for four proposed high-BTU coal gasification plants are shown in Table III-1.

TABLE III-1

COAL GASIFICATION PLANT STATISTICS(a)

	Plant			
	A	B	C	D
Rated plant capacity(b)	275	ND	270	288
Capacity for 365 days per year operation(b)	250	250	246	266
Coal feed rate, Total tons/day	30,000	33,400	32,470	28,250
Number of gasifiers, total	34	ND	ND	28
Plant site, acres	1,070	1,440	ND	960
Area actually occupied, acres	300	640	334	ND
Personnel, plant only	612	ND	800	883

(a) Data for plants A-D adapted from references 3 through 6, respectively
(b) In millions of standard cubic feet per day (scfd)

Each of these proposed plants will require 600-1,000 employees. By 1985, 4,000 persons could be employed in high-BTU coal gasification plants. It is estimated that 40-90 of these facilities could be in operation by the year 2000 [2]. The principal product of these plants will be a pipeline-quality (high-BTU) gas with a heating value of approximately 1,000 BTU/standard cubic foot (scf). Byproducts may include coal tar, naphtha, phenolic compounds, sulfur, and ammonia.

The unit operations of the Lurgi process are: Coal handling and preparation, coal feeding, coal gasification, ash removal, quenching, shift conversion, gas cooling, gas purification (acid gas removal), methanation, sulfur removal, gas-liquor separation, phenol and ammonia recovery, and byproduct storage and cleanup. Brief discussions of these operations follow (more detailed information is presented in Chapter XI).

(1)   Coal Handling and Preparation

Coal is delivered from the mine to the plant unloading hopper from which it is transferred by feeders and conveyors to primary and secondary mechanical crushers and is then stockpiled (Figure III-1). Later the coal is moved from the stockpile to sizing screens and to the coal-cleaning operation, for removal of fines which may present a dust and/or explosion hazard. The cleaned, sized coal is then used to produce gas and steam and, in some cases, power. Reject material can be returned to the mine for final disposal.

Occupational health hazards associated with the coal handling and preparation process include exposure to coal dust, noise, and fires from possible spontaneous combustion of coal in the storage areas, with the potential attendant inhalation of the products of combustion.

(2)   Coal Feeding

After passage through the preparation operation, the coal is moved by conveyor either to intermediate storage or directly to the gasifier coal bunker (Figure III-2). Coal is then fed from this bunker to the coal lockhopper (Figure XI-2), the operation of which is cyclic, ie, the lockhopper is charged with coal, pressurized to gasifier pressure (with CO_2, raw gas, etc), opened to discharge the coal to the gasifier, closed, depressurized, and then recharged with coal, the entire cycle taking 10-30 minutes. Each depressurization releases an estimated 280 cubic feet (cu ft) of pressurizing gas (which is incinerated or otherwise disposed of) [6]. It is conceivable that pressurizing gas or raw gas (see Table III-2) could be released into the coal bunker and result in exposure of operators.
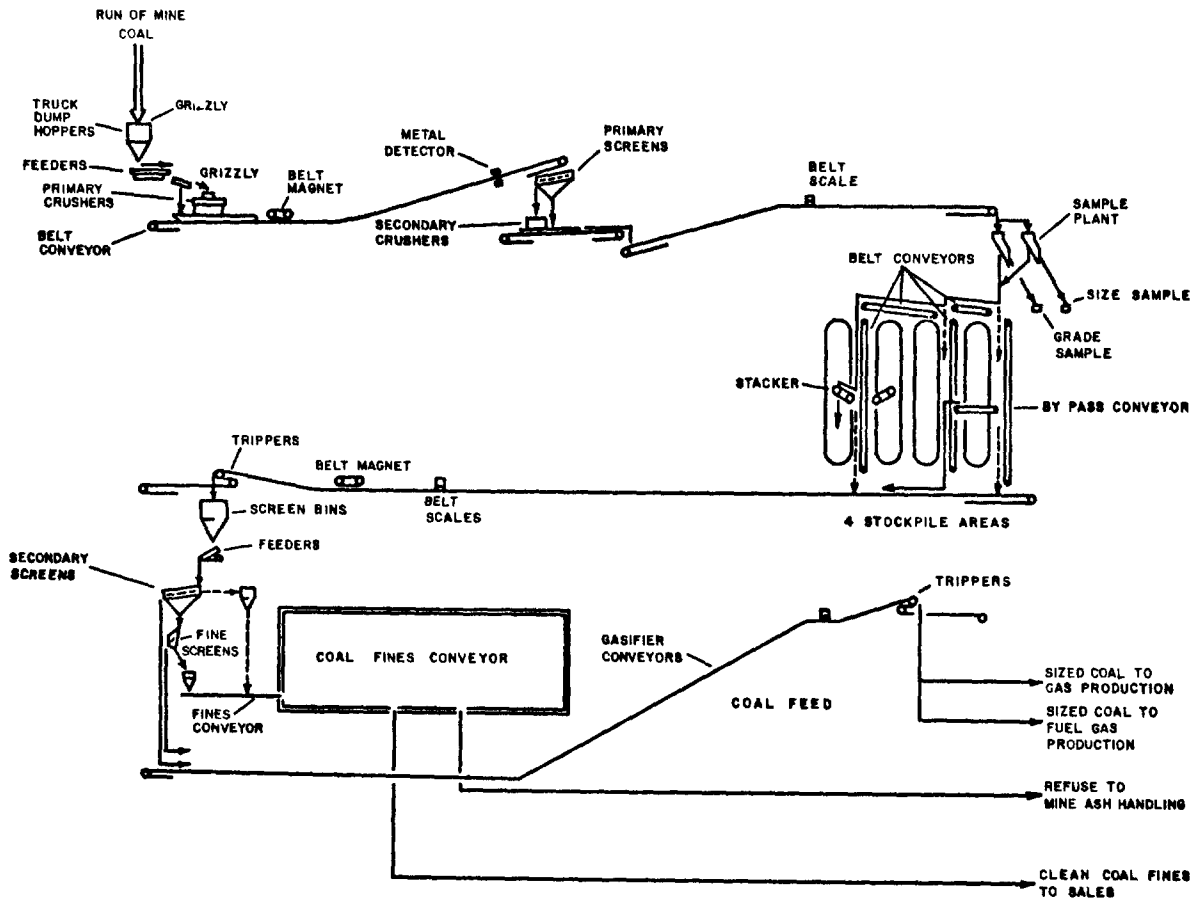
Figure III-1
Flow Scheme for Coal Handling and Preparation

Adapted from Reference 6

SIZED COAL

LOCK FILLING GAS

BFW

COAL BUNKER

COAL LOCK GAS

STEAM DRUM

JACKET STEAM

COAL LOCK

RECYCLE GAS LIQUOR

CRUDE GAS TO SHIFT CONVERSION

CRUDE GAS TO GAS COOLING

CRUDE GAS

WASH COOLER

LURGI PRESSURE GASIFIER

CRUDE GAS

WASTE HEAT BOILER

100 psig STM

L.P. BFW

STEAM TO GASIFIER

OXYGEN

ASH LOCK

TARRY GAS LIQUOR

WASH COOLER PUMP
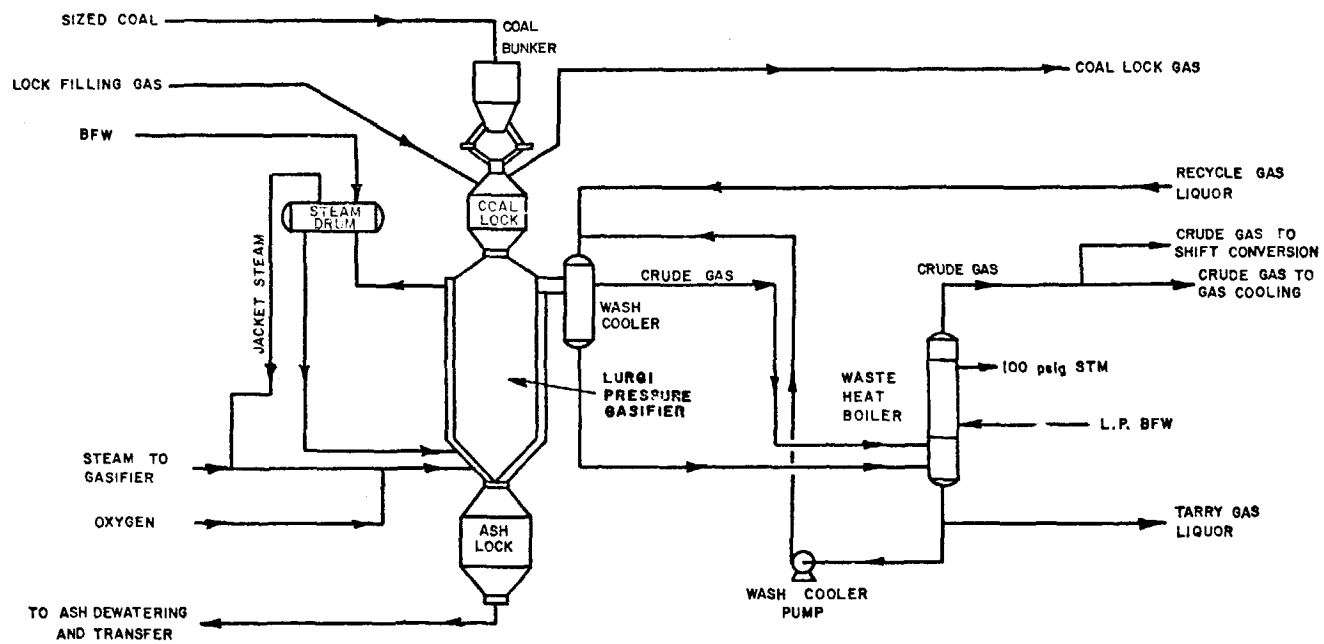
TO ASH DEWATERING AND TRANSFER

