

IV. WORKPLACE MONITORING

Employees of coal gasification plants may be exposed, at least occasionally, to the physical and chemical agents discussed in this document. Routine employee interaction with equipment during operation and maintenance may present exposure situations that are not readily defined. Real-time monitoring of all work areas for all anticipated hazards, though desirable, is not technologically feasible at present.

Methods for the sampling and analysis of a variety of these agents have been described in previous NIOSH criteria documents. These documents have discussed workplace monitoring specifically for the agent(s) of interest.

To measure worker exposure to potentially carcinogenic polycyclic aromatic hydrocarbons (PAH's) in coal gasification plants, a monitoring program is required. In addition, leak testing is necessary to locate sources of emissions. Methods are needed to analyze large numbers of samples rapidly at a reasonable cost. Such methods should have high sensitivity because the compounds are often present only in trace amounts. They should also be very selective because compounds that differ only slightly in chemical structure may vary considerably in the hazard they present [79].

The open nature of coal gasification plants presents problems in obtaining representative environmental samples. The difficulties are in choosing monitoring sites that will provide an accurate reflection of the hazard potential. Some aspects of this problem have been dealt with in a NIOSH document that presents recommended procedures for air-contaminant sampling [80].

The Indicator Monitoring Concept

The ideal program for worker protection would utilize continuous monitoring for all potentially hazardous chemical agents expected to be present in the coal gasification plant. Due to the large number of these agents, however, such monitoring would be extremely expensive and time-consuming. Additionally, technology is not currently available for such monitoring.

An indirect, theoretical method for real-time monitoring has been proposed by NIOSH specifically for coal gasification pilot plants [79] and is applicable to commercial-scale facilities as well. The proposed monitoring scheme uses a single indicator chemical as an index of exposure to an array of other chemicals present in the product streams of specific unit processes. Leading candidates for use as indicators are carbon monoxide (at the

gasification, quenching, and shift conversion units), hydrogen sulfide (at the gas purification and sulfur removal units), and methane (at the methanation unit). Ideally, an indicator should (1) be easily monitored in real time by commercially available personal or remote samplers, (2) be suitable for analysis where resources and technical skills are limited, (3) not be present in ambient air at high or widely fluctuating concentrations, (4) be measurable without interference from other substances in the process stream or ambient air, and (5) be a regulated agent so that the measurements serve the two purposes of quantitative sampling for compliance purposes and indicator monitoring.

The rationale for adopting carbon monoxide, as an example, as an indicator gas for monitoring in designated confined areas, as a basis for an alarm mechanism in selected areas, and as a potential index of worker exposure to an array of toxic chemicals can be summarized as follows. Based on material-balance data for unit processes in a US coal gasification pilot plant [79], the concentration of carbon monoxide is higher than that of other toxic gases and vapors (eg, ammonia, hydrogen sulfide, coal tar volatiles, and trace metals) in the gas stream. Monitoring and alarm systems are currently available that can detect carbon monoxide at concentrations as low as 0.2 mg/cu m. It is assumed that the ratio of carbon monoxide to other constituents is the same for emissions as for the process stream; thus, the approximate concentrations of these constituents in any emissions can be calculated from measurements of the concentration of carbon monoxide. It is further assumed that all gases and vapors present in any fugitive emission will behave according to the ideal gas laws. (This is not the case for tar vapors and particulates. For these and other constituents whose behavior cannot reasonably be assumed to be ideal, specific analyses are required to verify the carbon monoxide indicator model.)

Taking into account these assumptions and inherent limitations, a procedure is proposed for determining the ratio of carbon monoxide to any other gas-stream component based on data from stream sample analysis or a materials balance for each unit process. To be reliable, the ratio of indicator to toxic substance must be determined empirically in each plant for each type of coal feedstock.

The following examples are based on data on gas stream composition [81,82]. Tables IV-1 and IV-2 present the concentration ratios of various components to carbon monoxide in the gas stream, in this instance at the gasifier outlet. The ratio of any stream component to the carbon monoxide indicator is calculated on a volume percent basis. Table IV-1 presents data for major stream components, and Table IV-2 presents data for trace stream components.

TABLE IV-1
RATIO OF STREAM COMPONENTS TO CARBON MONOXIDE

Stream Component	Concentration (vol %)	Ratio of Component to Carbon Monoxide
Ammonia	0.8	0.15
Carbon dioxide	18.9	3.63
Carbon monoxide	5.2	1.0
Ethane	0.4	0.08
Hydrogen	12.7	2.44
Hydrogen sulfide	0.4	0.08
Methane	12.4	2.39
Nitrogen	0.9	0.17
Heavy oil (a)	0.04	0.008
Light oil (a)	0.01	0.002
Middle oil (a)	0.05	0.010
Coal fines	(b)	(b)
Residue	(b)	(b)
Steam	48.2	9.0

(a) Estimated average molecular weights: Light oil, 150; middle oil, 190; heavy oil, 230.

(b) Remain as solids in the gasifier and are not used in volume calculations.

