FE-2495-6
Distribution Category UC-90i

# THE DESIGN AND IMPLEMENTATION OF AN ENVIRONMENTAL MONITORING PROGRAM FOR ERDA FOSSIL FUEL FACILITIES

## TASK SUMMARY REPORT III

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Date Published: February 1977

Prepared for
Energy Research and
Development Administration

Under Contract No. E(49-18)-2495

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# III. POTENTIAL ENVIRONMENTAL IMPACTS FROM COAL CONVERSION AND UTILIZATION PLANTS

## A. CATEGORIES OF PROCESSES ASSOCIATED WITH COAL PLANTS AND GENERAL TYPES OF ENVIRONMENTAL IMPACT GENERATORS ASSOCIATED WITH EACH

### 1. General Considerations.

The initial step in determining the monitoring needs of ERDA's coal program is to identify the processes being supported by ERDA funds and to characterize the types of environmental impact generators associated with each. The degree of specificity of this characterization is limited by availability of data, since most of the processes funded by ERDA are in very early stages of development. In many cases, one can only surmise the kinds of pollutants that will be produced and make an order-of-magnitude guess as to their amounts.

The processes considered in this study are listed in Table III-1, along with an indication of the status or degree of development of each. Emphasis in the report will be on those processes for which the greatest amount of data exists, the pilot plants in operation. In some cases, useful environmental impact data were provided by process development unit (PDU) work.

The remainder of this section is concerned with identifying the general kinds of environmental impact generators associated with each process. The next section will deal with more specific chemical characterization of the pollutants identified in general here.

Most coal conversion and utilization processes have a number of ancillary sub-processes in common--for example, coal handling and storage, coal preparation, gas clean-up, wastewater treatment, etc. Further, the specific kind of sub-process may change between pilot plant and demonstration plant for a given process. To illustrate, a coal gasification plant could accomplish sulfur recovery from the waste gas stream using the Stretford process at one stage of development and the Klaus process at another. Therefore, we will consider the general environmental impact generators associated with ancillary sub-processes in one place, rather than repeating them in various permutations, plant-by-plant. These impact generators are presented in Table III-2 in terms of three waste streams (air, water, and solids), noise, and intensive resource use.

The impact generators associated with equipment (such as reactor vessels) specific to a given process are presented in Table III-3.

Table III-1. Coal conversion and combustion processes funded by ERDA.

| Process | Status* | Location | Prime Contractor |
|---|---|---|---|
| **LIQUEFACTION** | | | |
| **Direct Hydrogenation:** | | | |
| H-Coal | PP in construction | Catlettsburg, KY | Hydrocarbon Research, Inc. |
| Synthoil | PDU in construction | Bruston, PA (PERC) | Foster Wheeler Energy Corp. |
| Zinc Chloride Catalyst | PDU in construction | Pittsburgh, PA | Continental Oil |
| Disposable Catalyst Hydrogenation | PDU in construction | Bruston, PA (PERC) | |
| **Solvent Extraction:** | | | |
| Solvent Refined Coal, 50 tpd | PP in operation | Ft. Lewis, WA | Pittsburgh & Midway Coal Mining Co. |
| Solvent Refined Coal, 6 tpd | PDU in operation | Wilsonville, AL | Electric Power Research Institute |
| Solvent Extraction of Lignite | PDU in operation | Grand Forks, ND | University of North Dakota |
| CO-Steam Process | Lab Studies | PERC & GFERC | |
| Donor Solvent I | PDU in operation | Bloomfield, NJ | Lummus Co. |
| Donor Solvent II | PDU in operation | Baytown, TX | Exxon Research & Development |
| Consol Synfuel Process | PP reactivated | Cresap, WV | Fluor Engineers & Constructors, Inc. |
| **Pyrolysis:** | | | |
| Char-Oil Energy Development (COED) | PP decommissioned | Princeton, NJ | FMC Corporation |
| Clean Metallurgical Coke/Liquids | PDU in operation | Monroeville, PA | United States Steel Engineers & Consultants, Inc. |
| Entrained Pyrolysis | Lab studies | | Occidental Research Corp. |
| Flash Liquefaction | Lab studies | | Rocketdyne/Rockwell |
| Hydrocarbonization | PDU in operation | Oak Ridge National Laboratory | |
| Hydrocarbonization | DP in design | New Athens, IL | Coalcon |

Table III-1. Coal conversion and combustion processes funded by ERDA (Continued).

| Process | Status* | Location | Prime Contractor |
|---|---|---|---|
| Fluid Coke | PDU in operation | | Exxon Research & Development |
| Indirect Liquefaction: | | | |
| Transportation Fuels | PDU in operation | | Mobil Research & Development |
| GASIFICATION | | | |
| High-Btu: | | | |
| Bi-Gas | PP in operation | Homer City, PA | Bituminous Coal Research, Inc. |
| HYGAS | PP in operation | Chicago, IL | Institute for Gas Technology |
| U-Gas | | Chicago, IL | Institute for Gas Technology |
| $CO_2$ Acceptor | PP in operation | Rapid City, SD | Conoco Coal Development Co. |
| Self-Agglomerating Ash | PDU in operation | Columbus, OH | Battelle-Columbus Laboratories |
| Synthane | PP in operation | Bruceton, PA (PERC) | Lummus Co. |
| Hydrane | PDU in construction | Bruceton, PA (PERC) | |
| Low-Btu: | | | |
| Fixed Bed, Stirred | PDU in operation | Morgantown, WV (MERC) | |
| Fixed Bed, Slagging | PP reactivated | Grand Forks, SD (GFERC) | |
| Fluidized Bed, 2 Stage | PDU in operation | Waltz Mill, PA | Westinghouse |
| Fluidized Bed, 3 Stage | PDU in operation | Monroeville, PA | Bituminous Coal Research, Inc. |
| Entrained Bed, Atmospheric | PDU in design | Windsor, CT | Combustion Engineering |
| Molten Salt, Pressurized | PDU in construction | Norwalk, CT | Atomics International/ Rockwell |
| Gasification/Combined Power Cycle | PP in construction | Sioux Falls, SD | Foster Wheeler Energy Corp. |

Table III-1. Coal conversion and combustion processes funded by ERDA (Continued).

| Process | Status* | Location | Prime Contractor |
|---|---|---|---|
| **In-Situ:** | | | |
| Linked Vertical Well Process | PDU tests | Hanna Field, WY (LERC) | |
| Packed Bed Process | Shallow site tests | Powder River Basin | Lawrence Livermore Laboratory |
| Longwall Generator Process | Field Tests | Princetown, WV (MERC) | |
| Steeply Dipping Bed Process | Field Studies | | |
| **DIRECT COMBUSTION** | | | |
| **Closed Cycle Power Systems** | | | |
| Gas Turbine/Steam Turbine | Pre-design | | |
| Alkali Metal Vapor Turbine/Steam Turbine | Pre-design | | |
| **Fluidized Bed Burners, Atmospheric:** | | | |
| Multicell Fluidized Bed Boiler | PP in operation | Rivesville, WV | Pope, Evans and Robbins, Inc. |
| Modular Integrated Utility System | PDU in design | Oak Ridge National Laboratory | |
| Component Test Integration Unit | CTIU in design | Morgantown, WV (MERC) | |
| Boiler Conversion Project | Design | | |
| **Fluidized Bed Burners, Pressurized:** | | | |
| Combustor Gas Turbine/Steam Turbine Power System | PP in design | Woodbridge, NJ | Curtis-Wright Corp. |
| Component Test Integration Unit | CTIU in operation | Argonne National Laboratory | |
| Combustor Gas Turbine Power System | PDU in operation | Menlo Park, CA | Combustion Power Company, Inc. |
| Combustor for Combined Power Cycle | PDU in operation | London, England | National Research Development Corp. |

Table III-1. Coal conversion and combustion processes funded by ERDA (Continued).

| Process | Status* | Location | Prime Contractor |
|---|---|---|---|
| <u>Combustion Test Facilities</u>: | | | |
| Coal-Oil Slurry Combustion | CTF in construction | Bruceton, PA (PERC) | |
| Solvent Refined Coal Combustion | CTF in operation | Bruceton, PA (PERC) | |
| Anthracite Refuse Combustion | CTF in operation | Morgantown, WV (MERC) | |
| <u>MAGNETOHYDRODYNAMICS</u> | | | |
| Open Cycle Component Test Integration Unit | CTIU in construction | Missoula, MT | Montana State University |
| MHD Power Generation Test Facility | PDU in operation | | University of Texas |
| Closed Cycle/Plasma | Lab studies | | |
| Closed Cycle/Liquid Metal | Lab studies | | |

* <u>Key to Acronyms</u>:

| | |
|---|---|
| CTIU | Component Test Integration Unit |
| CTF | Combustion Test Facility |
| DP | Demonstration Plant |
| GFERC | Grand Forks Energy Research Center |
| LERC | Laramie Energy Research Center |
| MERC | Morgantown Energy Research Center |
| PDU | Process Development Unit |
| PERC | Pittsburgh Energy Research Unit |
| PP | Process Plant |

Table III-2. General categories of environmental impact generators associated with processes often used in conjunction with advanced coal technology plants.

| Category | Waste Stream: Air | Waste Stream: Water | Waste Stream: Solids | Intense Noise | Intensive Resource Use |
|---|---|---|---|---|---|
| Mining | Dust<br>Smoke (Spont. comb.) | Mine Drainage<br>Gob Pile Runoff | Gob Piles<br>Overburden | Yes | Stripped Land<br>Subsidence |
| Handling And Storage Of Coal and/or Acceptor | Dust<br>Smoke (Spont. comb.) | Coal Pile Runoff<br>Acceptor Pile Runoff | | Yes | |
| Coal Cleaning Waste Storage and Disposal | | Coal Waste Runoff | Coal Wastes | | Landfill Sites |
| Coal Ash/Slag Storage and Disposal | Dust<br>Fumes | Ash or Slag Pile Runoff<br>Slag Quench Water<br>Groundwater Pollution | Ash or Slag | | Landfill Sites |
| Solid Product Storage (Solid Refined Coal) | Dust<br>Phenols | SRC Pile Runoff | Off-Spec SRC | | Landfill Sites |
| Liquid or Gaseous Hydrocarbon Storage | Hydrocarbon Vapors | Oil Spills | | | |
| Preparation Of Coal and/or Acceptor | | | | | |
| • Crushing | Dust | | | Yes | |
| • Pneumatic Cleaning | Dust | | | | |
| • Washing | | Spent Wash Medium | Coal Wastes | | Water |
| • Drying | Dust<br>Hydrocarbon Vapors<br>Sulfur Gases<br>Water Vapor | | | | |
| • Sizing | Dust | | | | |
| Boilers | | Blowdown | | Yes | Water |
| • Fired Boilers Only | Flue Gases | | Ash (Some fuels) | | |
| Demineralizers/Deionizers | | Regeneration Backwash | | | |
| Cooling Towers | | | | | |
| • Wet | Water Vapor<br>Aerosol Solids | Blowdown | | | Water |
| • Dry | | Blowdown | | Yes | |

Table III-2. General categories of environmental impact generators associated with processes often used in conjunction with advanced coal technology plants (Continued).

| Category | Waste Stream | | | Intense Noise | Intensive Resource Use |
|---|---|---|---|---|---|
| | Air | Water | Solids | | |
| Once-Thru-Cooling | | Anti-Corrosion Agents<br>Biocides<br>Heat | | | Water |
| Fired Burners/Heaters | Flue Gases | | Ash (some fuels) | | |
| Air Separation Plant (for Oxygen) | Nitrogen<br>Misc. Atmospheric Gases | Condensate | | Yes | Electricity |
| Hydrogen Reactor (partial oxidation of coal) | Fumes from Ash | Ash Quench Water | Ash | | |
| Shift Reactors | | | Spent Fe Catalyst | | |
| Methanators | Nickel Carbonyl<br>Nickel Subsulfide | | Spent Ni Catalyst | | |
| Wastewater Treatment Plant | Odors | Treated or Partially Treated Effluent | Sludge<br>Grease | | |
| Gas Clean-Up | | | | | |
| • Cyclone | | | Fines (ash, accepter, char) | | |
| • Water Scrubber/Quency | | Foul Water | | | |
| • Alkali Scrubber | | Alkaline Foul Water | | | |
| • Selexol | $CO_2$, traces of $H_2S$, COS, CO, $H_2$ | Condensate | | | |
| • Rectisol | $CO_2$, traces of $H_2S$, COS, CO, $H_2$ | Foul Water<br>Hydrocarbon By-Products | | | |
| • Stretford | $CO_2$, traces of $H_2$ CO, $H_2S$ | Filter Wash Water | Sulfur | | |
| • Claus | traces $H_2S$ | | Sulfur | | |
| • Thermal Oxidizer | $CO_2$, $SO_2$. NOX | | | | |
| Ammonia Stripper | $NH_3$<br>dust | Filter Water | | | |
| Condensers | | Foul Water | | | |

Table III-3. General categories of impact generators associated with specific advanced coal technologies.

| | Waste Stream | | |
|---|---|---|---|
| Category | Air | Water | Solids |
| **LIQUEFACTION** | | | |
| **Direct Hydrogenation:** | | | |
| **H-Coal** | | | |
| Reactor | | | Spent Catalyst |
| Liquid-Solid Separator | | | Char<br>Ash |
| **Synthoil** | | | |
| Reactor | | | Spent Co/Mo Catalyst |
| **Solvent Extraction:** | | | |
| **Solvent Refined Coal** | | | |
| Slurry Mix Tank | Hydrocarbon Vapors<br>Phenol | | |
| Fired Preheater | Hydrocarbon Vapors<br>Phenol | | |
| Rotary Filter | Asbestos Particles<br>Phenol | | Spent Filter Medium (diatomaceous earth and asbestos) |
| **Consol** | | | |
| Slurry Mix Tank | Hydrocarbon Vapors<br>Phenol | | |
| Fired Preheaters | Hydrocarbon Vapors<br>Phenol | | |
| Carbonizer | "Vapor" (hydrocarbons, phenol, $H_2S$) | | Char<br>Ash |
| Hydrogenator | "Vapor" (hydrocarbons, phenol, $H_2S$) | | |

Table III-3. General categories of impact generators associated with specific advanced coal technologies (Continued).

| Category | Waste Stream | | |
|---|---|---|---|
| | Air | Water | Solids |
| Pyrolysis: | | | |
| Clean Metallurgical | | | |
| Coke/Liquids | | | |
| Vapor Stripper | | | Ash |
| Still | | Residual Tars | |
| Flash Liquefaction | | | |
| Reactor | Quench Vapors | Quench Water | |
| Vapor-Mist Separator | $H_2S$ | | |
| Light Oil Decanter | | Oily Water | |
| Heavy Oil Decanter Filters | | Oily Water | Char<br>Ash |
| Hydrocarbonization | | | |
| Fractionator Condenser | | Foul Condensate | |
| Fractionator Decanter | | Oily Water | |
| Ammonia Recovery System | $NH_3$ | $NH_4^+$ | |
| GASIFICATION-HIGH BTU | | | |
| Bi-Gas | | | |
| Slurry Feed Cyclone | Water Vapor<br>"Inert" Recycle<br>Gas From Methanator | | |
| Reactor | | Slag Quench Water | Slag<br>Char |

Table III-3. General categories of impact generators associated with specific advanced coal technologies (Continued).

| Category | Waste Stream | | |
|---|---|---|---|
| | Air | Water | Solids |
| Hygas | | | |
| Ash Slurry Filter | Ash Vapors | Ash Filtrate | Ash |
| $CO_2$ Acceptor | | | |
| Reactor | | | Spent Acceptor |
| Foul Water Stripper | $H_2S$ | | |
| Regenerator | | | Ash |
| Self-Agglomerating Ash | | | |
| Reactor | | | Ash Agglomerates<br>Char |
| Fluidized-Bed Burner | | | Ash Agglomerates |
| Synthane | | | |
| Reactor | | | Ash<br>Char |
| Hydrane | | | |
| GASIFICATION-LOW BTU | | | |
| Fixed Bed, Stirred | | | |
| Separator | | Foul Water<br>Tars | |
| Fixed Bed, Slagging | | | |
| Reactor | Slag Vapors | Slag Quench Water | Slag |
| Spray Cooler | | Tars<br>Foul Water | |
| Coke Scrubber | Regenerate Off-Gases | | |

Table III-3. General categories of impact generators associated with specific advanced coal technologies (Continued).

| Category | Waste Stream |  |  |
|---|---|---|---|
|  | Air | Water | Solids |
| DIRECT COMBUSTION |  |  |  |
| Fluidized Bed Combustion, Atmospheric |  |  |  |
| Multicell Fluidized Bed Boiler |  |  |  |
| Boiler |  |  | Ash<br>Acceptor |
| Stack | NOX, SOX |  |  |
| Fluidized Bed Combustion, Pressurized |  |  |  |
| Coal-Oil Slurry Combustion |  |  |  |
| Slurry Mixing Tank | Hydrocarbon Vapors |  |  |
| Combustor | Flue Gases |  | Ash<br>$Na_2SO_4$ |
| Combustion Test Facilities |  |  |  |
| Coal-Oil Slurry Combustion |  |  |  |
| Slurry Mixing Tank | Hydrocarbon Vapors |  |  |
| Combustor | Flue Gases |  | Ash<br>$Na_2SO_4$ |
| Anthracite Refuse Utilization |  |  |  |
| Fluidized Bed Boiler |  |  |  |
| Boiler | Flue Gases |  | Ash<br>$CaSO_4$ |
| MAGNETOHYDRODYNAMICS |  |  |  |
| Open Cycle MHD |  |  |  |
| Combustor |  |  | Slag |
| Slag Separator |  |  | Slag |
| Stack | $NO_x$ |  |  |
| Seed Condenser/Extractor |  |  | $K_2SO_4$ |
| Seed Regenerator | Sulfur Gases |  | Sulfur |

Table III-3. General categories of impact generators associated with specific advanced coal technologies (Continued).

| Category | Waste Stream | | |
|---|---|---|---|
| | Air | Water | Solids |
| SUPPORT TECHNOLOGIES | | | |
| Steam-Iron Hydrogen Generator | | | |
| Reducer Vessel | $N_2$, $H_2O$, $CO_2$, CO | | |
| Producer Vessel | | | Ash |
| Liquid Phase Methanation | | | |
| Methanator Vessel | | Spent "Inert" Hydrocarbon Medium | Spent Ni Catalyst (w/trace of ruthenium) |
| Decanter | | Oily Water | |
| Incinerator | Flue Gases | | Ash |
| Hot Gas Clean-Up: | | | |
| Molten Salt Process | | | |
| Molten Salt Pot | | | $CaCO_3$<br>$Li_2CO_3$<br>$K_2CO_3$ |
| Detrainer | | | $Al_2O_3$ |
| Salt Scrubber | | | Spent Silica Gel<br>Salt Fines (Ca, Li, K) |
| Salt Regenerator | $H_2S$ | | |
| Sand Filter | | Suspended solids in dilute acid | |
| Iron Oxide Process | | | |
| Absorber/Regenerator | $SO_2$ (on regeneration) | | Spent Absorber $Fe_2O_3$/FeS fly ash pellets |
| Condenser Knock-Out Pot | | Condensate | |
| $H_2S$ Absorber | $N_2$ | Aqueous $CuSO_4$ | |

Table III-3. General categories of impact generators associated with specific advanced coal technologies (Continued).

| Category | Waste Stream | | |
|---|---|---|---|
| | Air | Water | Solids |
| Iron Oxide (MERC) Process | | | |
| $H_2S$ Absorber | $SO_2$ (on regeneration) | | $Fe_2O_3/FeS$ fly ash pellet |
| Carbon Bed Reducer | $Co_2$ | | Ash |
| Condensers | Steam | | Sulfur<br>Ash |
| Catalytic Reactor | | | Spent Catalyst |

Table III-4. Quantities of input materials, products, by-products and wastes associated with some ERDA-funded gasification processes.*

High-Btu Processes

| Process | Input Materials: Material | Input Materials: Amount | Output Materials: Material | Output Materials: Amount |
|---|---|---|---|---|
| Hygas | Coal | 24,200 tpd | Solid Waste | 1,577 tpd |
| | Water | 19 mgd | Air Emissions | 35 tpd |
| | Nickel | 1,000 lbs/ 4 mo. | Ammonia | 124 tpd |
| | | | Sulfur | 103 tpd |
| | | | Tar | $2.3 \times 10^{10}$ Btu/day |
| | | | Light Oils | 46,000 gpd |
| | | | High-Btu Gas | 250 mcf/day |
| Bigas | Coal | 19,600 tpd | Solid Waste | 1,330 tpd |
| | Water | 34.4 mgd | Air Emissions | 27.7 tpd |
| | Nickel | 1,000 lbs/ 4 mo. | Ammonia | 98.5 tpd |
| | | | Sulfur | 93.1 tpd |
| | | | High-Btu Gas | 950 Btu/gas, $236 \times 10^9$ Btu/day |
| Synthane | Coal | 23,400 tpd | Solid Waste | 1,650 tpd |
| | Water | 25 mgd | Air Emissions | 63.0 tpd |
| | Nickel | 1,000 lbs/ 4 mo. | Sulfur | 100 tpd |
| | | | Ammonia | 150 tpd |
| | | | Benzene, Toluene, Xylene | 25,000 tpd |
| | | | High-Btu Gas | 250 mcf/day |
| $CO_2$ Acceptor | Coal | 22,700 tpd | Solid Waste | 3,440 tpd |
| | Water | 23.7 mgd | Air Emission | 42.4 tpd |
| | Nickel | 1,000 lb/ 4 mo. | Ammonia | 137 tpd |
| | Dolomite | 1,260 tpd | Sulfur | 197 tpd |
| | | | High-Btu Gas | 250 mcf/day |

Low-Btu Processes

| Process | Input Materials: Material | Input Materials: Amount | Output Materials: Material | Output Materials: Amount |
|---|---|---|---|---|
| Fixed Bed, Stirred (Bureau of Mines) | Coal | 10,000 tpd | Intermediate Btu Gas | 48,732 tpd |
| | Steam | 5,224 tpd | Tar | 353 tpd |
| | Air | 37,533 tpd | Ammonium Sulfide | 696 tpd |
| | Water | 12.3 mgd | Ash & Solids | 1,104 tpd |
| | | | Gaseous wastes | 1,336 tpd |
| Fluidized Bed, 2 Stage (Westinghouse) | Dolomite | 4,000 tpd | Low-Btu Gas | $215 \times 10^9$ Btu |
| | Coal | 8,754 tpd | Solid Waste as Ash | 1,201 tpd |
| | Water | N.Q. | Spent Dolomite | 4,000 tpd |

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* From Energy Alternatives: A Comparative Analysis, Science & Public Policy Program, University of Oklahoma, 1975, pp. I-81 to I-91. Abbreviations: tpd, tons per day; gpd, gallons per day; mgd, million gallons per day; mcf, million cubic feet; N.Q., not quantified.

Table III-4 gives some idea of the quantities of input and output materials that are associated with some of the processes in question.

## 2. Mining and Coal Cleaning.

Although mining is not directly related to pilot plant operation, mining-related environmental impacts are identified because both demonstration and commercial plants are likely to be located at the mine mouth. Environmental monitoring of such plants must take into account the effects of mining. Therefore, a brief description of coal and acceptor extraction processes and impacts are presented in the following sections.

Coal may be mined either at the surface or underground, depending on the thickness of the seam, the thickness of the overburden, and the technology available. Surface mining or strip mining may be of one of two types, contour or area, depending on the topography. Contour mining, prevalent in the mountainous regions of Appalachia, involves stripping overburden and coal around the ridges at approximately the same elevation. In areas with less topographic relief, e.g. Illinois and North Dakota, broad, flat areas are stripped (area mining). In areas where coal seams are too deep to be strip mined, underground mining techniques are used. Generally, underground mining may use either the room and pillar or longwall methods. In the room and pillar method, a passageway is excavated in the coal seam away from the main shaft. Rooms are then developed off the passageway. Large blocks of coal pillars are left standing to support the overlying materials. In longwall mining, the mine is advanced by shearing strips of coal perpendicular to the direction of movement. The unsupported roof rock is temporarily held in place by hydraulic jacks. As the mine face advances, the jacks are moved forward and the roof collapses.

Acceptor used in the $CO_2$-Acceptor and fluidized bed processes consists of limestone or dolomite, both of which are extracted in quarries. Quarries are simply large open pits, similar to strip mines, for the extraction of stone.

Water quality issues are related to the formation of acid from strip mine spoil materials or underground mine gob and the release of these materials into the surface and groundwater systems. Water quantity changes in relation to changes in runoff-infiltration rate and mine de-watering activities. Changes in terrestrial and aquatic biota are affected by surface/soil disruption, habitat disruption, and changes in water quantity and quality. Other areas sensitive to mining disruption are soils and the overlying earth materials. Soils are removed in the strip mining processes and usually stockpiled for later use. The re-development of soil cover strongly affects the reclamation of the mined-out area.

Overlying earth materials may be adversely affected by subsidence caused by collapse of the underground mine roof. This subsidence may damage buildings, roads, sewers, and utility transmission facilities, alter surface drainage patterns, and disrupt groundwater flow in aquifers.

Coal cleaning is not practiced at any of the existing ERDA coal conversion or utilization plants. However, if demonstration and commercial plants are located at the mine mouth, it will be necessary to clean the coal at the plant prior to use. The purpose of coal cleaning is to separate the coal from rock which may have been mined. Essentially two types of coal cleaning processes exist: (1) pneumatic separation and (2) floatation. Pneumatic separation utilizes air currents and jigs, tables, or launders to separate the coal and the rock according to density. The waste product is solid rock. The floatation process may be either the bulk oil, skin, or froth floatation process. Floation is accomplished using oil in the bulk oil process, water in the skin process, and gas bubbles in an oil-water mixture in the froth floatation process. The waste product of floatation separation is a liquid (water/oil or oil) and rock slurry.

Potential environmental impacts of coal cleaning result from the waste product and the separation process. Pneumatic separation creates large quantities of dust and noise.

The solid rock waste is usually disposed of in a fill and could affect surface and groundwater quality and quantity. Skin and froth floatation require large amounts of water and the effects of these withdrawals should be monitored under some conditions. The disposal of the liquid slurry waste in lagoon/evaporation ponds may affect surface and groundwater quality. The geological stability of these features should also be evaluated periodically.

### 3. Coal and Acceptor Handling and Storage.

The purpose of handling and storage is to unload the coal or acceptor and provide sufficient backlog to allow for the efficient operation of the plant. Frequently coal must be rehandled to prevent development of "hot spots" leading to spontaneous combustion. Acceptor is used in very small quantities at the pilot plant level and, therefore, is usually transported by dump truck to the site and then dumped and stored in hoppers, open piles on the ground, or some type of impermeable pad, e.g. concrete or asphalt.

Coal is delivered to the site either by truck or rail. Truck delivery of coal is similar to that described for the acceptor. Coal delivered to the plant by rail is removed from the car by bottom dropping into a pit, tipping the car, or manually or mechanically lifting the material from the car. The coal may be either stored at the dumping point or transferred to a storage area. The coal may be transferred by front end loader or conveyor to the final storage site. Coal may be stored in open piles on the ground or on an impermeable pad, in covered sheds on the ground or an impermeable pad, in hoppers, or in vertical concrete silos.

Various methods of coal and acceptor handling and storage result in various environmental impacts. For example, truck or rail dumping results in large amounts of dust, while open storage results in the formation of leachate. The difference between coal and acceptor lies in the composition of the dust and the leachate, i.e. coal dust versus calcium and magnesium carbonate dust, and acidic water with high iron and sulfate content versus water with high hardness. This leachate may enter either the surface water or groundwater systems (if the coal is not stored on a properly drained impermeable pad). Also, since coal is more friable than acceptor, the dust problem associated with coal handling is more significant. Coal also presents a unique environmental problem: its high volatility may lead to spontaneous combustion, resulting in air pollution and a health and safety hazard. Also, coal handling can be quite noisy.

As stated previously, air emissions result from burning coal piles (spontaneous combustion) and dust emissions from coal and acceptor handling; water pollutants result from leachate and runoff; and health and safety hazards result from burning coal piles. Runoff from the area changes the runoff-infiltration ratio of surface and groundwater.

### 4. Coal and Acceptor Preparation.

Prior to its use in the gasification process, both coal and acceptor may undergo a preparation process to produce a desired size distribution, moisture content, ash content, sulfur content, and heat value. Acceptor materials undergo particle size alteration only, while coal may undergo all aspects of the preparation process. In order to decrease particle size, the material may pass through crushing, screening, and grinding operations; small particles may be briquetted into larger particles. Moisture content rarely needs to be increased but often requires reduction. Moisture content is commonly reduced by de-watering equipment such as screens and centrifuges, thickening equipment such as cyclones and thickeners, filtration equipment such as vacuum and pressure filtration, and thermal drying techniques. Ash content is reduced by such operations as the wet jig process, heavy media separation, hydrocyclone separation, or froth floatation. Since heat or Btu content is inversely related to ash content, the procedures used to decrease ash content will simultaneously increase the heat content of the coal.

Sulfur content is reduced by removing the pyritic and organic sulfur. Pyritic sulfur can be removed by froth floatation, bacterial or chemical leaching, and hydrothermal processes; organic sulfur can be removed by bacterial or chemical leaching and hydrothermal processes.

These processes tend to be noisy; and, in some cases, dusty and waste products may be in either the solid or liquid forms.

Surface and water quality degradation results from residual fluids which must be disposed of, as in the case of (1) some moisture content change processes, and (2) pollution relating to solid and slurry residuals disposal from processes involving sulfur and ash content reduction and particle size alteration. The second category refers specifically to solid waste disposal problems in the terrestrial environment. Noise is generated by crushing and grinding processes. Air quality is affected by dust from particle size alteration and vapors and gases produced by chemical sulfur removal and heating for the purpose of changing moisture and ash content.

## 5. Coal Conversion.

a. High-Btu Gasification: High-Btu gasification processes involve the mixing of coal (usually pulverized, dried, and preheated) and steam at high temperatures and pressures. Most of the current ERDA processes, including Bi-Gas, Hygas, Synthane, and Hydrane, require that oxygen be added directly to the gasifier vessel. This reacts with the coal to produce the necessary heat of reaction. This heat energy is supplied in other processes, particularly the $CO_2$ Acceptor and Self-agglomerating Ash processes, by circulating heated solids (limestone or dolomite and ash agglomerates, respectively).