21

Figure III-2
Flow Scheme for Gas Production

Adapted from Reference 6

Occupational health hazards associated with the coal-feeding process include exposure to coal dust, noise, and gaseous toxicants (Table III-2). There is also a potential for asphyxiation by inert gases used for lockhopper pressurization.

TABLE III-2

TYPICAL RAW GAS COMPOSITION (DRY)

Constituent	Concentration (vol %)
Carbon dioxide	28.4
Carbon monoxide	19.9
Ethane	0.6
Ethylene	0.1
Hydrogen	38.7
Hydrogen sulfide	0.5
Methane	10.3
Nitrogen and argon	0.3
Other hydrocarbons(a)	0.2

(a) "Other hydrocarbons" include propane, butane, benzene, toluene, xylene, napthalene, and phenols

Adapted from Reference 3

(3)   Coal Gasification

High-BTU gasifiers operate at pressures of 350-450 pounds per square inch gauge (psig), and at temperatures of 870 C (1,598 F) in the combustion zone and 345 C (653 F) at the gas offtake. The feed streams to the gasifier are coal, steam, and oxygen [3].

Traveling by gravity, coal from the lockhopper encounters the hot gas rising to the top of the gasifier and is gradually heated to combustion temperature through successive, overlapping zones of preheat, devolatilization, gasification, and combustion. It is in the preheat and devolatilization zones, where temperatures range from 345 to 620 C (653 to 1,148 F), that the crude gas, tar, tar oil, naphtha, phenols, and other complex compounds are formed. Trace elements are volatilized from all parts of the bed. Steam and oxygen enter the gasifier near the bottom and are heated by the hot ash moving downward from the combustion zone.

22

Occupational health hazards associated with the gasifier operation include potential exposure to coal dust, high-pressure hot gases, trace elements, tar, fire, and noise.

(4)   Ash Removal

Ash from the gasifier is continuously removed by a rotating grate and collected in a steam-pressurized lockhopper from which it is discharged. The ash is then dewatered and disposed of. The ash lockhopper pressurizing steam is condensed after passing through a cyclone for particulate removal and is vented to the atmosphere. Particulates collected in the cyclone are transferred to the ash disposal area. At the end of the ash discharge cycle, the ash lockhopper is repressurized [3,6].

The quantity of radioactive material in coal varies widely with geographic location and type of coal, but it is generally less than that in sedimentary rock [7]. At a gasification plant, any radioactivity would be found mainly in the product gas and the ash, neither of which should lead to significant worker exposure. There would also be furnace-stack emissions of gas and fly ash from any coal burned for steam generation. Fly ash removal by modern control methods, and elevated-stack emission of hot gases should result in negligible exposure. Even in the vicinity of a large (1,960 megawatt, electrical) electricity-generating plant with inefficient stack gas cleaning and short stacks, air samples have shown maximum lung and bone radiation dose rates of only about 1% of the maximum permissible rate recommended by the International Commission on Radiological Protection. It was also found that soil samples downwind from the plant showed no radioactivity above the natural background levels [8]. It is not possible at present to provide a more definitive assessment of potential radiation hazards.

Occupational health hazards associated with the ash removal process include potential exposure to heat, high-pressure steam, high-pressure oxygen, hot ash, and dust. Trace elements in coal, although averaging only 0.03% of the total weight, present a potential hazard for plant employees because of the large quantities of coal consumed.

(5)   Quenching

The hot raw gas from the gasifier will contain tar oil and trace elements volatilized from the coal, excess steam, and solids (primarily coal fines entrained from the top of the gasifier). This gas is quenched (cooled) with recycled gas-liquor to 195 C (383 F) and passes to the wash cooler, located next to the gasifier. A major portion of the volatilized trace elements is also condensed and removed from the gas stream at this point. Excess heat is

removed in the waste heat boiler. The condensate (gas-liquor), containing tar, tar oil, water, water-soluble compounds, and solids, is then recycled to the quench spray by a wash cooler pump.

Occupational health hazards associated with the quenching process include potential exposure to high-pressure, hot raw gas (see Table III-2), hot tar, hot tar oil, hot gas-liquor, fire, and noise.

(6) Carbon Monoxide Shift Conversion

Approximately half of the quenched and washed raw gas (which still contains light oil and phenols) is preheated and passed through the shift conversion unit (Figure III-3) and then to the gas cooling unit (see section 7 below); the other half is passed directly to the gas cooling unit (without shift conversion) [6].

The shift-conversion unit consists of a series of catalytic reactors in which carbon monoxide and steam are converted ("shifted") at 400 C (752 F) to hydrogen and carbon dioxide [9]. Operating conditions are chosen to permit conversion in the presence of tar oil. Other reactions that occur in the shift-conversion unit are desulfurization of sulfur-containing hydrocarbons and hydrogenation of organic compounds.

Occupational health hazards associated with the shift-conversion process include potential exposure to high-pressure hot raw gas (see Table III-2), high-pressure hot shifted gas, high-pressure steam, tar, tar oil (especially the naphtha fraction), hydrogen cyanide, fire, catalyst dust (during loading and unloading), fire, and heat.

(7) Gas Cooling

The gas cooling unit (Figure XI-5) cools the hot raw gas that bypasses the shift conversion unit and the shifted gases in two separate, but similar, trains. Condensate (gas-liquor) is transferred to the primary gas-liquor separator (see Section 11 below). The cooled gases are mixed and then transferred to the Rectisol unit (see Section 8 below) for purification [3,9].

Occupational health hazards associated with gas cooling include potential exposure to high-pressure hot raw gas, hot tar, hot tar oil, hot gas-liquor, fire, heat, and noise.

(8) Gas Purification (Acid-Gas Removal)

The Rectisol process (Figure XI-6) is a licensed gas purification process in which methanol is used to absorb acid gases such as carbon dioxide, hydrogen sulfide, carbonyl sulfide, and organic sulfur-containing compounds at cryogenic temperatures and at process pressure [9]. Methanol is regenerated by a combination of
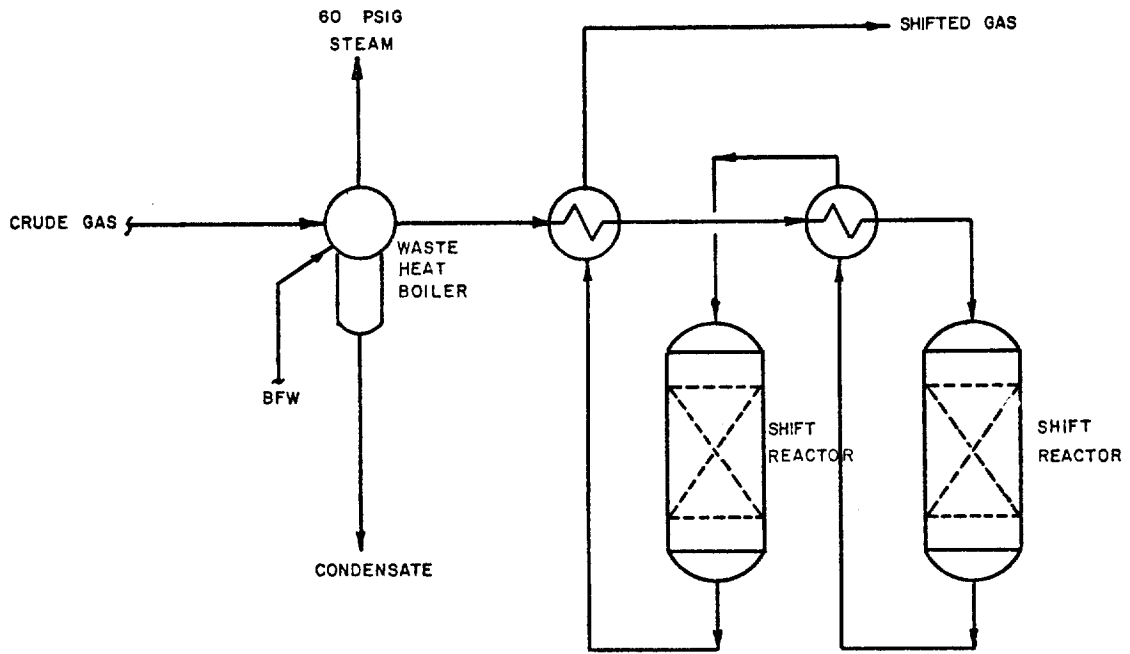
24

Figure III-3

Flow Scheme for the Shift Reaction Section

Adapted from Reference 6

flashing to atmospheric or subatmospheric pressure and heating to as high as 65 C (149 F). Naphtha (Table III-3) and residual heavy hydrocarbons are removed from the raw gas and recovered by extracting the methanol from the water at 75 C (167 F) [4].