TABLE IV-2

RATIO OF TRACE COMPONENTS TO CARBON MONOXIDE

Stream Component (trace)	Concentration (ppm)	Ratio of Component to Carbon Monoxide
Carbon disulfide	10	0.0001
Carbon monoxide	79,000	1.0
Carbonyl sulfide	150	0.002
Dimethyl thiophene	10	0.0001
Methyl mercaptan	60	0.0008
Methyl thiophene	10	0.0001
Thiophene	31	0.0004
Arsenic	0.50	0.000006
Cadmium	0.03	0.0000004
Lead	0.13	0.000002
Mercury	0.01	0.0000001
Nickel	0.30	0.000004
Data from references 81,82		

Table IV-3 illustrates the calculated carbon monoxide concentrations that, when detected by a workplace environmental sampler, would indicate the presence of various other gas-stream components at 50% of their permissible exposure limits. This indicates the "action level" [83] at which there is a need to initiate sampling for the specific gas-stream component. Following the table are explanations of the calculations and examples of how to use the table.

The "probable minimum detectable level" in Table IV-3 is calculated for each stream component by multiplying the "component to CO ratio" by the background level of CO. In Table IV-3, a background level of 5.7 mg/cu m (5 ppm) is used, as this is assumed to be the maximum average ambient carbon monoxide concentration due to nonplant sources. The "probable minimum detectable level" is also expressed as a percentage of the permissible exposure limit. This value gives the sensitivity of CO indicator monitoring for the specific component. For example, the margin of error for CO indicator monitoring for ammonia is 2.47% of the permissible exposure limit for ammonia. The margin of error for monitoring for

TABLE IV-3

CALCULATED CARBON MONOXIDE (CO) CONCENTRATIONS FOR ACTION LEVELS OF STREAM COMPONENTS

Stream Component	Permissible Exposure Limits (NIOSH Recommended Standard Unless Otherwise Noted)	Component to CO Ratio (from Tables IV-1 and IV-2)	Probable Minimum Detectable Level (Based on Background Concentrations of CO)		CO Level Required (Indicates Action Level of Stream Component)
	mg/cu m		mg/cu m	% PEL	mg/cu m
Ammonia	34.8	0.15	0.86	2.47	116
Carbon dioxide	9,000 (a)	3.63	20.7	0.23	1,240
Carbon disulfide	3.0	0.0001	0.0006	0.002	15,000
Carbon monoxide	40	1.00	5.7	14.2	20
Carbonyl sulfide	None	0.002	0.01	None	None
Ethane	None	0.08	0.46	None	None
Hydrogen	None	2.44	13.9	None	None
Hydrogen sulfide	15	0.08	0.46	3.07	94
Methane	None	2.39	13.6	None	None
Dimethyl thiophene	None	0.0001	0.0006	None	None
Methyl mercaptan	20 (a)	0.0008	0.005	0.025	12,500
Methyl thiophene	None	0.0001	0.0006	None	None
Thiophene	None	0.0004	0.002	None	None
Arsenic	0.002	0.000006	0.000034	1.7	167
Cadmium	0.04	0.0000004	0.000002	0.005	50,000
Lead	0.10	0.000002	0.000011	0.011	25,000
Mercury	0.05	0.0000001	0.0000006	0.0012	250,000
Nickel	0.015	0.000004	0.000023	0.15	1,875
Heavy oil (b)	0.1	0.008	0.046	46.0	6.25
Light oil (c)	375.0	0.002	0.011	0.003	93,750

(a) Current Federal Occupational Standard.

(b) Calculated as cyclohexane-soluble fraction of total particulate matter, molecular weight 230.

(c) Calculated as toluene.

heavy oil is 46% of the limit. Thus, the insensitivity of CO monitoring due to background levels of CO is of little consequence when indicating ammonia, but is severe enough to preclude indicator monitoring for heavy oil.

The "CO level required" in Table IV-3 is calculated for each stream component as follows: (permissible exposure limit) divided by (component to CO ratio) x (1/2). This gives the calculated carbon monoxide concentration that would indicate the concentration of stream components to be 50% of their permissible exposure limit. This indicates the "action level" at which there is a need to initiate sampling for the specific gas-stream component. For example, when a CO monitor at the location where these data were taken (gasifier outlet) reads 116 mg/cu m, the action level for ammonia has been reached.

In Table IV-3, the permissible exposure limit for the heavy oil fraction is assumed to be the same as the current NIOSH recommended standard for coal tar products, as determined by the cyclohexane-soluble fraction of the total particulate matter. Although this assumption overestimates the hazard by grouping all heavy oils into the same toxicity rating as coal tar products, it is used for the purposes of this example because no data are available on the amount of carcinogenic substances in the heavy oil fraction.

By using this method at each unit process, the concentration of any agent in the emission can be estimated from the carbon monoxide concentration.

A significant consideration is that as the quality of the gas improves from operation to operation, the carbon monoxide concentration decreases. This decrease is paralleled by a reduction in other toxic components, particularly PAH's [79]. The carbon monoxide indicator model is most sensitive in detecting gas-stream emissions at the unit processes where the hazard associated with leaks is most severe [79].

Real-time monitoring for carbon monoxide in enclosed areas or areas subject to leaks or emissions can serve, in theory, as an indicator for substances that cannot be readily analyzed in real time or are difficult or impossible to analyze at prevailing concentrations. The utility of carbon monoxide as an index of worker exposure or of plant performance in terms of toxic emissions remains to be determined. This model has been evaluated only in theory; actual evidence of reliability must await the results of ongoing and proposed studies in plants.