Products of the actual gasification step are char, ash, and a gas of varying composition. All processes require subsequent gas clean-up and methanation steps to bring the heat value of the product gas up to the high-Btu level (950-1000 Btu per standard cubic foot) and to remove impurities. Char removed from the gasifiers is a solid hydrocarbon, also of varying composition, which is generally burned to provide heat for steam production or some other process component. However, it does appear in small quantities entrained in gas streams leaving the gasifiers. Ash, or slag (molten or solidified molten ash), is a material whose composition reflects the mineral content of the coal feedstock. Small amounts of slag also become entrained in gas streams and must be removed by using cyclones, scrubbers, or other conventional particulate removal devices.

The major impact generators from the high-Btu processes generally include ash vapors, off-gases with $H_2S$ and hydrocarbon traces, slag quench water, ash filtrate, slag, ash, and char. Spent acceptor is produced by the $CO_2$ Acceptor process.

b. <u>Low-Btu Gasification</u>: Because of the low heating value of low-Btu gas (120 to 500 Btu per cubic foot), most of these gasification processes are linked directly to steam generators or combined steam and gas turbine power cycles as it is not economical to transport such gas long distances. The actual gasification steps are similar to those for the high-Btu process. One exception is the use of air rather than oxygen in most cases. This means that low Btu gasification is more likely to produce nitrogen oxides ($NO_x$).

Gaseous impact generators include slag or ash vapors from the solids drawn from the reactor vessels and off-gases with $H_2S$ and $SO_2$ from reactors and regenerators. Waste water streams include slag quench water and foul water from scrubbers and coolers. Tars and other hydrocarbons also may be in these streams. Solids are primarily ash, char, and spent acceptor. The Molten Salt process results in a sodium carbonate dragout.

c. <u>Liquefaction</u>: Coal liquefaction requires an increase in the hydrogen-to-carbon ratio of the original feed stock. One means of accomplishing this is to expose pulverized coal to hydrogen gas or a hydrogen-bearing solvent. High pressures and, in many processes, a catalyst are used. In general, temperatures are kept below 900°F so that hydrocarbon molecules are not entirely destroyed as they are in gasification processes.

The H-Coal and Synthoil processes are catalytic direct hydrogenation processes. Both require a fired preheater (fueled by natural gas in pilot plant and PDU installations) and a source of hydrogen. Cobalt molybdate serves as the catalyst for both processes. Both processes produce a slurry of liquids, solids and gas, and spent catalyst. A series of coolers, condensers, stills, and centrifuges separates fractions of the slurry. The gas is then passed through a gasification system. Liquids are stored as product fuel or further refined to heavy and light distillates and residual fuel oil. Solids are removed as waste or may be pyrolized to produce hydrogen and additional product fuel.

Solvent extraction processes (SRC and Consol) utilize a hydrogen-rich solvent to liquefy coal. The solvent and coal are first combined in a slurry mix tank. This initiates hydrogenation and depolymerization of the coal, hydrocracking of the solvent, and removal of sulfur in the form of hydrogen sulfide. These reactions continue in the preheater and pressurized dissolver. Hydrogen is added directly to the slurry (in SRC) or after liquid-solids separation (in Consol). An asbestos/diatomaceous earth filter separates solids from liquids in the SRC process. Both processes gasify the char solids to provide process hydrogen.

The pyrolysis liquefaction processes heat coal in the absence of oxygen. The coal decomposes, leaving a carbon-rich char, gases, and liquid hydrocarbons. This char may itself be a commercially valuable product, as in the Clean Metallurgical Coke/Liquids process, or may be gasified to produce hydrogen to aid in the main process step. The extremely short reaction time (10 to 100 milliseconds) for the flash liquefaction process requires a water quench to control the high temperature and pressure reaction. In all pyrolysis processes, a series of condensers, decanters, separators, and filters separates the various solid, liquid, and gaseous processes. Additional liquid processes produce the desired classes of oil products.

### 6. Coal Combustion.

a. Fluidized Bed Combustion: Fluidized bed combustion, both atmospheric and pressurized, requires a flow of air upward through a boiler at a rate sufficient to suspend and "fluidize" a bed of particulates, normally pulverized coal, and limestone or dolomite. The advantages of such a process are (1) the relatively low operating temperatures (1500-2000°F) which allow use of a wide variety of coals and (2) the direct absorption of sulfur dioxide in the combustor by the limestone or dolomite acceptor.

Stack gases, ash, and spent acceptor are the main impact generators associated with fluidized bed combustion. The gases should meet standards for $SO_2$, but efficiency of sulfur removal by the acceptor is not yet completely established. Relatively low combustion temperatures should minimize the formulation of nitrogen oxides ($NO_x$). Particulate removal from the flue gas is by conventional methods. Ash will generally not be melted to a slag, and so may present special handling problems. The spent acceptor, containing calcium sulfate and magnesium sulfate, must be disposed of as a solid.

b. Coal-Oil Slurry Combustion: This approach involves blending pulverized coal with No. 6 fuel oil in a proportioning feeder tank and storing it in a slurry hold tank. The slurry is withdrawn from this tank, pre-heated to 300°F and then combusted with air. Hot flue gas from the combustor is combined with sodium bicarbonate for sulfur dioxide reduction and then passed through a bag house for particulate removal. Hydrocarbon vapors can be expected to escape from the slurry mixing tank. Flue gases and the ash and $Na_2SO_4$ solid from the gas cleaning processes will result from the combustion.

## 7. Magnetohydrodynamics.

Three basic types of magnetohydrodynamic (MHD) systems are being researched: (1) Open-Cycle Plasma System; (2) Closed-Cycle Plasma System; and (3) Closed-Cycle Liquid Metal System. Actual commercial-scale plants may consist of a binary MHD system combining the Open-Cycle Plasma and the Liquid Metal systems. (D18)

Because the open cycle system requires burning coal at a temperature sufficiently high to ionize product gases, $NO_x$ emissions will be higher than for typical combustion systems. "Seed" material, typically salts of potassium and cesium, is added to hot combustion gases (plasma) to increase electrical conductivity. This material must be extracted from the plasma before venting to the atmosphere. Electricity is produced by electromagnetic induction due to the flowing ionized gases. After the pass through the MHD generator, the heat of the plasma can be used to generate steam for a conventional steam turbine or to drive the low-temperature liquid metal MHD system.

The closed-cycle and liquid metal MHD systems require an indirect heat source, such as a conventional fossil fuel boiler, nuclear reactor, or open-cycle MHD system. Being closed, these systems are not of themselves special impact generators, but impacts from their indirect heat source must be considered.

## 8. In-Situ Gasification.

In-situ gasification is the production of low-Btu gas from coal without removing the coal from the ground. The process is essentially a controlled underground fire resulting in partial combustion of the fuel. It utilizes the forced diffusion of gaseous reactants along the solid coal and host rock surfaces. Oxygen may be supplied to the reaction surface along a rectangular channel cut at the coal-host rock contact (open channel method) or by forced diffusion into the coal seam (mass or pillar method). In both cases some sort of injection channel is required to introduce the gaseous reactants to the coal. After the reaction has taken place, these channels collapse, exposing a fresh coal reaction face. Raw product gases are extracted from the earth by means of gas wells. The necessary gas clean-up and methanation processes are located on the surface.

Groundwater quality problems from in-situ gasification result from process solid residues being leached by migrating groundwaters. Changes in groundwater quantity result from disruption of aquifers by subsidence or deliberate grouting to keep groundwater out of the coal seam. Air quality changes result from vent-off emissions from the gasification process, including $H_2S$ and CO. Land subsidence is caused by the collapse of the underlying reaction channel. Usually, smooth depressions result; however, cratering may occur. Methanation and gas clean-up processes are discussed in later sections.

### 9. Gas Clean-Up.

Several processes are required to clean product gas of particulate and unwanted gaseous matters. These are essentially the same processes as those used to clean flue gases from conventional combustion processes and/or gas streams in conventional refineries.

a. Cyclones: A cyclone is a simple and widely used method of particulate removal. The process depends on density separation in a vortex. It is a dry process requiring no moving parts. The only waste stream consists of removed particulates (ash, char, and/or acceptor).

b. Scrubbers and Quench Towers: Scrubbers and quench towers remove particulate matter and at least some soluble gas by passing the gas through a fine mist of water. The resultant foul water contains a variety of fines and soluble materials. Alkali scrubbers involve a very similar process; they are effective in removing acid gases ($CO_2$ and $H_2S$, etc.) from the product gas stream. This foul water contains not only particulates but also dissolved gases and the alkaline absorber. Most of the absorber solution is regenerated.

c. Selexol Process: The Selexol process uses a special solvent, the dimethyl ether of polyethylene glycol, to absorb $H_2S$, $CO_2$, COS, mercaptans, etc. from gas streams. These impurities are subsequently removed from the solvent by flash evaporation or stripping with hot nitrogen. In some applications, the sulfur in the gas stream has been previously removed, and the $CO_2$ removed by this process can be vented directly to the atmosphere. In other instances, sulfur is removed by this process, and the resulting sulfur-rich by-product gas is sent to a sulfur recovery unit. A liquid condensate from the evaporation stage must also be properly treated before disposal.

d. Rectisol Process: The Rectisol process is somewhat similar to the Selexol method, but uses methanol as a solvent instead. It too produces a waste product gas that must be further processed for sulfur recovery, $CO_2$, and water from the evaporation step. Methanol will dissolve hydrocarbons if present in the product gas stream. These will be separated from the methanol in a decantation step or may be part of the contaminated water.

e. Stretford Process: The Stretford process is a sulfur recovery system, usually coupled with a purification step, such as Selexol or Rectisol. It produces elemental sulfur by absorbing hydrogen sulfide in a solution of sodium vanadate, anthroquinone disulfonic acid, and sodium carbonate. The reaction produces an elemental sulfur froth which is collected and filtered. Impact generators include trace amounts of $H_2S$, $H_2$, and CO in vent gas, a contaminated filter wash, and solid sulfur.

f. Claus Process: The Claus Process is similar to Stretford, but involves the gaseous reaction of $H_2$ and $SO_2$. The reaction takes place at high temperatures, but is incomplete, resulting in a tail gas containing about 5% of the input sulfur as $H_2S$ and $SO_2$. Elemental sulfur formed is adsorbed onto a variety of solid or liquid catalysts such as alumina, cobalt-molybdenum, and proprietary nonbauxite mixtures. Trace amounts of COS and $CS_2$ may also appear in the tail gas.

g. Benfield Process: This process is similar to the Selexol and Rectisol ones in which $CO_2$, $H_2O$ and other impurities are removed from product gas. An $H_2S$-enriched stream is produced which is suitable for recovery of elemental sulfur (e.g. Stretford or Claus). The raw product gas is contacted with potassium carbonate solution containing Benfield additives at elevated pressures. The solution containing the absorbed $CO_2$ and $H_2S$ is stripped at reduced pressure and high temperature to remove these volatile gases. The solution is then recycled and the waste gases sent to sulfur recovery.

h. Thermal Oxidizer: A thermal oxidizer is sometimes used to dispose of combustible waste gases or off-specification product gas. The main products of this combustion are $CO_2$, $H_2O$, $SO_2$, and traces of hydrocarbons and nitrogen oxides. Low temperatures and use of oxygen rather than air favor very low production of nitrogen oxides. Flue gases may be collected and scrubbed to remove $SO_2$.

## 10. Methanation and Shift Reaction.

High-Btu gasification requires the conversion of the hydrogen and carbon monoxide gases in the product stream to methane. This methanation step is accomplished in a catalytic reactor at high pressure and at a temperature in the 550°F to 900°F range.

The catalyst used is generally nickel. Products of the reaction are primarily methane and water, but may include some nickel compounds (i.e., nickel carbonyl). In a liquid methanation process being developed, there may be possible contamination of water by the organic solvent (aromatic hydrocarbons or parafinic oil) used to suspend the catalyst and feed gas. Impurities in the gas, particularly sulfur, eventually foul the catalyst, requiring its replacement and disposal.

A "shift reaction" usually precedes methanation. It adjusts the hydrogen-to-carbon monoxide ratio to one favoring maximum methane production. The process involves reacting the gases with steam in the presence of an iron catalyst. The product gases are all passed to the methanator and gas clean-up processes: thus, no gaseous impact generators are produced directly by the shift reaction. However, the iron catalyst used in the reaction may pose some slight environmental hazard when eventually disposed of.

### 11. Wastewater Treatment.

Wastewater treatment is designed to remove the suspended solids, oil, grease, and dissolved constituents, oxidize organic compounds, and to adjust the pH value of the effluent. Generally, the wastewater treatment process uses some form of settling basin plus anaerobic or aerobic decomposition to improve water quality. Chemicals are often added for pH control and to precipitate dissolved solids.

The major environmental questions concern the efficiency and completeness of the treatment process, solid residuals disposal, and, in some cases, methane gas disposal. Surface and groundwater quality and quantity relate to the type (e.g. lagoons versus land application) and efficiency (e.g. primary versus tertiary) of treatment and leachate formation from residuals disposal. Air quality problems relate to odors from wastewater treatment facilities and residuals disposal areas and the release or burning of methane and/or hydrogen sulfide waste gases. Wastewater treatment may involve land resources if land application techniques are utilized. Residual solids disposal utilizes land and landfill resources.

### 12. Solid Waste Disposal.

Solid wastes from the gasification, gas clean-up, and wastewater treatment processes are generally disposed of in a sanitary landfill. Process wastes include coal fines, slag, char, bottom ash, fly ash, and spent acceptor. Gas clean-up produces elemental sulfur while wastewater treatment produces sewage sludge. Some solid wastes may also be incinerated, leaving an ash residue to be disposed of in a landfill.

Many of the solid wastes of coal conversion and utilization have actual or potential commercial value (char, sulfur, calcium sulfate, fly ash, etc.). In some cases, the fate of such materials as are sold may be an appropriate subject for environmental monitoring.

Surface and groundwater quality questions relate to leachate formation and the solution of solid wastes in the hydrologic environment. Surface waters receive coal and ash fines and dissolve solids and metals. Surface water pH may also be adversely affected. Groundwater also dissolves solids and metals, and its pH may be affected. Air quality is affected by landfill gas generation and solid waste incineration which produce methane, organics, CO, and which release some metals to the atmosphere. Coal fines, char, grease and oil, etc. could support combustion, resulting in air pollution from a landfill fire.

The major resource utilized is the landfill site. In areas where suitable sites are rare, landfill availability could be a factor which should be monitored to ascertain the effect of solid wastes from gasification and utilization activities on competing landfill uses.

## 13. Other Ancillary Processes.

a. Fired Boilers and Heaters: Process requirements for steam, preheated reactants, and other heat-requiring steps in most of the coal conversion processes are supplied by conventional fired boilers and heaters. In many instances, these are fueled by char recycled from the primary reactor vessels. Natural gas, oil, and direct coal combustion may also be used.

Impact generators from these process components are limited to flue gases and, for some fuels, ash. The char burns relatively cleanly and with little ash because most of these fractions remain in the main reactor vessel from which the char is obtained.

b. Cooling Processes: Cooling of product streams is required in a number of processes to separate product fractions and to remove heat prior to heat-sensitive processes. This is generally indirect, non-contact water cooling, resulting in impact generators common to conventional combustion processes. In some applications, the waste heat is used to generate steam for other process steps; in others, the heat is vented to the atmosphere, with resulting water vapor and some aerosol solids, or is discharged to water bodies, causing increased ambient temperatures in aquatic ecosystems. In some situations, large-scale waste heat rejection can result in localized meterological disturbances. The water used in waste heat rejection can be expected to contain various anti-corrosion agents and biocides intended to protect process components. Noise and water consumption may be considerable, depending on process components and configuration.

c. Oxygen Production: The use of oxygen is preferred over air in high-Btu gasification because nitrogen in the latter will dilute the product gas, thereby reducing its heat value on a volume basis. The typical oxygen production process involves a multi-staged air separation. Air is filtered, then stripped of water and carbon dioxide by a molecular sieve. It is then liquified by refrigeration. Nitrogen, oxygen, and other gases are then separated by fractional distillation of this liquid.

Impact generators include (1) the atmospheric gases and particulates removed and concentrated by the process and (2) condensate water produced in the liquification step. In addition to the oxygen, both liquid nitrogen and argon have commercial value and are unlikely to be discarded. The process also requires a great amount of electric power to refrigerate the gases to a liquid state. This power requirement is likely to be provided by a generator remote from the site; if not, the impacts of power generation need to be considered in a monitoring program. In any case, there will be a large waste-heat rejection requirement.

## B. CHEMICAL NATURE OF RAW MATERIALS, PRODUCTS, BY-PRODUCTS, AND WASTES OF COAL PLANTS.

### 1. Coals.

Coals are ranked from anthracite, bituminous, and sub-bituminous, to lignite (highest to lowest rank), based on their heat content and physical and chemical characteristics. However, only bituminous, sub-bituminous, and lignite are used in coal conversion processes. The following discussion divides coal constitutents into three broad categories: organics, minor inorganics, and trace inorganics.

The typical concentrations of the macro-constituents of coals are shown in Table III-5. Most of the carbon, hydrogen, oxygen and nitrogen present in coal is in an organic form.

Coal consists predominantly of organic matter, usually ranging (by weight) from 80 to 97 percent and averaging 90 percent. However, coal may contain as little as 50 percent organic matter by weight. Structurally, coals consist of a large number of condensed aromatic ring units linked together by C-C linkages or aliphatic groups. The higher the number of rings per structural unit, the higher the coal ranking (i.e. anthracite contains 5 or 6 rings per unit, while lignite and lower rank coals contain 4 or 5 rings). Generally, the higher the number of rings, the lower the amount of inorganic or mineral matter is likely to be contained in the coal. In higher-rank coals, 60 to 90 percent of the carbon present may be tied up in aromatic ring compounds. The remaining carbon is usually bound up with oxygen and hydrogen in functional groups such as hydroxyl, carboxyl, and carbonyl groups. In addition to binding carbon into one of several functional groups, oxygen decreases the heating value of the coal. The higher the oxygen content, the lower the rank of coal (e.g., lignites contain up to 30 percent oxygen by weight while anthracites have as little as 1.5 percent). Nitrogen in coal is almost completely bound in organic compounds such as pyrroles and pyritines. Sulfur is present in both organic and inorganic forms. Organic forms, primarily ring sulfur compounds (thiophene and benzothiophene derivatives), are the primary sulfur compounds in low-sulfur coals. Inorganic sulfur is mainly in the form of pyrite.

Mineral matter in coal, all of which is inorganic, may account for up to 50 percent of the coal by weight; however, it averages ten percent and generally ranges from 3 to 20 percent (see Table III-5).

Table III-5. Typical concentrations of macro-constituents in coal (percent dry weight basis).

| Constituent | Anthracite[1] | Bituminous[2] |  | Sub-Bituminous[2] | Lignite[2] |
|---|---|---|---|---|---|
|  |  | Low Volatile | High Volatile |  |  |
| Carbon | 92-94 | 83.8 | 77.1 | 72.9 | 64.5 |
| Hydrogen | 3.0-4.0 | 4.2 | 5.1 | 5.3 | 4.3 |
| Oxygen | 3.4 | 2.6 | 6.4 | 14.8 | 18.0 |
| Nitrogen | - | 1.2 | 1.5 | 1.2 | 1.0 |
| Sulfur | - | 0.6 | 1.5 | 0.9 | 1.1 |
| Ash | - | 7.6 | 8.4 | 4.9 | 11.1 |
| Volatile Matter | 15 | 17.3 | 36.5 | 41.5 | 40.8 |
| Moisture in Raw State | <5 | - | - | - | - |

[1] Wilson, P.J., 1950.
[2] Wender, I., 1975 in Mezey, 1976.

Mineral matter, or ash, consists of minor constitutents and micro or trace constitutents. Minor elements--i.e. sodium, potassium, iron, calcium, magnesium, silicon, aluminum, and titanium--occur in concentrations of about one percent (or more), dry weight ash basis, while the trace elements listed in Table III-6 occur in concentrations of 0.1 percent or less, dry weight ash basis. The sources of minor and trace elements found in coal ash are presented in Table III-7.

Potential environmental impacts derive from the volatility of these materials during combustion and gasification and/or their solubility. During combustion, vanadium may react with alkali to form a vanadate slag at high temperatures. Fluorides are released in fly ash. Most of the other trace metals are converted to oxides and are released as fly ash or remain in bottom ash. Germanium and gallium are contained in fly ash. Several heavy metals such as mercury, gold, and silver may appear in free elemental form.

Solubility is a factor in both coal and process solid waste products. Coal pile runoff and seepage are similar in quality to acid mine drainage. Sulfides in the coal are oxidized, forming soluble sulfate. At the same time, iron may enter into solution, and the hydrogen ion concentration is elevated. In addition, trace elements, i.e. zinc, copper, and chromium, enter into solution. Coal pile runoff also contains large concentrations of total dissolved solids. Concentrations of pollutants in coal pile runoff and leachate are presented in Table III-8. Information on the solubility of other minor and trace elements in coal is not available at this time.

Table III-6. Minor and trace elements in coal ash.

| Name of Element | Symbol | Twelve Raw Coals[a] Range of Concentration | Twelve Raw Coals[a] Frequency of Occurrence | NBS-EPA Round Robin Coal Sample Mean Concentration, | Illinois State Geol. Survey - Mean Analytical Values for Chemical Element in coal |
|---|---|---|---|---|---|
| Aluminum | Al | 3,000-23,000 | 100 | 15,700 | 12,900 |
| Antimony | Sb | <0.1-2 | 92 | 6.4 | 1.26 |
| Arsenic | As | 1-10 | 100 | 5.9 | 14.02 |
| Barium | Ba | 20- 1,600 | 100 | 337 | --- |
| Beryllium | Be | 0.4- 3 | 100 | --- | 1.61 |
| Bismuth | Bi | <0.1-0.2 | 31 | --- | --- |
| Boron | B | 1-230 | 100 | --- | 102.21 |
| Bromine | Br | 1-23 | 100 | 20 | 15.42 |
| Cadmium | Cd | <0.01-0.7 | 92 | --- | 2.52 |
| Calcium | Ca | 800-6,100 | 100 | 4,070 | 7,700 |
| Cesium | Ce | 1-30 | 100 | 17,340 | --- |
| Chlorine | Cl | 10-1,500 | 100 | 750 | 1,400 |
| Chromium | Cr | 26-400 | 100 | 19 | 13.75 |
| Cobalt | Co | 1-90 | 100 | 5.48 | 9.57 |
| Copper | Cu | 3-180 | 100 | 14.1 | 15.16 |
| Dysprosium | Dy | <0.1-5 | 85 | 0.85 | --- |
| Europium | Eu | <0.1-04 | 100 | 0.312 | --- |
| Fluorine | F | 1-110 | 100 | --- | 60.94 |
| Gallium | Ga | 0.3-10 | 100 | 5.4 | 3.12 |
| Germanium | Ge | 0.03-1 | 100 | 70 | 6.59 |
| Gold | Au | <0.1 | 0 | 0.146 | --- |
| Hafnium | Hf | 0.3-4 | 46 | 0.92 | --- |
| Indium | In | --- | -- | 0.04 | --- |
| Iodine | I | <0.1-4 | 85 | 2.78 | --- |
| Iridium | Ir | <0.2 | 0 | 2.48 | --- |
| Iron | Fe | 1,400-12,000 | 100 | 7,517 | 19,200 |
| Lanthanum | La | 0.3-29 | 100 | 11.3 | --- |
| Lead | Pb | 1-36 | 100 | --- | 34.78 |
| Lithium | Li | 4-163 | 100 | --- | --- |
| Lutetium | Lu | <0.1-0.3 | 38 | 0.416 | --- |
| Magnesium | Mg | 500-3.500 | 100 | 980 | 500 |
| Manganese | Mn | 5-240 | 100 | 38.0 | 49.40 |
| Mercury | Hg | <0.3-0.5 | 38 | 0.95 | 0.20 |
| Molybdenum | Mo | 1-5 | 100 | --- | 7.54 |
| Neodymium | Nd | 4-36 | 100 | 6.4 | --- |
| Nickel | Ni | 3-60 | 100 | --- | 21.07 |
| Phosphorus | P | 6-310 | 100 | --- | 71.10 |
| Potassium | K | 300-6,500 | 100 | 3,500 | 1,600 |
| Rubidium | Rb | 1-150 | 100 | 19 | --- |
| Samarium | Sm | 1-6 | 100 | 1.3 | --- |
| Scandium | Sc | 3-30 | 100 | --- | --- |
| Selenium | Se | 0.04-0.3 | 100 | 3.8 | 2.08 |
| Silicon | Si | 5,000-41,000 | 100 | --- | 24,900 |
| Silver | Ag | <0.1-3 | 92 | --- | --- |
| Sodium | Na | 100-1,000 | 100 | 370 | 500 |
| Strontium | Sr | 17-1,000 | 100 | 93 | --- |
| Sulfur | S | 700-10,000 | 100 | --- | --- |
| Tantalum | Ta | <0.1-8 | 62 | 0.360 | --- |
| Tellurium | Te | <0.1-0.4 | 85 | --- | --- |
| Terbium | Tb | <0.1-2 | 85 | 0.03 | --- |
| Thallium | Tl | <0.1-0.3 | 31 | --- | --- |
| Thorium | Th | <0.1-5 | 92 | 3.1 | --- |
| Tin | Sn | 1-47 | 100 | 125 | 4.79 |
| Titanium | Ti | 200-1,800 | 100 | 1,312 | 700 |
| Tungsten | W | <0.1-0.4 | 69 | 1.9 | --- |
| Uranium | U | <0.1-1 | 92 | 0.980 | --- |
| Vanadium | V | 2-77 | 100 | 36 | 32.71 |
| Ytterbium | Yb | <0.1-0.5 | 62 | 0.55 | --- |
| Yttrium | Y | 3-25 | 100 | --- | --- |
| Zinc | Zn | 3-80 | 100 | --- | 272.29 |
| Zirconium | Zr | 28-300 | 100 | --- | 72.46 |
| Number of Elements Reported | 61 | 60 | 60 | 42 | 32 |

Footnotes:

a. 13 Raw coals analyzed by Spark Source Mass Spectrometry; all values in parts per million weight, frequency of occurrence values in percent. Source: Kessler, *et. al.* (1973) *in* Mezey *et. al.* (1976).

b. Analysis performed by NASA Lewis Research Center, values in parts per million, weight. Source: Sheibley (1975) *in* Mezey, *et. al.* (1976), and Ruch, *et. al.* (1974).

c. Analyses primarily by neutron activation, 101 varieties of coals.

Table III-7. Source of minor and trace elements in coal.

| Source | Minor Element | Trace Element |
|---|---|---|
| Shales and Clays | Silicon, Aluminum, Titanium, Potassium | Boron, Copper, Fluorine, Mercury, Tin, Vanadium |
| Sulfides | Iron | Zinc, Cadmium, Lead, Nickel, Copper, Mercury, Boron, Arsenic, Beryllium, Antimony, Germanium |
| Carbonates | Magnesium, Calcium | Manganese, Boron, Molybdenum, Selenium, Uranium |
| Chlorides | Sodium, Potassium, Magnesium, Calcium | Chlorine, Bromine, Iodine |
| Quartz | Silicon | Boron, Chromium, Manganese, Cadmium, Molybdenum, Germanium, Selenium, Vanadium, Zinc |
| Apatite | Calcium, Potassium | Fluorine, Arsenic, Vanadium, Chlorine Manganese, Cesium |
| Sulfates | Iron, Calcium | Manganese |

Source: Mezey, 1976.

Table III-8. Concentrations of pollutants in coal pile runoff and leachate (mg/l).

| Pollutant | Mean | Range |
|---|---|---|
| pH | 2.7 | 2.1-3.0 |
| Iron | 19,540 | 0.17-93,000 |
| Sulfate | 9,006 | 525-21,920 |
| Zinc | 3.64 | 1.6-23.0 |
| Copper | 2.10 | 1.6-3.4 |
| Chromium | 3.27 | 0-15.7 |
| Total Dissolved Solids | 16,440 | 720-44,050 |

Source: Anderson, W.C. & M.P. Youngstrom, 1976. Journal of Environmental Engineering Div., ASCE, Vol. EE6, 1239-125

## 2. Acceptors.

Acceptors are used in fluidized bed combustion and the $CO_2$ Acceptor gasification process to remove sulfur and carbon dioxide from the process gas within the combustion chamber or reactor vessel. In the $CO_2$ Acceptor process, the acceptor also provides a source of oxygen for the reaction. Limestone ($CaCO_3$--calcium carbonate) and dolomite ($(Ca,Mg)\ CO_3$--calcium, magnesium carbonate) are the two types of acceptors. However, dolomite is favored because it has a higher regenerative capacity after each process run (dolomite requires the addition of only 25 percent new materials to maintain reactivity after 10 runs; limestone requires in excess of 25 percent). Therefore, use of dolomite as acceptor reduces solid waste production.

Limestone and dolomite, by the nature of their formation, contain several common impurities: silica (quartz, chalcedony, chert), feldspar, clay minerals (illite and kaolinite), glauconite, collophane, pyrite, and bituminous matter. All occur in minor amounts except chert, which may be a major impurity. The types and sources of minor and trace elements in limestone and dolomite are presented in Table III-9. Chemical compositional information for limestones is presented in Table III-10 and for dolomites in Table III-11.

Table III-9. Types and sources of minor and trace elements in limestone and dolomite.

| Source | Element |
|---|---|
| Quartz, Chalcedony, Chert | Silicon, Nickel, Iron |
| Feldspar | Potassium, Sodium, Aluminum, Silicon |
| Illite, Kaolinite (Clay Minerals) | Aluminum, Silicon, Iron, Magnesium, Calcium, Potassium, Sodium, Titanium |
| Glauconite | Potassium, Magnesium, Iron, Aluminum, Silicon |
| Collophane | Calcium, Fluorine, Chlorine, Phosphorus |
| Pyrite | Iron, Sulfur |

Potential environmental impacts relate to the solubility of stored acceptor and landfilled spent acceptor. Calcium and magnesium carbonate ($CaCo_3$ and $MgCO_3$) are highly soluble, and all minor and trace elements are free to enter the aqueous system.

### 3. Product Gases.

Composition of low-Btu product gases for the various gasification processes is presented in Table III-12. Low-Btu product gas consists predominantly of carbon monoxide and hydrogen, with lesser amounts of carbon dioxide and nitrogen.

High-Btu product gases for the various gasification processes are also presented in Table III-12. All product gases consist predominantly of methane ($CH_4$) with hydrogen gas and carbon dioxide being the two major impurities after methanation. Methanation reacts both carbon monoxide and carbon dioxide with hydrogen to produce methane and water.