TABLE III-3

NAPHTHA COMPOSITION

Major Constituents (>10% each)	Minor Constituents (<10% each)
Paraffins and olefins	Thiophenes
Benzene	Styrene
Toluene	Ethyl toluene
Xylenes and ethyl benzene	Indane
Trimethyl benzene	Indene
	Naphthalene
	Benzofuran

Adapted from reference 10

Two separate absorption steps are used to further purify the raw gas. These steps reduce the carbon dioxide content of the gas stream to about 8 vol %, and the concentration of hydrogen sulfide and other sulfides to a level of approximately 0.1 ppm as total sulfur.

Three offgas streams are produced in the Rectisol unit: (1) A 10% or higher hydrogen sulfide (rich) stream that is delivered to the Claus plant (see Section 10 below); (2) A 1% hydrogen sulfide (lean) stream that is directed to the Stretford plant (see Section 10 below); and (3) an expansion gas stream, containing approximately 30 ppm hydrogen sulfide, that is either incinerated [6] or recombined with the cooling section product upstream of the acid gas removal section [10]. Aqueous condensate is transferred to the water treatment area, and naphtha is delivered to storage for possible sale [10].

Occupational health hazards associated with the gas purification process include potential exposure to sulfur-containing gases, methanol, naphtha, cryogenic temperatures, high-pressure steam, refrigerant gases, and noise.

26

(9)   Methanation

After purification, the gas is transferred to the methanation unit (Figure XI-7) where the catalytic reaction of carbon monoxide, carbon dioxide, and hydrogen takes place to produce methane and water.   Synthesis equipment consists essentially of fixed-bed reactors charged with a form of pelleted nickel catalyst, and heat exchangers for heating incoming gas to reaction temperatures and for cooling the product gas either by heating incoming gas or by generating steam.   (The incoming gas should be heated sufficiently to prevent nickel carbonyl formation [3].)

Gas from the methanation unit is returned to the Rectisol unit for final carbon dioxide and water removal. Dry product gas (Table III-4), which has an approximate heat content of 980 BTU/scf, is compressed to 1,000 psig before it is pumped into the pipeline.

TABLE III-4

TYPICAL PRODUCT GAS COMPOSITION
(DRY)

Constituent	Concentration (vol %)
Carbon dioxide	0.50
Carbon monoxide	0.06
Hydrogen	1.45
Methane	96.84
Nitrogen and argon	1.15
Hydrogen sulfide	≤ 0.2 ppm

Adapted from reference 3

Occupational health hazards associated with the methanation process include potential exposure to high-pressure Rectisol product gas, high-pressure methanated gas (Table III-4), steam, nickel carbonyl, nickel catalyst dust, fire, and noise.

27

(10)   Sulfur Removal Processes

In some plant designs, the hydrogen sulfide-rich offgas streams from the Rectisol process are treated in the Claus unit as shown in Table III-5.

TABLE III-5

CLAUS UNIT FEED AND PRODUCT GASES

Constituent	Feed Gas (wt %)	Product Gas (wt %)
Carbon dioxide	87.5	75.7
Carbon disulfide	0.005	ND
Carbon monoxide	Trace	ND
Carbonyl sulfide	0.1	0.03
Hydrogen sulfide	12.2	0.5
Naphtha	0.6	ND
Nitrogen and argon	ND	17.4
Sulfur	ND	0.1
Sulfur dioxide	ND	0.5
Water vapor	ND	5.5

Adapted from reference 10

ND = no data

The Claus unit utilizes a series of high-activity catalytic (bauxite) beds to decompose at least 85% of any carbonyl sulfide or carbon disulfide fed to them and to minimize sulfur dioxide entrainment. The offgas may be incinerated or fed to a Stretford unit (see below) for additional sulfur removal. It is estimated that the overall sulfur removal will be 99.5% [10].

The Stretford process treats the hydrogen sulfide-lean offgas from the phenol recovery unit (see Section 12 below) and the Rectisol process, as well as other gas streams containing low concentrations of hydrogen sulfide. The estimated compositions of the feed and product gases are shown in Table III-6.

TABLE III-6

STRETFORD FEED AND PRODUCT GASES

| Constituent | Concentration | |
	Feed Gas (wt %)	Product Gas (wt %)
Carbon dioxide	95.2	86.3
Carbon disulfide	trace	trace
Carbon monoxide	0.6	0.5
Carbonyl sulfide	0.02	0.01
Hydrogen	0.05	0.05
Hydrogen sulfide	0.9	0.001
Light oil	0.8	0.8
Nitrogen	0.9	8.6
Oxygen	ND	7.9
Water vapor	1.6	2.0

Adapted from reference 10

ND = no data

The Stretford process utilizes an aqueous solution of sodium and vanadium salts of anthraquinonedisulfonic acid (ADA) to precipitate elemental sulfur from the product stream. The Stretford offgas streams may be incinerated in the coal-fired boilers, or a thermal or catalytic incinerator, to eliminate the hydrocarbon content. These incinerated gases may be subsequently treated in the stack-gas treating unit [3].

The elemental sulfur may be stored on the ground within a retaining curb to prevent runoff [6] or in a heated sulfur pit [4].

Occupational health hazards associated with these unit processes include potential exposure to hydrogen sulfide, other sulfides, and sulfur oxides.

(11)   Gas-Liquor Separation

In the gas-liquor separation process (Figure XI-9), absorbed ammonia, carbon dioxide, hydrogen sulfide, hydrogen cyanide, carbon monoxide, cyanide, tar, tar oil, and gas-liquor are separated by gravity in a series of atmospheric pressure, moderate temperature vessels. Feed to this unit includes overflow from raw-gas quenching, condensate from raw gas and from shifted-gas cooling, and perhaps condensate from gas purification.

29

At atmospheric pressure, the gases absorbed in liquids at the high operating pressures of the gas-processing units come out of solution. This expansion gas (approximately 96% carbon dioxide) may be either recompressed or incinerated [3,10]. The tar oil component is either fractionated for sale as refined products, or burned for its fuel value [3,6,9].

Tar containing up to 40% fines is withdrawn from the bottom of the separator and may be either returned to the top of the gasifier bed for further cracking, or used as a binder for briquetting coal fines [3,6].

Gas-liquor is processed to recover phenols and ammonia [3,6,10,11,12]. Analyses of tar oil, tar, and gas-liquor indicate that trace elements condensed from the crude gas tend to concentrate in the gas-liquor [11].

Occupational health hazards associated with the gas-liquor separation process include potential exposure to tar oil, tar, noise, and gas-liquor with high concentrations of phenols, ammonia, hydrogen cyanide, hydrogen sulfide, carbon dioxide, and trace elements.

(12)   Phenol and Ammonia Recovery

The phenol recovery unit (Figure XI-10) utilizes an organic solvent such as isopropyl ether or n-butyl acetate to remove phenolic compounds from the recycled gas-liquor and clarified aqueous liquor streams [3,12]. Phenols are recovered from the solvent by steam-stripping and are either stored or further refined for subsequent sale.

The clean (dephenolized) gas-liquor is steam-stripped to remove acid gases, including hydrogen sulfide and carbon dioxide, which are recycled through the phenol recovery unit. The same liquor is then steam-stripped at a higher temperature to remove ammonia which is condensed for sale or further processed to produce pure anhydrous ammonia. Clean gas-liquor may be used for cooling-tower makeup [10] or transferred to a biological oxidation system before further use or disposal [3,12]. The ammonia may be stored, purified, or used to manufacture ammonium sulfate [3,10,12] for subsequent sale.

A second gas-liquor stream, about one-sixth the size of the clean gas-liquor stream from the gas-liquor separation process, is treated as described above in a parallel train. It is not subjected to acid-gas stripping or ammonia recovery because of process problems caused by its high solids content. Rather, it is transferred directly to the biotreatment system [3] or to the ash-dewatering system [11].