The following limitations should be noted with regard to the indicator monitoring concept:

- * It is an unproven method that has yet to be validated in an operational facility.
- * It cannot provide an absolute quantification of employee exposure to agents other than carbon monoxide.
- * It provides a hazard index only for gas and vapor phase contaminants.
- * It does not provide an index of exposure to particulates or toxic agents adsorbed on particulate matter.
- * It consistently overestimates employee exposure to vapor-phase tars.
- * It requires stable process-stream composition.

In summary, NIOSH does not propose that the indicator concept be used for compliance purposes. It is proposed as a tool to indicate possible noncompliance situations so that remedial action can be taken. Monitoring for a single substance should provide for more rapid identification of process leaks and noncompliance situations than would be possible by conventional monitoring procedures.

Once procedures are validated for continuous monitoring of the indicator substances, full-time monitoring for the entire array of chemical agents need not be initiated until the action level has been indicated.

Carbon monoxide has been presented as an example of an appropriate indicator. However, the choice of the indicator depends on the specific process and the specific coal. Other possible indicator substances, eg hydrogen sulfide and methane, may be appropriate for specific unit processes such as sulfur removal and methanation.

Polycyclic Aromatic Hydrocarbons (PAH's)

As noted above, one of the limitations of indicator monitoring is that it cannot provide an absolute quantification of exposure to specific agents other than the indicator substance. This is critical with respect to PAH exposures, which should not exceed the lowest concentration that can be reliably detected. The recommended methods for workplace monitoring for PAH's are described in Chapter XV.

Surface Contamination

If equipment and other surfaces are contaminated with condensed polycyclic hydrocarbons not visible to the unaided eye, examination of these surfaces with a hand-held UV lamp will render the residue visible by fluorescence. A UV scan of workers' clothing and equipment will indicate whether the risk of contact contamination is significant. This nonspecific test does not, however, indicate whether the compounds causing the fluorescence are carcinogenic nor whether nonfluorescent carcinogens are present. Nonetheless, the general rationale is that, since most PAH compounds fluoresce and since many members of the class are known carcinogens, this test gives an indication of the presence of suspect carcinogenic agents. A portable, battery-operated UV lamp (253.7 nm) could be used in a fabric-skirted box to permit surface viewing in a brightly lighted environment. Problems due to individual variations in dark adaptation and color sensitivity could be avoided by using a photovoltaic detector and meter or recorder.

V. ENGINEERING CONTROLS

General Engineering Control Objectives

Engineering control concepts that are generally applicable to all coal gasification processes, regardless of operating temperature and pressure, size, nature, and concentration of toxicants, etc, are discussed in this chapter.

Most health and safety hazards will arise during maintenance work or because of a failure in any one of a large number of pieces of equipment or process lines. Therefore, to reduce the potential for exposure, all possible failure modes during normal operation and during maintenance must be anticipated, examined, rated for risk factors (frequency and severity), and controlled to the greatest extent possible.

One way of approaching this formidable task is fault-tree system analysis and failure-mode evaluation. The requirement of a system safety analysis imposes a disciplined and inclusive approach to safety and health considerations. The analysis should include, but not be limited to, procedures for operational start-up, normal onstream operation, shutdown, and emergencies. This technique should be used before and during plant construction, throughout the life of the plant, and whenever changes in the process are contemplated. Fault-tree analysis has been used in coal gasification pilot plants [84] and is currently used by the world's oldest and largest plant to provide advice to engineers working on the design and construction of new facilities [12].

System safety analyses afford the opportunity for all responsible departments--including process engineering, mechanical engineering, safety engineering, maintenance, operations, and plant management--to become involved in decisions that will affect employee protection.

A very significant source of worker exposure in all coal gasification plants will likely be periodic, unpredictable leaks from process lines, vessels, flanges, valves, pumps, and other equipment. In pipes containing toxicants, welded joints should be used wherever possible. However, certain equipment must be readily accessible because maintenance is frequent, and flange connections are certainly necessary. Flat-face flanges have been reported to minimize leaks if the connections are maintained and inspected frequently and if the proper gasketing material is used [12,14]. Grooved, concentric, or other nonflat mating surfaces may reduce the frequency and severity of leaks by presenting a more circuitous and difficult path for gas escape. In some instances, increasing the

number of flange bolts may improve performance. Retightening the flange bolts before and after the piping has reached operating temperature is another method of preventing leaks [9,85]. Periodic leak testing is necessary for all flange connections in pipes containing toxic materials.

It is important that leaks be located while small. This could be accomplished by banding the flanges, leaving only a small bleed connector to which the gas sampling apparatus could be attached. This allows small, otherwise nondetectable leaks to be located and repaired before the occurrence of workplace contamination. However, bleed connectors should be large enough to permit safe depressurization without blockage should a significant leak occur and go undetected. Thus, the connectors should be directed away from work areas or other equipment. In high-pressure gasification systems, leaks can usually be detected by the noise produced by the high-velocity escaping gas [12].

Proper selection of pump, compressor, and shaft seals should minimize worker exposure by reducing the frequency of leaks. Site visits and discussions with companies involved in coal gasification [9,12,18,37] have led NIOSH to the following conclusions that: (1) pressurized, double mechanical seals are not necessarily effective for gas streams containing entrained solids or liquids; and (2) the consequences of failure are more severe for pressurized double mechanical seals than for pressurized stuffing boxes. The increased severity would include both higher exposure to workers and relatively greater damage to equipment due to loss of pressurizing liquid and massive erosion. Thus, mechanical seals are not recommended for all conditions and process services. Process lines carrying liquids or gases should be designed to prevent erosion, leaks, and blockages. Design considerations should include adequate dimensions (both diameter and wall thickness), long-radius elbows, and minimization of stream velocities (above minimum transport velocities if the stream carries solids). Where blockages cannot be prevented by other means, mechanical means for line clearing should be installed. (Elbows that continue to experience erosion should be reinforced with welded metal sleeves with single-bleed nipples to allow early leak detection.)