### 4. Synthetic Crude Oils and Liquid Boiler Fuels.

Synthetic liquid boiler fuels and synthetic crude oils (syncrude) are the products of coal liquefaction processes (COED, H-Coal, and SRC). The crude chemical composition of the products of the first two of these processes is presented in Table III-13. Organic constituents of H-Coal residual fuel oil are available and are presented in Table III-14, as defined by temperature of distillation.

Chemical analyses of the Solvent Refined Coal product are not available at present. The only information at hand is:

| | |
|---|---|
| Ash Content | 0.3% |
| Sulfur Content | 0.6%. |

Table [illegible]-10. Chemical composition of limestones (in percent).

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 5.19 | 0.70 | 7.41 | 2.55 | 1.15 | 13.80 | 2.38 | 0.09 | 1.27 | 1.02 | 15.05 | 1.23 | 8.33 | 6.72 | 4.13 | 7.11 | 13.44 | 0.56 | 1.90 | 19.82 |
| $TiO_2$ | 0.06 | - | 0.14 | 0.02 | - | - | - | - | - | - | - | - | 0.25 | - | - | - | 0.23 | 0.01 | 0.04 | - |
| $Al_2O_3$ | 0.81 | 0.68 | 1.55 | 0.23 | 0.45 | 7.00 | 1.57$^{a}$ | 0.11$^{b}$ | 0.73$^{b}$ | 0.24$^{b}$ | 9.02 | 2.76$^{b}$ | 0.43 | 5.92$^{b}$ | 0.78 | 2.10 | 4.55 | 0.45 | 1.06 | 5.40 |
| $Fe_2O_3$ | 0.54$^{c}$ | 0.08 | 0.70 | 0.02 | - | 4.55 | 0.56 | b | b | b | 1.27 | b | 0.11 | b | 0.42 | 0.86 | 0.56 | 0.03 | 1.10 | ND |
| FeO | c | - | 1.20 | 0.18 | 0.26 | - | - | b | b | b | - | b | - | b | - | - | 0.88 | 0.17 | 2.01 | - |
| MnO | 0.05 | - | 0.15 | 0.04 | - | 0.29 | - | - | - | - | - | - | - | - | - | - | 0.06 | 0.05 | 0.21 | - |
| MgO | 7.90 | 0.59 | 2.70 | 7.07 | 0.56 | 1.32 | 0.59 | 0.35 | 1.39$^{d}$ | 0.93$^{d}$ | 3.96$^{e}$ | 1.05$^{e}$ | 5.68$^{d}$ | 0.66 | 4.36$^{d}$ | 2.42 | 1.94 | 2.74 | 0.44 | 2.72 |
| CaO | 42.61 | 54.54 | 45.44 | 45.65 | 53.81 | 38.35 | 52.48 | 55.30 | 97.24$^{d}$ | 97.81 | 70.10$^{d}$ | 80.71$^{d}$ | 85.40$^{d}$ | 47.84 | 89.76$^{e}$ | 47.94 | 41.84 | 51.63 | 51.05 | 38.90 |
| $Na_2O$ | 0.05 | 0.16 | 0.15 | 0.01 | 0.07$^{f}$ | 2.61 | - | - | - | - | - | - | - | - | - | - | 0.31 | <0.01 | 0.02 | - |
| $K_2O$ | - | - | - | 0.03 | f | 0.86 | - | 0.04 | - | - | - | - | - | - | - | - | 0.72 | <0.01 | 0.04 | - |
| $H_2O+$ | 0.56$^{g}$ | - | 0.38 | 0.05 | 0.69 | - | - | 0.32$^{h}$ | - | - | - | - | - | - | - | - | 1.55$^{h}$ | 0.12 | 0.35 | - |
| $H_2O-$ | 0.21 | - | 0.30 | 0.18 | 0.23 | - | - | h | - | - | - | - | - | - | - | - | h | 0.10 | 0.14 | - |
| $P_2O_5$ | 0.04 | - | 0.16 | 0.04 | - | 0.25 | - | - | - | - | - | - | - | 40.20$^{i}$ | - | - | 0.22 | 0.05 | 0.16 | - |
| $CO_2$ | 41.58 | 42.90 | 39.27 | 43.60 | 42.69 | 31.31 | 41.85$^{j}$ | 43.11 | - | - | - | - | - | i | - | 39.79 | 32.94 | 43.64 | 41.62 | 33.10 |
| $SO_3$ | 0.05 | 0.06 | 0.02 | 0.03 | - | - | - | 0.44 | - | - | - | - | - | i | - | - | - | <0.01 | 0.02 | - |
| S | 0.09 | 0.25 | 0.25$^{k}$ | 0.30$^{k}$ | - | - | - | - | - | - | - | - | - | i | - | - | 0.33 | 0.42 | 0.06 | - |
| Cl | 0.02 | - | - | - | - | - | - | - | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| BaO | - | - | - | 0.01 | - | - | - | - | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| SrO | - | - | - | 0.01 | - | - | - | - | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| $Li_2O$ | T | - | - | - | - | - | - | - | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Organic | - | T | 0.09 | 0.04 | - | - | - | 0.17 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |

**Notes:**

a. includes $TiO_2$
b. includes $Al_2O_3$, $Fe_2O_3$, and FeO
c. includes $Fe_2O_3$ and FeO
d. MgO = 47.8% of $MgCO_3$
e. quoted as $CaCO_3$ and $MgCO_3$, CaO=56.15% $CaCO_3$
f. includes $Na_2O$ and $K_2O$
g. includes organic matter
h. includes $H_2O+$ and $H_2O-$
i. Includes $P_2O_5$, $CO_2$, $SO_3$, and S
j. calculated from MgO and CaO
k. calculated as pyrite
T trace
ND no data

Sources:

1 - Composite analyses of 345 limestones. H.N. Stokes, analyst, Clark, 1924, 564.
2 - Indiana limestone (Salem, Mississippian). E.W. Epperson, analyst, Laughlin, 1929, 150.
3 - Crystalline crinoidal limestone (Brassfield, Silurian), Ohio. D. Schaaf, analyst, Stout, 1941, 77.
4 - Dolomite limestone (Monroe, Devonian), Ohio. D. Schaaf, analyst, Stout 1941, 132.
5 - Lithographic limestone (Solenhofen, Bavaria). G. Steiger, analyst, Clark, 1924, 195.
6 - Argillaceous limestone, Natural Cement Rock (Lower Freeport), Ohio. P. Demerest, analyst, Stout and Lamborn, 1924, 195.
7 - Chalk (Fort Hayes, Cretaceous), Kansas. Runnels and Dubins, 1949.
8 - Travertine, Mammoth Hot Springs (Arkansas). F. Gooch, analyst, Clarke, 1924, 323.
9 - Coeymans at Howes Cave, N.Y., N.Y. State Museum Bulletin 223-4, 161.
10- Quarry No. 22, Bellefonte, Pa. Quoted by Butts and Moore.
11- Typical cement rock (Trenton), Bethlehem, Pa. E. Eckel, "Portland Cement Materials in the U.S.," U.S.G.S. Bulletin 522, 1913, 318.
12- Selma Chalk, Dallas County, Alabama.
13- St. Louis (Mississippian), South Central Indiana. M. Coller, analyst, D. McGregor, Ind. Geol. Survey.
14- LaSalle, Illinois. J. Lamar, personal communication.
15- St. Louis (Mississippian), Missouri Cement Co. quarry.
16- Platteville, Dixon, Illinois. J. Lamar, personal communication.
17- Northampton, Pa., Cement Rock, Dexter, Portland Cement Co. R. Miller, Limestones of Pennsylvania, 121.
18- Brassfield Limestone, West Milton, Miami County, Ohio. Ohio Geol. Survey Bulletin 42, 43.
19- Vanport Limestone, Puritan Brick Co., near Hamden, Vinton County, Ohio. Ohio Geol. Survey, Bulletin 48, 431.
20- Typical limestone in Lehigh Valley. W. Meyers, "Cement Materials," Ind. Minerals and Rocks, 2nd ed., 165.

Table III-11. Chemical composition of dolomites (in percent).

| Constituent | Source | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| $SiO_2$ | - | 2.55 | 7.96 | 3.24 | 24.92 | 0.73[a] | 0.70 | 0.18 | 0.11 | 4.46 | 0.65 | 0.14 |
| $TiO_2$ | - | 0.02 | 0.12 | - | 0.18 | - | - | - | - | - | - | 0.01 |
| $Al_2O_3$ | - | 0.23 | 1.97 | 0.17 | 1.82 | 0.20 | 0.63 | 0.08 | 0.30 | 0.34 | 0.92[b] | 0.04 |
| $Fe_2O_3$ | - | 0.02 | 0.14 | 0.17 | 0.66 | - | - | 0.21 | 0.19 | 0.47 | [b] | 0.02 |
| FeO | - | 0.18 | 0.56 | 0.06 | 0.40 | 1.03 | - | - | - | - | - | 0.10 |
| MnO | - | 0.04 | 0.07 | - | 0.11 | - | - | - | - | - | - | - |
| MgO | 21.9 | 7.07 | 19.46 | 20.84 | 14.70 | 20.48 | 43.00[c] | 41.20[c] | 20.45 | 20.22 | 43.22[c] | 21.12 |
| CaO | 30.4 | 45.65 | 26.72 | 29.58 | 22.32 | 30.97 | 55.41[c] | 58.30[c] | 31.20 | 29.40 | 55.23[c] | 29.45 |
| $Na_2O$ | - | 0.01 | 0.42 | - | 0.03 | - | - | - | 0.06 | - | - | 0.01 |
| $K_2O$ | - | 0.03 | 0.12 | - | 0.04 | - | - | - | - | - | - | 0.01 |
| $H_2O+$ | - | 0.05 | 0.33 | 0.30[d] | 0.42 | - | - | - | - | - | - | 0.01 |
| $H_2O-$ | - | 0.18 | 0.30 | [d] | 0.36 | - | - | - | - | - | - | 0.15 |
| $P_2O_5$ | - | 0.04 | 0.91 | - | 0.01 | 0.05 | - | - | - | - | - | 0.05 |
| $CO_2$ | 47.70 | 43.60 | 41.13 | 45.54 | 33.82 | 47.51 | - | - | 47.87 | - | - | 46.15 |
| $SO_3$ | - | 0.03 | - | - | 0.01[e] | - | ND | ND | ND | ND | ND | ND |
| S | - | 0.30[e] | 0.19 | - | 0.16[f] | - | ND | ND | ND | ND | ND | ND |
| BaO | - | 0.01[f] | - | - | - | - | ND | ND | ND | ND | ND | ND |
| SrO | - | 0.01[f] | - | - | - | - | ND | ND | ND | ND | ND | ND |
| Organic | - | 0.04[g] | - | - | 0.08[g] | - | ND | ND | ND | ND | ND | ND |

Notes:

a. includes $TiO_2$
b. includes $Al_2O_3$ and $Fe_2O_3$
c. reported as $CaCO_3$ and $MgCO_3$
d. includes $H_2O+$ and $H_2O-$
e. calculated as pyrite
f. constituent does not exceed figure given
g. organic carbon

Sources:

1 - Theoretical composition of pure dolomite.
2 - Monroe Formation (Devonian); D. Schaaf, analyst, Stout, 1941, 564.
3 - Niagara limestone (Silurian), Joliet, Illinois; D. Higgins, analyst, Fisher, 1925, 34.
4 - Knox dolomite (Cambro - Ordivician), Morrisville area; W. Hildebrand, analyst, Russell, 1889, 45.
5 - Cherty dolomite, Niagara Highland Co., Ohio; D. Schaaf analyst, Stout, 1941, 82.
6 - Randville dolomite (Cretaceous), Dickinson County, Michigan; E. Brewster, analyst, Bayley, 1904, 215.
7 - Ketona, quarried at Dolonah, Ala. for flux stone; E. Ball and A. Beck, Eng. Min. Jour., Sept. 1938.
8 - Huntington dolomite (Silurian), northern Indiana; M.Coller, analyst, D. McGregor, Ind. Geol. Survey.
9 - Niagara dolomite, Illinois; J. Lamar.
10- Knox dolomite, Norris Reservoir.
11- Merion Lime and Stone Co., Bridgeport, Pa.; B. Miller, Limestones of Pa., 84, analysis.
12- 80 feet of Guelph dolomite; D. Schaaf, analyst, Ohio Geol. Survey Bulletin 42, 414.

Adapted from Gillson, J.L. (ed.), 1960; and Pettijohn, F.J.

Table III-12. Typical chemical composition of product gases from coal gasification (in volume percent, dry gas).

| Component | Low Btu Gas | High Btu Gas |
|---|---|---|
| Methane ($CH_4$) | 0.1 | 90.5 - 95.9 |
| Carbon Monoxide (CO) | 60.9 | 0.1 |
| Hydrogen ($H_2$) | 32.6 | 0.8 - 6.6 |
| Carbon Dioxide ($CO_2$) | 5.2 | 0.1 - 3.7 |
| Hydrogen Sulfide ($H_2S$) and Carbonyl Sulfide (COS) | 0.03 | - |
| Nitrogen ($N_2$) | 1.2 | 0.2 - 2.1 |
| Higher Hydrocarbons | ND | ND |

Source: From Magee (1976), p. 32. Values for low Btu gas from Koppers-Totzek process; High Btu gas values from Synthane, Lurgi, $CO_2$ Acceptor, Bi-Gas, and Hygas processes. Minimum-maximum range given.

5. Liquid By-Products. Liquid by-products are produced mainly in liquefaction processes (Table III-15). The major by-products are light and heavy oils and distillates.

These liquid by-products consist of organic compounds, although the exact composition of these materials is unknown at this time. It is known that certain organic compounds are present in coal tars. The major constituents of coal tar derived by destructive distillation of coal are shown in Table III-16. The same compounds are probably predominant in the liquid by-products of coal conversion.

It is unlikely that these compounds will be released to the environment in massive amounts because they are commercially valuable. However, minor amounts may appear as components of waste streams.

Table III-13. Crude chemical composition of COED and H-Coal coal liquefaction products (in weight percent).

| Constituent | COED Syncrude |  | H-Coal Syncrude or Residual Fuel Oil |  |
|---|---|---|---|---|
|  | a | b (Sic) | a (Sic) | b |
| Carbon | 87.1 | ND | ND | 83.70-87.50 |
| Hydrogen | 10.9 | 9.48 | 9.48 | 8.60-11.00 |
| Nitrogen | 0.3 | 0.68 | 0.68 | 0.16-1.00 |
| Oxygen | 1.6 | ND | ND | 1.30-6.50 |
| Sulfur | 0.1 | 0.19 | 0.19 | 0.04-0.20 |
| Ash | <0.01 | ND | ND | 0 |
| Moisture | 0.1 | ND | ND | ND |

ND=no data

Sources: a. Magee, 1976
b. Lantz, 1975

Table III-14. Organic constitutents of H-coal residual fuel oil product (in weight percent)

| Constituent | Illinois No. 6 Coal | Wyoming Subbituminous Coal |
|---|---|---|
| > 400°F Fraction | | |
| Saturated $C_4$-$C_{12}$ Compounds | 11.99 | 14.70 |
| Olefins | | 4.24 |
| Alkyl Benzenes | 17.55 | 14.13 |
| Saturated Naphthenes | 51.33 | 42.91 |
| Unsaturated Naphthenes | 11.20 | 16.66 |
| Indans, Naphthalenes, and Phenols | 7.93 | 7.61 |
| | 100 | 100 |
| 400° to 650°F Fraction | | |
| Saturated Paraffins | 31.0 | 22.2 |
| Aromatics | 59.4 | 65.8 |
| Unsaturated Paraffins | 4.3 | 4.5 |
| Phenols and Others | 5.1 | 7.5 |
| | 100 | 100 |
| 650° to 919°F Fraction | | |
| Saturated Paraffins | 6.8 | 10.7 |
| Unsaturated Non-aromatics | 1.6 | 1.5 |
| Alkyl Benzenes, Indans, Phenolics and Other Aromatics | 91.6 | 87.4 |
| | 100 | 100 |

Source: Lantz, 1975 (pp. 14-15, 17-18)

Table III-15. Liquid by-products from coal conversion processes.

| Process | Liquid By-Product |
|---|---|
| SRC | None |
| CONSOL | Light Distillate |
| Synthoil | None |
| H-Coal | Heavy Distillate, Light Distillate |
| COED | None |
| Direct Hydrogenation | Light Oil |
| Clean Metallurgical Coke/Liquids | Gasoline, Benzene, Naphthalene, Residual Tars |
| Hy-Gas | Residual Tars |

Table III-16. Major constituents of coal tar.

| Fraction | Distillation Temperature (°C) | Constituent |
|---|---|---|
| Light Oil | <110 | Benzene<br>Toluene<br>Xylenes<br>Thiophene |
| | 110-140 | Xylenes |
| | 140-170 | Xylenes<br>Cumenes<br>Mesitylene |
| Middle Oil (Carbolic Oil) | 170-230 | Naphthalene<br>"Phenols"<br>Phenol<br>Cresols<br>Xylenols<br>Pitch<br>Pyridine<br>Picolines<br>Hemitene |
| Heavy Oil (Creosote Oil) | 230-270 | Naphthalene<br>Cresols<br>Higher Phenols<br>Naphthol<br>Quinoline |
| Green Oil (Anthracene Oil) | 270-360 | Anthracene<br>Phenanthrene<br>Carbazole |
| Pitch (residue left in retort) | | |

## 6. Waste Gases.

Waste gases from the gasification and liquefaction processes are characterized in Table III-17. The major waste gases are hydrocarbons, ammonia, and hydrogen sulfide from liquefaction reactors and, for gasification, carbon dioxide and tail gas from the acid gas removal process and sulfur removal plant, respectively. Trace or greater amounts of hydrogen, carbon monoxide, methane, hydrogen sulfide, carbonyl sulfide, carbon disulfide, ammonia, and volatile higher organics may escape as fugitive emissions or with gas clean-up process emissions. Waste gases may also include volatile trace metals such as mercury, bromine, fluorine, antimony, gallium, selenium, arsenic, molybdenum, and vanadium.

Table III-17. Composition of waste gases from coal gasification and liquefaction.

| Process | Waste Gas |
|---|---|
| Liquefaction: | |
| H-Coal | Hydrocarbon Gas, Ammonia, Hydrogen Sulfide[1] |
| SRC | Hydrocarbon Gas[1] |
| CONSOL | Hydrocarbon Gas[1] |
| Synthoil | Ammonia |
| Direct Hydrogenation | None[1] |
| COED | Hydrocarbon Gas, Hydrogen Sulfide, Ammonia[1] |
| Gasification: | |
| $CO_2$-Acceptor | Flue Gas, Carbon Dioxide, Tail-gas, Regenerator Off-gas, Regenerator Ash Desulfurization Off-gas[2] |
| Bi-Gas | Carbon Dioxide, Tail-gas[1] |
| Synthane | Carbon Dioxide, Tail-gas[1] |
| HYGAS | Carbon Dioxide, Tail-gas[1] |
| Self-Agglomerating Ash Burner | Carbon Dioxide, Tail-gas[1] |
| Fluidized Bed | Carbon Dioxide, Tail-gas[1] |

[1] Magee, 1976. (Note: Tail-gas is off-gas from desulfurization unit).

[2] Massey and Dunlap, 1976.

The waste gases from the coal gasification process will vary according to gas stream and process; however, Dunlap and Massey (1976) have developed a list of gas-phase constituents which are of primary interest and should be monitored:

- Sulfur species: $SO_2$, $SO_3$, COS, $CS_2$, $H_2S$
- Other acid gases: $NO_x$, HCS, HCN, HF
- Organic constituent: $C_2H_6$, $C_2H_4$, $C_3H_8$, $C_3H_6$, $C_4H_{10}$, $C_4H_8$, and other higher boiling point paraffins and aromatics
- Highly volatile trace elements: As, Cd, Hg, Pb, Sb, Se
- Non-volatile or low-volatile trace elements: Be, Cr, Cu, Mn, Mo, Ni, V, Zn.

## 7. Waste Liquids.

The major sources of waste liquids in gasification and liquefaction are the (1) process, (2) gas clean-up, (3) ancillary boilers and cooling towers, and (4) wastewater treatment stages. Process waste liquids include quench waters; residual tars and oils; ash, coal, and acceptor slurry waters; alkali-rich waters; and uncharacterized "foul water." Gas clean-up produces ammonia and "foul water." Boilers and cooling towers produce "blow-down" waters and demineralizers. Deionizers produce regenerant backwash waters high in dissolved solids. Liquid wastes from the plant are collected and sent to the wastewater treatment plant, either on-site or off, and then treated and discharged to the receiving waters.

The chemical characterization of liquid wastes from gasification and liquefaction processes are presented in Table III-18 Process liquids contain elements dissolved from coal and acceptor materials. Acceptor materials also contain large quantities of sulfur removed from the product gas. Ammonia is the major contaminant from the gas clean-up processes. Blow-down contains algicides and corrosion- and scaling-inhibitors.

## 8. Mine Wastes and Coal Cleaning Wastes.

Mine wastes consist of surrounding or overlying non-coal sedimentary rock which is removed in order to reach the desired rock unit. The nature of these materials varies with rock type from geographic locality to locality; however, average chemical and physical compositional values for sedimentary rocks indicate the range of compositions likely to be encountered. Igneous and metamorphic rocks will

Table III-18. Chemical characterization of liquid wastes from coal conversion and utilization processes.

| Type of Effluent | Characterization |
|---|---|
| Coal pile runoff )<br>Coal waste runoff )<br>Spent coal wash medium ) | Coal fines, acid water, organics, coal trace metals, Fe, $SO_4$ |
| Acceptor Pile Runoff | Acceptor fines, Ca and $MgCO_3$, dolomite trace metals |
| Ash or slag pile runoff<br>Ash or slag quench water | Al, Fe, K, Ca, Mg, Ti, Na, Cl, Ba, Sr, Mn, Ce, Sn, Rb, Cu, Y, Cr, Zn, As, La, Th, Br, Se, Co, Sc, I, U, Ca, Mo, Yb, Cs, Sm, Sb, W, Hf, Ta, Hg, In, Lu, Au* |
| Ash slurry filtrate | Hexane, phenols, $NH_3$, C, S, dissolved solids, CN, SCN, suspended solids, toluene**** |
| SRC pile runoff | fine SRC product |
| Boiler blowdown | Tanins, starches, sodium alginate, sodium hydroxide, sodium carbonate, sodium phosphate, sodium aluminate, ethylene diamine, tetracetic acid, nitrilo-triacetic acid, polyacrylates, sodium mannuronate, sodium sulfite, hydrazine, octadecylamine, morpholine, cyclohexylamine, polyglycols, silicones, polyamides** |
| Cooling tower blowdown | Dissolved solids, Cr, Cl, algacides, antifouling chemicals** |
| Once-through cooling water | Dissolved solids, Cr, Cl** |
| Demineralizer/deionizer backwash | Mg, $CO_3$, $SO_4$, Cl, Ca, Na, dissolved solids, Fe, Al, Zn, Cu |
| Gas quench water | Hexane, phenols, $NH_3$, C, S, dissolved solids, CN, SCN, suspended solids, toluene*** |
| Alkaline scrubber bottoms | $CaCO_3$ and other alkalies |
| Ammonia stripper water | Ammonia |
| Condenser water | Suspended solids, Cl, $CO_3$, S, Ca, Fe, Mg, Al, Se, K, Ba, P, Zn, Mn, Ge, As, Ni, Sr, Sn, Ni, Cr, V, Co** |
| Treated Effluent | Dissolved solids, refractory organics |

Sources:

| | |
|---|---|
| * | Guthrie and Cherry, 1976. |
| ** | Dalton•Dalton•Little•Newport, 1975. |
| *** | ERDA #90. |
| **** | Massey and Dunlap, 1976. |

probably not be encountered except in highly faulted and folded areas.

Average chemical compositional data are presented in Table III-19. As would be expected, sandstones are rich in silica ($SiO_2$, in the form of quartz and other silicate minerals); limestones are rich in calcium oxide (CaO, in the form of calcite); and shales are rich in silica ($SiO_2$) and alumina ($Al_2O_3$), the dominant components of clay minerals. Silica and alumina ($SiO_2$ and $Al_2O_3$) are the major components of non-indurated sediments.

Table III-19. Average chemical composition of typical sedimentary rocks (in percent).

| Constituent | Shale | Limestone | Sandstone | Sediment[1] | Sediment[2] |
|---|---|---|---|---|---|
| $SiO_2$ | 58.10 | 5.19 | 78.33 | 57.95 | 44.5 |
| $TiO_2$ | 0.65 | 0.06 | 0.25 | 0.57 | 0.6 |
| $Al_2O_3$ | 15.40 | 0.81 | 4.77 | 13.39 | 10.9 |
| $Fe_2O_3$ | 4.02 | 0.54 | 1.07 | 3.47 | 4.0 |
| FeO | 2.45 | ND | 0.30 | 2.08 | 0.9 |
| MgO | 2.44 | 7.89 | 1.16 | 2.65 | 2.6 |
| CaO | 3.11 | 42.57 | 5.50 | 5.89 | 19.7 |
| $Na_2O$ | 1.30 | 0.05 | 0.45 | 1.13 | 1.1 |
| $K_2O$ | 3.24 | 0.33 | 1.31 | 2.86 | 1.9 |
| $H_2O$ | 5.00 | 0.77 | 1.63 | 3.23 | - |
| $P_2O_5$ | 0.17 | 0.04 | 0.08 | 0.13 | 0.1 |
| $CO_2$ | 2.63 | 41.54 | 5.03 | 5.38 | 13.4 |
| $SO_3$ | 0.64 | 0.05 | 0.07 | 0.54 | - |
| BaO | 0.05 | ND | 0.05 | ND | - |
| C | 0.80 | ND | - | 0.66 | - |
| MnO | - | ND | - | ND | 0.3 |
|  | 100.00 | 99.84 | 100.00 | 99.93 | 100.0 |

[1] Shale 82, sandstone 12, limestone 6 percent; after Leith and Mead.

[2] Poldervaart, "Geol. Soc. of Amer." Spec. Paper 62, 132, 1955.

ND-no data

Source: Mason, 1966.

Elemental abundances in sedimentary rocks are presented in Table III-20. The dominant elements in sandstone and shale are silicon, sodium, magnesium, aluminum, potassium, calcium, titanium, and iron. The major trace elements in sandstone and shale, in addition to titanium, are boron, fluorine, lead, sulfur, vanadium, rubidium, strontium,

Table III-20. Abundances of elements in sedimentary rocks (ppm).

| Element | Shales | Sandstones | Carbonates | Element | Shales | Sandstones | Carbonates |
|---|---|---|---|---|---|---|---|
| Li | 66 | 15 | 5 | Nb | 11 | 0.0X | 0.3 |
| Be | 3 | 0.X | 0.X | Mo | 2.6 | 0.2 | 0.4 |
| B | 100 | 35 | 20 | Ag | 0.07 | 0.0X | 0.0X |
| F | 740 | 270 | 330 | Cd | 0.3 | 0.0X | 0.035 |
| Na | 9,600 | 3,300 | 400 | In | 0.1 | 0.0X | 0.0X |
| Mg | 15,000 | 7,000 | 47,000 | Sn | 6.0 | 0.X | 0.X |
| Al | 80,000 | 25,000 | 4,200 | Sb | 1.5 | 0.0X | 0.2 |
| Si | 73,000 | 368,000 | 24,000 | I | 2.2 | 1.7 | 1.2 |
| P | 700 | 170 | 400 | Cs | 5 | 0.X | 0.X |
| S | 2,400 | 240 | 1,200 | Ba | 580 | X0 | 10 |
| Cl | 180 | 10 | 150 | La | 92 | 30 | X |
| K | 26,600 | 10,700 | 2,700 | Ce | 59 | 92 | 11.5 |
| Ca | 22,100 | 39,100 | 302,300 | Pr | 5.6 | 8.8 | 1.1 |
| Sc | 13 | 1 | 1 | Nd | 24 | 37 | 4.7 |
| Ti | 4,600 | 1,500 | 400 | Sm | 6.4 | 10 | 1.3 |
| V | 130 | 20 | 20 | Eu | 1.0 | 1.6 | 0.2 |
| Cr | 90 | 35 | 11 | Gd | 6.4 | 10 | 1.3 |
| Mn | 850 | X0 | 1,100 | Tb | 1.0 | 1.6 | 0.2 |
| Fe | 47,200 | 9,800 | 3,800 | Dy | 4.6 | 7.2 | 0.9 |
| Co | 19 | 0.3 | 0.1 | Ho | 1.2 | 2.0 | 0.3 |
| Ni | 68 | 2 | 30 | Er | 2.5 | 4.0 | 0.5 |
| Cu | 45 | X | 4 | Tm | 0.2 | 0.3 | 0.04 |
| Zn | 95 | 16 | 20 | Yb | 2.6 | 4.0 | 0.5 |
| Ga | 19 | 12 | 4 | Lu | 0.7 | 1.2 | 0.2 |
| Ge | 1.6 | 0.8 | 0.2 | Hf | 2.8 | 3.9 | 0.3 |
| As | 13 | 1 | 1 | Ta | 0.8 | 0.0X | 0.0X |
| Se | 0.6 | 0.05 | 0.08 | W | 1.8 | 1.6 | 0.6 |
| Br | 4 | 1 | 6.2 | Hg | 0.4 | 0.03 | 0.04 |
| Rb | 140 | 60 | 3 | Tl | 1.4 | 0.8 | 0.0X |
| Sr | 300 | 20 | 610 | Pb | 20 | 7 | 9 |
| Y | 26 | 40 | 30 | Th | 12 | 1.7 | 1.7 |
| Zr | 160 | 220 | 19 | U | 3.7 | 0.45 | 2.2 |

Source: Twekian and Wedepohl, 1961, in Mason, 1966, pp. 80-81.

zirconium, and barium. The dominant elements of carbonate rocks (limestones and dolomites) are magnesium, calcium, aluminum, silicon, potassium, manganese, and iron; the major trace elements are fluorine, titanium, and strontium.

The major environmental problem associated with mine waste results from the oxidation of pyritic materials in the shales removed in the mining process. Oxidation of these materials (spoil in strip mining and gob in underground mining) results in the formation of acid mine drainage (AMD), which has variable chemical characteristics depending on the quantity of material oxidized. Normally, AMD is high in iron and sulfate, with a low pH. Typical chemical analyses for major constituents of effluents from coal refuse piles are presented in Table III-21.