Occupational health hazards associated with the phenol and ammonia recovery processes include potential employee exposure to phenols, ammonia, acid gases, and gas-liquor. In addition, isopropyl ether is a fire hazard and may form explosive peroxide compounds when exposed to light or evaporated to dryness in the absence of inhibitors.

(13)   Byproduct Storage, Handling, and Cleanup

The tar-oil or its byproducts may be stored in tanks [6]. If the liquid is to be used as fuel, it may be processed and/or burned.

Liquid byproducts, ammonia, and raw materials for the process may be shipped to and from the site by rail or truck. At one plant [11], 6.6 gallons of liquid byproduct were produced per ton of coal gasified. A coal feed rate of 22,000 tons/day would yield 145,000 gallons/day of liquid byproducts; tanks range in capacity from 21,000 to 1,680,000 gallons [6].

Occupational health hazards associated with byproduct storage, handling, and cleanup include potential exposure to tar, tar oil, phenols, ammonia, naphtha, methanol, and phenol recovery solvent. There is also a potential for fires in and around the storage tanks.

The wastewater treatment system for recovering the dephenolized gas-liquor may consist of oil-water separation for the bulk removal of suspended oils and solids, air flotation for the further removal of suspended oil and solids, biotreatment for the removal of residual phenols and other organics, and clarification and removal of activated sludge (ie, via microorganisms).

The various sludges produced in a high-BTU coal gasification plant are returned to the coal mining area for disposal, except for the calcium containing sludge, which is retained within a lined settling pond sized to have a 25-year life [3]. One company has applied for and received a state environmental permit for disposal in this manner [3].

Occupational exposures in both the water treatment and the disposal section of the plant should be low since there is little occasion for operators or maintenance personnel to be in the area. Those exposures which do occur will be to liquids or slurries, and primary potential exposure will be through skin contact.

(14)   Summary

Table III-7 is a summary of the potential occupational exposures in high-BTU coal gasification as presented in the preceding sections.

31

TABLE III-7

POTENTIAL OCCUPATIONAL EXPOSURES IN
HIGH-BTU COAL GASIFICATION

Unit Process	Potential Exposures
Coal handling and preparation	Coal dust, noise, fire
Coal feeding	Coal dust, noise, gaseous toxicants, and asphyxia
Gasifier operation	Coal dust, high-pressure hot raw gas, high-pressure oxygen, high-pressure steam, fire, noise
Ash removal	Heat stress, high-pressure steam, high-pressure oxygen under impact conditions, hot ash, and dust
Quenching	High-pressure hot raw gas, hot tar, hot tar oil, hot gas-liquor, fire, noise
Shift conversion	High-pressure hot raw gas, high-pressure hot shifted gas, high-pressure steam, tar, tar oil (naphtha), hydrogen cyanide, fire, catalyst dust, heat stress
Gas cooling	High-pressure hot raw gas, hot tar, hot tar oil, hot gas-liquor, fire, heat stress, noise
Gas purification	Sulfur-containing gases, methanol, naphtha, cryogenic temperatures, high-pressure steam, noise
Methanation	High-pressure Rectisol product gas, high-pressure methanated gas, steam, nickel carbonyl, nickel catalyst dust, fire, noise

Table III-7 cont'd

Unit Process	Potential Exposures
Sulfur removal	Hydrogen sulfide, other sulfides, and sulfur oxides
Gas-liquor separation	Tar oil, tar, gas-liquor with high concentrations of phenols, ammonia, hydrogen cyanide, hydrogen sulfide, carbon dioxide, trace elements, and noise
Phenol and ammonia recovery	Phenols, ammonia, acid gases, gas-liquor, ammonia recovery solvent, and fire
Byproduct storage	Tar, tar oil, phenols, ammonia, methanol, phenol recovery solvent, and fire

(b)   Low- or Medium-BTU Coal Gasification Utilizing
        Bituminous or Lower Ranked Feedstocks

Estimates of the extent of low- or medium-BTU gasification technology range from 75 to 500 plants by the year 1985 [13]. By the year 2000, as many as 12,000 of these plants may be in operation [13]. The plants may vary from a single unit gasifying 75 tons of coal per day to multiple units gasifying several thousand tons per day. The estimated manpower requirement for these plants is one operator per shift per three gasifiers [14].

The products, byproducts, and uses of low-BTU gasifiers are similar to those of the high-BTU gasification units described above, except for differences resulting from the Lurgi gasifier operating at a pressure of 350-450 psig; most fixed-bed low-BTU gasification units can operate at approximately 15 psig or less. Unit processes include coal delivery and storage, coal preparation (in large facilities), coal feeding, and coal gasification.

In many cases the coal feeding operation consists of delivering coal into the gasifier through an unpressurized lockhopper or rotary valve. Air (or in the case of medium-BTU coal gasification, oxygen) is blown through the bottom of the bed, and in many cases steam is added by saturating the feed air with hot water vapor from the gasifier heating jacket.

33

A rotary grate is used to remove the ash from the bed at a controlled rate. The ash may fall into a water trough [15] or into a low-pressure lockhopper, where it may be wetted by water precipitated from the feed air or by other means [14,16]. In smaller plants, the ash may be dumped directly into a truck for disposal. Solids from the cyclone separator may be disposed of in a similar manner. Ash disposal methods for larger plants may be similar to those used in high-BTU coal gasification plants.

In the simplest design, low- or medium-BTU product gas at 240-400 C (464-752 F) passes through a cyclone separator for removal of entrained solids and is then used without further processing (Figure III-4) [16]. In more sophisticated designs (Figure III-5) downstream unit operations may include gas quenching and separation of tar and gas-liquor (cyclone or electrostatic precipitator). It may also be desirable to remove the acid gases [17,18] directly from the unsweetened gas [17-19]. Auxiliary operations include tar storage or disposal, gas-liquor treatment or disposal, and sulfur storage or disposal. For more detailed process information the reader should refer to Chapter 12.

Occupational health hazards associated with low- or medium-BTU gasification unit operations are similar to those of the high-BTU process. They include potential exposure to carbon monoxide, coal dust, ash dust, hot raw gases, tar and/or tar oil, gas-liquor (decanter water) containing high concentrations of phenolic compounds, nitrogen compounds including ammonia, sulfur compounds including hydrogen sulfide, trace elements and lesser concentrations of other toxic agents, heat stress, and noise.

(c)   Low or Medium-BTU Gasification Utiling Anthracite
       Feedstocks or Very High Temperatures

   (1)   Anthracite Gasification

In comparison to lower ranked coals, anthracite has a very low volatile matter content, a low hydrogen to carbon ratio, and a low sulfur content [14,20]. A thorough investigation of the literature as well as discussions with those using US anthracite [14,20] indicate that the gasification of anthracite in a fixed-bed gasifier does not produce tar [21,22]. Examination of gasifier internal surfaces and piping downstream of operating units did not show the presence of tar deposits. Otherwise, from an occupational health and from a process viewpoint, the gasification of anthracite is similar to other low-BTU processes. Unit processes would include coal delivery and storage, coal feeding, gasification, ash removal, and product solids removal. Though not presently used, it is possible that downstream operations will include gas quenching, gas purification, and/or hydrogen sulfide removal. The latter may not be necessary because of the low sulfur content of most US anthracites.
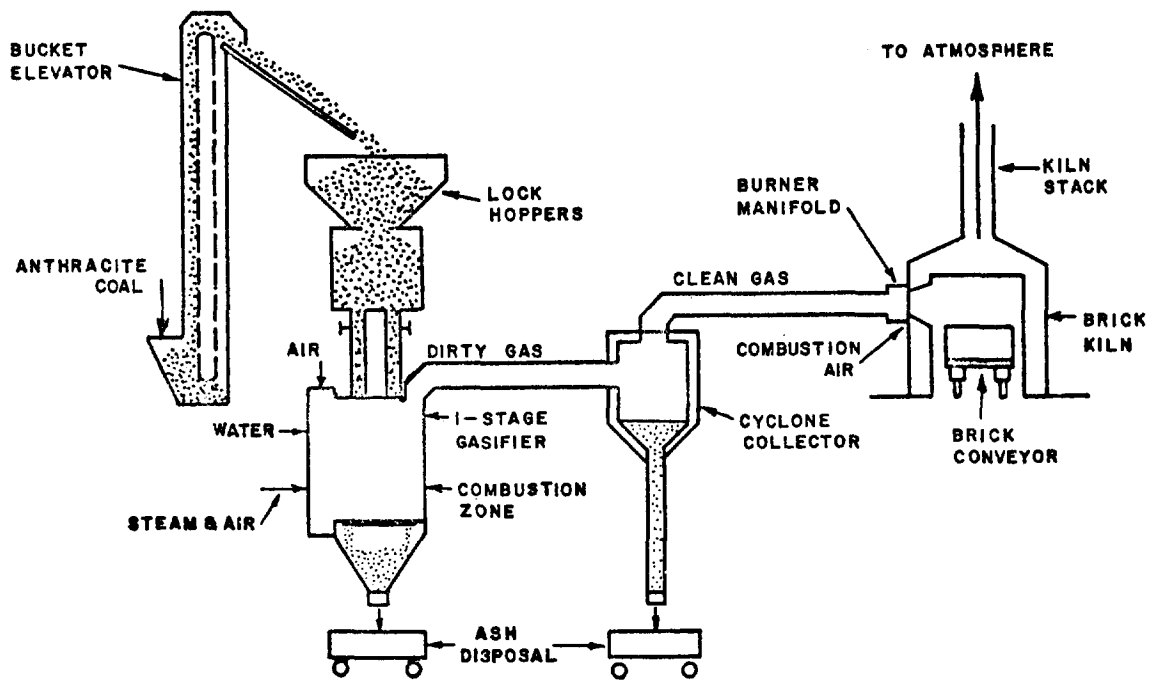
34