Ultrasonic inspection of process lines is recommended. In most petrochemical or related facilities, including coal gasification plants, two types of leaks occur: those that disturb the process and those that do not. Recommended health standards should not need to address the former--process continuity should dictate prompt corrective action. It is the latter category, leaks that do not adversely affect plant operation, that is critically important in reducing workplace contamination (particularly in regard to chronic low-level employee exposure). The leak-detection program and other procedures specified in the recommended standard provide the means

for locating low-level liquid or gaseous leaks. It is necessary to discourage the tolerance of small leaks of toxic materials, even though they do not affect plant operations. It is not reasonable to expect a plant to be shut down for the repair of a small leak from a pump or a valve. Conversely, considering the toxicity of many coal gasification products and the importance of maintaining employee health, it is not reasonable to allow leakage of toxic materials to continue for extended periods of time.

Conceivable solutions to the problem of leaks of toxic materials include the use of spared equipment, portable ventilation or ejector systems for small gas leaks, portable sumps (or eductors connected to closed sumps) for liquid leaks, and area isolation (restricted entry and provision of suitable protective equipment). To facilitate cleanup operations after a spill of toxic materials, adequate equipment and material (pumps, absorbent material, etc) should be readily available. To insure that process spills will be contained, process areas should be paved and appropriately curbed.

Process-area drains and sumps from which flammable or toxic vapors may be emitted should be covered and sealed to the extent possible to minimize employee exposure. Ventilation should be utilized to remove inflammable gases and vapors before explosive concentrations can build up in closed areas.

Process vessels containing toxic liquids should be designed to prevent overflow. Double block and bleed connections for process equipment to which access is needed are essential additions to line valves. Spectacle-type blanks, blinds, spool pieces, or the equivalent may be necessary to insure complete isolation before a vessel is breached and entered. Wherever possible, residual liquid in the isolated section should be drained into a closed treatment system. Gas lines must be thoroughly purged (also into a closed system and not directly to workplace air).

In closed process areas, adequate general ventilation should be provided to prevent hazardous buildups of toxic gases, vapors, or aerosols. The plant design should minimize recessed or low-lying areas in which toxic gases and vapors could accumulate. If such areas are unavoidable, they should be provided with adequate ventilation, even those that are open to the atmosphere.

Although the control measures discussed above should minimize persistent leaks, it may be determined in time that certain process points continue as sources of workplace contamination. If repeated efforts at process controls prove unsuccessful, local ventilation should be provided. An example of the applicability of local ventilation is an ejector system to exhaust the shrouded upper closure on the coal lockhoppers [9]. If the source of contamination is not continuous, it may be efficient to install a local ventilation system that can be damped or "deadheaded" when not needed.

As in any large manufacturing facility handling large quantities of toxic, flammable, or explosive materials, sensitive process monitoring should be conducted to warn of any impending danger and to allow corrective action to be taken to prevent a process upset or, more importantly, to allow employees to evacuate anticipated dangerous areas.

Pressurized vessels and tanks containing volatile liquids should be equipped with safety relief valves to prevent dangerous pressure buildups. The relief valves should be so located or designed that they will not become blocked with tars or other viscous materials. Where blockage could be a problem, redundant safety systems should be installed (eg, a rupture disc, and a pressure relief valve). If the vessels contain toxic materials, the relief valves should be piped into some type of emergency vent and flared to prevent workplace contamination. Furthermore, storage tanks containing hazardous materials should be located in diked areas capable of holding the maximum volume of the tanks. All tanks and other equipment containing flammable materials should be electrically grounded.

All flares should have a pilot flame equipped with a failure alarm. This control will reduce the potential for workplace contamination with combustible gases and vapors.

Process equipment or lines hot enough to cause burns on contact or to cause heat stress should be isolated or insulated where necessary. An exception would be lines for which safety considerations, such as the need to identify hot spots, preclude the use of insulation. Such lines might be sufficiently isolated by expanded metal mesh guards, heat shielding, barriers, or increased air movement.

Control rooms, eating and rest areas, and process areas in which employees will spend significant amounts of time or may seek refuge during gas leaks or other emergencies should be designed to exclude contaminated air.

Noise can present significant chronic and acute health hazards to coal gasification workers unless adequate controls are integrated into plant design and unless such controls are satisfactorily maintained and strictly enforced.

It is necessary to control noise from compressors, pumps, and valves. It may be assumed that in any plant where steam is used there will also be steam leaks. Such leaks are significant sources of high levels of noise.

Process equipment that contributes to excessive noise exposures should be fitted with noise abatement controls and/or acoustically enclosed or isolated so that employee exposure does not exceed 85 dBA calculated as an 8-hour time-weighted average [72]. Expansion valves and ventilation blower inlets and outlets should be provided with appropriate mufflers. Steam lines (particularly high-pressure lines) must be designed to minimize leaks. Air compressors, particularly those in the oxygen plant, should be acoustically isolated in a separate area.