Table III-21. Chemical analysis for effluents from coal refuse piles (mg/l).

| Sample | pH | Total Acidity | $SO_4$ | Fe | Conductivity (umhos/cm) |
|---|---|---|---|---|---|
| 1 | 3.0-5.8 | 6-690 | 60-3,000 | 0.1-30 | 130-4,400 |
| 2 | 2.1-7.5 | 0-34,300 | 106-40,500 | 0.1-6,168 | 600-13,600 |
| 3 | 2.0-4.9 | 85-6,940 | 2,400-10,054 | 170-2,940 | 3,200-16,500 |
| 4 | 3.1-5.2 | 11-300 | 310-3,300 | 40-120 | 640-5,200 |
| 5 | 3.8-6.9 | 7-210 | 690-1,066 | 2.0-6.2 | 840-1,200 |
| 6 | 2.4-2.5 | 2,380-7,020 | 3,629-9,827 | 630-3,400 | 4,200-6,800 |
| 7 | 2.2-8.0 | 0-16,400 | 850-15,200 | 25-5,500 | 1,200-15,000 |
| 8 | 2.4-3.6 | 640-14,400 | 1,200-3,550 | 50-13,500 | ND |

Samples:
1 from 5 sites in eastern Pennsylvania.
2 from 10 sites in western Pennsylvania.
3 from 4 sites in northern West Virginia.
4 from 3 sites in southern West Virginia.
5 from 3 sites in eastern Kentucky.
6 from 2 sites in western Kentucky.
7 from 7 sites in Indiana.
8 from 6 sites in Illinois.

ND: no data.

Source: Adapted from Martin, First Symposium on Mine and Preparation Plant Refuse Disposal, October 22-24, 1974, pp. 32-35.

Coal-cleaning wastes consist of non-coal impurities removed prior to gasification and combustion. Non-coal materials consist of surrounding wall rock and mineral matter.

Chemical characteristics of these materials have been discussed earlier. It should be noted that these wastes may contain pyrite ($FeS_2$) and other sulfides, sulfates, phosphates, and carbonate minerals which may be soluble in surface and groundwaters.

### 9. Process Solid Wastes.

Types of solid wastes vary with the process in question. These solid wastes may be classified as (1) unused raw materials (coal and acceptor), (2) potentially marketable materials (char and sulfur), and (3) waste material (slag, spent acceptor, spent catalyst, mineral residue, tars and solids, spent filter/asbestos and diatomaceous earth, and sludge). The unused raw materials consist of the fine fraction captured in cyclones or collected at the storage area or along the transportation route. These materials have the same elemental constituents as the original raw materials, many of which are soluble in surface and groundwaters. Organic constituents, however, will be comprised of molecules having molecular weights considerably less than the original coal polymers. Many of these compounds have high chemical and biological reactivities.

The potentially marketable materials of char and sulfur consist essentially of elemental carbon and sulfur, which are basically inert, although both may be contaminated with traces of other substances.

Trace elements in coal are concentrated in the process wastes after gasification or utilization. Spent acceptor contains sulfur and some coal trace elements in addition to the trace elements found in dolomite and limestone. Most of the carbonate compounds are water-soluble. Catalysts used in the various process reactions (cobalt, molybdenum, nickel) become ineffective and are replaced. These trace metals may be soluble in surface and groundwaters. The chemical nature of slags, tars, and solids from liquefaction and gasification processes has not been identified at this time. Mineral residue (produced by the SRC process) contains all the trace substances found in coal as well as various organic compounds and is believed to be highly toxic and carcinogenic. The mineral residue contains many trace elements which are water soluble. Toxicity, mutagenicity, and carcinogenicity tests are being conducted on this material at this time. An asbestos and diatomaceous earth filter aid is used to separate mineral residue from solvent in the SRC process. This filter must be replaced and disposed of periodically. Since this material contains both asbestos and mineral residue, it has high potential for environmental contamination. Asbestos is a carcinogenic material.

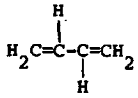
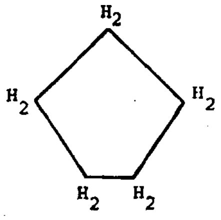
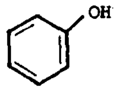
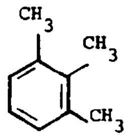
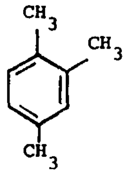
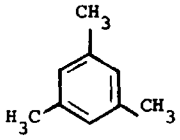
Most of the trace metals remain in ash as oxides during combustion, although some metals such as mercury, gold, and silver occur in the elemental state. Most of these materials are soluble in surface and groundwater systems.

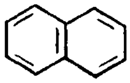
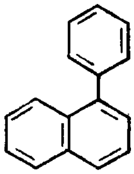
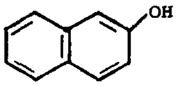
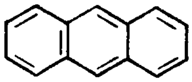
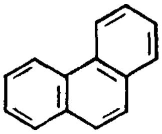
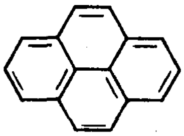
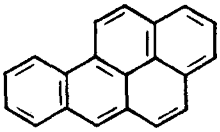
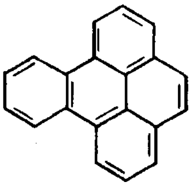
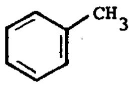
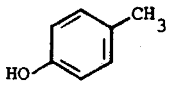
Sludge contains coal fines, oils, and greases collected in the wastewater treatment process, and may contain other precipitated materials.

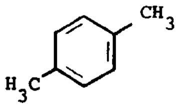
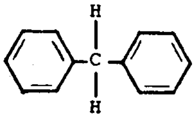
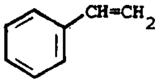
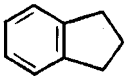
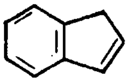
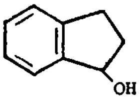
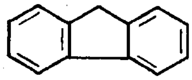
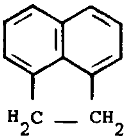
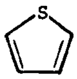
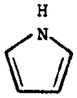
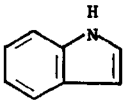
## 10. Nomenclature and Structure of Principal Organic Compounds Likely to be Encountered in Coal Products, By-Products, and Wastes.

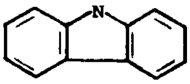
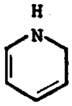
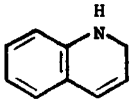
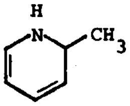
This section is essentially a glossary and review of the organic chemistry relevant to coal. The four major families of important organic compounds are the aliphatics, aromatics, arenes, and heterocyclics. Representative compounds of each family are presented in Table III-22.

Table III-22. Nomenclature and structure of classes of organic compounds found in coal tars and other products.

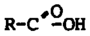
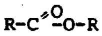
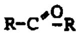
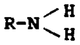
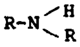
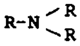
| | EXAMPLE | FORMULA |
|---|---|---|
| ALIPHATICS | | |
| Alkanes (paraffins) | methane | $CH_4$ |
| -single bonded (saturated) | ethane | $H_3C\text{-}CH_3$ |
| Alkenes (olefins)<br>-double bonded | ethene | $H_2C{=}CH_2$ |
| Dienes<br>-2 double bonds | 1, 3. butadiene |  $H_2C{=}\overset{H}{\overset{\vert}{C}}\text{-}\underset{H}{\underset{\vert}{C}}{=}CH_2$ |
| Alkynes<br>-triple bonded | ethylene | $HC{\equiv}CH$ |
| Cycloalkanes<br>(naphthenes) | cyclopentane |  |
| AROMATICS | | |
| Monocyclics | benzene |  |
| | phenol |  |
| | trimethylbenzenes | |
| | -hemimellitene |  |
| | - ψ - cumene |  |
| | -mesitylene |  |

| | | |
|---|---|---|
| Polycyclics<br>Naphthalenes | naphthalene |  |
| | phenylnaphthalene |  |
| Naphthols | naphthol |  |
| Anthracenes | anthracene |  |
| | phenanthrene |  |
| Pyrenes | pyrene |  |
| | benzo (a) pyrene |  |
| | benzo (e) pyrene |  |
| ARENES<br>-mixed aliphatic-aromatic | | |
| Alkylbenzenes<br>Monoalkylbenzenes | toluene |  |
| Cresols | cresol |  |

|  |  |  |
|---|---|---|
| Xylenes (dimethylbenzenes) | xylene |  |
| Phenylalkanes | diphenylmethane |  |
| Alkylbenzenes | styrene |  |
| Indans | indan |  |
|  | indene |  |
|  | indanol |  |
| Fluorenes | fluorene |  |
| Acenaphthenes | acenaphthene |  |
| HETEROCYCLICS<br>-have rings with more than one kind of atom |  |  |
| Furans | furan |  |
| Thiopenes | thiophene |  |
| Pyrroles | pyrrole |  |
|  | indol |  |

| | | |
|---|---|---|
| Pyridines | carbazole (dibenzopyrrole) |  |
| | pyridine |  |
| | quinoline |  |
| | picolines |  |

FUNCTIONAL GROUPS
(R=any organic molecule)

| | |
|---|---|
| methyl | $\text{R-CH}_3$ |
| phenolic (R is an aromatic) | R-OH |
| alcoholic (R is an aliphatic) | R-OH |
| carboxyl |  $\text{R-C}(=\text{O})\text{-OH}$ |
| ester |  $\text{R-C}(=\text{O})\text{-O-R}$ |
| keto |  $\text{R-C}(=\text{O})\text{-R}$ |
| thiol (or mercaptan) | R-SH |
| primary amine |  $\text{R-N}<^{\text{H}}_{\text{H}}$ |
| secondary amine |  $\text{R-N}<^{\text{H}}_{\text{R}}$ |
| tertiary amine |  $\text{R-N}<^{\text{R}}_{\text{R}}$ |
| nitrile | $\text{R-C}\equiv\text{N}$ |
| nitro | $\text{R-NO}_2$ |
| nitroso | R-N=O |

## C. IMPACTS ASSOCIATED WITH CONSTRUCTION, DECOMMISSIONING, AND DEMOLITION OF COAL PLANTS.

### 1. Construction.

Construction-related impacts focus on the disruption of the existing vegetative cover, alteration of topography, and the actual building of the facility. Clearing and grubbing remove the vegetation, exposing the soil surface to erosion. Grading, excavation, and other types of earthwork alter drainage patterns and reduce the internal cohesion of the soil, making the soil less resistant to erosion. Since vegetation intercepts rainfall and slows runoff velocities, it also reduces runoff and increases infiltration and groundwater recharge. Therefore, removal of the vegetation increases runoff and decreases infiltration and groundwater recharge. Paved areas and building roofs are impermeable areas which also accelerate surface runoff. Surface drainage is also altered by construction of storm drainage systems and culverts. Generally, these activities tend to degrade water quality by increasing sediment loads and by reducing normal stream flows and increasing peak flows. (See Figures III-1 and -2.)

Actual construction work such as equipment operation, painting, welding, drilling, and fencing also affect the ambient environment. Equipment operation, painting, and welding emit hydrocarbons, sulfur oxides, and inert gases (argon), while drilling may disrupt groundwater flow systems. Fence construction requires removal of vegetation along the fence line; the fence itself restricts animal migration.

Construction also causes temporary increases in energy consumption, traffic, and population. Construction also creates potential for spills and leaks of gasoline, oils, paints, and other construction materials which may enter and pollute the surface and groundwaters. Construction also produces residuals, e.g. dead vegetation, tars, cans, and scrap wood, which must be disposed of either by incineration (air emissions) or landfilling (surface and groundwater emissions).

### 2. Decommissioning.

Plant decommissioning results in employee relocations and/or unemployment, decreasing personal income for the area, thereby reducing personal spending. Unemployment also reduces personal income tax revenues for the community, possibly affecting community services. The abandoned facility also represents a potential safety hazard to children and animals in the area.

Water, air, and solids emissions from the plant will be eliminated, thereby improving water and air quality and increasing the available landfill space. Water consumption will be reduced to zero, but runoff quantities will remain constant. Water balances established during plant operation may be disrupted--e.g., water supplied by groundwater systems will no longer be discharged to the surface water system. This disruption may adversely affect water quality, biotic activity, and potential downstream water use. Since the plant is non-operational, it will cease to be a noise source.

### 3. Demolition.

Demolition activities increase noise levels and increase air pollutant emissions. Demolition generates large quantities of fugitive dust, and operation of equipment produces hydrocarbons, sulfur oxide, nitrogen oxide, carbon monoxide, and particulate emissions. These air and noise problems are short-term. The largest problem concerns the disposal of used materials from the plant such as pipe, ceramics, and sheet metal. This material may be stockpiled, junked, placed in a landfill, or sold.

| FACILITY<br>GENERATOR | HIGHWAY | RAIL | PIPELINE | GAS | ELECTRIC | WATER | STORM SEWER | SANITARY SEWER | WWTP | OFFICES | GARAGES | MAINTENANCE BLDS. | TANKS | PUMPS | TRANSPORT VEHICLES | CONSTRUCTION VEHICLES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SITING | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | | | |
| CLEARING & GRUBBING | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | | | |
| GRADING | ● | ● | | | | | ● | | ● | ● | ● | ● | ● | | | |
| EXCAVATION | | | ● | ● | | ● | ● | ● | ● | ● | | | ● | | | |
| EARTHWORK/FILL & CUT | ● | ● | | | | | | | | | | | | | | |
| PAVING/MAKE AREA IMPERM. | ● | | | | | | | | ● | ● | ● | ● | ● | | | |
| CONCRETE WORK | ● | | | | | | ● | ● | ● | ● | ● | ● | ● | | | |
| WELDING | | | ● | ● | | | | | ● | ● | ● | ● | ● | ● | | |
| PAINTING | | | | | | | | | ● | ● | ● | ● | ● | | | |
| DRAINAGE ALTERATION | ● | ● | | | | | ● | | ● | ● | ● | ● | ● | | | |
| FENCING | ● | ● | | | | | | | ● | ● | ● | ● | ● | | | |
| DRILLING | | | | | | ● | | | | | | | | | | |
| Δ POPULATION | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| Δ TRAFFIC | | | | | | | | | | | | | | | ● | ● |
| RESIDUAL DISPOSAL | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | | | |
| SPILLS & LEAKS | | | | | | | | | | | | | | | ● | ● |
| Δ ENERGY USE | | | | | | | | | | | | | | | ● | ● |

Δ Change

Figure III-1. Facilities/generator matrix, construction.

|  | RECEPTOR<br>GENERATOR | PHYSICAL SYSTEMS |  |  |  |  |  |  |  |  |  |  |  |  |  | BIOLOGICAL SYSTEMS |  |  |  |  |  |  |  |  |  |  |  |  | OTHER SYSTEMS |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | EARTH RESOURCES | PHYSIOGRAPHY | SURFACE WATER | GROUND WATER | WATER QUALITY | RECHARGE | AIR QUALITY | NOISE | CLIMATE | FLOODING | EROSION | DEPOSITION | SOLUTION | STABILITY | TREES | SHRUBS | GRASSES | CROPS | MICROFLORA | AQUATIC PLANTS | BIRDS | LAND ANIMALS | FISH & SHELL FISH | BENTHIC ORGANISM | INSECTS | MICROFAUNA | ENDANGERED SPECIES | LAND USE | AESTHETICS | STRUCTURES | TRANSPORTATION | UTILITIES | WASTE DISPOSAL | HOSPITALS | SCHOOLS | OTHER PUBLIC SERVICES |
| CONSTRUCTION - RELATED | SITING | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
|  | CLEARING & GRUBBING |  |  | ● | ● | ● | ● | ● | ● |  | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |  | ● |  |  |  | ● |  |  |  |
|  | GRADING | ● | ● | ● | ● | ● | ● | ● | ● |  | ● | ● | ● | ● | ● |  |  |  |  |  | ● |  |  | ● | ● |  |  | ● |  | ● |  |  |  | ● |  |  |  |
|  | EXCAVATION | ● | ● | ● | ● | ● | ● | ● | ● |  | ● | ● | ● | ● | ● |  |  |  |  |  |  |  |  | ● | ● |  |  | ● |  | ● |  |  |  |  |  |  |  |
|  | EARTHWORK/FILL | ● | ● | ● | ● | ● | ● | ● | ● |  | ● | ● | ● | ● | ● |  |  |  |  |  |  |  |  | ● | ● |  |  | ● |  | ● |  |  |  |  |  |  |  |
|  | PAVING |  |  | ● | ● | ● | ● | ● | ● |  | ● | ● | ● |  |  | ● | ● | ● | ● | ● |  |  |  | ● |  | ● | ● | ● |  |  | ● |  |  | ● |  |  |  |
|  | CONCRETE WORK |  |  |  |  |  |  | ● | ● |  |  |  |  |  |  |  |  |  |  |  | ● |  |  | ● | ● |  |  | ● |  |  |  |  |  | ● |  |  |  |
|  | WELDING |  |  |  |  |  |  | ● | ● |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | ● |  |  |  |
|  | PAINTING |  |  |  |  |  |  | ● | ● |  |  |  |  |  |  |  |  |  |  |  | ● |  |  | ● | ● |  |  | ● |  | ● |  |  |  | ● |  |  |  |
|  | DRAINAGE ALTERATION |  | ● | ● | ● | ● | ● |  | ● |  | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |  |  |  |
|  | FENCING |  |  |  |  |  |  |  | ● |  |  |  |  |  |  |  |  |  |  |  |  |  | ● |  |  |  |  | ● |  | ● |  |  |  | ● |  |  |  |
|  | DRILLING |  |  |  | ● | ● | ● | ● | ● |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | ● |  |  |  |
|  | POPULATION △ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | ● |  | ● | ● | ● | ● | ● | ● | ● |
|  | TRAFFIC △ |  |  |  |  |  |  | ● | ● |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | ● |  | ● | ● |  |  |  |  |  |
|  | RESIDUAL DISPOSAL | ● |  | ● | ● | ● |  | ● |  |  |  |  |  | ● | ● | ● | ● | ● | ● |  | ● |  |  | ● | ● |  |  | ● | ● | ● |  |  |  | ● |  |  |  |
|  | SPILLS & LEAKS | ● |  | ● | ● | ● |  | ● |  |  |  |  |  | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |  |  |  | ● |  |  |  |

Figure III-2. Generator/receptor matrix, construction.

## D. RESOURCE CONSUMPTION IMPACTS ASSOCIATED WITH COAL PLANTS

### 1. General Statement.

Resource consumption at coal conversion and utilization plants should be monitored (1) where the resource to be consumed is obtained locally and is locally scarce, and/or (2) where other aspects of the environment are sensitive to changes in availability of the consumed resource. Consumed resources were identified as water, air quality (in the form of Air Quality Maintenance Areas) and solid waste disposal sites.

### 2. Water Resources.

Where water resources, including both surface or groundwater supplies, are scarce, it is desirable to monitor for total withdrawals, changes in flow regime, changes in quality, and changes in biotic characteristics. Changes in water availability to industry, agriculture, and municipalities (residences) and its effects on land use and development in a region should be monitored in some cases.

Both surface and groundwaters may be appropriated according to the doctrines of land ownership (riparian rights) and prior appropriation. Monitoring requirements may be dictated by the doctrine of appropriation enforced in a region. For example, if prior appropriation is enforced, it will be necessary to monitor water supplies to ensure that downstream "prior users" have their guaranteed supplies.

Water consumption at coal conversion and utilization plants varies with the process and the type of coal used. As indicated in Table III-23, process water requirements are variable; however, most process water is used in gasification, scrubbing, quenching, and cooling. The single largest use of water is cooling, accounting for over 50 percent of the total. Requirements for coal washing vary with process requirements and coal quality. Also, pollution control equipment requirements (e.g., scrubbers) depend on the sulfur content of the coal, which varies within the coal seam and according to coal type and geographic locality.

The data presented in Table III-23 are approximate values but indicate that water consumption in coal conversion and utilization may adversely affect the environment in terms of water availability in the west and Great Plains states.

Table III-23. Approximate water requirements to make 250 x $10^6$ scf/day of high-Btu gas (in $10^6$ gallons/day).

| | Coal Washing | Process Water | Cooling Water | Pond Evaporation | Gasifier Ash Disposal | Sludge Disposal |
|---|---|---|---|---|---|---|
| Lurgi | 0.36 | 0.80 | 3.70 | 0.10 | 0.62 | 0.03 |
| Bigas | 0.36 | 1.50 | 3.70 | 0.10 | 0.62 | 0.03 |
| Synthane | 0.36 | 1.10 | 3.70 | 0.10 | 0.62 | 0.03 |
| Hygas/ Oxygen | 0.36 | 1.70 | 3.70 | 0.10 | 0.62 | 0.03 |

Source: D. J. Goldstein and R. F. Probstein, in Symposium Proceedings: Environmental Aspects of Fuel Conversion Technology, II, compiled by F. A. Ayer, for USEPA.

## 3. Air Quality.

Air emissions from coal conversion plants, expected to have opacities similar to those at coal utilization plants, are likely to reduce visibility in an area, adversely affecting the visual/aesthetic resources, as in the Four Corners, New Mexico area. Regional visibility and opacity can be monitored periodically as part of the ambient air quality monitoring program. Reduction of general visibility in a region is likely to be caused by a number of sources; therefore, monitoring of this type may be more appropriate for the regional air pollution control enforcement authority than for ERDA.

## 4. Solid Waste Disposal Sites.

Coal conversion and utilization processes produce varying types and quantities of solid wastes.

Quantities of solid wastes are not known at this time. These solid wastes vary from relatively inert char to potentially carcinogenic and toxic residues; therefore, finding appropriate disposal sites may be difficult. ERDA coal plants may compete for suitable disposal sites in areas of limited availability with other industrial plants that also produce toxic solid wastes. It may be appropriate to monitor periodically the availability of disposal sites.

# IV. POTENTIAL ENVIRONMENTAL SENSITIVITIES TO DISCHARGES FROM COAL CONVERSION AND UTILIZATION PLANTS.

## A. DISCHARGE AND AMBIENT STANDARDS FOR COAL PLANTS

Having identified the potential environmental impact generators from coal plants, we will now examine the potential sensitivity of the environment to these generators as a set in prioritizing parameters which should be monitored. We shall examine three related aspects of environmental sensitivity.

- Is the generator covered by an existing or evolving environmental quality standard?
- Does the generator have a known or suspected effect on human health and, if so, potentially how serious is the effect?
- Does the generator have a known or suspected effect on ecosystems and, if so, potentially how serious is the effect on the functioning of the ecosystem?

### 1. Air Pollutants

a. Ambient Air Quality Standards: There are two basic philosophies for the setting of air pollution control regulations, the state-of-the-art approach and the air quality management approach. The state-of-the-art approach requires the best source control that is technically possible given the state-of-the-art in emission control technology. The air quality management approach involves the determination of what ambient air quality levels are required to maintain the health and welfare of the community and requires that sources be controlled to the extent necessary to produce ambient air of the desired quality.

The Clean Air Act of 1967 provided for the federal publication of air quality criteria documents based on scientific studies which describe the harmful effects of major air pollutants on health, vegetation, and materials. It required states to set ambient air quality standards limiting the ambient levels of the pollutants described in the criteria documents and required states to establish comprehensive emission control regulations aimed at meeting the ambient standards and to set a timetable for compliance. As a result, the air quality management approach became national in scope.

The Clean Air Act of 1970 (303) required the Federal government (EPA) to set standards for ambient air for pollutants for which criteria documents have been published. Primary Standards had to be set strictly on the basis of protecting public health. These were to be based on evidence contained in the criteria documents and were to have a reasonable margin of safety. No consideration of feasibility or economic effects of such standards was required. Secondary Standards also had to be established on the basis of protecting the public welfare. Human welfare involves protection against material damage, vegetation damage, aesthetic disturbance, and other harm. States were required to submit to the EPA a comprehensive plan which provides for the implementation, maintenance, and enforcement of emission regulations sufficiently stringent to assure compliance with the federal ambient air standards. In addition, the EPA is required to write emission regulations based on the best practical method of control (state-of-the-art) for new sources. The EPA was also given the authority to set emission standards for hazardous air pollutants for which no ambient air quality standard is applicable or which, in the judgement of the EPA administrator, may cause or contribute to an increase in mortality or an increase in serious irreversible or incapacitating illness. Such standards have been written for major sources of asbestos, beryllium mercury, and vinyl chloride.

Because it is believed that long-term exposure to low levels of air pollutants causes certain problems and that short-term exposure to very high levels of air pollution causes other problems, the EPA has published both short-term and long-term ambient air quality standards. The short-term standards are written in terms of maximum one hour, three hour, eight hour or twenty-four hour standards not to be exceeded more than once per year. The long-term standards are expressed as a maximum annual geometric or arithmetic mean level not to be exceeded. These ambient air quality standards are summarized in Table IV-1. Some of the criteria cited in the criteria documents and used in designing the standards for sulfur dioxide and suspended particulates are summarized in Tables IV-2 and IV-3.

Individual states may promulgate primary and secondary ambient air quality standards that are more stringent than the federal standards, and many states have done so.

b. Primary versus Secondary Pollutants: Primary pollutants are those which are emitted directly from sources. Examples are suspended particulates, carbon monoxide, sulfur dioxide and nitric oxide. Secondary pollutants are those which are a result of chemical reactions of contaminants after they become a part of the ambient environment. One example is ozone. Hydrocarbons and oxides of nitrogen react with each other in the presence of sunlight to produce ozone and other "photochemical oxidants." Ozone is usually found in

Table IV-1. Federal ambient air quality standards.

| POLLUTANT | DURATION | RESTRICTION | CONCENTRATION STANDARDS† [in ug/$m^3$ (and ppm)] PRIMARY | SECONDARY |
|---|---|---|---|---|
| Suspended Particulates | Annual Mean (G) | Not to exceed | 75 | 60 |
| " | 24-hour concentration | Not to be exceeded more than once per year. | 260 | 150 |
| Sulfur Dioxide | Annual Mean (A) | Not to be exceeded. | 80(0.03)** | 60(0.02) |
| " | 24-hour concentration | Not to be exceeded more than once per year. | 365(0.14) | 260(0.1) |
| Carbon Monoxide | 8-hour mean (A) concentration | Not to be exceeded more than 1 eight-hour period per year. | 10*(9.0) | 10*(9) |
| " | 1-hour mean | Not to be exceeded more than once per year. | 40*(35) | 40*(35) |
| Photochemical Oxidants | 1-hour mean (A) concentration | Not to be exceeded. | 160(0.08) | 160(0.08) |
| Non-methane Hydrocarbons | 3-hour mean (A) concentration | Not to be exceeded between 6 am to 9am. | 160(0.24) | 160(0.24) |
| Nitrogen Dioxide | Annual mean (A) | Not to be exceeded. | 100(0.05) | 100(0.05) |

(A) Arithmetic (G) Geometric

* Only standard expressed in milligrams per cubic meter
** Values in parentheses are equivalent values in parts per million by volume.

†*Federal Register*. Nov. 23, 1971.

Table IV-2. Basis for an ambient $SO_2$ air quality standard.

| Concentration | Effects | Conditions | Measurement |
|---|---|---|---|
| 1500 ug/m$^3$ (0.52ppm) | Increased mortality may occur. | In presence of suspended particulate matter as a soiling index of 6 cohs or greater. | 24-hour average |
| 715 ug/m$^3$ (0.25ppm) | Increased daily death rate may occur. | Accompanied by smoke at a concentration of 750 ug/m$^3$. | 24-hour mean |
| 715 ug/m$^3$ (0.25ppm) | A sharp rise in illness rates for patients over age 54 with severe bronchitis may occur. | Accompanied by particulate matter. | 24-hour mean |
| 860 ug/m$^3$ (0.3ppm) | Some species of trees and shrubs show injury. | (Not Given) | 8-hours |
| 600 ug/m$^3$ (0.21ppm) | Patients with chronic lung disease may experience accentuation of symptoms. | With smoke concentrations of about 300 ug/m$^3$. | 24-hour mean |
| 500 ug/m$^3$ (0.19ppm) | Increased mortality rates may occur. | With low particulate livels. | 24-hour mean |
| 300 ug/m$^3$ (0.11ppm) to<br>500 ug/m$^3$ (0.19ppm) | Increased hospital admissions of older people for respiratory disease may occur; absenteeism from work, particularly with older people, may also occur. | With low particulate levels. | 24-hour mean |
| 345 ug/m$^3$ (0.12ppm) | The corrosion rate for steel panels may be increased by 50%. | Accompanied by high particulate levels. | (Not Given) |
| 285 ug/m$^3$ (0.10ppm) | Visibility may be reduced to about five miles. | With comparable concentration of particulate matter and relative humidity of 50%. | (Not Given) |
| 105 ug/m$^3$ (0.037ppm) to<br>265 ug/m$^3$ (0.092ppm) | Increased frequency of respiratory symptoms and lung disease may occur. | Accompanied by smoke concentrations of about 185 ug/m$^3$. | Annual mean |
| 145 ug/m$^3$ (.05ppm) to<br>715 ug/m$^3$ (0.25ppm) | Moderate to severe injury produced in sensitive plants. | Accompanied by either ozone or nitrogen dioxide. | Short Term exposures e.g. 4 |
| 120 ug/m$^3$ (0.046ppm) | Increased frequency and severity of respiratory diseases in school children may occur. | Accompanied by smoke concentrations of about 100 ug/m$^3$. | Annual mean |
| 115 ug/m$^3$ (0.040ppm) | Increase in mortality from bronchitis and from lung cancer may occur. | Accompanied by smoke concentrations of about 160 ug/m$^3$. | Annual mean |
| 85 ug/m$^3$ (0.03ppm) | Chronic plant injury and excessive leaf drop may occur. | (Not Given) | Annual mean |

Table IV-3. Basis for ambient particulate matter air quality standard

| Concentration | Effects | Conditions | Sampling |
|---|---|---|---|
| >200 ug/m$^3$ | Increased absence from work due to Illness | In presence of 250 ug/m$^3$ $SO_2$ | Average seasonal smoke (British) levels based on 24-hour measurements |
| >200 ug/m$^3$ | Rise in infant mortality and deaths in cancer patients | In presence of 2860 ug/m$^3$ $SO_2$ maximum | Three-day mean for suspended particulate matter |
| >200 ug/m$^3$ | Possible excess bronchitis mortality | In presence of >200 ug/m$^3$ $SO_2$ | Daily average smoke (British) measurements |
| 150 ug/m$^3$ (Range: 73-300 ug/m$^3$) | Visibility reduced to as low as 5 miles | Particle sizes from 0.2-1.0 u and R.H. <70% | Short-term high volume sampling |
| >130 ug/m$^3$ | Likely increase in frequency and severity of lower respiratory diseases in British school children | In presence of >130 ug/m$^3$ $SO_2$ | Annual mean smoke (British) measurements |
| 100 ug/m$^3$ | Total sunlight reduced 5% for every doubling of particle concentration | ________ | Annual geometric mean (High volume sampling) |
| 80-100 ug/m$^3$ | Death rate for white males 50-69 yrs. old may be 20% higher them area with <80 ug/m$^3$ particulates | ________ | Annual geometric mean (High volume sampling) |
| 80 ug/m$^3$ | Public awareness and concern for pollution may become evident | In presence of other pollutants and number of days acute pollution | Annual geometric mean (High volume sampling) |
| 60-180 ug/m$^3$ | Accelerated corrosion of steel and zinc | In presence of $SO_2$ and moisture | Annual geometric mean (High volume sampling) |
| Decrease to 60 | Decrease in mean sputum volume of West London workers. Shows apparent health improvement with better air quality | ________ | Annual mean smoke (British) level |

NOTE: British "smoke" measurements are proportional to the concentration of "dark suspended matter" resulting from combustion and are not considered proportional to total particle concentration as measured by the high volume sampler. Results are dissimilar and comparisons should be made cautiously.

maximum concentrations several miles downwind of the source of hydrocarbons and nitrogen oxides. Nitrogen dioxide is also mostly a secondary pollutant, forming as a result of the reaction of nitric oxide and ozone or other oxidants.

$$NO + O_3 \longrightarrow NO_2 + O_2$$

For all but the extremely large or most isolated of sources, it is very difficult if not impossible to directly measure the concentration of secondary pollutants due to the source. This is because secondary pollutants form far downwind, and the effects of one source are often mixed with the effects of other sources.

c. New Source Performance Standards: The Federal EPA has not yet published New Source Performance Standards for coal conversion plants. However, standards do exist for specific components of coal conversion plants, such as boilers and coal preparation plants. These standards are based on the "best adequately demonstrated technology" (the state-of-the-art in emission control technology).