Figure III-4
Wellman-Galusha Gasifier, Single Stage
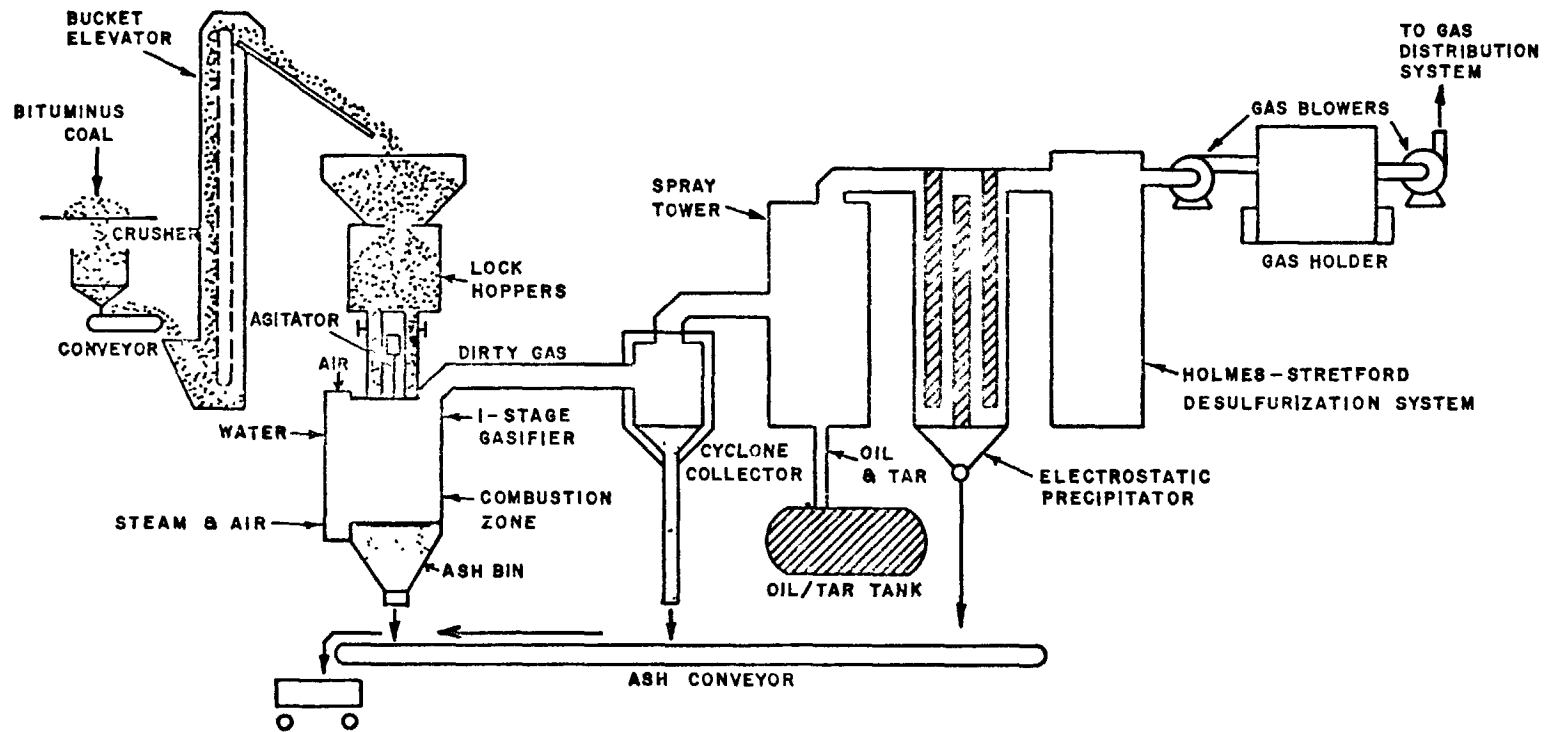
Adapted from Reference 102

Figure III-5

Wellman Galusha Gasifier, Single Stage

Adapted from Reference 102

Occupational health hazards associated with these plants include potential exposure to carbon monoxide, coal dust, ash dust, hot raw gas, nitrogen compounds including ammonia, gas-liquor, trace elements, and sulfur compounds including hydrogen sulfide.

At present, 8 of 23 commercial low-BTU coal gasifiers in the United States use anthracite feedstock, and it is estimated that this ratio of anthracite to bituminous units will not diminish through 1985 [13] . The manpower requirement for these plants is approximately 2.8 man-hours per shift per operating gasifier for units using up to 75 tons/day of coal [14].

(2)   Very-High-Temperature Coal Gasification

Very-high-temperature coal gasification may also eliminate tar production because tar molecules may be destroyed by heat in the reaction zone [18,19,23]. Coal feed (Fig III-6) is ground to 70-200 mesh and is conveyed with nitrogen.

The operating pressure of one high-temperature gasifier is less than one atmosphere[24]. Flame temperature is 1925 C (3497. F), and outlet temperature is approximately 1480 C (2696 F). The coal is fed into the gasifier by twin helical screws and then is fed through the burning nozzle with a combination of steam and oxygen. Some 40-80% of the ash is entrained in the product offgas. The remaining ash flows into the slag-quenching portion of the vessel. After passing through the steam superheater at the top of the gasifier, the product gas is quenched and the solids are removed by water scrubbing. The scrubbing should also eliminate the major portion of volatilized and entrained trace elements [18,24].

After scrubbing, the product gas may or may not be passed through a sulfur recovery unit, depending on its final use and the sulfur content of the coal. For more detailed process information, refer to Chapter XIII.

Occupational health hazards associated with operation of very-high-temperature gasification plants include potential exposures to ammonia, carbon dioxide, carbon monoxide, fire, high-pressure steam, hot raw gas, hydrogen sulfide, and trace elements, as well as coal dust and noise during maintenance. Upstream of the quenching unit, the concentrations of trace elements may be much higher than those in low-temperature processes.