Specific Engineering Control Applications

(a) High-BTU Gasification

This section presents, on a unit-process basis, specific engineering control recommendations for high-BTU coal gasification plants. The specific hazards of each unit process are discussed in Chapter III. The recommended controls do not include all of the safety and health control measures necessary in such complex plants, and the recommendations may not be applicable to all unit processes. More efficient and effective control technologies very likely will become available as the commercial coal gasification industry develops in the United States. It should also be noted that not all unit processes are included in these discussions; in particular, ancillary operations that are not unique to coal gasification are omitted.

(1) Coal Storage and Transfer

The principal occupational hazards associated with coal handling (excluding mining) result from chronic dust inhalation, fire, and explosions. Although the degree and probability of these hazards vary in a coal-specific manner, control measures can be considered generally. Environmental problems such as leaching and water runoff can be significant but are beyond the scope of this document.

Coal may be stored in outdoor piles, closed bins, or silos. Surface fires and dust dispersion may be significant problems with outdoor piles. These potential hazards may be minimized by periodic surface wetting, compacting, and maintenance of the pile at a proper angle of repose. It has been suggested [9] that "dead" storage piles be compacted in 1-foot layers (compaction reduces contact with air and the resulting oxidation). The safest handling procedure, if consistent with other operational constraints, would be minimization of coal-storage retention time.

When such equipment as front-end loaders is used to handle coal before storage and preparation, significant amounts of dust will be generated. Unless the coal is kept thoroughly moistened (the only effective dust-control method), the cabs of all loading equipment, including continuous wheel excavator loaders and front-end loaders, should be enclosed and provided with filtered air supplies.

Occupational hazards in coal transfer operations are similar to those encountered in coal storage, including dust generation, fire, and explosions. Since a large amount of coal dust becomes airborne at conveyor transfer points, the number of transfer points should be minimized to the extent possible. Where transfer points cannot be avoided, water sprays and/or local ventilation should be used [9,12]. Two points deserve consideration: (1) a wet scrubbing system appears to be preferable for dust removal because of the potential for explosion in baghouse collectors and (2) the ventilation system must be designed for a transport velocity high enough to prevent settling of dust particles and resultant system blockage.

During coal transfer, dust particles may be dispersed by wind or other air disturbances. Partial or total enclosure of conveyors offers a simple solution.

To minimize fire hazards in coal conveyor systems, one US company plans to install water spray systems throughout the coal transfer network [9]. These systems will be designed for automatic activation controlled by temperature, temperature rise, and/or smoke monitors. (National Fire Protection Association Standard 15 provides design assistance and specifications.) Operation of the water spray system immediately shuts down the conveyor belt to confine the problem area for easier control.

(2) Coal Preparation

Coal preparation equipment consists of grinders, pulverizers, and screens. Occupational hazards are similar to those associated with coal storage and transfer, except that high levels of noise may be a serious problem. Often, only one or two employees are required in the coal preparation area, and they may spend much of their time in nonexposure areas such as a control room.

There are two critical requirements for a coal preparation area that is free from occupational health and safety hazards. First, frequent and thorough equipment maintenance is essential because the workplace environment can deteriorate rapidly should equipment, structures and seals develop leaks. Because such leaks will inevitably occur, liberal use of local ventilation is necessary. In addition, effective general ventilation should be provided. Second, dust explosions must be prevented. Despite the best housekeeping efforts, coal dust often accumulates on overhead rafters and other

relatively inaccessible horizontal surfaces. These surfaces must be frequently cleaned (vacuum or equivalent) or hosed down. Good housekeeping in this area cannot be overemphasized because neglect can create secondary sources of airborne dust and increase the danger of serious dust explosions. Wet coal preparation techniques can reduce health, fire, and explosion hazards but because of the feed requirements these are not feasible in Lurgi gasification.

General safety precautions that apply to coal storage, preparation and transfer include use of explosion-proof electrical systems, properly grounded electrical connections, and adequate ventilation.

(3) Coal Feeding

Potential occupational hazards associated with the operation of coal lockhoppers include potential exposure to coal dust, crude gas, and high temperatures. The nature and extent of exposure depend on the kind of gas used to pressurize the lockhopper (carbon dioxide, crude gas, etc). Major sources of exposure include leakage from the upper lockhopper closure during pressurization, gas displacement through the upper lockhopper closure during charging, passage of crude gas upward through the lower closure when the gasifier is charged, and workplace reentry of gases vented during depressurization.

One proposed lockhopper design appears to offer effective worker protection [9]. The differential pressure between the lockhopper and the gasifier is constantly monitored. If the pressure in the gasifier approaches that in the lockhopper, the pressurizing gas injector automatically increases the lockhopper pressure, reducing the possibility of gasifier gases migrating into the lockhopper. During lockhopper depressurization, the lockhopper pressurizing gas is vented to a superheating stack. The remaining gas pressure in the lockhopper is reduced to atmospheric pressure with a nitrogen ejector, and any displaced gas is evacuated through a scrubber and vented to the atmosphere. Throughout the lockhopper charging sequence, a nitrogen ejector maintains a negative pressure in the upper closure shroud to prevent gas leakage into the workplace.

(4) Gasification

The most significant occupational hazards of Lurgi gasifiers will probably occur during start-up and shutdown operations. Start-up gas should be flared or equivalently disposed of in order to prevent the entry of crude gas into the workplace. Appropriate gas mixtures should be added to the gasifier and vent system during start-up to preclude the formation of explosive gas mixtures.