Federal New Source Performance Standards for air emissions from fossil fuel fired steam generators of more than 63 million kcal per hour heat input (250 million Btu per hour) are published in sections 60.4 through 60.44 of the regulations published by the U.S. Environmental Protection Agency, and are shown in Table IV-4.

The term fossil fuel in these regulations means natural gas, petroleum, coal, or any form of solid, liquid or gaseous fuel derived from such materials for the purpose of creating useful heat. EPA's legal staff is interpreting the regulations such that steam generators burning gaseous or liquid products from coal conversion plants fall under coal fired boiler regulations (Sedman, 1977).

These regulations also require the operators of such boilers to install, calibrate, maintain, and operate continuous emission monitoring instrumentation for $SO_2$, $NO_x$, opacity, $CO_2$ and $O_2$. Reports which translate the readings of these instruments into units comparable to those of applicable emission regulations and specifying the periods of noncompliance with the standards are also required. This requirement often makes monitoring of the discharged gas flow rate necessary, since the standards are sometimes expressed in units of pollutant per unit of flow.

Monthly fuel analysis can substitute for continuous $SO_2$ monitoring where the analysis of the fuel confirms that the source will comply with applicable $SO_2$ emission regulations

Table IV-4. Implication of existing state and federal emission standards for Future Coal Refineries.

| | Federal NSPS | | New Mexico Regulations | |
|---|---|---|---|---|
| Pollutant | Petroleum Refineries | Fossil-fueled Steam Generators | Gas-fired power plant associated with coal gasification plants | Gasification Plants |
| Sulfur dioxide | 0.10 gr $H_2S$/dscf in fuel gas (plant gas fuel combustion)[a] | 1.2 lb/$10^6$ Btu (solid)<br>0.8 lb/$10^6$ Btu (liquid) | 0.16 lb/$10^6$ Btu | N/A |
| Particulate matter | 0.27 gr/dscf + 0.10 lb/$10^6$ Btu aux.fuel<br>30% opacity, except for 3 min/hr (catalytic cracking unit catalyst regenerator) | 0.1 lb/$10^6$ Btu<br>20% opacity | 0.03 lb/$10^6$ Btu | 0.03 gr/scf |
| Hydrocarbons | Specified vapor pressure limits and required control devices (petroleum storage vessels) | N/A | N/A | N/A |
| Nitrogen oxides | N/A | 0.7 lb/$10^6$ Btu (solid)<br>0.3 lb/$10^6$ Btu (liquid)<br>0.2 lb/$10^6$ Btu (gas) | 0.20 lb/$10^6$ Btu | N/A |
| Sulfur(total) | N/A | N/A | N/A | 0.008 lb/$10^6$ Btu |
| Reduced sulfur (sum of hydrogen sulfide, carbon disulfide, and carbonyl sulfide) | See Text | N/A | N/A | 100 ppm |
| Hydrogen Sulfide | See Text | N/A | N/A | 10 ppm |
| Hydrogen cyanide | N/A | N/A | N/A | 10 ppm |
| Hydrogen chloride and hydrochloric acid | N/A | N/A | N/A | 5 ppm |
| Ammonia | N/A | N/A | N/A | 25 ppm |

[a] Equivalent to 0.1 lb/$10^6$ Btu for gas with 250 Btu/$ft^2$

N/A: Not Applicable

Source: Rubin and McMichael, 1974.

without fuel blending. Nitrogen oxide monitoring is not required if the boiler emits less than 70 percent of the maximum allowable discharge during compliance testing.

Opacity monitoring is not required if there is enough liquid water in the plume to cause an appreciable opacity.

If the source is exempt from $SO_2$ and $NO_x$ monitoring, then it is exempt from monitoring $CO_2$, $O_2$, and gas flow rate. One can also get an exemption from the requirement of monitoring these parameters if it can be shown that an alternate system will be used to translate concentration readings into units comparable to those of the emission regulations without the use of such monitors. In such cases, it must be established that the alternate system will give results similar to those from systems that monitor CO, $O_2$, and flow rates, with similar degrees of error as well (Sedman, 1977).

Federal air pollution emission regulations for coal preparation plants which process more than 200 tons of coal per day are published in sections 60.250 through 60.254 of EPA regulations. These regulations limit the opacity of particulate emissions from all operations (except pneumatic coal cleaning equipment) to 20 percent opacity. Pneumatic coal cleaning equipment is limited to a 10 percent opacity. Particulate emissions from thermal driers are limited to 0.07 g/dscm (0.031 gr/dscf), and they are limited to 0.04 g/dscm (.018 gr/dscf) for pneumatic coal cleaning equipment. Continuous monitoring of thermal drier gas temperature, scrubber water flow rate, and Venturi scrubber pressure drop is also required by these regulations.

Emission regulations for sources not covered by EPA regulations are established by state and local pollution control agencies. Many states have regulations on sulfur dioxide emissions that are more stringent than the EPA standards for fossil fuel fired steam generating plants. Some states have regulations covering sulfur recovery plants which require about 99 percent efficient emission controls for such plants. New Mexico even has regulations that are specific to coal gasification processes, shown on Table IV-4. The coal gasification plant regulations are applicable to all process, product, and by-product effluent streams and all storage and associated facilities connected with the process, except process gas streams (after they undergo combustion in a boiler) and facilities in the coal preparation plant. Separate regulations cover these facilities.

In addition to these emission standards, EPA has a policy published in the December 21, 1976 <u>Federal Register</u>

concerning new sources in areas having ambient air quality worse than the standards. No new sources emitting more than 100 tons per year of the pollutant above the relevant standard (1000 tons per year for carbon monoxide) would be allowed to locate in areas having air quality worse than the primary ambient air quality standards, unless existing sources reduce their emissions an equivalent amount. Also, all existing sources owned by a company in the same air quality control region as the area above the standards must be in compliance with applicable State Implementation Plan emission control standards, or be on a compliance timetable. Furthermore, the new facility must apply appropriate control technology to achieve the lowest possible emission rate.

Where only secondary ambient air quality standards are exceeded, no major source will be allowed in the area, unless the state can at least demonstrate eventual compliance with the standards despite the new source. A state may have to modify its Implementation Plan to reflect the resulting change in the date for compliance with the secondary standards due to the new source, unless the plan includes some provision for new sources and the new source is consistent with the plan.

Some insight into possible air pollution emission regulations for coal conversion processes might be gained by examining current standards for petroleum refining, especially those proposed for sulfur recovery systems, those in effect for storage of petroleum liquids, and those for monitoring emissions from such sources. EPA air pollution emission standards for petroleum refineries are found in regulations 60.100 through 60.106. They have been converted to units expressed in terms of the amount of heat energy in the feedstock (if burned in air) and are presented in Table IV-4 (Rubin and McMichael, 1975). The regulations covering sulfur recovery systems are only proposed regulations, and they are too complicated for inclusion in the table. Those for petroleum storage are engineering controls, and are also excluded. The term "sulfur recovery plant" in the proposed standards (published in the October 4, 1976 Federal Register) refers to a process unit which converts hydrogen sulfide produced within a refinery into elemental sulfur.

Where gases discharged by the catalyst regenerator of a fluid catalytic cracking unit pass through an incinerator or waste heat boiler wherein solid or liquid fossil fuels are burned, the amount of particulate matter emitted due to such fuels shall not exceed 43 g/MJ (0.1 lb/$10^6$ Btu).

Sulfur dioxide emissions would not be allowed to exceed 0.025 percent by volume at zero percent oxygen on a dry gas basis. If the emission control system installed to comply with these standards discharges residual emissions of hydrogen sulfide, carbonyl sulfide (COS), and carbon disulfide ($CS_2$), the standard would limit the hydrogen sulfide emissions to 0.001 percent by volume, and the amount of reduced sulfur gases ($H_2S$, COS, and $CS_2$) to 0.03 percent by volume. These percentages would be at zero percent oxygen on a dry gas basis. These concentrations are calculated as $SO_2$. This means that $CS_2$ concentration is multiplied by a factor of two before adding it to the concentrations of $H_2S$ and COS. Burning gases containing more than 230 mg/dscm (0.1 gr/dscf) hydrogen sulfide is prohibited, unless sulfur dioxide emissions are effectively prevented from entering the atmosphere.

If a pollution control system which reduced emissions from sulfur recovery plants by converting them to sulfur dioxide is installed, or a system that converts the emissions to hydrogen sulfide followed by incineration is installed, then continuous $SO_2$ monitoring is required. If a system converting emissions to hydrogen sulfide is installed that is not followed by incineration, then monitoring of $H_2S$, COS and $CS_2$ is required. The reference method for this monitoring is a gas chromatographic separation system with a flame photometric detector.

Existing air pollution regulations for refineries require the monitoring of (1) the opacity of catalytic cracker regenerator effluent, (2) coke burn-off rate, (3) the rate of use of liquid and solid fuels in waste heat boilers, and (4) either sulfur dioxide out of gas combustion systems or hydrogen sulfide into such combustion systems. Standards for air emissions from petroleum storage facilities having a capacity greater than 40,000 gallons are contained in section 60.110 through 60.113 of the EPA regulations. These standards require floating roofs on storage tanks holding liquid petroleum products with vapor pressures, as stored, between 58 mm and 570 mm Hg. Liquids with higher vapor pressure must be stored in vessels with vapor recovery systems. Monitoring of monthly average temperature and vapor pressure is required if the vapor pressure is between 26 and 78 mm of Hg and the storage vessel does not have a floating roof or vapor recovery, or if the vapor pressure is above 470 mm of Hg and the vessel does not have vapor recovery. Petroleum liquids are defined in these regulations as products of petroleum refineries, except Number 2 through Number 6 fuel oils.

Future coal conversion standards could be quite different from the standards examined here. EPA is actively considering standards for suspended particulates, sulfur dioxide, sulfur gases in general, carbon monoxide, oxides of nitrogen, and non-methane hydrocarbons. They could be based on pounds per million Btu of coal input or some other type of unit. One proposal would even have limited $SO_2$ emissions as a function of COS emissions, but it was dropped. EPA is currently examining the economic effects of proposed regulations and plans to use this economic analysis to determine the best control technology. This information will help to form a basis for the proposed standards (Vionde, 1976).

Although it is not possible to state with certainty when EPA will publish proposed standards for coal conversion processes, or what they will be like, Mr. Charles Sedman, of the EPA Emission Standards and Engineering Division, has made some preliminary information available on this. Sometime after April 1, 1977, EPA will publish proposed standards for existing types of high-Btu gasification plants. These will apply to processes based on Lurgi and Koppers-Totzek gasifiers. These regulations should cover non-methane hydrocarbon and total sulfur gas emissions at least. General regulations covering low-Btu gasification processes should be published about a year later. Separate regulations covering units used for making industrial fuel gas and units for power production are being considered. Regulations covering boilers using synthetic gaseous fuels derived from coal are also expected then. Regulations covering coal liquefaction processes are expected about a year after general regulations for general low Btu gasification are published. General regulations covering all high-Btu gasification processes are expected at the same time. The lead time until all of these proposed standards become finalized will depend, among other factors, on the amount of opposition to them.

The standards will apply to plants above certain sizes. Plants using coal having a heating potential of 2 to 4 billion Btu per day are being considered as the minimum size for which such regulations will apply. This would make the regulations applicable to plants using more than about 100 to 200 tons per day of coal. The economics of the situation, and the new standards, are likely to encourage industrial plants to combine their coal conversion facilities into centralized facilities. The regulations may not be enforced for pilot plants if EPA is convinced that all reasonable precautions are being taken to reduce emissions to the lowest possible levels. Interagency agreements and other factors may affect EPA regulation of pilot plant facilities.

Some emission monitoring requirements are likely to be included in the standards. Total sulfur monitoring might be required at the sulfur recovery plant outlet, and hydrocarbon monitoring might be required at the $CO_2$ vents. Opacity monitoring might be required at the coal preparation plant. CO, $NO_x$ and $SO_2$ monitoring might be required on other selected process streams. Regulations covering trace constituents are not likely in the near future (Sedman, 1977).

d. Non-Degradation: The Clean Air Act of 1970 also contains provisions against "significant deterioration" of air quality in areas that have air quality better than the national standards. Unfortunately, the amount of deterioration considered to be significant was not well defined. As a result, the EPA has written regulations in which each state was requested to propose how much deterioration of air quality will be considered significant in each area within the state by classifying such areas as Class I, Class II, or Class III.

Areas designated as Class I or II shall be limited to the following increases in pollution concentration occurring since January 1, 1975:

Table IV-5. Increase limits of pollutants by class.

| | Area Designations | |
|---|---|---|
| Pollutant | Class I ug/m$^3$ | Class II ug/m$^3$ |
| Particulate matter: | | |
| Annual geometric mean | 5 | 10 |
| 24-hour maximum | 10 | 30 |
| Sulfur dioxide | | |
| Annual arithmetic mean | 2 | 15 |
| 24-hour maximum | 5 | 100 |
| 3-hour maximum | 25 | 700 |

[40 FR 2500 - June 12, 1975]

Areas designated as Class III shall be limited to concentrations of particulate matter and sulfur dioxide no greater than those allowed by the national ambient air quality standards.

e. Air Quality Maintenance Areas: Because population, industrial activity, fuel usage and traffic patterns change, periodic review and revision of state emission regulations is necessary to insure continued compliance with the federal ambient air quality standards. As a result, every five years states are required to review existing air quality, existing regulations, and the projected growth of emissions throughout the state and to determine which areas have the potential for exceeding any national standard within the subsequent 10 year period if existing regulations are not changed. Such areas are called Air Quality Maintenance Areas, and states are required to revise their emission regulations in such areas to insure that the standards are not violated.

f. Emergency Action Criteria: States are required to specify as episode criteria those ambient pollutant concentrations at which specific emission control actions will be taken to reduce or prohibit emissions when the specified concentrations are reached at any one monitoring station. Emissions are to be reduced if meteorological conditions indicate that such episode criteria will continue to be exceeded in the absence of emission reductions. Such criteria include Alert, Warning, and Emergency ambient air pollution levels, requiring different degrees of emission reduction and/or other action if they are exceeded. These are designed to protect the population against severe health effects due to extremely high levels of air pollution. Such episode criteria are written for all pollutants for which there are federal ambient air quality standards except hydrocarbons. They usually include episode criteria for the coefficient of haze or soiling index. This index of particulates in the ambient air is a function of both particulate mass concentration and the size distribution, measured by the amount of absorption of light due to particulates collected on a paper tape per 1000 linear feet of air pumped through the tape. Criteria for the product of 24-hour average particulate concentration, and/or coefficient of haze, times the 24-hour average sulfur dioxide concentration are also included. These criteria are designed to reflect the synergistic effect of particulates and sulfur dioxide. Table IV-6 summarizes the episode criteria for the State of Ohio.

g. State and Local Air Quality Standards and Regulations: Executive Order 11752 requires heads of federal agencies to insure that all facilities under their jurisdiction are designed, constructed, managed and operated so as to conform with all federal, state, interstate and local air quality standards and emission limitations adopted in accordance with, or effective under, provisions of the Clean Air Act. Furthermore, the heads of such agencies are required to cooperate with interstate, state, and local pollution control agencies; and, in accordance with guidelines issued by the EPA Administrator, provide those agencies with such information as is necessary to determine compliance with applicable standards. Such cooperation is to include the development of an abatement plan and a schedule for meeting applicable standards.

Table IV-6. State of Ohio air pollution emergency episode criteria.

| Pollutant | Averaging Time | Units | Episode Standards<br>Alert | <br>Warning | <br>Emergency |
|---|---|---|---|---|---|
| Suspended Particulates | 24 hours | $\frac{ugm}{m^3}$ | 375 | 625 | 875 |
| Sulfur Dioxide | 24 hours | $\frac{ugm}{m^3}$ | 800 | 1600 | 2100 |
| Sulfur Dioxide Suspended Particulate | 24 hours | $\frac{ugm^2}{m^3}$ | 650 | 261000 | 393000 |
| Carbon Monoxide | 8 hours | $\frac{mgm}{m^3}$ | 17 | 34 | 46 |
| Oxidants | 1 hour | $\frac{ugm}{m^3}$ | 200 | 800 | 1200 |
| Nitrogen Dioxide | 24 hours | $\frac{ugm}{m^3}$ | 282 | 565 | 750 |
| Nitrogen Dioxide | 1 hour | $\frac{ugm}{m^3}$ | 1130 | 2260 | 3000 |
| Soiling Index | 24 hours | $\frac{COH}{Kft}$ | 3.0 | 5.0 | 7.0 |
| Soiling Index x Sulfur Dioxide | | $(\frac{COH}{Kft})$ x ppm | 0.2 | 0.8 | 1.20 |

This order does not require federal facilities to comply with state or local administrative procedures with respect to pollution abatement and control; but it does require that all budget requests for the design and construction of new facilities, or for the modification of existing facilities, include such measures as may be necessary to insure compliance with applicable standards. Where activities are carried out at federal facilities acquired by leasing or other federal agreements, the head of the agency may require the leasee or permittee to assume full responsibility for compliance with standards for the prevention, control, and abatement of environmental pollution.

Office of Management and Budget Circular A-106 requires federal agencies to develop plans for compliance of existing facilities with the standards, and defines general reporting requirements. The EPA has published detailed procedures for such reporting. Some states and counties have regulations covering maximum permissible ambient concentrations of trace gases for which the EPA has not yet set national standards. An example related to coal conversion is hydrogen sulfide. Table IV-7 shows some of these hydrogen sulfide standards.

Table IV-7: Ambient hydrogen sulfide standards.

| Concentration (ppm) | Duration | Restriction | Location of Standard |
|---|---|---|---|
| 0.1 | 1 hour | not to be exceeded. | Pennsylvania |
| 0.6 | 3 minute | Not to be exceeded more than twice per year. | Delaware |
| 0.05 | 30 minute | Not to be exceeded more than twice per per year. | Missouri, Montana Minnesota, North Dakota, Wyoming |
| 0.03 | 30 minute | Not to be exceeded more than once in five consecutive days. | Missouri, Minnesota Montana, North Dakota, Wyoming |
| 0.01 | 30 minute | Not to be exceeded more than two consecutive 30 minute periods. | Nebraska |
| 0.005 | 24 hour | Not to be exceeded | Allegany County, Pa. |
| 0.003 | 1 hour | Not to be exceeded | New Mexico, except for one region |

Additional local ambient air standards exist for nuisances, odors, and visible emissions. The nuisance regulations are the oldest and most general of air pollution regulations. They stem from the demand of the public to be protected against blatantly dangerous or obnoxious sources of contaminants in the community. An example of a nuisance regulation can be found in the regulations of the Ohio Air Pollution Control Board:

> "The emission or escape into the open air from any source or sources whatsoever, of smoke, ashes, dust, dirt, grime, acids, fumes, gases, vapors, odors, or any other substances or combinations of substances, in such manner or in such amounts as to endanger or tend to endanger the health, comfort, safety or welfare of the public, or is unreasonably offensive and objectionable to the public, or shall cause unreasonable injury or damage to property or interfere with the comfortable enjoyment of property or normal conduct of business, is hereby found and declared to be a public nuisance. It shall be unlawful for any person to cause, permit or maintain any such public nuisance."

The City of Cleveland, in its air pollution code, has a functional definition of the point at which an emission becomes sufficiently objectionable as to constitute a nuisance:

> "An emission shall also be deemed a nuisance when thirty percent or more of a sample of people exposed to it believe it to be objectionable in usual places of occupancy, the sample size to be at least twenty people or seventy-five percent of those exposed if fewer than twenty people are exposed."

Odors, while they are often handled by nuisance provisions, are also often handled by specific regulations, such as those in the City of Cleveland Air Pollution Code:

> "4.1102. Emission of Odors into the Atmosphere.
>
> "(A) No owner, occupant or person in charge, by himself, his agent or employee, shall cause, suffer or allow the emission of odorous matter into the atmosphere so as to cause an objectionable odor, as determined by the Commissioner or his duly authorized representative:
>
> "(1) On or adjacent to residential, recreational, institutional, retail sales, hotel or educational premises;

> "(2) On or adjacent to industrial premises when air containing such odorous matter is diluted with 20 or more volumes of odor-free air;
>
> "(3) On or adjacent to premises other than those in paragraphs (1) and (2) when air containing such odorous matter is diluted with four or more volumes of odor-free air.
>
> "(B) An odor shall also be deemed objectionable when thirty percent or more of a sample of the people exposed to it believe it to be objectionable in usual places of occupancy, the sample size to be at least twenty people or seventy-five percent of those exposed if fewer than twenty people are exposed.
>
> "(C) After an odor is deemed objectionable as provided in paragraph (B) of this section or by the Commissioner of Air Pollution Control or his duly authorized representative under paragraph (A) of this section, the Commissioner shall issue an order for abatement as provided in Section 4.0504."

Regulations concerning visible emissions prohibit plumes, not due to uncombined water, above specified opacity levels or Ringlemann numbers (degrees of darkness) for specified periods of time. As an example, consider the regulations adopted by Ohio.

> "AP-3-07 Control of visible air contaminants from stationary sources.
>
> "(A) Emission limitation.
>
> "(1) No person shall discharge into the atmosphere from any single source of emission whatever, any air contaminant of a shade or density equal to or darker than that designated as No. 1 on the Ringelmann chart, or 20 percent opacity, except as set forth in subsection (A) (2) and section (B) of this regulation.
>
> "(2) A person may discharge into the atmosphere from any single source of emission for a period or periods aggregating not more than three minutes in any sixty minutes or for a period of time deemed necessary by the Board, air contaminants of a shade not darker than No. 3 on the Ringelmann chart, or 60 percent opacity.
>
> "(B) Uncombined water.
>
> "It shall be deemed not to be a violation of this regulation where the presence of uncombined water is

> the only reason for failure of an emission to meet the requirements of this regulation."

In addition, some states and local communities have adapted regulations prohibiting any source from creating a traffic hazard or any public street, even if the plume is due to uncombined water. Sometimes they go so far as to prohibit opacities above a given level at ground level on public streets.

A survey of ambient air quality standards for dustfall and trace constituents was published in Part I of the American, Industrial Hygiene Association's Air Pollution Manual in 1972 (Giever, 1972). Tables IV-8 through IV-14 summarize these standards for various states of the union.

h. Threshold Limit Value and Occupational Safety and Health Administration: Threshold limit values (TLV's) and Occupational Safety and Health Administration (OSHA) standards are designed to protect normal, healthy workers against the adverse effects of exposure to hazardous substances found in the work environment. These standards are usually stated in terms of a maximum permissible 8-hour average exposure. For some substances, TLV standards exist for time periods that are much shorter.

These standards are relevant to ambient air pollution since they summarize the substances and exposures that have been found to be hazardous to healthy workers. Certainly, if a TLV were exceeded in a residential neighborhood, there would be an ambient air pollution problem. The EPA ambient standards are designed to protect sensitive people, not healthy workers, and ambient standards genrally are more restrictive than TLV's (See Table IV-15).

Table IV-8. Ambient air quality deposited particulate matter dustfall standards[a].

| | | Standard | | |
|---|---|---|---|---|
| Jurisdiction | Land Use | Original Units | Tons/sq mi/Month | Notes |
| Missouri | Non-industrial | tons/sq mi/month | 10 | b |
| Missouri | Heavy Industrial | tons/sq mi/month | 25 | b |
| Montana | Residential | tons/sq mi/month | 15 | c |
| Montana | Heavy Industrial | tons/sq mi/month | 30 | c |
| New York | | tons/sq mi/month | | |
| Oregon | Residential and Commercial | tons/sq mi/month | 15 | d, e |
| Oregon | Industrial | tons/sq mi/month | 30 | d, e |
| Oregon (Eugene and Springfield) | Residential and Commercial | tons/sq mi/month | 20 | |
| Oregon (Eugene and Springfield) | Industrial | tons/sq mi/month | 50 | |
| Pennsylvania | Any | 1.5 mg/cm$^2$/month | 48 | f |
| Pennsylvania | Air Basin | 1.mg/cm$^2$/month | 32 | g |
| Pennsylvania | Emission Standard | 0.6 mg/cm$^2$/month | 19 | h |

[a] Adapted from Air Pollution, A.C.Stern, Ed., 2nd Ed., Vol. III, page 681.

[b] St. Louis Metropolitan Area--3 months average above 5 tons/sq mi/month background value.

[c] Includes 5 ton/sq mi/month basic background.

[d] Above normal background value.

[e] Also Virginia.

[f] Not to be exceeded as the average of three successive sampling periods.

[g] Based on results from geographically uniformly spaced sampling stations.

[h] At any point outside a person's property.

Table IV-9. Air quality standards for solid particulate pollutants (in mg/m$^3$ at STP).

| Pollutant | Averaging Time | Percent of Time Not Allowed | Air Quality Standard | Jurisdiction | Remarks |
|---|---|---|---|---|---|
| Beryllium | 30 days | 100 | 0.00001 | Montana | |
| | | 100 | 0.00001 | Pennsylvania | |
| | 24 hours | 100 | 0.00001 | New York | |
| | | 100 | 0.00001 | Texas | Off Source's Property |
| Calcium Oxide | [Not Stated] | 100 | 0.02 | Oregon | |
| Lead (as Pb) | 30 days | 100 | 0.005 | Montana | |
| | | 100 | 0.005 | Pennsylvania | Tentative |
| Sulfates | 1 year | 100 | 0.004 | Missouri | St. Louis Metropolitan Areas |
| | | 100 | 0.004 | Montana | |
| | 30 days | 100 | 0.01 | Pennsylvania | (As $H_2SO_4$) |
| | 24 hours | 100 | 0.03 | Pennsylvania | (As $H_2SO_4$) |
| | [Not Stated] | 99 | 0.012 | Missouri | St. Louis Metropolitan Areas |
| | | 99 | 0.012 | Montana | |

Source: Giever, 1972.

Table IV-10. Air quality standards for gaseous pollutants.

| | | | Air Quality Standard | | | |
|---|---|---|---|---|---|---|
| Pollutant | Averaging Time | Percent of Time Not Allowed | mg/m· at STP | ppm | Jurisdiction | Remarks |
| Ethylene | 8 hours | 100 | 0.13 | 0.1 | California | Adverse Level |
| | 1 hour | 100 | 0.62 | 0.5 | California | Adverse Level |
| Nitrogen Dioxide | 1 hour | 100 | 0.45 | 0.25 | California | Adverse Level |
| | 1 hour | 100 | 5.5 | 3.0 | California | Serious Level |
| Nitrogen Oxides (As $NO^2$) | 1 hour | 99 | 0.18 | 0.1 | Colorado | |

Source: Giever, 1972.

Table IV-11. Air quality standards for hydrogen sulfide.

| | | Air Quality Standard | | | |
|---|---|---|---|---|---|
| Averaging Time | Percent of Time Not Allowed | $mg/m^3$ at STP | ppm | Jurisdiction | Remarks |
| 24 hours | 100 | 0.008 | 0.005 | Pennsylvania | |
| 1 hour | 100 | 0.15 | 0.1 | California | Adverse Level |
| | 100 | 0.15 | 0.1 | New York | |
| | 100 | 0.15 | 0.1 | Pennsylvania | |
| 30 minutes | 100 | 0.12 | 0.08 | Texas | Residential-Commercial |
| | 100 | 0.18 | 0.12 | Texas | Industrial-Other |
| | 99.9 | 0.075 | 0.05 | Missouri | St. Louis Metropolitan Area |
| | 99.9 | 0.075 | 0.05 | Montana | |
| | 99 | 0.045 | 0.03 | Missouri | St. Louis Metropolitan Area |
| | 99 | 0.045 | 0.03 | Montana | |

Source: Giever, 1972.

Table IV-12. Air quality standards for fluorides (as HF unless otherwise noted).

| Averaging Time | Percent of Time Not Allowed | Air Quality Standard mg/m³ at STP | Air Quality Standard ppm | Jurisdiction | Remarks |
|---|---|---|---|---|---|
| 24 hours | 100 | 0.0007 | 0.001 | Montana | |
| | 100 | 0.0007 | 0.001 | New York | Rural |
| | 100 | 0.0013 | 0.002 | New York | Urban |
| | 100 | 0.0026 | 0.004 | New York | Industrial |
| | 100 | 0.005 | 0.007 | Pennsylvania | Soluble |

[a] Although this is listed as an ambient air quality standard, it is the maximum ground level concentration from a single point source measured on the centerline downwind from the stack and, as such, has the characteristics of an emission standard.

Source: Giever, 1972.

Table IV-13. Air quality standards for sulfuric acid (in $mg/m^3$ at STP).

| Averaging Time | Percent of Time Not Allowed | Air Quality Standard | Jurisdiction | Remarks |
|---|---|---|---|---|
| 1 year | 100 | 0.004 | Missouri | St. Louis Metropolitan Area |
| | 100 | 0.004 | Montana | |
| 24 hours | 100 | 0.1 | New York | |
| | 99 | 0.01 | Missouri | St. Louis Metropolitan Area |
| 1 hour | 99 | 0.03 | Montana | |
| 30 minutes | 99 | 0.03 | Missouri | St. Louis Metropolitan Area |
| [Not Stated] | 99 | 0.012 | Missouri | St. Louis Metropolitan Area |
| | 99 | 0.012 | Montana | |

Source: Giever, 1972.