Currently there are no very-high-temperature coal gasification plants in the United States. However, at least one such plant is being designed for installation in Kentucky [25]. It is estimated that by 1985 several such plants may be operating in the United States [13].
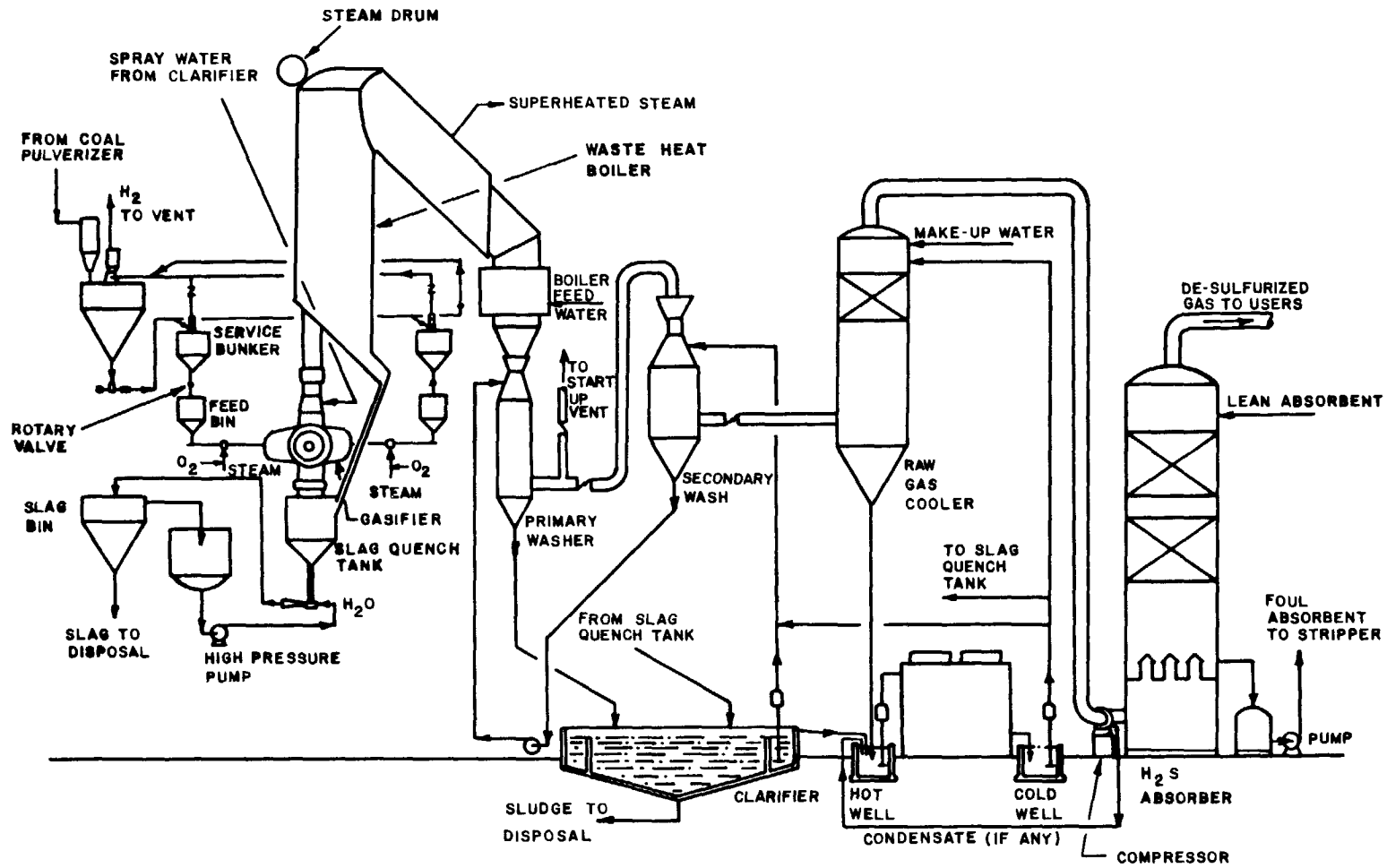
37

Figure III-6

K-T Gasification Process

Adapted from Reference 24

Biological Effects

(a)   Introduction

Several factors complicate the analysis of the health hazards inherent in coal gasification processes. A large number of different toxicants are present in mixtures, varying with coal feedstock and with process type. Also, the effects of exposure may vary from transitory irritation, as in the case of ammonia, to death in a few minutes, as in the case of hydrogen sulfide, to cancer which may develop as the consequence of exposure to polycyclic aromatic hydrocarbons after up to 30 years. Some toxicants such as carbon monoxide are both acutely and chronically toxic.

In addition, exposure intensities may also vary enormously. A given worker may receive a relatively constant low-level exposure for many years plus intermittent high-level exposures. A single toxicant may be inhaled as aerosols and also absorbed through the skin, eg, polycyclic aromatic hydrocarbons.

Furthermore, the exposure received is only partly correlated with job classification. For example, ash-handlers may be performing similar duties both near the gasifiers (high exposure) and remote from the gasifiers (low exposure).

Effects of single chemicals are not discussed below. Though the potential hazards of exposure to such chemicals may be severe, there is very little information available that is specific to exposures in coal gasification plants. In addition, as shown in Table III-10, NIOSH has previously evaluated the biological information and thus assessed the hazard potential to workers of many of the chemicals potentially present in the environments of coal gasification plants. The workplace exposure limits recommended previously by NIOSH should be adhered to in coal gasification plants until such time as new data become available indicating the need for changes in the limits.

(b)   Effects Observed in Humans and Experimental Animals

A medical study of health hazards at a coal liquefaction (hydrogenation) pilot plant in the United States was published in 1960 [26,27]. Except for follow-up of this study, no other reports of studies of hazards at coal gasification or liquefaction plants have been located within the United States or abroad. During the search for such data, representatives of NIOSH discussed with eyewitnesses occupational health programs that existed in some of the German facilities in the 1940's [28,29], and reviewed accident, fire, and explosion reports [30] from some of these facilities. The information so obtained was found to be of limited utility in developing recommended controls for future plants to be built in the United States.

39

(1)   Coal Liquefaction Pilot Plant

Sexton [26] stated that at the time when a large West Virginia coal liquefaction pilot plant went into formal operation in 1952, its management realized that many toxic chemicals would be present, ie, over 200 individual chemicals had been identified in the process streams, including "at least one high boiling polycyclic aromatic chemical...known to be carcinogenic," and that toxicologic studies were therefore undertaken to ascertain "the existence of a problem."

Feedstock for the process included pulverized coal mixed with various carriers or "pasting oils," some of which consisted of blends of purchased coal tar and plant-produced materials, and others which consisted solely of plant-produced materials (see stream 3, below). The resulting pastes were preheated and reacted with hydrogen at high temperatures and pressures, after which unreacted solids were removed and the liquid products were separated in the "heavy products separation unit," into four major streams: (1) A "light oil" stream (boiling point 260 C) which, in turn, was separated, in the "light products separation unit," into four major crude fractions, ie, "stabilizer overhead," from which benzene and a number of other aromatic as well as aliphatic (C5-C7) compounds were refined, an acidic (phenolic) fraction containing phenol, cresols, etc, a basic (nitrogen bases) fraction containing aniline, etc, and a neutral fraction containing such aromatic and aliphatic compounds as toluenes and decane, as well as a phenolic pitch residue (boiling range = 260-380 C); (2) A "middle oil" stream (boiling range = 260-320 C) which was either sold as a semirefined product or recycled; (3) A "heavy oil" stream (boiling point 320 C) that was either recycled as pasting oil or distilled to obtain such polycyclic aromatic hydrocarbons as phenanthrene, chrysene, etc; (4) a "pitch" stream, ie, the nonvolatile residue, produced as a hot, molten material that solidified at 200 C, and which was either sold or diverted for further processing in the pitch polymerization unit.

The potential carcinogenic hazard associated with the process was demonstrated when samples from several process streams and residues were applied to the skins of mice [31]. It was observed that the light and heavy oil products were mildly tumorigenic; the light oil stream and its derivatives were not tumorigenic; and the higher boiling, ie, middle oil, light oil (phenolic pitch) residue, pasting oil (heavy oil stream), and pitch product materials were "highly" carcinogenic. The "degree of carcinogenicity" increased, and the length of the median latent periods decreased, with increasing boiling point. On the basis of these toxicologic findings, the plant medical director, in cooperation with plant safety and production personnel, initiated certain preventive measures.

Medical surveillance findings reported by Sexton [27] included the results of regular examinations of 359 workers over a 5-year period, during which 63 skin abnormalities were seen in 52 men, ie, despite the preventive measures. Of the 60 lesions excised, 55 tumors were examined microscopically by local pathologists, of which 11 were diagnosed as skin cancers, although later review of the sections confirmed only 5 of these as epitheliomas. Of 54 suspected "precancerous" lesions of the skin, 42 were verified as "precursors of skin cancer" by several pathologists.

The diagnoses supported by one or more microscopic evaluations showed 10 men with cutaneous cancer and 42 with precancerous lesions (see Table III-8). All lesions of significance were in men with less than 10 years of exposure, and one subject was found to have 2 skin cancers, one after only 9 months of exposure and one after 11 months of exposure.

TABLE III-8

PRECURSORS OF SKIN CANCER CASES (FINAL ANALYSIS)

Number of Cases	Mean Age (Years)	Length of Exposure (Months)	Diagnosis
3	30	10-74	Pitch acne(a)
1	39	41	Calcifying epithelioma malherbes
1	40	116	Keratoacanthoma
3	33	3.5-42	Chondrodermatitis helicis(a)
17	39	10-116	Keratoses(b)
8	44	17-96	Keratoses
9	40	4-108	Acanthoses and hyperkeratoses

(a) Clinical diagnosis only
(b) Diagnosis by a single pathologist only

Adapted from reference 27

An industrial hygiene study was undertaken [32] to ascertain the extent and nature of sources of airborne and other contamination, and to develop operational and engineering-related corrective measures. Because it seemed unreasonable to attempt

analyses of their air samples for even a small fraction of the some 200 individual chemicals that had been isolated and identified in the process, the investigators decided to select for measurement a carcinogenic "tracer" material. They selected 3,4-benzpyrene (BaP) in that it was readily identifiable and quantifiable, and it was likely to be present in all of the middle and heavy oil fractions, ie, those fractions that had been found [31] to have the greatest carcinogenic potential.