Without these precautions, explosive concentrations of crude gas could develop during the first few minutes of air operation and again after switching to oxygen operation.

Rapid shutdown will be necessary from time to time for process or safety considerations. A reliable, preferably redundant, system for immediately interrupting the steam and oxygen feeds to the gasifier is essential. Gas production ceases without this gas feed.

The crude-gas discharge line from the gasifier to the quench system is subject to blockage as a result of tar precipitation. This increases maintenance activities and undoubtedly subjects workers to dermal contact with carcinogenic tars. An automatic system for clearing the line of condensed tars is warranted. The Lurgi gasification system uses an automated ram to periodically clear the line [12,37]. The ram shaft assembly in the line has a significant leak potential due to the potential for extraordinary wear. Seal design must be given special attention and supplemental controls may be necessary. The crude gas discharge line and quench system are especially subject to both temperature and process stresses, including both erosion and corrosion. A means of monitoring the effects of these stresses should be included in system design.

To minimize the potential for burns, heat stress, materials-handling accidents, and other safety hazards during maintenance, the gasifier section must be designed with adequate clearances for operations and maintenance personnel.

(5) Ash Removal and Disposal

The most significant occupational health hazards associated with ash removal are heat stress, burns from hot lockhoppers and steam leaks, and dust exposure resulting from dumping lockhopper contents onto the ground. It is important that the lockhopper be well insulated, shielded, or isolated and that the system be designed to minimize steam leaks. Dust generation should be minimized by the use of wet handling methods. The ash lockhopper should be designed as part of a closed system, with the ash dumped into a liquid conveyor system, eg, a sluiceway [9,12]. Infrequently, the sluiceway water will be lost, and hot steaming ash will be dumped on the ground. Dust will be generated, and there is a significant burn hazard. However, this eventuality can be anticipated, and precautions such as isolation of the area and the use of personal protective equipment can be employed.

(6) Quenching

Except during maintenance operations, workers probably will spend little time in this process area. System design and operating efforts should be directed toward preventing leakage of crude gas,

hot gas liquor, and tars, and toward minimizing the frequency of maintenance operations. The primary leak point will probably be at the recycle gas liquor pump. In the past mechanical seals for this pump have not been successful. One company has indicated that some of the new mechanical seals currently available may prove superior to stuffing boxes [9]. Because of the importance of preventing leaks from this pump, the best seals available at the time should be used. Two companies have indicated that they will use an interlock device to automatically activate a water-flush system should the gas temperature exceed a prescribed level [9,86]. The emergency flush system would be used either until repair of the recycle pump is accomplished or until the gasifier is taken offstream.

Another very effective method of exposure control is to reduce the frequency of maintenance operations. One company intends to design the waste-heat boiler to minimize both tar deposition on the cooling or boiler tubes and solids buildup at the bottom of the vessel [9]. All piping in this section should be heavy-walled, with long-radius elbows, and should be sized for minimum velocity. To prevent problems associated with thermal expansion of the piping network at high temperatures, the gas-liquor recycle pump could be suspended or the piping could be specially designed to minimize stress on the pump suction and offtake piping. The gas-quenching system should be designed to remove particulate matter elutriated from the gasifier or formed during quenching to minimize downstream problems associated with particles entrained in the gas stream.

(7) Gas-Liquor Separation

Occupational hazards in this process unit include potential exposure to escaping expansion gases, leaking tar separation equipment and pumps, and overflow of the tar separation vessel. Offgas lines should be properly sized to prevent plugging by entrained tar particles. Expansion gases should be scrubbed and incinerated [9], vented to the start-up vent line [86], or similarly disposed of in a safe manner.

Occupational exposure could occur should the gas-liquor separators overflow. This could result from a gas breakthrough at high pressure into the tar separation unit, causing raw gas liquor to overflow. The problem can be minimized by control of gas-liquor flow to the separation unit, using restrictive orifices, minimum orifice control valves, and fail-safe flow monitoring systems [9,12]. Emulsion formation in the tar separator can also cause overflow of raw gas-liquor. Methods of breaking and/or preventing these emulsions should be employed.

(8) Gas Purification (Rectisol)

Experience has shown that the potential occupational exposure from this process unit is low, except during sample collection, because the equipment is very reliable and leaks and/or maintenance

requirements are likely to be minimal [9,12,86]. All pumps in the system should be designed for closed drainage into a separate "slop" system. Leaks also increase fire hazard; design should minimize both risk and potential consequences (eg, by ventilation).

(9) Phenol Recovery Unit

The phenol recovery unit may use either isopropyl ether or *n*-butyl acetate as the extraction medium. From a safety and health standpoint, the better of these is *n*-butyl acetate because of its relatively high 65 C (149 F) flashpoint and low toxicity. Isopropyl ether, on the other hand, is very volatile, with a flashpoint of -9.4 C (15 F) and a boiling point of 68 C (154.4 F), and can pose a severe fire hazard if not properly contained. Of greater concern is the fact that isopropyl ether forms potentially explosive peroxides when exposed to heat, light, and air (especially when evaporated to dryness). If this solvent is used, the system (including storage) must be completely tight. Leaked isopropyl ether must be contained and removed immediately. The formation of peroxides must be retarded by the addition of oxidation inhibitors such as diphenylamine, alpha-naphthol, beta-naphthol, or hydroquinone (approximately 0.05% addition) to the stored isopropyl ether. Water, at a concentration of 1% by weight, is also effective as an inhibitor [51].