Table IV-14. Air quality standards for suspended particulate matter (in mg/m$^3$ at STP).

| Averaging Time | Percent of Time Not Allowed | Air Quality Standard | Jurisdiction | Remarks |
|---|---|---|---|---|
| 1 year | 100 | 0.06 | Ontario | Residential-Rural |
| | 100 | 0.075 | Missouri | St. Louis Metropolitan Area |
| | 100 | 0.075 | Montana | |
| | 100 | 0.11 | Ontario | Industrial-Commercial |
| 3 months | 100 | 0.12 | Colorado | |
| 30 days | 100 | 0.1 | Pennsylvania | Air Basin |
| | 100 | 0.15 | Pennsylvania | |
| 24 hours | 100 | 0.025 | South Carolina | Residential |
| | 100 | 0.05 | South Carolina | Non-Residential |
| | 100 | 0.5 | Pennsylvania | |
| | 99 | 0.2 | Missouri | St. Louis Metropolitan Area |
| | 99 | 0.2 | Montana | |
| | 95 | 0.13 | Delaware | Rural |
| | 95 | 0.15 | Delaware | Residential |
| | 95 | 0.17 | Delaware | Commercial |
| | 95 | 0.2 | Delaware | Industrial |
| | 90 | 0.09 | Ontario | Residential-Rural |
| | 90 | 0.125 | Texas | Residential |
| | 90 | 0.15 | Texas | Commercial |
| | 90 | 0.175 | Texas | Industrial |
| | 90 | 0.2 | Texas | Range-Agricultural |
| | 50 | 0.06 | Delaware | Rural* |
| | 50 | 0.075 | Delaware | Residential* |
| | 50 | 0.095 | Delaware | Commercial* |
| | 50 | 0.125 | Delaware | Industrial* |
| 1 hour | 100 | 0.05 | South Carolina | Residential |
| | 100 | 0.1 | South Carolina | Non-Residential |
| | 100 | 0.5 | Delaware | All Areas |
| 15 minutes | 100 | 0.1 | South Carolina | Residential |
| | 100 | 0.2 | South Carolina | Non-Residential |
| 10 minutes | 100 | 2. | Pennsylvania | Fugitive Dust |
| [Not Stated] | 100 | 0.15 | Oregon | Other than industrial--Above normal background |
| | 100 | 0.15 | Pennsylvania | Off Source's property |
| | 100 | 0.2 | Oregon | Other than Industrial |
| | 100 | 0.25 | Oregon | Industrial--Above normal background |
| | 100 | 0.3 | Oregon | Industrial |

* "zoned standards."

Source: Giever, 1972.

Table IV-15. Comparison of EPA ambient air quality standards and OSHA 8-hour TLV's.

| Pollutant | TLV (in ug/m$^3$) | EPA Standard (in ug/m$^3$) | |
|---|---|---|---|
| | | Primary | Secondary |
| $SO_2$ | 13,000 | 365 (24 hr) | 260 (24 hr) |
| CO | 55,000 | 10,000 (8 hr) | 10,000 ( 8 hr) |
| $NO_2$ | 9,000 | 100 (annual) | 100 (annual) |
| $O_3$ | 200 | 160 (1 hr) | 160 (1 hr) |
| Total suspended Particulates | --- | 260 (24 hr) | 150 (24 hr) |

## Table IV-16. Maximum permissible exposure values for various chemicals (TLV's).

| Substance | p.p.m.[a] | mg./$M^3$ [b] |
|---|---|---|
| Ethanethiol, see Ethylmercaptan |  |  |
| Ethanolamine | 3 | 6 |
| 2-Ethoxyethanol—Skin | 200 | 740 |
| 2-Ethoxyethylacetate (Cellosolve acetate)—Skin | 100 | 540 |
| Ethyl acetate | 400 | 1,400 |
| Ethyl acrylate—Skin | 25 | 100 |
| Ethyl alcohol (ethanol) | 1,000 | 1,900 |
| Ethylamine | 10 | 18 |
| Ethyl sec-amyl ketone (5-methyl-3-heptanone) | 25 | 130 |
| Ethyl benzene | 100 | 435 |
| Ethyl bromide | 200 | 890 |
| Ethyl butyl ketone (3-Heptanone) | 50 | 230 |
| Ethyl chloride | 1,000 | 2,600 |
| Ethyl ether | 400 | 1,200 |
| Ethyl formate | 100 | 300 |
| C Ethyl mercaptan | 10 | 25 |
| Ethyl silicate | 100 | 850 |
| Ethylene chlorohydrin—Skin | 5 | 16 |
| Ethylenediamine | 10 | 25 |
| Ethylene dibromide, see 1,2-Dibromoethane |  |  |
| Ethylene dichloride, see 1,2-Dichloroethane |  |  |
| C Ethylene glycol dinitrate and/or Nitroglycerin—Skin | [d] 0.2 | 1 |
| Ethylene glycol monomethyl ether acetate, see Methyl cellosolve acetate |  |  |
| Ethylene imine—Skin | 0.5 | 1 |
| Ethylene oxide | 50 | 90 |
| Ethylidine chloride, see 1,1-Dichloroethane |  |  |
| N-Ethylmorpholine—Skin | 20 | 94 |
| Ferbam |  | 15 |
| Ferrovanadium dust |  | 1 |
| Fluoride (as F) |  | 2.5 |
| Fluorine | 0.1 | 0.2 |
| Fluorotrichloromethane | 1,000 | 5,600 |
| Formic acid | 5 | 9 |
| Furfural—Skin | 5 | 20 |
| Furfuryl alcohol | 50 | 200 |
| Glycidol (2,3-Epoxy-1-propanol) | 50 | 150 |
| Glycol monoethyl ether, see 2-Ethoxyethanol |  |  |
| Guthion ®, see Azinphos-methyl |  |  |
| Hafnium |  | 0.5 |
| Heptachlor—Skin |  | 0.5 |
| Heptane (n-heptane) | 500 | 2,000 |
| Hexachloroethane—Skin | 1 | 10 |
| Hexachloronaphthalene—Skin |  | 0.2 |
| Hexane (n-hexane) | 500 | 1,800 |
| 2-Hexanone | 100 | 410 |
| Hexone (Methyl isobutyl ketone) | 100 | 410 |
| sec-Hexyl acetate | 50 | 300 |
| Hydrazine—Skin | 1 | 1.3 |
| Hydrogen bromide | 3 | 10 |
| C Hydrogen chloride | 5 | 7 |
| Hydrogen cyanide—Skin | 10 | 11 |
| Hydrogen peroxide (90%) | 1 | 1.4 |
| Hydrogen selenide | 0.05 | 0.2 |
| Hydroquinone |  | 2 |
| C Iodine | 0.1 | 1 |
| Iron oxide fume |  | 10 |
| Isoamyl acetate | 100 | 525 |
| Isoamyl alcohol | 100 | 360 |
| Isobutyl acetate | 150 | 700 |
| Isobutyl alcohol | 100 | 300 |
| Isophorone | 25 | 140 |
| Isopropyl acetate | 250 | 950 |
| Isopropyl alcohol | 400 | 980 |
| Isopropylamine | 5 | 12 |
| Isopropylether | 500 | 2,100 |
| Isopropyl glycidyl ether (IGE) | 50 | 240 |
| Ketene | 0.5 | 0.9 |
| Lead arsenate |  | 0.15 |
| Lindane—Skin |  | 0.5 |
| Lithium hydride |  | 0.025 |
| L.P.G. (liquified petroleum gas) | 1,000 | 1,800 |
| Magnesium oxide fume |  | 15 |
| Malathion—Skin |  | 15 |
| Maleic anhydride | 0.25 | 1 |
| C Manganese |  | 5 |
| Mesityl oxide | 25 | 100 |
| Methanethiol, see Methyl mercaptan |  |  |
| Methoxychlor |  | 15 |
| 2-Methoxyethanol, see Methyl cellosolve |  |  |
| Methyl acetate | 200 | 610 |
| Methyl acetylene (propyne) | 1,000 | 1,650 |
| Methyl acetylene-propadiene mixture (MAPP) | 1,000 | 1,800 |
| Methyl acrylate—Skin | 10 | 35 |
| Methylal (dimethoxymethane) | 1,000 | 3,100 |
| Methyl alcohol (methanol) | 200 | 260 |
| Methylamine | 10 | 12 |
| Methyl amyl alcohol, see Methyl isobutyl carbinol |  |  |
| Methyl (n-amyl) ketone (2-Heptanone) | 100 | 465 |
| C Methyl bromide—Skin | 20 | 80 |
| Methyl butyl ketone, see 2-Hexanone |  |  |
| Methyl cellosolve—Skin | 25 | 80 |
| Methyl cellosolve acetate—Skin | 25 | 120 |
| Methyl chloroform | 350 | 1,900 |
| Methylcyclohexane | 500 | 2,000 |
| Methylcyclohexanol | 100 | 470 |
| o-Methylcyclohexanone—Skin | 100 | 460 |
| Methyl ethyl ketone (MEK), see 2-Butanone |  |  |
| Methyl formate | 100 | 250 |
| Methyl iodide—Skin | 5 | 28 |
| Methyl isobutyl carbinol—Skin | 25 | 100 |
| Methyl isobutyl ketone, see Hexone |  |  |
| Methyl isocyanate—Skin | 0.02 | 0.05 |
| C Methyl mercaptan | 10 | 20 |
| Methyl methacrylate | 100 | 410 |
| Methyl propyl ketone, see 2-Pentanone |  |  |
| C α Methyl styrene | 100 | 480 |
| C Methylene bisphenyl isocyanate (MDI) | 0.02 | 0.2 |
| Molybdenum: |  |  |
| Soluble compounds |  | 5 |
| Insoluble compounds |  | 15 |
| Monomethyl aniline—Skin | 2 | 9 |
| C Monomethyl hydrazine—Skin | 0.2 | 0.35 |
| Morpholine—Skin | 20 | 70 |
| Naphtha (coaltar) | 100 | 400 |
| Naphthalene | 10 | 50 |
| Nickel carbonyl | 0.001 | 0.007 |
| Nickel, metal and soluble cmpds, as Ni |  | 1 |
| Nicotine—Skin |  | 0.5 |
| Nitric acid | 2 | 5 |
| Nitric oxide | 25 | 30 |
| p-Nitroaniline—Skin | 1 | 6 |
| Nitrobenzene—Skin | 1 | 5 |
| p-Nitrochlorobenzene—Skin |  | 1 |
| Nitroethane | 100 | 310 |
| Nitrogen dioxide | 5 | 9 |
| Nitrogen trifluoride | 10 | 29 |
| Nitroglycerin—Skin | 0.2 | 2 |
| Nitromethane | 100 | 250 |
| 1-Nitropropane | 25 | 90 |
| 2-Nitropropane | 25 | 90 |
| Nitrotoluene—Skin | 5 | 30 |
| Nitrotrichloromethane, see Chloropicrin |  |  |
| Octachloronaphthalene—Skin |  | 0.1 |
| *Octane | 500 | 2,350 |
| *Oil mist, mineral |  | [e] 5 |
| Osmium tetroxide |  | 0.002 |
| Oxalic acid |  | 1 |
| Oxygen difluoride | 0.05 | 0.1 |
| Ozone | 0.1 | 0.2 |
| Paraquat—Skin |  | 0.5 |
| Parathion—Skin |  | 0.1 1 |
| Pentaborane | 0.005 | 0.01 |
| Pentachloronaphthalene—Skin |  | 0.5 |
| Pentachlorophenol—Skin |  | 0.5 |
| *Pentane | 1,000 | 2,950 |
| 2-Pentanone | 200 | 700 |
| Perchloromethyl mercaptan | 0.1 | 0.8 |
| Perchloryl fluoride | 3 | 13.5 |
| Petroleum distillates (naphtha) | 500 | 2,000 |
| Phenol—Skin | 5 | 19 |
| p-Phenylene diamine—Skin |  | 0.1 |
| Phenyl ether (vapor) | 1 | 7 |
| Phenyl ether-biphenyl mixture (vapor) | 1 | 7 |
| Phenylethylene, see Styrene |  |  |
| Phenyl glycidyl ether (PGE) | 10 | 60 |
| Phenylhydrazine—Skin | 5 | 22 |
| Phosdrin (Mevinphos ®)—Skin |  | 0.1 |
| Phosgene (carbonyl chloride) | 0.1 | 0.4 |
| Phosphine | 0.3 | 0.4 |
| Phosphoric acid |  | 1 |
| Phosphorus (yellow) |  | 0.1 |
| Phosphorus pentachloride |  | 1 |
| Phosphorus pentasulfide |  | 1 |
| Phosphorus trichloride | 0.5 | 3 |
| Phthalic anhydride | 2 | 12 |
| Picric acid—Skin |  | 0.1 |
| Pival ® (2-Pivalyl-1,3-indandione) |  | 0.1 |
| Platinum (Soluble Salts) as Pt |  | 0.002 |
| Propargyl alcohol—Skin | 1 |  |
| Propane | 1,000 | 1,800 |
| n-Propyl acetate | 200 | 840 |
| Propyl alcohol | 200 | 500 |
| n-Propyl nitrate | 25 | 110 |
| Propylene dichloride | 75 | 350 |
| Propylene imine—Skin | 2 | 5 |
| Propylene oxide | 100 | 240 |
| Propyne, see Methylacetylene |  |  |
| Pyrethrum |  | 5 |
| Pyridine | 5 | 15 |
| Quinone | 0.1 | 0.4 |
| RDX—Skin |  | 1.5 |
| Rhodium, Metal fume and dusts, as Rh |  | 0.1 |
| Soluble salts |  | 0.001 |
| Ronnel |  | 10 |
| Rotenone (commercial) |  | 5 |
| Selenium compounds (as Se) |  | 0.2 |
| Selenium hexafluoride | 0.05 | 0.4 |
| Silver, metal and soluble compounds |  | 0.01 |
| Sodium fluoroacetate (1080)—Skin |  | 0.05 |
| Sodium hydroxide |  | 2 |
| Stibine | 0.1 | 0.5 |
| *Stoddard solvent | 500 | 2,950 |
| Strychnine |  | 0.15 |
| Sulfur dioxide | 5 | 13 |
| Sulfur hexafluoride | 1,000 | 6,000 |
| Sulfuric acid |  | 1 |
| Sulfur monochloride | 1 | 6 |
| Sulfur pentafluoride | 0.025 | 0.25 |
| Sulfuryl fluoride | 5 | 20 |
| Systox, see Demeton ® |  |  |
| 2,4,5T |  | 10 |
| Tantalum |  | 5 |
| TEDP—Skin |  | 0.2 |
| Tellurium |  | 0.1 |
| Tellurium hexafluoride | 0.02 | 0.2 |
| TEPP—Skin |  | 0.05 |
| C Terphenyls | 1 | 9 |
| 1,1,1,2-Tetrachloro-2,2-difluoroethane | 500 | 4,170 |
| 1,1,2,2-Tetrachloro-1,2-difluoroethane | 500 | 4,170 |
| 1,1,2,2-Tetrachloroethane—Skin | 5 | 35 |
| Tetrachloroethylene, see Perchloroethylene |  |  |
| Tetrachloromethane, see Carbon tetrachloride |  |  |
| Tetrachloronaphthalene—Skin |  | 2 |
| Tetraethyl lead (as Pb)—Skin |  | 0.075 |
| Tetrahydrofuran | 200 | 590 |
| Tetramethyl lead (as Pb)—Skin |  | 0.07 |
| Tetramethyl succinonitrile—Skin | 0.5 | 3 |
| Tetranitromethane | 1 | 8 |
| Tetryl (2,4,6-trinitrophenylmethylnitramine)—Skin |  | 1.5 |
| Thallium (soluble compounds)—Skin as Tl |  | 0.1 |
| Thiram |  | 5 |
| Tin (inorganic cmpds, except oxides |  | 2 |
| Tin (organic cmpds) |  | 0.1 |
| C Toluene-2,4-diisocyanate | 0.02 | 0.14 |
| o-Toluidine—Skin | 5 | 22 |
| Toxaphene, see Chlorinated camphene |  |  |
| Tributyl phosphate |  | 5 |
| 1,1,1-Trichloroethane see Methyl chloroform |  |  |
| 1,1,2-Trichloroethane—Skin | 10 | 45 |
| Titaniumdioxide |  | 15 |
| Trichloromethane, see Chloroform |  |  |
| Trichloronaphthalene—Skin |  | 5 |
| 1,2,3-Trichloropropane | 50 | 300 |
| 1,1,2-Trichloro 1,2,2-trifluoroethane | 1,000 | 7,600 |
| Triethylamine | 25 | 100 |
| Trifluoromonobromomethane | 1,000 | 6,100 |
| 2,4,6-Trinitrophenol, see Picric acid |  |  |
| 2,4,6-Trinitrophenylmethylnitramine, see Tetryl |  |  |
| Trinitrotoluene—Skin |  | 1.5 |
| Triorthocresyl phosphate |  | 0.1 |
| Triphenyl phosphate |  | 3 |
| Turpentine | 100 | 560 |
| Uranium (soluble compounds) |  | 0.05 |
| Uranium (insoluble compounds) |  | 0.25 |
| C Vanadium: |  |  |
| $V_2O_5$ dust |  | 0.5 |
| $V_2O_5$ fume |  | 0.1 |
| Vinyl benzene, see Styrene |  |  |
| Vinylcyanide, see Acrylonitrile |  |  |
| Vinyl toluene | 100 | 480 |
| Warfarin |  | 0.1 |
| Xylene (xylol) | 100 | 435 |
| Xylidine—Skin | 5 | 25 |
| Yttrium |  | 1 |
| Zinc chloride fume |  | 1 |
| Zinc oxide fume |  | 5 |
| Zirconium compounds (as Zr) |  | 5 |

*1970 Addition.

[a] Parts of vapor or gas per million parts of contaminated air by volume at 25° C. and 760 mm. Hg pressure.

[b] Approximate milligrams of particulate per cubic meter of air.

(No footnote "c" is used to avoid confusion with ceiling value notations.)

[d] An atmospheric concentration of not more than 0.02 p.p.m., or personal protection may be necessary to avoid headache.

[e] As sampled by method that does not collect vapor.

[f] For control of general room air, biologic monitoring is essential for personnel control.

[Vinyl chloride deleted at 39 FR 12343, April 5, 1974]

# Table IV-16. Maximum permissible exposure values for various chemicals (TLV's) (continued).

| Substance | p.p.m.[a] | mg./M$^3$ [b] |
|---|---|---|
| Acetaldehyde | 200 | 360 |
| Acetic acid | 10 | 25 |
| Acetic anhydride | 5 | 20 |
| Acetone | 1,000 | 2,400 |
| Acetonitrile | 40 | 70 |
| Acetylene dichloride, see 1, 2-Dichloroethylene | | |
| Acetylene tetrabromide | 1 | 14 |
| Acrolein | 0.1 | 0.25 |
| Acrylamide—Skin | | 0.3 |
| Acrylonitrile—Skin | 20 | 45 |
| Aldrin—Skin | | 0.25 |
| Allyl alcohol—Skin | 2 | 5 |
| Allyl chloride | 1 | 3 |
| **C Allyl glycidyl ether (AGE) | 10 | 45 |
| Allyl propyl disulfide | 2 | 12 |
| 2-Aminoethanol, see Ethanolamine | | |
| 2-Aminopyridine | 0.5 | 2 |
| **Ammonia | 50 | 35 |
| Ammonium sulfamate (Ammate) | | 15 |
| n-Amyl acetate | 100 | 525 |
| sec-Amyl acetate | 125 | 650 |
| Aniline—Skin | 5 | 19 |
| Anisidine (o, p-isomers)—Skin | | 0.5 |
| Antimony and compounds (as Sb) | | 0.5 |
| ANTU (alpha naphthyl thiourea) | | 0.3 |
| Arsenic and compounds (as As) | | 0.5 |
| Arsine | 0.05 | 0.2 |
| Azinphos-methyl—Skin | | 0.2 |
| Barium (soluble compounds) | | 0.5 |
| p-Benzoquinone, see Quinone | | |
| Benzoyl peroxide | | 5 |
| Benzyl chloride | 1 | 5 |
| Biphenyl, see Diphenyl | | |
| Bisphenol A, see Diglycidyl ether | | |
| Boron oxide | | 15 |
| C Boron trifluoride | 1 | 3 |
| Bromine | 0.1 | 0.7 |
| Bromoform—Skin | 0.5 | 5 |
| Butadiene (1, 3-butadiene) | 1,000 | 2,200 |
| Butanethiol, see Butyl mercaptan | | |
| 2-Butanone | 200 | 590 |
| 2-Butoxy ethanol (Butyl Cellosolve)—Skin | 50 | 240 |
| Butyl acetate (n-butyl acetate) | 150 | 710 |
| sec-Butyl acetate | 200 | 950 |
| tert-Butyl acetate | 200 | 950 |
| Butyl alcohol | 100 | 300 |
| sec-Butyl alcohol | 150 | 450 |
| tert-Butyl alcohol | 100 | 300 |
| C Butylamine—Skin | 5 | 15 |
| C tert-Butyl chromate (as $CrO_3$)—Skin | | 0.1 |
| n-Butyl glycidyl ether (BGE) | 50 | 270 |
| *Butyl mercaptan | 10 | 35 |
| p-tert-Butyltoluene | 10 | 60 |
| Calcium arsenate | | 1 |
| Calcium oxide | | 5 |
| **Camphor | 2 | |
| Carbaryl (Sevin ®) | | 5 |
| Carbon black | | 3.5 |
| Carbon dioxide | 5,000 | 9,000 |
| Carbon monoxide | 50 | 55 |
| Chlordane—Skin | | 0.5 |
| Chlorinated camphene—Skin | | 0.5 |
| Chlorinated diphenyl oxide | | 0.5 |
| *Chlorine | 1 | 3 |
| Chlorine dioxide | 0.1 | 0.3 |
| C Chlorine trifluoride | 0.1 | 0.4 |
| C Chloroacetaldehyde | 1 | 3 |
| α-Chloroacetophenone (phenacylchloride) | 0.05 | 0.3 |
| Chlorobenzene (monochlorobenzene) | 75 | 350 |
| o-Chlorobenzylidene malononitrile (OCBM) | 0.05 | 0.4 |
| Chlorobromomethane | 200 | 1,050 |
| 2-Chloro-1,3-butadiene, see Chloroprene | | |
| Chlorodiphenyl (42 percent Chlorine)—Skin | | 1 |
| Chlorodiphenyl (54 percent Chlorine)—Skin | | 0.5 |
| 1-Chloro,2,3-epoxypropane, see Epichlorhydrin | | |
| 2-Chloroethanol, see Ethylene chlorohydrin | | |
| Chloroethylene, see Vinyl chloride | | |
| C Chloroform (trichloromethane) | 50 | 240 |
| 1-Chloro-1-nitropropane | 20 | 100 |
| Chloropicrin | 0.1 | 0.7 |
| Chloroprene (2-chloro-1,3-butadiene)—Skin | 25 | 90 |
| Chromium, sol. chromic, chromous salts as Cr | | 0.5 |
| Metal and insol. salts | | 1 |
| Coal tar pitch volatiles (benzene soluble fraction) anthracene, BaP, phenanthrene, acridine, chrysene, pyrene | | 0.2 |
| Cobalt, metal fume and dust | | 0.1 |
| Copper fume | | 0.1 |
| Dusts and Mists | | 1 |
| Cotton dust (raw) | | 1 |
| Crag® herbicide | | 15 |
| Cresol (all isomers)—Skin | 5 | 22 |
| Crotonaldehyde | 2 | 6 |
| Cumene—Skin | 50 | 245 |
| Cyanide (as CN)—Skin | | 5 |
| Cyclohexane | 300 | 1,050 |
| Cyclohexanol | 50 | 200 |
| Cyclohexanone | 50 | 200 |
| Cyclohexene | 300 | 1,015 |
| Cyclopentadiene | 75 | 200 |
| 2, 4-D | | 10 |
| DDT—Skin | | 1 |
| DDVP, see Dichlorvos | | |
| Decaborane—Skin | 0.05 | 0.3 |
| Demeton®—Skin | | 0.1 |
| Diacetone alcohol (4-hydroxy-4-methyl-2-pentanone) | 50 | 240 |
| 1,2-diaminoethane, see Ethylenediamine | | |
| Diazomethane | 0.2 | 0.4 |
| Diborane | 0.1 | 0.1 |
| Dibutylphthalate | | 5 |
| C o-Dichlorobenzene | 50 | 300 |
| p-Dichlorobenzene | 75 | 450 |
| Dichlorodifluoromethane | 1,000 | 4,950 |
| 1,3-Dichloro-5,5-dimethyl hydantoin | | 0.2 |
| 1,1-Dichloroethane | 100 | 400 |
| 1,2-Dichloroethylene | 200 | 790 |
| C Dichloroethyl ether—Skin | 15 | 90 |
| Dichloromethane, see Methylenechloride | | |
| Dichloromonofluoromethane | 1,000 | 4,200 |
| C 1,1-Dichloro-1-nitroethane | 10 | 60 |
| 1,2-Dichloropropane, see Propylenedichloride | | |
| Dichlorotetrafluoroethane | 1,000 | 7,000 |
| Dichlorvos (DDVP)—Skin | | 1 |
| Dieldrin—Skin | | 0.25 |
| Diethylamine | 25 | 75 |
| Diethylamino ethanol—Skin | 10 | 50 |
| Diethylether, see Ethyl ether | | |
| Difluorodibromomethane | 100 | 860 |
| C Diglycidyl ether (DGE) | 0.5 | 2.8 |
| Dihydroxybenzene, see Hydroquinone | | |
| Diisobutyl ketone | 50 | 290 |
| Diisopropylamine—Skin | 5 | 20 |
| Dimethoxymethane, see Methylal | | |
| Dimethyl acetamide—Skin | 10 | 35 |
| Dimethylamine | 10 | 18 |
| Dimethylaminobenzene, see Xylidene | | |
| Dimethylaniline (N-dimethylaniline)—Skin | 5 | 25 |
| Dimethylbenzene, see Xylene | | |
| Dimethyl 1,2-dibromo-2,2-dichloroethyl phosphate, (Dibrom) | | 3 |
| Dimethylformamide—Skin | 10 | 30 |
| 2,6-Dimethylheptanone, see Diisobutyl ketone | | |
| 1,1-Dimethylhydrazine—Skin | 0.5 | 1 |
| Dimethylphthalate | | 5 |
| Dimethylsulfate—Skin | 1 | 5 |
| Dinitrobenzene (all isomers)—Skin | | 1 |
| Dinitro-o-cresol—Skin | | 0.2 |
| Dinitrotoluene—Skin | | 1.5 |
| Dioxane (Diethylene dioxide)—Skin | 100 | 360 |
| Diphenyl | 0.2 | 1 |
| Diphenylmethane diisocyanate (see Methylene bisphenyl isocyanate (MDI) | | |
| Dipropylene glycol methyl ether—Skin | 100 | 600 |
| Di-sec, octyl phthalate (Di-2-ethylhexylphthalate) | | 5 |
| Endrin—Skin | | 0.1 |
| Epichlorhydrin—Skin | 5 | 19 |
| EPN—Skin | | 0.5 |
| 1,2-Epoxypropane, see Propyleneoxide | | |
| 2,3-Epoxy-1-propanol, see Glycidol | | |

## Table IV-17. TLV's for twenty-two substances.

| Material | 8-hour time weighted average | Acceptable ceiling concentration | Acceptable maximum peak above the acceptable ceiling concentration for an 8-hour shift. | |
|---|---|---|---|---|
| | | | Concentration | Maximum duration |
| Benzene (Z37.4-1969) | 10 p.p.m. | 25 p.p.m. | 50 p.p.m. | 10 minutes. |
| Beryllium and beryllium compounds (Z37.29-1970). | 2 μg./M³ | 5 μg./M³ | 25 μg./M³ | 30 minutes. |
| Cadmium fume (Z37.5-1970) | 0.1 mg./M³ | 3 mg./M³ | | |
| Cadmium dust (Z37.5-1970) | 0.2 mg./M³ | 0.6 mg./M³ | | |
| Carbon disulfide (Z37.3-1968) | 20 p.p.m. | 30 p.p.m. | 100 p.p.m. | Do. |
| Carbon tetrachloride (Z37.17-1967) | 10 p.p.m. | 25 p.p.m. | 200 p.p.m. | 5 minutes in any 4 hours. |
| Ethylene dibromide (Z37.31-1970) | 20 p.p.m. | 30 p.p.m. | 50 p.p.m. | 5 minutes. |
| Ethylene dichloride (Z37.21-1969) | 50 p.p.m. | 100 p.p.m. | 200 p.p.m. | 5 minutes in any 3 hours. |
| Formaldehyde (Z37.16-1967) | 3 p.p.m. | 5 p.p.m. | 10 p.p.m. | 30 minutes. |
| Hydrogen fluoride (Z37.28-1969) | do. | | | |
| Fluoride as dust (Z37.28-1969) | 2.5 mg./M³ | | | |
| Lead and its inorganic compounds (Z37.11-1969). | 0.2 mg./M³ | | | |
| Methyl chloride (Z37.18-1969) | 100 p.p.m. | 200 p.p.m. | 300 p.p.m. | 5 minutes in any 3 hours. |
| Methylene Chloride (Z37.3-1969) | 500 p.p.m. | 1,000 p.p.m. | 2,000 p.p.m. | 5 minutes in any 2 hours. |
| Organo (alkyl) mercury (Z37.30-1969) | 0.01 mg./M³ | 0.04 mg./M³ | | |
| Styrene (Z37.15-1969) | 100 p.p.m. | 200 p.p.m. | 600 p.p.m. | 5 minutes in any 3 hours. |
| Trichloroethylene (Z37.19-1967) | do. | do. | 300 p.p.m. | 5 minutes in any 2 hours. |
| Tetrachloroethylene (Z37.22-1967) | do. | do. | do. | 5 minutes in any 3 hours. |
| Toluene (Z37.12-1967) | 200 p.p.m. | 300 p.p.m. | 500 p.p.m. | 10 minutes. |
| Hydrogen sulfide (Z37.2-1966) | | 20 p.p.m. | 50 p.p.m. | 10 minutes once only if no other measurable exposure occurs. |
| Mercury (Z37.8-1971) | | 1 mg./10M³ | | |
| Chromic acid and chromates (Z37.7-1971) | | do ³ | | |

## Table IV-18. TLV's for mineral dusts.

| Substance | Mppcf[a] | Mg/M³ |
|---|---|---|
| Silica: | | |
| Crystalline: | | |
| Quartz (respirable) | $\frac{250}{\%SiO_2+5}$ [k] | $\frac{10mg/M^3}{\%SiO_2+2}$ [m] |
| Quartz (total dust) | | $\frac{30mg/M^3}{\%S_2O_2+2}$ |
| Cristobalite: Use ½ the value calculated from the count or mass formulae for quartz. | | |
| Tridymite: Use ½ the value calculated from the formulae for quartz. | | |
| Amorphous, including natural diatomaceous earth | 20 | $\frac{80mg/M^3}{\%SiO_2}$ |
| Silicates (less than 1% crystalline silica): | | |
| Mica | 20 | |
| Soapstone | 20 | |
| Talc (non-asbestos-form) | 20[n] | |
| Talc (fibrous). Use asbestos limit | | |
| Tremolite (see talc, fibrous) | | |
| Portland cement | 50 | |
| Graphite (natural) | 15 | |
| Coal dust (respirable fraction less than 5% SiO₂) | | 2.4mg/M³ or |
| For more than 5% SiO₂ | | $\frac{10mg/M^3}{\%SiO_2+2}$ |
| Inert or Nuisance Dust: | | |
| Respirable fraction | 15 | 5mg/M³ |
| Total dust | 50 | 15mg/M³ |

NOTE: Conversion factors—
mppcf×35.3=million particles per cubic meter
=particles per c.c.