Air samples (Hi-vol) were collected both on the plant premises and in surrounding community areas, and concentrations of BaP were found to range from a few micrograms per 100 cu m (typical of community air in several locales) in nearby residential areas to over 1,000 micrograms (ug) per cu m in the immediate vicinity of pitch treatment and solids removal operations.

The investigators also conducted "fallout" sampling, using horizontal plates to collect the large droplets of oily, fluorescent material that they had discovered upon the "otherwise clean" skins of certain plant employees. By integrating these results with those of the air sampling, they were able to locate a number of specific sources of airborne contamination, including windblown or otherwise disturbed piles of hydrogenation residue (pitch), solids removal equipment blowdown operations, liquid aeration operations, and the steam condensate from a vacuum system ejection jet discharge.

Many modifications were made in operations and in equipment at the plant as a result of this study, including installation of new or improved local exhaust ventilation systems and use of improved pump packing materials and methods. In addition, the use of protective clothing and encouragement of personal hygienic procedures were stressed. Employee preferences were taken into consideration in ordering protective clothing, and procedures were implemented for daily changes of underwear, outer clothing, and socks, plus daily inspections of each employee's hands, face and neck.

A follow-up of Sexton's medical study was reported by Coomes [33], who referred to a 1976 personal communication alleging that no systemic effects or additional cancers had been observed upon reexamination of "all workers who were employed in the early coal-synthetic fuel program" 15 years after their exposures. The number of workers reexamined was not reported; NIOSH followed up the personal communication reported by Coomes and could not determine the number of workers reexamined [34]

According to Weil [35] the skin cancer incidence in the plant was at least 20 times as high as the expected incidence ("normal" = 30-40/100,000/year). Weil also stated that since the end of December, 1958, the workers have been followed, and that, whereas at

first there were 1-2 new cases of skin cancer every year, the incidence is now about 1 new case every 5 years, with no evidence of increases in systemic (including lung) cancers.

A follow-up mortality study was reported by NIOSH in 1977 [36] in which the records from the Sexton study were reviewed. An adjustment in numbers was found necessary because of previous double counting, giving 10 cutaneous cancer cases and 40 cases with skin cancer precursors. All but one of the 50 cases were followed up; their status as of 1977 is given in Table III-9.

TABLE III-9

FOLLOW-UP IN 1977 OF 50 WORKERS WITH SKIN CANCER OR
SKIN-CANCER PRECURSORS REPORTED BY SEXTON IN 1960

	Deaths Other than Cancer	Retired	Still Working	Lost to Follow-up	Ill with Cancer	Total Cases
Confirmed Skin Cancer	2	1	5	1	1 (a)	10
Confirmed Precursor of Skin Cancer	3	13	23	0	1 (b)	40
Total	5	14	28	1	2	50

(a) Lung cancer: Age 60, lifetime heavy smoker
(b) Prostate cancer: Age 77

Adapted from reference 36

The five deaths were all reported as cardiac-related, two with pulmonary involvement; however, none had been autopsied. It was noted that, although the data had not undergone statistical analysis, the results suggested that the group was not at an increased risk of systemic cancer, which was the initial hypothesis that prompted this study.

A significant point that was not referred to in the report 36] is that 6 of the 10 cases of skin cancer were found in maintenance workers. (Job descriptions were not provided for the precursor cases.) It is conjectured that this finding is related to the fact that maintenance workers were likely to have worked in the pilot plant when it was not in operation and thus would have been at low or negligible risk of exposure to carcinogens by inhalation; however, they would have been at exceptionally high risk of exposure by direct skin contact. This group of workers would therefore not be expected to necessarily have exhibited a significantly increased incidence of systemic cancer. The most significant group of workers

for follow-up for systemic cancer would appear to be those identifiable from the industrial hygiene survey [32] as having been exposed to the highest concentrations of airborne BaP. It cannot be determined from the follow-up reports whether any of these were included.

The finding that only skin cancers were observed, except for one heavy smoker who developed lung cancer [36], may have been due to the generally long induction period for lung and other systemic cancers and the lack of adequate follow-up either in the United States or abroad. This finding may be explained with equal plausibility by the possibility that the carcinogenic and tumorigenic fractions, ie, every stream and product except the light oil stream and its derivatives, had a boiling point above 260 C, meaning that their existence as vapors or in other air-suspended forms were probably quite short-lived. This hypothesis is supported by the BaP distribution pattern observed in the industrial hygiene study [32], which showed very high concentrations within about 200 feet of major sources of contamination but concentrations of only a few micrograms per 100 cu m in various plant areas and in surrounding community areas. Therefore, these materials tended not to volatilize, and must have been deposited near the sources of contamination.

No other report has been found of increased skin cancer incidence or other serious health effects in coal gasification or liquefaction plants, despite a thorough literature search and inquiries at coal gasification plants both in the United States and abroad [12,14-16,18-21,37-42]. There is, however, evidence of the presence of potential carcinogenic hazards, eg, a recent examination [42] of a pilot plant by ultraviolet light showed extensive surface contamination, visible by its bright fluorescence; the contaminant very likely included carcinogenic hydrocarbons.

(2)   Other Related Industries

Gasworks, where coal is heated in retorts for the primary purpose of producing flammable gas, or coke ovens, where the coke is the primary product, have provided much more evidence of associated health effects than have coal gasification plants, and some of it is quantitative. It should be noted, however, that this evidence does not imply comparable degrees of hazard in coal gasification plants, gasworks, and coking plants. Gasworks and coking plants heat coal with minimal containment of the volatiles. Gasification plants typically operate at high pressure as well as high temperature, and therefore containment is essential under normal operating conditions.

Epidemiologic studies [43-46] of gasworkers and coke oven workers have provided evidence of work-associated cancers. The nature of the toxicants and their concentrations within the various process streams at future coal gasification plants are expected to be generally similar to those at gasworks and coke plants, although proper design and work practices can substantially reduce the quantitative aspects of exposures in coal gasification plants.

Mortality studies of gasworkers, coke-oven workers, and workers exposed to coal tar, coal tar pitch, creosote, and the emissions from coke ovens have been reviewed by NIOSH in preparation of the coke oven emissions and the coal tar products criteria documents [47,48]. The latter document also contains reviews of approximately 20 studies of morbidity, primarily of the skin and including eye effects, caused by coal tar products. From the epidemiologic and experimental toxicologic evidence on coke oven emissions, coal tar, coal tar pitch, and creosote, NIOSH concluded that coke oven emissions and these specific coal tar products are carcinogenic and can increase the risk of lung and skin cancer in workers, and perhaps cancer at other sites [48].

(c)   Summary of Hazardous Agents

A tabular summary is presented in Table III-10 of the regulatory status of various hazardous agents that are potentially present in coal gasification plants, together with brief notes on significant health effects.

Most of Table III-10 is based on NIOSH criteria documents. For chemical substances not covered by NIOSH recommended standards, the current Federal occupational exposure standard is listed [49], and data on significant health effects have been derived from reference [50]. For substances covered by neither NIOSH recommendations nor OSHA standards, the table entry is limited to a notation on health effects based on information contained in Industrial Hygiene and Toxicology [51].

(d) Special Hazards

Exposure to several constituents of the coal gasification process and waste streams could cause severe acute effects if a plant malfunction or catastrophic accident resulted in massive leakage or if significant exposures were encountered on entering confined spaces. The specific toxicants of significance are hydrogen sulfide and carbon monoxide. In addition, there are simple asphyxiants, eg nitrogen, which can cause harm to exposed employees in confined spaces.

(1)   Hydrogen Sulfide

Hydrogen sulfide is found in all process gas streams upstream of the gas purification systems. Process lines between the gas purification unit and the sulfur recovery systems and in the sulfur recovery systems themselves may contain up to 20% or more hydrogen sulfide. Hydrogen sulfide will also be absorbed in the gas-liquors or quench waters and may be evolved over a period of time after the gas-liquor is depressurized.