(10) Oxygen Plants

Detailed safety procedures for oxygen plants are provided by the vendors of specific equipment. These should be followed carefully, and the hazards of accidental release of pure oxygen should be made familiar to all employees. Oxygen plants should be distant from areas where oils and tars are handled.

(b) Other Coal Gasification Processes

The general engineering control objectives discussed at the beginning of this chapter are applicable to all coal gasification processes. As with high-BTU processes, certain controls are unique to low- and medium-BTU coal gasification. These are discussed in this section. The controls described for high-BTU coal gasification are also applicable to Lurgi low- and medium-BTU processes.

In discussions of health and safety, the best classification of the various low- and medium-BTU processes is by (1) pressure and (2) tar and liquids production. Operating pressure affects not only the propensity for leakage but also, and possibly more importantly, the

tolerance of personnel toward leaks. Obviously, in a high-pressure process leaks cannot be tolerated from an operational standpoint. Conversely, in a low pressure process, such as many low-BTU processes, small leaks do no great harm to operations, and thus there may be a tendency to tolerate leaks that may be significant from a health standpoint. The second factor of concern is the production of tar and potentially hazardous liquids. High-temperature gasification processes (eg, Koppers-Totzek) and processes using anthracite coal as feedstock do not produce these materials. In other processes, these materials are a substantial byproduct, and additional controls are necessary.

The methods of receiving and storing coal vary greatly in these processes, but the dust- and fire-control techniques discussed for high-BTU processes are basically applicable to all cases. However, the potential for dust and fire hazards is somewhat diminished because much smaller quantities of coal may be involved in low- and medium-BTU processes and because coal turnover is generally more rapid.

Some of these processes do not include coal preparation operations since coal sized to process specifications is delivered to the plant. The most notable exception is the Koppers-Totzek process, in which feed coal is ground very fine (90% less than 90 microns, 10% less than 7 microns) and which therefore has a high potential for dust generation. The enclosures and seals for coal pulverizing and transfer equipment must be very tight, and local exhaust ventilation may be necessary. In particular, the seals for the pumps that transfer the ground coal to a pneumatic conveyor system must be well designed, well constructed, and properly maintained. One company has indicated that leakage problems may be reduced by substituting stuffing boxes pressurized with nitrogen for the original mechanical seals [18]. In addition, stuffing-box wear was reduced by reducing pump speed. The coal preparation and handling areas of this plant, when observed in 1977 [18], were without significant traces of airborne or settled coal dust. Another exception is a process in which the coal is subjected to wet grinding and sizing [19]. There is little potential for dust generation since the coal is slurried.

Coal-feeding techniques for medium- and low-BTU processes vary greatly from those used in high-BTU processes. In low-pressure processes, there is no need for pressurized lockhoppers. Typically, there is a storage bin and a separate feed bin fitted with interlocked disc-type valves to control coal feed. The systems are generally manually operated, and the interlocks prevent the opening of the feed bin valve unless the storage bin valve is closed (and vice versa). As with a lockhopper system, some gas enters the feed bin when the gasifier is charged, either by simple displacement or by a small pressure differential between the two vessels. This gas

can escape into the workplace through either of the disc valves or, more likely, up through the storage bin and into the coal bunker. Up to 500 ppm of carbon monoxide was measured in the coal bunkers of one such facility before ventilation was installed (carbon monoxide levels are now reported to be below the detectable level [14]). Methods should be devised to control this gas escape from the gasifier through the feed bin. At one facility, the coal bunker is connected to the gasifier through rotary barrel valves [15]. Emissions during gasifier charging are removed to the atmosphere via a discharge line above each valve [15]. Another installation minimizes gasifier pressure, applies general ventilation, and enforces restricted entry to the coal bunker area. An alternative method would be the use of local ventilation for the coal feed bin (conceivably by using the gasifier air blower). Any of these methods is acceptable if gas concentrations in the workplace are maintained at acceptable levels and if condensed tars are reduced to a minimum [15].

A temperature probe should be installed in the coal feed bin as a fire safety device [14].

There are other methods of coal feeding that require different types of controls. At one plant [18], fine coal from the service bin is fed to a feed bin where pressure-sensitive switches control the level of the coal. The system ensures a continuous feed of uniform density to the feed screw. The feed screws are designed to force the coal past a restricting plug inserted at the tip of the screw. This insert produces a large pressure drop across the front end of the screw, which keeps the screw filled at all times and helps to prevent the backflow of gas from the gasifier unit into the coal feed bunkers. The coal is picked up at the end of the screw feeder by oxygen and steam feed gas and is conveyed into the burner at a velocity of 300 ft/sec over the length of the 6-foot blowpipe. The high velocity prevents backflash into the conveying tube. At another gasifier that presently uses a lockhoppering feed system, a technique is being developed for extruding finely ground coal, bound with coal tar, into the gasifier [87]. This technique would provide a use for process tar, but special controls obviously would have to be used to minimize worker exposure to coal tar volatiles.

Another possible source of leakage from low-pressure gasifiers would be the rod-out ports where coal feed dip legs are used. When the ports are opened, producer gas can escape into the workplace. This exposure source should be controlled, particularly for tar producers, ideally by eliminating the necessity for the procedure. This should not be difficult in the case of new gasifiers, but process modifications (eg, larger dip legs, external vibrators, or local ventilation) may be necessary for existing facilities.