[a] Millions of particles per cubic foot of air, based on impinger samples counted by light-field technics.

[k] The percentage of crystalline silica in the formula is the amount determined from air-borne samples, except in those instances in which other methods have been shown to be applicable.

[l] As determined by the membrane filter method at 430×phase contrast magnification.

[m] Both concentration and percent quartz for the application of this limit are to be determined from the fraction passing a size-selector with the following characteristics:

[n] Containing < 1% quartz; if > 1% quartz, use quartz limit.

In the EPA Source Assessment Program 24-hour ambient levels of one three-hundreth of a TLV are considered sufficient cause for developing air pollution control technology for the pollutant in question. If ambient levels are more than one three-thousandth of the TLV, but less than one three-hundreth, the source may or may not be a candidate for control technology development, depending on the possibility of additive effects, synergism, and other factors. If the concentration is less than one three-thousandth of a TLV, the development of additional controls is not justified. Tables IV-16, IV-17, and IV-18 summarize the threshold limit values as of May 1975.

i. National Institute of Occupational Safety and Health Suspected Carcinogens List: In addition to the OSHA and Ambient Air Quality Standards, any substance not currently under regulation that is suspected of causing cancer, mutations, or other adverse reactions is of environmental interest. While it is not possible to list all such substances, the National Institute for Occupational Safety and Health (NIOSH) has listed hundreds of compounds that are suspected of causing cancer. The EPA has arranged these substances according to the relative degree of concern that might be warranted based on carcinogenic potential. This listing could be important in prioritizing the compounds to be analyzed from coal conversion and utilization projects.

j. Future Air Quality Standards: The Pollutant Strategies Branch of EPA is actively involved in setting new ambient air quality standards. They have investigated the necessity of setting standards for various chemical compounds and materials that have come to their attention as a result of past research, public interest, litigation, and interest among professionals involved with air pollution or environmental effects. The EPA at present (November 1976) is developing a more systematic and objective scheme for determining which compounds to investigate, and have hired a contractor to prioritize 637 compounds. Researchers at the Pollutants Strategies Branch are actively working on sulfates, hydrogen sulfide, cadmium, lead, hexavalent chromium, benzene, polycyclic organic matter (especially benzo(a)pyrene), ethlyene dibromide, chlorinated biphenyls and various other organic and inorganic compounds and elements. Respirable particles (less than 3 microns) are also being investigated. They do not expect to set any new standards in the immediate future unless they are forced to as a result of a court case currently pending. The EPA may be forced to set a standard for lead, but they are working on many possibilities. They have preliminary priority lists of inorganic compounds developed for internal use, but they are subject to change. Interested government officials may obtain copies of the latest draft list for internal use by contacting Richard Johnson of the EPA Pollutant Strategies Branch at (919) 688-8145, Ext. 355. Generally, substances for which OSHA has published TLV's, substances suspected of being carcinogens, and substances of ecological significance according to the literature or implicated as being involved in the formation of such substances, are most important. Fluorinated hydrocarbons are an example, since they may affect the Earth's ozone layer, which protects the lower levels of the atmosphere from potentially harmful ultraviolet radiation.

## 2. Water Pollutants.

a. National Water Standards for Coal Plants: The Federal Water Pollution Act Amendments of 1972 (P.L. 92-500) control the discharge of liquid pollutants from point sources. Such sources are generally considered to include pipes, sewers, or similar conduits which carry wastewater or other liquids and empty into streams, lakes, or other bodies of water. Storm water collection systems may be included if the stormwater is contaminated by a particular source (e.g., coal pile or feedlot).

In general, P.L. 92-500 makes the discharge of any pollutant from a point source unlawful without a "National Pollutant Discharge Elimination System" (NPDES) Permit. The permit must stipulate that certain minimum technology be utilized in treating the effluent. It may also require that a minimum quality be attained by the treatment technology and that provisions be made for monitoring and inspection. In addition, the law provides for the establishment of "standards of performance" for the control of new sources of pollutants from various categories of discharges (generic types of industries, manufacturing concerns, food and fiber processing plants, etc.).

To date, no New Source Performance Standards have been established for coal conversion or other advanced coal technology plants. (In fact, one goal of an ERDA Coal Plant Environmental Monitoring Program might be to provide data for such rule-making). Table IV-19 summarizes pollutants which are controlled specifically for industrial processes similar to those in ERDA coal research activities. Quantities of pollutants in some standards are stated in terms of process production rates rather than effluent concentrations. Although not directly applicable to coal conversion processes, they do indicate order-of-magnitude control requirements.

Tables IV-20 and IV-21 indicate water contaminants identified as particularly harmful by EPA. Drinking water supply systems must insure that their treated water meets minimum

Table IV-19. Effluent limitation guidelines and new source performance standards: point source discharges to navigable waters.

| 40 CFR Subsections | Source Categories Related to Coal Gasification Processes | | | | Notes |
|---|---|---|---|---|---|
| | Source | Effluent Parameter | BPT[1] | BAT[2]/NSPS[3]PS[4] | |
| 434.10 | Coal Preparation Plant | | [no discharge] | | |
| 434.20 | Coal Storage, etc. | Total Iron | 7.0-3.5 mg-1 | | first number: Maximum for any day.<br>second number: daily average for consecutive days. |
| | | Total Manganese | 4.0-2.0 mg/l | | |
| | | Total Suspended Solids | 70-35.0 mg/l | | |
| | | pH | 6.0-9.0 | | |
| 420.10 | Slot-type Coke Ovens | Ammonia | 0.2736-0.0912 kg/kkg product | 0.0126-0.0042 kg/kkg product | First and second numbers as above. |
| | | Cyanide | 0.0657-0.0219 kg/kkg product | | |
| | | Oil and Grease | 0.0327-0.0109 kg/kkg product | 0.0126-0.0042 kg/kkg | Greater amounts of all parameters for ovens with desulfurization units (15% BPT and 25% BAT/NSS) or indirect ammonia recovery (30% BPT and 70% BAT/NSS). |
| | | Phenol | 0.0045-0.0015 kg/kkg product | 0.0006-0.0002 kg/kkg | |
| | | Total Suspended Solids | 0.1095-0.0365 kg/kkg product | 0.0312-0.0104 kg/kkg | |
| | | pH | 6.0-9.0 | 6.0-9.0 | |
| | | Cyanide A[5] | | 0.0003-0.0001 lb/1000 lb. | |
| | | Sulfide | | 0.0003-0.0001 lb/1000 lb. | |
| 420.20 | Beehive Coke Ovens | | [no discharge] | [no discharge] | |
| 419 | Petroleum Refining Processes (various) | Biochemical Oxygen Demand, 5 day | [various]<br>[various] | [various]<br>[various] | Various effluent limitations and standards for topping, cracking, lube oil manufacturing, and petrochemical operations. |
| | | Total Suspended Solids | [various] | [various] | |
| | | Chemical Oxygen Demand | [various] | [various] | |
| | | Oil & Grease | [various] | [various] | |
| | | Phenolic Compounds | [various] | [various] | |
| | | Ammonia, as N | [various] | [various] | |
| | | Sulfide | [various] | [various] | |
| | | Total Chromium | [various] | [various] | |
| | | Hexavalent Chromium | [various] | [various] | |
| | | pH | [various] | [various] | |

Table IV-19 (Continued)

| 40 CFR Subsections | Source Categories Related to Coal Gasification Processes |  |  |  | Notes |
|---|---|---|---|---|---|
|  | Source | Effluent Parameter | BPT$^1$ | BAT$^2$/NSPS$^3$PS$^4$ |  |
|  | Process Area Runoff Petroleum Process Area | Biochemical Oxygen Demand, 5 day | 0.048-0.026/kg/m$^3$ of flow | 0.0105-0.0085 | First and second as above. NSPS same as BPT. |
|  |  | Total Suspended Solids | 0.033-0.021 | 0.010-0.0085 |  |
|  |  | Chemical Oxygen Demand | 0.37-0.19 | 0.028-0.022 |  |
|  |  | Oil & Grease | 0.015-0.008 | 0.0020-0.0016 |  |
|  |  | pH | 6.0-9.0 | 6.0-9.0 |  |
|  | Once-through Cooling Water | Total Organic | 5 mg/l | 5 mg/l |  |

NOTES:

[1] BPT: Best Practicable Control Technology; required by July 1, 1977.

[2] BAT: Best Available Technology Achievable; required by July 1, 1983.

[3] NSPS: New Source Performance Standards.

[4] PS: Pretreatment Standards for new source users of publicly owned treatment plants.

[5] Cyanide A: Fraction of total cyanide which is amenable to chlorination, i.e. the uncomplexed and most toxic fraction.

Table IV-20. Maximum permissible concentrations of hazardous pollutants, National Interim Primary Drinking Water Standards, 40 CFR 141

| Characteristic | Maximum Contaminant Level |
|---|---|
| Inorganic Chemicals: | |
| Arsenic | 0.05 mg/l |
| Barium | 1. |
| Cadmium | 0.010 |
| Chromium | 0.05 |
| Lead | 0.05 |
| Mercury | 0.002 |
| Nitrate | 10. |
| Selenium | 0.01 |
| Silver | 0.05 |
| Fluoride | |
| Organic Chemicals: | |
| Endrin | 0.0002 mg/l |
| Lindane | 0.004 |
| Methoxychlor | 0.1 |
| Toxaphene | 0.005 |
| 2-4-D | 0.1 |
| 2-4-5 TP Silvex | 0.01 |
| Turbidity | 1 Turbidity Unit |
| Coliform Bacteria | 1/100 ml (membrane filter technique; arithmetic mean) |

standards for the indicated characteristics. The toxic substances listed in Table IV-21 have been identified on the basis of their toxicity, persistence, degradability, and effect on various organisms. Special effluent limitations for these substances are currently being proposed by EPA.

ERDA advanced coal technology facilities may be considered in the future as a "new source" category under Section 306 of the Federal Water Pollution Control Act Amendments of 1972. Present EPA priorities indicate that it will be at least two years before that agency will begin the rulemaking process which would set effluent standards for some or all of the coal processes (Tielliard, 1977, personal communication). Establishment of these standards will require a background document which demonstrates for the various processes the nature of pollutants generated and the degree of treatment possible. An environmental monitoring program at one or more ERDA facilities, perhaps operated in conjunction with EPA, would provide valuable data for this document.

Table IV-21. EPA toxic water pollutants, 40 CFR.

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Aldrin/Dieldrin
Benzidine and Benzidine Salts
Cadmium and All Cadmium Compounds
Cyanide and All Cyanide Compounds
DDT/DDD/DDE
Endrin
Mercury and All Mercury Compounds
Polychlorinated Biphenyls
Toxaphene

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b. State and Local Water Standards: Primary responsibility for attaining and maintaining water quality remains with the States. However, they are required to meet minimum federal standards, and in most cases their programs are not stricter. States must consent to NPDES permits granted by EPA, or they may qualify to administer the permit program themselves.

States have been required to classify the waters of their states according to their potential water quality. No discharges can be allowed which would degrade streams or water bodies below their designated classification. Special "water quality limited" effluent limitations may be imposed to insure that the designated water quality is maintained or attained. Table IV-20 indicates water characteristics by which state water quality classifications may be specified maximum.

Local water quality programs may affect coal processing plants through "pretreatment standards" which may be imposed on any wastes introduced into local sewer systems. Imposition of such standards is a condition placed on the local treatment facilities through its NPDES permit. These pretreatment standards are essentially the same as the performance standards to which the effluent would be subject if it were directly discharged to streams or water bodies.

The water quality standards and/or pretreatment standards which would apply at the site of a coal processing plant should be considered in the design of a monitoring program.

### 3. Solid Wastes

a. National Standards: Federal legislators have considered solid waste as both a potential resource and a source of surface and groundwater pollution through the formation and migration of leachate. The purpose of the Solid Waste Disposal Act (P.L. 89-272, 1965 as amended by the Resource Recovery Act, 1970, PL 91-512; P.L. 93-14, 1973; and P.L. 93-611, 1975) was to promote the development of solid waste management and resource recovery systems which protect the quality of air, water, and land resources. It was also the purpose of the Act to provide for the development of solid waste collection, transport, separation, recovery, and disposal system design and operation guidelines.

In 1972, the EPA issued Administrator's Decision Statement No. 2 on the EPA Solid Waste Management Program. In this statement the goals of the agency's solid waste management program were identified as follows: (1) demonstrate that solid waste problems can be solved by available or nearly available technology; (2) perfect sanitary landfilling as a disposal method; (3) focus efforts on areas of solid waste management where chance of success is highest; (4) develop techniques for the disposal of hazardous materials; and (5) evaluate alternative solid waste management techniques.

The EPA issued recommended procedures for disposal of Polychlorinated biphenyl-containing wastes (PCB's) by industrial facilities in 1976. This statement encourages the use of chemical landfills for the disposal of PCB wastes. Chemical landfills provide long-term protection of surface and subsurface waters by (1) siting the facility so that no hydraulic continuity between the landfill and water resources exists; (2) containing leachates; (3) eliminating groundwater flow into the area; and (4) monitoring the groundwater system quality.

In 1974 and 1975, the EPA developed guidelines for the thermal processing of solid wastes and for the land disposal of solid wastes. The guidelines presented a recommended method of land disposal of solid wastes that would protect the surface and groundwater resources of the country and included sections on water and air quality. The guidelines further indicated that unsuitable solid wastes, defined on the basis of site hydrogeology and chemical and biological characteristics, must be disposed of in another manner.

The Resource Conservation and Recovery Act of 1976 )P.L. 94-580) amends the Solid Waste Disposal Act, regulates hazardous wastes, and provides financial assistance to states for solid waste management planning and funding for research and development of new technology. During 1977-1978, the EPA will establish criteria for identifying hazardous wastes based on toxicity, persistance, degradability in nature, accumulation in tissues, and other characteristics. Once the criteria have been established, the EPA will develop a specific list of hazardous materials which will be subject to regulation. The new law also sets standards for hazardous wastes, with violations resulting in possible fines of $25,000 per day.

The Resource Conservation and Recovery Act of 1976, Hazardous Waste Regulation, is certainly a large-scale attempt at improving the quality of our surface and groundwater resources. Based on the health effects information available for solid wastes from coal conversion and utilization plants, it appears likely that disposal of many of these wastes will be regulated by the Act. Design of an environmental monitoring program should consider the possibility of using chemical landfills for their disposal. As noted above, the use of chemical landfills requires monitoring of groundwater quality.

b. State Standards: Every state in the Union and the District of Columbia have some form of solid waste legislation, ranging from recommended disposal techniques to management planning rules/guidelines. Table IV-22 categorizes the various types of state legislation.

Table IV-22. Categorization of state solid waste legislation.

| Type of Legislation | Number of States |
|---|---|
| Landfill Siting | 38 |
| Landfill Operation | 38 |
| Management Planning Guidelines | 50 |
| Hazardous Wastes | 2 |
| Industrial Wastes | 2 |

Since the type of legislation varies from state to state, it will be necessary to review state policy on a case-by-case basis. However, it should be noted that although only two states have specific legislation covering hazardous materials, most states prohibit disposal of hazardous wastes in municipal landfills.

The Resource Conservation and Recovery Act of 1976 specifies that states may take over hazardous waste regulation provided that the state standards meet federal requirements. It appears likely that many states may take over the program in the next two to five years.

### 4. Noise

a. Noise Descriptors: The most common descriptor of noise intensity is the decibel (dB). Most noise standards are written in terms of noise levels as measured on the A-scale of the American National Standards Institute (ANST) Type 2 sound level meter. This scale uses a standard internal filter, the frequency response of which corresponds very closely to that of human perceptions of relative sound level. Noise levels in decibels, as measured on the A-scale, are referred to as dBA.

In the analysis of fluctuating noise levels, two descriptors are in common use, the $L_{10}$ level and the $L_{eq}$ level. They are defined as follows:

$L_{10}$ - The sound level that is exceeded 10 percent of the time (the 90th percentile) for the period under consideration. This value is an indicator of both the magnitude and frequency of occurrence of the loudest noise events.

$L_{eq}$- The equivalent steady state sound level which, in a stated period of time, would contain the same acoustic energy as the time-varying sound level during the same time period.

A statement of decibel level alone is not a definitive measure of the environmental quality of sound, however, since time of day, environment, mood, and information value of sound also affect perceptions of noise. Research has provided data on noise levels that are perceived as a nuisance or an annoyance by a majority of the public. Threshold levels have been established beyond which speech, sleep, and other activities will usually be disrupted.

b. National Noise Standards: The Federal Highway Administration (FHWA), based upon this research, has established goal maximum noise levels for the various land uses through

Table IV-23. Design noise level/activity relationships.

| Activity Category | Design Noise Levels - dBA<br>$L_{eq}$ | <br>$L_{10}$ | Description of Activity Category |
|---|---|---|---|
| A | 57<br>(Exterior) | 60<br>(Exterior) | Tracts of land in which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose. Such areas could include amphitheaters, particular parks or portions of parks, open spaces, or historic districts which are dedicated or recognized by appropriate local officials for activities requiring special qualities of serenity and quiet. |
| B | 67<br>(Exterior) | 70<br>(Exterior) | Picnic areas, recreation areas, playgrounds, active sports areas, and parks which are not included in Category A and residences, motels, hotels, public meeting rooms, schools, churches, libraries, and hospitals. |
| C | 72<br>(Exterior) | 75<br>(Exterior) | Developed lands, properties or activities not included in Categories A or B above. |
| E | 52<br>(Interior) | 55<br>(Interior) | Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums. |

which highways must pass. Table IV-23 summarizes these levels, known as "Design Noise Levels." These levels represent a balancing between that which may be desirable and that which may be achievable. Consequently, noise impacts may occur even though the design noise levels are achieved.

In cases where the exterior land use is not critically sensitive to noise, or where the abatement of exterior noise is not feasible, the FHWA has established the interior noise level of 55 dBA as the desired goal level. Table IV-24 indicates the general noise reductions due to various building exteriors. These can be applied to the exterior noise levels to predict interior levels. When compared to the 55 dBA interior design noise level established above, it is possible to assess impact.

Table IV-24. Exterior/interior noise reduction factors.

| Building | Window Condition | Noise Reduction Due to Exterior of the Structure | Corresponding Highest Exterior Noise Level to Achieve Interior Design Noise Level of 55 dBA |
|---|---|---|---|
| All | Open | 10dBA | 65dBA |
| Light Frame | Ordinary Sash Closed | 20dBA | 75dBA |
| | With Storm Windows | 25dBA | 80dBA |
| Masonry | Single Glazed | 25dBA | 80dBA |
| Masonry | Double Glazed | 35dBA | 90dBA |

Compliance with these FHWA standards is not required for sources such as the ERDA coal plants, but comparison with the standards is useful. Ambient levels are compared to predicted levels to measure increases or decreases. Both are compared to the design noise levels previously discussed. By using the Noise Impact Assessment Criteria (Table IV-25), it can be determined that a given change represents impact along a scale ranging from no impact to severe impact.

Table IV-25. Noise impact assessment criteria.

| Change in Ambient Noise Level (dBA) | Criteria |
|---|---|
| 0-2 | No impact |
| 2-5 | No impact (noticeable) |
| 5-10 | Minor impact |
| 10-15 | Moderate impact |
| 15+ | Severe impact |

In addition to the design noise levels, there are OSHA standards for noise. These standards are considerably higher than the FHWA design noise levels. They are summarized in Table IV-26. Another set of standards that were proposed by the U.S. Department of Health Education and Welfare, but which were not officially made into regulations, is shown in Table IV-27.

Table IV-26. Maximum occupational noise exposure

| Sound Level (dBA) | Daily Exposure Time (hr) |
|---|---|
| 90 | 8 |
| (92) | (6) |
| 95 | 4 |
| (97) | (3) |
| 100 | 2 |
| (102) | (1-1/2) |
| 105 | 1 |
| 110 | 1/2 |
| 115 | 1/4 or less |

Table IV-27. Maximum suggested non-occupational noise exposure.

| Sound Level (dBA) | Daily Exposure Time |
|---|---|
| 70 | 16-24 hours |
| 75 | 8 hours |
| 80 | 4 hours |
| 85 | 2 hours |
| 90 | 1 hour |
| 95 | 0.5 hours |
| 100 | 0.25 hours |
| 105 | 8 minutes |
| 110 | 4 minutes |
| 115 | 2 minutes |

The Noise Control Act of 1972 designated the Environmental Protection Agency as the coordinator of all federal noise control programs. The act requires EPA to publish reports which identify major sources of noise, as well as information on abatement costs and technology for control of such sources. Noise emission standards must be proposed by EPA for all products listed in the reports where abatement is feasible.

In addition, the Department of Housing and Urban Development (HUD) has established standards to be observed in the approval or disapproval of all HUD projects. These are shown in Table IV-28. Consequently, local and state governments are sensitive to industrial activities that may generate noise levels in adjacent land areas where federally sponsored projects are, or may be, located.

Table IV-28. External and interior noise exposure standards Department of Housing and Urban Development.

| General External Exposures | Assessment |
|---|---|
| Exceeds 80 dBA 60 minutes per 24 hours | Unacceptable<br>Exceptions are strongly discouraged and require a 102(2) C environmental statement and the Secretary's approval |
| Exceeds 75 dBA 8 hours per 24 hours | |
| Exceeds 65 dBA 8 hours per 24 hours | Discretionary - Normally Unacceptable |
| Loud repetitive sounds on site | Approvals require noise attenuation measures, the Regional Administrator's concurrence, and a 102(2)C environmental statement |
| Does not exceed 65 dBA more than 8 hours per 24 hours | Discretionary - Normally Acceptable |
| Does not exceed 45 dBA more than 30 minutes per 24 hours | Acceptable |

Interior noise levels should not exceed the following in sleeping quarters:

- 55 dBA for more than 60 minutes per 24 hours.
- 45 dBA for more than 30 minutes from 11 p.m. to 7 a.m.
- 45 dBA for more than 8 hours per 24 hours.

c. <u>State And Local Noise Standards</u>: In addition to the federal standards, some states and local communities have adopted noise standards. For example, in Montgomery County, Maryland, no more than 62 dBA are permitted at the property line in areas zoned industrial or commercial, and no more than 55 dBA are allowed at the property line in residential zones during operation of industrial sources. If the noise is periodic, impulsive, or a steady-state audible tone such as a hum, whine, or screech, these maximum levels are reduced by 5 dBA. Noise during construction, repair or demolition is allowed to exceed the standard for short periods of time during the hours from 8:00 A.M. to 9:00 P.M. by:

(1) no more than 5 dBA for a duration not to exceed 12 minutes in any one-hour period.

(2) no more than 10 dBA for a duration not to exceed 3 minutes in any one-hour period.

(3) no more than 15 dBA for a duration not to exceed 30 seconds in any one-hour period.

Some communities have gone as far in their standards as to specify the maximum noise level in dBA at various frequencies. The New Jersey nighttime noise limit is summarized in Table IV-29.

Table IV-29. New Jersey nighttime noise limits, by octave band.

| Octave band center frequency (Hz) | 1976 NJ. Reg. (10:00 P.M.-7:00 A.M.) |
|---|---|
| 31.5 | 86 |
| 63.0 | 71 |
| 125.0 | 61 |
| 250.0 | 53 |
| 500.0 | 48 |
| 1,000.0 | 45 |
| 2,000.0 | 42 |
| 4,000.0 | 40 |
| 8,000.0 | 30 |
| 16,000 | -- |

## B. KNOWN AND POTENTIAL HEALTH EFFECTS OF SUBSTANCES WHICH MAY BE RELEASED BY COAL PLANTS.

### 1. Types of Health Effects.

a. Acute Toxicity: Acute toxicity refers to the ability of a chemical element or compound to produce a deleterious physiological effect over a relatively short time period, generally less than 96 hours. Measurement of acute toxicity is complicated by a number of factors. Perhaps the most important for purposes of ERDA monitoring is the route of entrance of the toxicant. Most toxicological studies have been concerned with oral toxicities of various substances; unfortunately these data are of little use for the purposes of determining ERDA monitoring priorities, since it is very unlikely that coal plant wastes, etc., will be eaten. Consumption of trace amounts of coal plant wastes in drinking water is more likely, of course. More likely routes of entry for toxicants are via inhalation and skin penetration, but the data on such toxicities are more limited.

Species specificity of toxicity is another complicating factor. Direct knowledge of toxicities for humans is very limited, since humans cannot be used as experimental organisms for such purposes. Rats and mice are general surrogates for toxicity testing for mammals, including humans. A given substance, of course, may be more or less toxic for humans, on a per-unit-weight basis, than it is for rats or mice. Another complication is the dose-time relationship, i.e., a large dose may be fatal in a short time, but the effects of a lower dose may not be evident until hours or days later. Toxicity tests are, therefore, generally run for standardized time periods-- 24, 48 or 96 hours.

Another complication is the individual differences in response to a toxic substance among members of a single species. Toxicity tests have been developed which standardize as many factors as possible--e.g., all test organisms of the same age, sex, weight and in good physiological condition--but nonetheless, individual differences exist. Therefore, toxicity tests seek to establish the median lethal dose for a test population of some minimum size, at least 10 individuals. Such doses are referred to as $LD_{50}$ or MTL (median tolerance limits).

Due to the various ways that toxicities are measured, it is very difficult to compare toxicities to determine which substances should be monitored for a given purpose.

b. Bioamplification: Bioamplification, also called bioconcentration, is the accumulation of a chemical element or compound in one or more tissues of a living organism.

Such bioamplification can result in tissue concentrations several thousand times greater than in the ambient environment. In some cases this is a normal process, such as the accumulation of calcium in bone tissue. In other cases, it is abnormal and potentially pathological, such as the accumulation of radioactive strontium-90 in bone tissue due to its chemical similarity to calcium. Bioamplification of abnormal substances is generally more pronounced in organisms which occupy higher positions in a food web, since they are heirs to all the previous bioaccumulation performed by their prey. Humans are particularly vulnerable to bioamplification because they generally are the top predators in their ecosystems. Since many organisms can accumulate enormous amounts of toxic substances without apparent ill effect, the ultimate expression of toxicity in a top predator can occur without warning.

Bioamplification is a potentially adverse environmental effect of wastes from coal plants. It is also a phenomenon that can be used to monitor the discharge of such wastes by checking for their accumulation in some appropriate plant or animal species.

c. Carcinogenicity: Carcinogenicity is the ability of a substance (or ionizing radiation) to induce cancer in an organism. Tests for carcinogenicity are generally conducted on rats or mice by various routes of administration. Conclusions regarding carcinogenicity of a substance for humans are generally tentative. Most substances should be regarded as potentially carcinogenic regardless of negative test results. Some substances have been proven carcinogenic to humans on the basis of their nature and prior human exposure, generally in an industrial setting. Many coal tar derivatives are in this class. The lesser carcinogenicity of some compounds is more difficult to establish because of long delays between exposure and the onset of symptoms and/or the low incidence of cancers thus induced.

d. Mutagenicity: Mutagenicity is the ability of a substance (or ionizing radiation) to induce changes in the hereditary material of a cell. If such a cell is a germ-cell, the genetic change may be transmitted to the next generation. As a rule, mutations are undesirable. Most cells or individuals that result from mutations do not live long enough to be recognized and those that do are usually at a selective disadvantage, or "handicapped" in the case of humans. A genetic change, of course, may not be expressed for several generations if the affected gene is recessive.

The high correlation between mutagenicity and carcinogenicity is the basis of the "Ames Test," a recently developed technique for rapid screening of substances for chemical carcinogenesis.

In the Ames Test, the test organism is a mutant strain of bacterium which cannot synthesize the nutritionally essential amino acid, tryptophane. To survive, it must be grown in a medium containing tryptophane. A suspension of the bacterium is mixed with the test chemical and poured over a gelled growth medium which is deficient in tryptophane. Thus, only those cells which back-mutate to the normal type can survive and grow on this medium. Growth of such cells results in visible "colonies" after several days of incubation. The more such colonies, the more mutagenic, and presumably the more carcinogenic, is the test substance. Such a test can be completed in a few days, whereas the traditional rat or mouse test may take months or years. The problem, of course, is that because the correlation between bacterial mutagenicity and mammalian carcinogenicity is not 100 percent accurate, false positives and false negatives may occur. The Ames Test, currently the subject of intensive research, is highly controversial among biomedical scientists as a screening test for chemical carcinogenesis.

e. Teratogenicity: Teratogenicity is the ability of a substance (or ionizing radiation) to induce a developmental abnormality in an embryo or fetus. Such abnormalities may or may not be due to genetic changes. Tests for teratogenicity generally involve exposing a population of rats or mice in early pregnancy to the substance in question and subsequently examining the offspring for anatomical abnormalities and/or for an increased level of intrauterine mortality. Obviously, coal plant workers and the public in general should not be exposed to critical levels of such substances, particularly in the early stages of pregnancy. The simplest way to assure this is to prevent the release of such substances to the environment at all times.