45

TABLE III-10

SUMMARY OF HEALTH EFFECTS OF AGENTS POTENTIALLY PRESENT
IN COAL GASIFICATION PLANTS

Agent	Current Federal Occupational Exposure Standard[a]	NIOSH Recommendation for Permissible Exposure Limit[b]	Health Effects[b]	Reference
Ammonia	50 ppm (34.8 mg/cu m)	50 ppm ceiling (34.8 mg/cu m) (5 min)	Airway irritation	52
Arsenic, inorganic	0.5 mg/cu m	2 (u)g/cu m ceiling (15 min)	Dermatitis, lung and lymphatic cancer	53
Benzene	1 ppm (3.2 mg/cu m); 5 ppm maximum ceiling (15 min)	1 ppm ceiling (3.2 mg/cu m) (60 min)	Blood changes including leukemia	54
Beryllium	2 (u)g/cu m; 5 (u)g/cu m acceptable ceiling; 25 (u)g/cu m maximum ceiling (30 min)	0.5 (u)g/cu m (130 min)	Lung cancer; berylliosis	55
Cadmium	0.1 mg/cu m; fumes = 0.3 mg/cu m ceiling; (erroneously published as 3 mg/cu m); 0.2 mg/cu m; dust = 0.6 mg/cu m ceiling	40 (u)g/cu m; 200 (u)g/cu m ceiling (15 min)	Lung and kidney	56
Carbon dioxide	5,000 ppm (9,000 mg/cu m)	10,000 ppm (18,000 mg/cu m); 30,000-ppm ceiling (54,000 mg/cu m) (10 min)	Respiratory	57
Carbon monoxide	50 ppm (55 mg/cu m)	35 ppm (40 mg/cu m); 200 ppm ceiling (229 mg/cu m)	Respiratory	58
Carbonyl sulfide	None	None	Similar to hydrogen sulfide, probably less hazardous	51
Chromium (VI)	100 (u)g/10 cu m ceiling	1 (u)g/cu m for carcinogenic Cr(VI); 25 (u)g/cu m for other chromium; 50 (u)g/cu m ceiling (15 min)	Lung cancer, skin ulcers, lung irritation	59
Coal dust	2.4 mg/cu m, if respirable dust fraction less than 5% SiO2; if respirable fraction is more than 5% SiO2, respirable mass formula is (10 mg/cu m)/(% SiO2 + 2)	None	Lung	50

46

Table III-10 cont'd

Agent	Current Federal Occupational Exposure Standard[a]	NIOSH Recommendation for Permissible Exposure Limit[b]	Health Effects[b]	Reference
Coal tar products	0.2 mg/cu m (for benzene-soluble fraction of tar pitch volatiles)	0.1 mg/cu m (cyclohexane-extractable fraction of coal tar, coal tar pitch, creosote or mixtures)	Lung and skin cancer	48
Coke-oven emissions	150 (u)g/cu m	Work practices to minimize exposure to emissions	Lung cancer	47
Cresol	5 ppm (22 mg/cu m) (skin)	10 mg/cu m	Skin, liver, kidney, and pancreas	60
Cyanide, hydrogen and cyanide salts	10 ppm (alkali cyanides); 5 mg CN/cu m (cyanides)	5 mg CN/cu m ceiling (4.7 ppm) (10 min)	Thyroid, blood, respiratory	61
Fluorides, inorganic	2.5 mg/cu m	2.5 mg/cu m	Kidney and bone	62
Hot environments	None	Variable (sliding scale)	Heat stress	63
Hydrogen chloride	5 ppm (7 mg/cu m)	None	Corrosive to eyes, skin, and membranes. Respiratory irritant	50
Hydrogen sulfide	20 ppm acceptable ceiling; 50-ppm maximum ceiling (10 min)	15 mg/cu m ceiling (approximately 10 ppm) (10 min)	Irritation; severe acute nervous and respiratory systems	64
Isopropyl ether	500 ppm (2,100 mg/cu m)	None	Anesthesia, irritation to skin and eyes	65
Lead, inorganic	0.2 mg/cu m	Less than 100 (u)g/cu m	Kidney, blood and nervous system	66
Manganese	5 mg/cu m ceiling	None	Deposited in liver, spleen, and certain nerve cells of the brain and spinal cord	50
Mercury, inorganic	0.1 mg/cu m ceiling	0.05 mg/cu m	Central nervous system and behavioral	67
Methanol	200 ppm (260 mg/cu m)	200 ppm (262 mg/cu m); 800 ppm (1,048 mg/cu m) ceiling (15 min)	Blindness; metabolic acidosis	68

47

Table III-10 cont'd

Agent	Current Federal Occupational Exposure Standard[a]	NIOSH Recommendation for Permissible Exposure Limit[b]	Health Effects[b]	Reference
Nickel, inorganic, and compounds	1 mg/cu m (metal and soluble compounds as Ni)	15 (u)g Ni/cu m	Skin; lung and nasal cancer	69
Nickel carbonyl	0.001 ppm (0.007 mg/cu m)	0.001 ppm (0.007 mg/cu m)	Lung, heart, liver and spleen carcinogen	70
Nitrogen oxides	NO2: 5 ppm (9 mg/cu m) NO: 25 ppm (30 mg/cu m)	NO2: 1 ppm (1.8 mg/cu m) ceiling (15 min); NO: 25 ppm (30 mg/cu m)	Airway irritation Blood	71
Noise	90 dBA	85 dBA (8-hour TWA); 115 dBA ceiling	Hearing damage	72 dBA???
Phenol	5 ppm (skin)	20 mg/cu m (5.2 ppm); 60 mg/cu m (15.6 ppm) ceiling (15 min)	Skin, eye, central nervous system, liver, and kidney	73
Selenium	0.2 mg/cu m compounds as Se	None	Irritation of the mucous membranes of the nose, eyes, and upper respiratory tract	50
Silica, crystalline	(250)/(% SiO2 + 5) in mppcf, or (10 mg/cu m)/(% SiO2 + 2) respirable quartz	50 (u)g/cu m respirable free silica	Chronic lung disease (silicosis)	74
Sulfur dioxide	5 ppm (13 mg/cu m)	0.5 ppm (1.3 mg/cu m)	Respiratory	75
Toluene	200 ppm; 300 ppm acceptable ceiling; 500 ppm maximum peak above acceptable ceiling (10 min)	100 ppm (376 mg/cu m); 200 ppm (750 mg/cu m) ceiling (10 min)	Central nervous system depressant	76
Vanadium	Vanadium pentoxide: dust = 0.5 mg/cu m ceiling; fume = 0.1 mg/cu m ceiling	Vanadium compounds: 0.05 mg/cu m ceiling (15 min)	Eye, skin, and lung	77
Xylene	100 ppm (435 mg/cu m)	100 ppm (434 mg/ cu m); 200 ppm (868 mg/cu m) ceiling (10 min)	Central nervous system depressant; airway irritation	78

(a) Adapted from reference 48; up to 8-hour time-weighted average unless otherwise noted
(b) Adapted from reference noted in final column of Table III-10; up to a 10-hour time-weighted average unless otherwise noted

48

Brief exposures to high concentrations of hydrogen sulfide may lead to rapid unconsciousness, respiratory paralysis, and death [64]. Exposure to hydrogen sulfide at concentrations above 140 mg/cu m rapidly abolishes the sense of smell, which thus cannot be relied on to warn against high concentrations [64]. In cases of hydrogen sulfide poisoning, immediate first aid can be lifesaving.

(2)   Carbon Monoxide

The dry raw product gas from the gasifier contains as much as 20% carbon monoxide. Gas purification increases the carbon monoxide concentration in the gas stream by removing carbon dioxide and hydrogen sulfide. All gas streams except the final product stream contain potentially hazardous concentrations of carbon monoxide. Carbon monoxide may be absorbed in water or tar streams that come in contact with the process gas, and be released over a period of time when these liquors are depressurized to ambient pressure.

Acute carbon monoxide poisoning can result in dizziness, drowsiness and collapse [58]. Recommended first aid if breathing has stopped is artificial respiration, and the administration of oxygen. Behavioral impairment is a possible safety hazard at lower exposure levels [58]. In cases of carbon monoxide poisoning, immediate first aid can be lifesaving.

(3)   Simple Asphyxiants

Each of the three gas-related deaths reported at coal gasification plants visited by NIOSH resulted from simple asphyxiation following the use of inert gas for vessel purging [12,18,20]. The simple asphyxiants that are present are usually nitrogen, carbon dioxide, and methane.

The oxygen plant is the largest source of nitrogen in high- and medium-BTU coal gasification plants. Nitrogen is used in the gasification process only as a purge gas. Relatively pure carbon dioxide is produced in the gas purification system; it may be piped directly to a stack, it may be used as a purge gas (eg, in coal lockhoppers), or it may be processed for commercial use (eg, as solid carbon dioxide). Methane and product gas are less often hazards as simple asphyxiants, partly because of the vigilance their other hazards (eg, fire, explosion) require.

(4)   Burns

The presence of hot, pressurized gas and liquid streams creates a significant potential for burns in coal gasification plants. Employees should be trained in emergency aid procedures for burns.

(e)   Conclusions

From a review of the available epidemiologic and toxicologic evidence, including that previously published, NIOSH concludes that there are insufficient data to support the development of new limits for occupational exposures to the variety of chemical and physical agents that are present in the environment of coal gasification plants. NIOSH recognizes the probability that exposures are likely to involve complex mixtures of toxicants. Currently, however, there is no reliable way of estimating overall response for given levels of exposure, because such exposures may or may not be simply additive and the extent of possible interactive effects is not predictable. To guard against possible synergistic effects, it is particularly important that exposures be minimized by application of the best available engineering control technology and work practices.