Most low-pressure gasifiers visited by NIOSH used metal pokers to prevent coal agglomeration in the gasifiers, to gauge ash height, and to locate the combustion zone [14-16]. Sealing methods for the "pokeholes" at the tops of the gasifiers ranged from iron balls loosely covering the holes to close-fitting covers tightened by dogs. Observation revealed the latter to provide superior sealing. At one such facility [14] the fire-bed depth is checked twice per shift. This operation is reported to require an average of 20 minutes, during which time the local carbon monoxide level rises to about 40 ppm [14]. In new plants, the gasifier should be designed to eliminate the use of "pokeholes." Consideration may also be given to purging steam or inert gas into the pokeholes during this operation to prevent the escape of gases. In existing plants, the holes should be tightly sealed during normal operation and provided with local exhaust ventilation when the pokers are inserted.

Gasifier pressures should be minimized to the extent possible, either by operating practices or external methods. The potential for leakage from the gasifier and surrounding lines is almost directly proportional to the internal pressure.

Another potential exposure source for low-pressure gasifiers is the gases vented during cold or hot start-up. For environmental reasons, these vent gases should be incinerated before release to the atmosphere. Vent flares should be designed to incinerate all materials vented. (One gas manufacturer [87] reported that tar condensation in the flare muffler resulted in tar droplets passing through the flame. The muffler was redesigned with a baffle plate, which ended the problem. During start-up operations, a technician is stationed at the flare to drain tar from the muffler.) Flares should be equipped with a pilot and a pilot alarm.

Other safety and health controls noted at low-pressure gasifiers include alarms in the producer gas stream to warn of excessive oxygen content, and directionally controlled blowout vents to minimize damage from an explosion in the gasifier area.

Ash removal and disposal do not appear to constitute a significant source of worker exposure in any of the low- and medium-BTU processes. At one facility [14], a slowly revolving grate removes ash to an ash hopper. Water is placed around the inside circumference at the top of the ash hopper to flush out the ash as a slurry (generally after a 24-hour accumulation). The ash is then taken to a landfill.

At one plant, approximately 80% of the ash is entrained in the product offgas, and the remaining 20% melts and flows downward as molten slag into a slag quench tank beneath the gasifier. At the top of the gasifier sufficient water is injected into the offgas to reduce the temperature, causing some of the ash to resolidify. Most of the remaining ash is removed from the gas in the water wash tower

[18]. For most coals, more than 50% of the ash flows down from the gasifier as molten slag and drains into the slag quench tank; the remainder of the ash leaves the gasifier as fine fly ash entrained in the exit gas. Approximately 90% of this fly ash is removed in the water wash tower. The remainder is removed in the electrostatic precipitators [24].

At one medium-BTU facility [18], the ash-laden quench water and slag discharge water are discharged to one of several long drag tanks. The ash settles to the bottom of the tank and is removed, while clean water overflows the tank and is sent to a cooling tower for subsequent recycle to the gasifier. Small quantities of hydrogen cyanide (6-17 ppm) in the gas stream are retained in the quench water. The plant [18] has reported an average hydrogen cyanide concentration of 10 ppm at the top of the cooling tower. Although workers probably would rarely spend much time in the cooling tower area, the exposure potential must be considered. In all cases where quench water is recirculated through cooling towers, the potential for exposure to toxicants (either from mist carryover or vaporization) must be evaluated and control measures taken. In this plant, the most persistent and serious area of potential employee exposure has been the compressor house, where the clean process gas is compressed to 30 atm. Even though the compressors are equipped with triple mechanical seals, leaks are common, and a 12-point automatic (sequential sampling) carbon monoxide monitoring system was installed. The sampling heads were installed on the compressors at areas of high leak potential. Problems with the mechanical seals evidently related to difficulty in balancing the nitrogen seal pressure between sections and maintaining adequate nitrogen pressure.

Basic control methods for toxic liquids in low- or medium-BTU plants using bituminous or lower ranking coals are similar to those discussed for high-BTU processes; equipment should be designed and maintained to contain the process liquids. Closed drains, separators, and sumps should be provided.

At one plant [15], tar and dust from the first water spray are collected in an open water seal. The heavy tar flows over a weir into a large open decanter. Float tar and solids are periodically raked from the surface of the water into a bucket or collector directly below the lip of the seal. The container is manually emptied into a chute leading to a dumpster, from which it is periodically taken to a landfill. Over the years, tar has grossly contaminated work surfaces in the area. New plants should be equipped with closed, automatic systems for removing the float tar and solids.

The decanter also collects contaminated water from the secondary and tertiary water sprays. The tar that settles at the bottom of the vessel is pumped to a steam plant for use as fuel. Excess water is recycled through a cooling tower for reuse as seal water, in scrubbers, and in the gas line. Controls to minimize drift carryover from the cooling tower should be considered (as well as the potential for escape of volatile liquids and gases), and an enclosed decanter system may be justified. One facility has developed [87] an effective method for controlling tar dispersion; gas is passed sequentially through a venturi contactor, a countercurrent gas cooler, and a washer. Condensed liquids are recycled through closed sump systems with underground storage. American Petroleum Institute (API) gravity separators are used to concentrate the tars for transfer to the extruder.