## 2. Health Effects of Elements and Inorganic Compounds.

A review of the literature indicates some 150 chemical compounds (gases, aerosols, particulates, and leachates) to be associated with coal conversion processes. Table IV-30 displays known or measured inorganic pollutants for coal gasification and liquefaction processes. A great many of these pollutants are associated with particulate emissions and leachates of ashes and chars, and thus present potential problems in handling and disposal of solid wastes.

At least eight inorganic compounds are known to be carcinogenic (cancer-causing agents). These include:

- Diarsenic Trioxide: $As_4O_6$
- Cobalt Oxide: CoO
- Cobalt Sulfide: CoS

- Nickel Carbonyl: $Ni(CO)_4$
- Nickel Oxide: $NiO_2$
- Ammonia: $NH_3$
- Silicon Dioxide: $SiO_2$
- Thorium: Th(oxides)

An additional eight compounds are classified as neoplastic (tumor-causing); these may also be implicated as carcinogenic or teratogenic (causing developmental abnormalities). These include the following:

- Aluminum Oxide: $Al_2O_3$
- Cobalt: Co (elemental)
- Gold: Au (elemental)
- Lead Chromate: $PbCrO_4$
- Mercury: Hg (elemental)
- Ozone: $O_3$
- Thallium: Tl (elemental)
- Ytterbium: Yb (elemental)

Acute oral toxicities of compounds have been rated on a scale from 1 to 6 (Gosselin et al., 1976), with 6 being the most toxic. Inorganic compounds and elements in categories 4 through 6 are listed below.

4 - Very Toxic. Lethal dose between 50-500 mg/kg.

Boron Oxide: $B_2O_3$
Calcium Sulfide: CaS
Thiocyanide: SCN
Chromates: $[M{+}{+}]CrO_4$
Copper Sulfate: $CuSO_4$
Gold Salts: Au Salts
Lead Chromate: $PbCrO_4$
Lead Dioxide: $PbO_2$
Silver Salts: Ag Salts
Zinc Sulfide: ZnS

5 - Extremely Toxic. Lethal dose between 5-50 mg/kg.

Diantimony Trioxide: $Sb_4O_6$
Tricalcium Arsenate: $Ca_3(AsO_4)_2$

Arsenic Vapor: $As_4$
Barium Carbonate: $BaCO_3$
Cadmium Sulfide: CdS
Iodine: $I_2$
Thallium: Th Salts
Sodium Vanadate: $NaVO_3$

6 - Super toxic. Lethal dose less than 5 mg/kg.

Diarsenic Trioxide: $As_4O_6$
Cyanide: $CN^-$ (as NaCN)
Hydrogen Cyanide: HCN
Selenium Salts: [M++] Se

In addition, OSHA standards (chiefly for inhalation exposure) apply to 42 compounds listed in Table IV-30.

Occupational Safety and Health Standards are an indication of health impairment based on inhalation, skin irritation, mucous membrane irritation, and the neoplastic or carcinogenic qualities of a substance.

### 3. Health Effects of Organic Compounds.

At least 170 organic compounds are known to be associated with coal conversion processes. These occur as gases (emissions, volatile substances), oils (such as anthracene oils), and tars and pitches.

a. Aliphatic Compounds: The thermal decomposition of the complex, highly polymerized organic compounds of coal yields a variety of relatively less complex organic compounds. Among these are several aliphatic compounds. Aliphatic compounds characteristically include alkanes (paraffins), alkenes (olefins), and alkynes (triple bonded compounds). Examples of aliphatics generated in coal gasification and liquefaction processes include methane, ethane, propane, butane, pentane, and dodecane. Others include carboxylic acids such as propanoic, butanoic, pentanoic, and hexanoic acids, as well as highly substituted compounds such as methyl-N-Nitro-N-Nitrosoguanidine.

Gosselin, et al. (1976) classifies these compounds generically as "moderately toxic" with a rating of 3. Most are central nervous system depressants with low anesthetic potency. Some are skin and mucous membrane irritants (methyl chloride, acetic acid). Nine of the compounds are regulated by U.S. Occupational Health Standards (Christensen et al., 1974):

| | |
|---|---|
| • Methyl Chloride | $CH_3Cl$ |
| • Methylene Chloride | $CH_2Cl_2$ |
| • Chloroform | $CHCl_3$ |
| • Methyl Mercaptan (Methanethiol) | $CH_2SH$ |

| | |
|---|---|
| • Ethyl Sulfide | $(CH_3CH_2)_2S$ |
| • Ethyl Mercaptan (Ethanethiol) | $CH_3CH_2SH$ |
| • Propane | $CH_3CH_2CH_3$ |
| • Pentane | $CH_3CH_2CH_2CH_2CH_3$ |
| • Acetic Acid | $CH_3COOH$ |

Christensen et al. (1974) and NIOSH (1976) list three compounds as demonstrated (Christensen et al.) or potential (NIOSH) carcinogens, teratogens, mutagens, or neoplastic agents. These are listed below in Table IV-31.

b. Aromatic Compounds: Aromatic compounds are carbocyclic or ring compounds containing at least one benzene ring. Aromatics exist as monocyclic and polycyclic forms; this presentation treats monocyclic and polycyclic compounds separately. Arenes are included in this discussion as aromatics.

(1) Monocyclic compounds identified include such things as benzene, phenol, cresols, toluenes, and xylenes.

A total of 21 monocyclic compounds have been identified in coal conversion processes, including derivatives and bicyclic forms such as biphenyl, biphenyl oxide, triphenyl benzene, and various methylated forms (see Table IV-32). Of the 21, Gosselin, et al (1976) classifies 15 with toxicity ratings ranging from 3 (moderately toxic) to 4 (very toxic). Very toxic compounds include:

| | |
|---|---|
| • Benzene | $C_6H_6$ |
| • Phenol | $C_6H_5OH$ |
| • Dimethyl Phenol | $C_6H_3OH(CH_3)_2$ |
| • Cresol | $C_6H_4OH(CH_3)$ |
| • Toluene | $C_6H_5(CH_3)$ |
| • Xylene | $C_6H_4(CH_3)_2$ |

U.S. Occupational Health Standards (Christensen, 1974) regulate the following:

| | |
|---|---|
| • Benzene | $C_6H_6$ |
| • 4-Dimethyl Amino Azobenzene | $C_{14}H_{15}N_3$ |
| • Phenol | $C_6H_5OH$ |
| • Biphenyl | $C_{12}H_{10}$ |
| • Biphenyl Oxide | $C_{12}H_9O$ |
| • Dowtherm (mixture of Biphenyl and biphenyl oxide) | $C_{12}H_{10}$ and $C_{12}H_9O$ |
| • Cresol | $C_6H_4OH(CH_3)$ |
| • Toluene | $C_6H_5(CH_3)$ |
| • Xylene | $C_6H_4(CH_3)_2$ |

Compounds that are potential carcinogens (NIOSH, 1976) or demonstrated carcinogens and neoplastic agents (Christensen, et al, 1974) are listed in Table IV-32.

(2) Polycyclic Aromatic Compounds identified in coal conversion processes include a wide range of compounds ranging from fused 4 and 5 carbon rings to multiple fused 6 carbon rings. Polycyclic compounds are also referred to as polynuclear compounds. Examples of polycyclic compounds follow:

Representative Compounds

- Naphthalenes
  Phenylnaphthalenes
  Thianaphthalenes
  Acenaphthalenes
  Acenaphthenes
  Naphthols
  Naphthalamines

- Azulene

- Indanes
  Indenes

- Anthracenes
  Benz anthracenes (2,3)
  Dibenz anthracenes (1, 2, 5, 6)
  Anthrenes

- Phenanthrenes
  Benzo phenanthrenes (9, 10)
  Chrysenes [benzo(a)phenanthrenes]

- Fluorenes
  Benzofluorenes (2,3)

- Fluoranthenes

- Pyrenes
  Benzo(a)pyrene (1, 2)
  Benzo(b)pyrene (2,3)

- Coronene

- Perylene

- Cholanthrenes

Not including bicyclic compounds, the polycyclic aromatic compounds identified to date comprise a total of 63; many of these are methylated, benzylated, and aminated forms of the above representative examples. Most are present in coal tars and pitches; anthracene oil is estimated to comprise 6 percent of most coal tars (Finar, 1973). Others are liberated as ashes (particulates) and gases during oxidation and pyrolysis processes.

Gosselin, et al. (1976) classifies only six of these compounds, with toxicity ratings ranging from 3 to 4--"moderately" to "very toxic"; these are listed below:

Moderately Toxic

| | | |
|---|---|---|
| 1 - methyl | Naphthalene | $C_{10}H_7(CH_3)$ |
| 2 - methyl | Naphthalene | $C_{10}H_7(CH_3)$ |

Very Toxic

| | |
|---|---|
| Naphthalene | $C_{10}H_8$ (more hazardous than its methylated forms) |
| b-Naphthol | $C_{10}H_7OH$ |
| Anthracene | $C_{14}H_{10}$ |
| Phenanthrene | $C_{14}H_{10}$ |

U.S. Occupational Health Standards (Christensen et al., 1974) regulate the following:

| | |
|---|---|
| Naphthalene | $C_{10}H_8$ |
| Naphthalamine | $C_{10}H_7NH_2$ |
| 2-Naphthalamine | $C_{10}H_7NH_2$ |
| 2-Acetyl Amino Fluorene | $C_{13}H_8(CH_2CO_2H)\ NH_2$ |

Compounds that are potential carcinogens (NIOSH, 1976) or demonstrated carcinogens and neoplastic agents (Christensen et al., 1974) are listed in Table IV-33.

It should be noted here that toxicologic studies of high-molecular-weight, polycyclic aromatic compounds are proceeding slowly because of difficulty in isolating them chemically from other compounds in tars and pitches. Another factor involves the recent isolation and determination of chemical structures and properties of various isomers. The large number of demonstrated (and suspected) carcinogens indicates the need for health research which will likely add many new entries to these listings.

c. *Heterocyclic Compounds*: Heterocyclic compounds are cyclic (ring) compounds containing elements other than carbon in the ring. Heterocyclic compounds generated by coal conversion processes usually involve oxygen, nitrogen, and sulfur in the ring structures, and multiples of 4 and 5 chemical members are involved in ring formation. Fused ring compounds predominate, and benzene ring structures are commonly involved in many of the basic structures of the chemical species. Most heterocyclic compounds are contained in chars, tars, and ashes (particulates). Examples of heterocyclic compounds follow:

### Representative Compounds

- Furans
  - Dibenzofuran
- Thiophenes
  - Dibenzo Thiophene
  - Naphthothiophene (2,3,6)
  - Bithiophene
- Pyridenes
- Pyranes
  - Thiopyrane
- Pyrones
  - Tiopyrone
- Anthrones
  - Benz anthrone
- Indoles
  - Dibenz Indole
  - Anthra Indole
- Quinolines
  - 4 Nitro Quinoline-N-Oxide
- Carbazoles
  - Benzo(a)Carbazole
  - Phenanthro(c)Carbazole
  - Anthra(1,9-ab)Carbazole
- Thianthrenes
- Acridines
  - Benz(c)Acridine
  - Dibenz(a,h)Acridine
  - Indeno(7,1,A,b)Acridine
- Thioxantrene
- Thioxantrone
- Dithiin

Based on available literature, a total of 47 heterocyclic compounds are known to be associated with coal liquefaction and gasification processes. Many of these are methylated, benzylated, hydrogenated, nitrogenated, and aminated forms of the above representative examples.

Gosselin, *et al.* (1976) classifies only one heterocyclic compound--pyridene--as "moderately toxic" with a rating of 3. Pyridene is a skin irritant, causes central nervous system depression, and causes nausea and related symptoms. Other heterocyclics have not been rated due to insufficient information. Christensen *et al.* (1974) also lists pyridene as the only heterocyclic compound regulated by U.S. Occupational Health Standards.

Five compounds which are demonstrated or suspected carcinogens and neoplastic agents are listed in Table IV-34. Future research may expand this listing substantially, as new methylated, benzylated, and aminated forms are chemically isolated.

Table IV-30. Inorganic pollutants associated with coal conversion process.

| | | | | OSHA Toxic Substances List, 1974 | | Toxicity Gosselin et al., 1976 | | |
|---|---|---|---|---|---|---|---|---|
| Symbol | Element | Compound | Chemical Structure | Route | Dose | Rating | Notes | Comments |
| Al | Aluminum | Aluminum oxide, | $Al_2O_3$ | Inhalation | 367 ppm | 1 | Insoluble | Neoplastic effects, tumors |
| | | Kaolin (shale)/ Silica-alumina | $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$ | ---------- | ------- | --- | -------- | |
| | | Nacrite | $Al_2Si_2O_5(OH)_4$ | | | | | |
| Sb | Antimony | Diantimony tri-oxide | $Sb_4O_6$ | Air, time-weighted | 1320 ppb | 5 | Expressed as salts | Parallels arsenic poisoning |
| As | Arsenic | Tricalcium arsenate | $Ca_3(AsO_4)_2$ | Air, NIOSH | 50 ug/m$^3$ | 5 | Expressed as calcium arsenate | May approach rate of 6 |
| | | Arsine | $AsH_3$ | Inhalation<br>Air, time-weighted | 0.5 ppm<br>10.05 ppm | None | | Red blood cell effects, highly toxic, acute renal failure |
| | | Arsenic vapor | $As_4$ | | | 5 | Less toxic than arsinites | |
| | | Diarsenic trioxide | $As_4O_6$ | Air, NIOSH | 50 ug/m$^3$ | 6 | Fatal dosage to man: 0.1-0.5 gm | Carcinogenic, skin effects |
| Ba | Barium | Barium sulfate | $BaSO_4$ | ---------- | ------ | 1(?) | Insoluble, inert, but has impurities | |
| | | Barium carbonate | $BaCO_3$ | ---------- | ------ | 5 | Toxicity varies with cases | |
| Be | Beryllium | Beryllium oxide | BeO | Air, time-weighted | 2 ug/m$^3$<br>max.25 ug/m$^3$ | None | | Inhalation causes acute pneumonitis, granulomatosis, and skin ulcers |
| Bi | Bismuth | [No data] | | ---------- | ------ | 3 | Expressed as salts | Ingestion toxicity is low--headaches, skin rashes, kidney damage |
| B | Boron | Diborane | $B_2H_6$ | Inhalation<br>$LC_{50}$, time-weighted | 159 ppb/15 min.<br>0.1 ppm | None | | |
| | | Tetraborane | $B_4H_{10}$ | ---------- | ------ | None | | |
| | | Borosilicate | | ---------- | ------ | | | |
| | | Boron oxide | $B_2O_3$ | Air, time-weighted | 15 mg/m$^3$ | 4 | Reacts with water slowly, forms boric acid | |

Table IV-30. Inorganic pollutants associated with coal conversion process (cont.)

| | | | | OSHA Toxic Substances List, 1974 | | Toxicity Gosselin et al., 1976 | | |
|---|---|---|---|---|---|---|---|---|
| Symbol | Element | Compound | Chemical Structure | Route | Dose | Rating | Notes | Comments |
| Br | Bromine | Bromine gas | $Br_2$ | Air, time-weighted | 0.1 ppm | None | | Strong oxidant, causes pneumonitis |
| | | Metal bromides | $[M+]Br$, $[M++]Br_2$ | ---------- | ------ | 3 | Expressed as salts | Usually causes vomiting; 1 oz. may cause death |
| Cd | Cadmium | Cadmium sulfide | $CdS$ | Rat, injection | lowest: 90 mg/kg | 5-6 | Inhalation | Fatal pulmonary injury |
| Ca | Calcium | Calcium sulfate | $CaSO_4$ | ---------- | ------ | None | | |
| | | Calcium sulfide | $CaS$ | ---------- | ------ | 4 | Strong irritant | Mucous membranes, skin damage |
| | | Calcium carbonate | $CaCO_3$ | ---------- | ------ | 1 | Very low toxicity | Alkalosis |
| | | Calcium chloride | $CaCl_2$ | Rat, injection | lowest: 90 mg/kg | None | | |
| | | Dolomite, calcium-magnesium carbonates | $CaCO_3 \cdot MgCO_3$ | ---------- | ------ | | | |
| | | Quicklime, calcium oxide | $CaO$ | Air, time-weighted | $5\ mg/m^3$ | None | | May cause thermal or caustic burns |
| C | Carbon | Cyanide | $CN^-$ | Injection | $LD_{50}$: 3 mg/kg | 6 | As sodium cyanide | Fastest poison known |
| | | Cyanogen | $CN_2$ | Inhalation, man | lowest tox: 16 ppm | --- | | Causes irritant effects |
| | | Hydrogen cyanide | $HCN$ | Rat, oral | $LD_{50}$: 125 mg/kg | 6 | As 2% aqueous solution | Fastest poison known |
| | | Thiocyanic acid | $HSCN$ | Mouse, injection | $LD_{50}$: 500 mg/kg | None | | |
| | | Thiocyanide, sulfur cyanide | $SCN$ | ---------- | ------ | 4 | Expressed as salts | 15-30 gm is lethal dose |
| | | Carbon monoxide | $CO$ | Inhalation, time-weighted | 50 ppm | None | | Affects central nervous system |
| | | Carbon dioxide | $CO_2$ | Inhalation | Lowest: 2000 ppm | --- | | Affects pulmonary system |

## Table IV-30. Inorganic pollutants associated with coal conversion process (cont.)

| Symbol | Element | Compound | Chemical Structure | OSHA Toxic Substances List, 1974 | | Toxicity Gosselin et al., 1976 | | Comments |
|---|---|---|---|---|---|---|---|---|
| | | | | Route | Dose | Rating | Notes | |
| | Carbon (continued) | Carbon trioxide | $CO_3$ | ---------- | ------ | | | |
| | | Carbon disulfide | $CS_2$ | Time-weighted, inhalation | 20 ppm | 3-4 | | |
| | | Carbonyl sulfide | COS | Mouse, inhalation | Lowest: 2900 ppm | None | | Highly toxic; hydrolyzes to $CO_2$ + $H_2S$; respiratory failure |
| Ce | Cesium | Cesium-137 | $Ce^{137}$ | ---------- | ------ | | | Radiation exposure |
| Cl | Chlorine | Hydrochloric acid | HCl | Inhalation, man | Low: 1000 ppm | None | | |
| | | Chlorapatite | $Ca_{10}(PO_4)_6Cl_2$ | ---------- | ------ | | | |
| | | Hydroxy metal chlorides | Mg(OH)Cl | ---------- | ------ | | | |
| | | Hydroxy metal chlorides | Ca(OH)Cl | ---------- | ------ | | | |
| Cr | Chromium | Metal chromate complexes | $[M{+}{+}]CrO_4$ | ---------- | ------ | 4-5 | As sodium or potassium compounds | Burns skin & mucous membranes; ingestion causes circulatory collapse |
| Co | Cobalt | Cobalt carbonyl | $Co(CO)_4$ | Rat, inhalation | Lowest: 1400 $mg/m^3$ | | | |
| | | Cobalt-69 | $Co^{69}$ | With no radiation, time-weighted | 100 $ug/m^3$ | 4 | Cobalt salts, i.e. cobalt chlorides | Radiation exposure neoplastic effects |
| | | Cobalt oxide | CoO | Rat, injection | Lowest: 135 mg/kg | --- | | Carcinogenic effects |
| | | Cobalt molybdate | $Co \cdot MoO_3$ | ---------- | ------ | --- | | |
| | | Cobalt arsenate | $CoAs_2$ | ---------- | ------ | --- | | |
| | | Cobaltite | CoAsS | ---------- | ------ | --- | | |
| | | Cobalt sulfide | CoS | Injection, rat | Lowest: 180 mg/kg | --- | | Carcinogenic effects |

Table IV-30. Inorganic pollutants associated with coal conversion process (cont.).

| | | | | OSHA Toxic Substances List, 1974 | | Gosselin et al., 1976 | | |
|---|---|---|---|---|---|---|---|---|
| Symbol | Element | Compound | Chemical Structure | Route | Dose | Rating | Notes | Comments |
| Cu | Copper | Copper sulfide | CuS | ---------- | ------ | --- | | |
| | | Copper oxides | CuO, $Cu_2O$ | Rat, oral | $LD_{50}$: 470 mg/kg | 3 | As red copper oxide | |
| | | Copper sulfate | $CuSO_4$ | Air, time-weighted | 1 mg/$m^3$ | 4 | Expressed as copper salts | Potent emetics |
| Dy | Dysprosium | | | As $DyCl_3$, rat, injection | 196 mg/kg | --- | | |
| Eu | Europium | | | As $EuCl_3$, mouse, injection | $LD_{50}$: 156 mg/kg | --- | | |
| F | Fluorine | Hydrogen fluoride | HF | Time-weighted, inhalation | 3 ppm | None | | Highly corrosive, skin burns, irritant effects |
| Ga | Gallium | | | Rat, injection | Lowest: 110 mg/kg | --- | | |
| Ge | Germanium | | | Rat, injection | Lowest: 586 mg/kg | --- | | |
| Au | Gold | | | Rat, implantation | Lowest: 17 mm disc/ 8/animal | 4 | As gold salts | Neoplastic effects |
| Hf | Hafnium | | | As $HfCl_2O$, time-weighted | 0.5 mg/$m^3$ | --- | | |
| H | Hydrogen | Hydrogen | $H_2$ | ---------- | ------ | --- | | |
| In | Indium | | | Rat, oral | Lowest: 10 mg/kg | 3 | Generally non-toxic except by injection | |
| I | Iodine | | | Inhalation | Lowest level: 0.1 ppm | 5 | Between 4 & 5 | |
| Ir | Iridium | | | ---------- | ------ | --- | | |
| Fe | Iron | Iron carbonyl | $Fe(CO)_5$ | Mouse, inhalation | $LD_{50}$: 7 mg/$m^3$ | 3 | As iron salts | Corrosive irritants |
| | | Iron sulfate | $FeSO_4$ | Mouse, injection | $LD_{50}$: 81 mg/kg | --- | | |
| | | Iron sulfide | $FeS_2$ | ---------- | ------ | --- | | |

Table IV-30. Inorganic pollutants associated with coal conversion process (cont.).

| | | | | OSHA Toxic Substances List, 1974 | | Toxicity Gosselin et al., 1976 | | |
|---|---|---|---|---|---|---|---|---|
| Symbol | Element | Compound | Chemical Structure | Route | Dose | Rating | Notes | Comments |
| | Iron (cont.) | Iron carbonate | $FeCO_3$ | --------- | ------ | 3 | Similar to iron salts | |
| | | Iron chloride | $FeCl_2$ | Mouse, injection | $LD_{50}$: 68 mg/kg | 3 | Similar to iron salts | |
| | | Iron oxide | $Fe_2O_3$ | Air, time-weighted | 10 mg/$m^3$ | --- | | Affects pulmonary system |
| | | Iron chromium oxide | $FeCrO_4$ | --------- | ------ | --- | | |
| La | Lanthanum | | | Rat, injection | $LD_{50}$: 3500 ug/kg | --- | | |
| Pb | Lead | Lead chromate | $PbCrO_4$ | Air, time-weighted | 212 ug/$m^3$ | 4 | Ingestion & inhalation | Neoplastic effects |
| | | Lead sulfide | PbS | Inhalation, time-weighted | 231 ug/$m^3$ | --- | | |
| | | Lead dioxide | $PbO_2$ | Inhalation, time-weighted | 230 ug/$m^3$ | 4 | Similar to lead salts | |
| Li | Lithium | | | As LiCl, mouse injection | $LD_{50}$: 604 mg/kg | 3 | As lithium salts | Resembles sodium deficiency |
| Mg | Magnesium | Magnesium sulfate | $MgSO_4$ | Dog, injection | Lowest: 750 mg/kg | 3 | Low toxicity, purging | |
| | | Magnesium oxide | MgO | Air, time-weighted | 15 mg/$m^3$ | 3 | Low toxicity, purging | Toxic effects—unspecified |
| | | Magnesium sulfide | MgS | --------- | ------ | --- | | |
| | | Magnesium carbonate | $MgCO_3$ | --------- | ------ | 3 | As magnesium salts | |
| | | Magnesium chloride | $MgCl_2$ | Mouse, injection | $LD_{50}$: 14 mg/kg | 3 | As magnesium salts | |
| Mn | Manganese | Manganese oxide | MnO, $MnO_4$ | --------- | ------ | --- | | |
| | | Manganese sulfide | MnS | --------- | ------ | --- | | |
| Hg | Mercury | Elemental mercury | Hg | Air | Ceiling limit: 1 mg/10 $m^3$ | | | Neoplastic effects |

Table IV-30. Inorganic pollutants associated with coal conversion process (cont.).

|  |  |  |  | OSHA Toxic Substances List, 1974 |  | Toxicity Gosselin et al., 1976 |  |  |
|---|---|---|---|---|---|---|---|---|
| Symbol | Element | Compound | Chemical Structure | Route | Dose | Rating | Notes | Comments |
| Mo | Molybdenum | Nickel molybdate | $NiMoO_3$ | ---------- | ------ | --- |  |  |
|  |  | Cobalt molybdate | $CoMoO_3$ | ---------- | ------ | --- |  |  |
|  |  | Molybdenite | $MoS_2$ | ---------- | ------ | --- |  |  |
| Nd | Neodymium |  |  | Guinea pig, injection | 70 mg/kg | --- |  | Blood effects |
| Ni | Nickel | Nickel carbonyl | $Ni(CO)_4$ | Air, time-weighted | 7 ug/m$^3$ | None |  | Pulmonary effects; carcinogenic |
|  |  | Nickel oxides | $NiO_2$ | Air, time-weighted | 1.3 mg/m$^3$ | --- |  | Carcinogenic |
|  |  | Nickel molybdate | $NiMoO_3$ | ---------- | ------ | --- |  |  |
| N | Nitrogen | Nitrogen oxide | $NO$ | Time-weighted | Avg.: 25 ppm | None |  |  |
|  |  | Nitroso | $HONO$ | ---------- | ------ |  |  |  |
|  |  | Nitrogen | $N_2$ | ---------- | ------ |  |  |  |
|  |  | Nitrogen dioxide | $NO_2$ | Air, time-weighted | 5 ppm | None |  | Pulmonary system |
|  |  | Ammonia | $NH_3$, $NH_4$ | Air, time-weighted | 50 ppm | None |  | Carcinogenic |
|  |  | Nitrogen tetroxide | $NO_4$ | Rabbit, inhalation | $LC_{50}$: 315 ppm/ 15 min. | None |  |  |
|  |  | Ammonium sulfate | $(NH_4)_2SO_4$ | Rat, oral | $LD_{50}$: 58 mg/kg | None |  |  |
|  |  | Nitric acid | $H_2NO_3$ | Air, time-weighted | 2 ppm | None |  | Highly caustic |
| O | Oxygen | Oxygen | $O_2$ | ---------- | ------ | --- |  |  |
|  |  | Ozone | $O_3$ | Air, time-weighted | 200 ug/m$^3$ |  |  | Neoplastic effects |
| P | Phosphorus | Phosphate | $PO_4$, $P_2O_5$ | ---------- | ------ | None |  |  |
| K | Potassium | Potassium chloride | $KCl$ | Rat, injection | $LD_{50}$: 660 mg/kg | 3 | Potassium salts | Vomiting, diarrhea |
|  |  | Potassium chromate | $KCrO_3$ | Air | Ceiling: 100 ug/m$^3$ | 4 or 5 | Corrosive | Corrosive effects |
|  |  | Dipotassium oxide | $K_2O$ | ---------- | ------ | --- |  |  |

Table IV-30. Inorganic pollutants associated with coal conversion process (cont.).

| | | | | OSHA Toxic Substances List, 1974 | | Toxicity Gosselin et al., 1976 | | |
|---|---|---|---|---|---|---|---|---|
| Symbol | Element | Compound | Chemical Structure | Route | Dose | Rating | Notes | Comments |
| | Potassium (cont.) | Dipotassium carbonate | $K_2CO_3$ | Rat, oral | $LD_{50}$: 1870 mg/kg | --- | | |
| | | Potassium bicarbonate | $KHCO_3$ | ---------- | ------ | | | |
| | | Dipotassium sulfate | $K_2SO_4$ | Injection, guinea pig | Lowest: 3000 mg/kg | --- | | |
| Rb | Rubidium | | | As RbCl, rat, injection | $LD_{50}$: 1200 mg/kg | --- | | |
| Sm | Samarium | | | As $SmCl_3$, mouse, injection | 365 mg/kg | --- | | |
| Sc | Scandium | | | As $ScCl_3$, mouse, oral | $LD_{50}$: 4000 mg/kg | --- | | |
| Se | Selenium | Metal complex | $[M{+}{+}]$ Se | Air, time-weighted | 0.2 $mg/m^3$ | 6 | As selenium salts | Highly toxic in all routes |
| | | Hydrogen selenide | $H_2Se$ | Air, time-weighted | 0.2 $mg/m^3$ | --- | | |
| Si | Silicon | Silicon dioxide | $SiO_2$ | Injection, rat | $LD_{50}$: 15 mg/kg | 1 | Generally inert | Silicosis possible, carcinogenic |
| | | Silica-alumina complex | $SiO_2 \cdot Al_2O_3$ | ---------- | ------ | --- | | |
| | | Sodium silicate | $Na_2SiO_3$ | ---------- | ------ | 3 | Caustic | Skin, eyes, and mucous membranes |
| | | Kaolinite | $Si_4Al_4O_{10}(OH)_8$ | ---------- | ------ | --- | | |
| | | Illite | $K_2(Si_6 \cdot Al_2)(OH_4)$ $Al_4 \cdot O_{20}$ | ---------- | ------ | --- | | |
| | | Nacrite | $Al_2Si_2O_5(OH)_4$ | ---------- | ------ | --- | | |
| Ag | Silver | | | Air, time-weighted | 10 $ug/m^3$ | 4 | As silver salts | Gastroenteritis, shock, skin effects |

## Table IV-30. Inorganic pollutants associated with coal conversion process (cont.).

| | | | | OSHA Toxic Substances List, 1974 | | Toxicity Gosselin et al., 1976 | | |
|---|---|---|---|---|---|---|---|---|
| Symbol | Element | Compound | Chemical Structure | Route | Dose | Rating | Notes | Comments |
| Na | Sodium | Sodium chloride | NaCl | Oral, rat | $LD_{50}$: 3000 mg/kg | 3 | Dehydration | Rats, $LD_{50}$: 3.75 gm/kg; affects blood pressure |
| | | Disodium oxide | $Na_2O$ | ---------- | ------ | None | | Caustic |
| | | Sodium hydroxide | NaOH | Air, time-weighted | 2 ug/$m^3$ | None | | Caustic |
| | | Sodium vanadate | $Na_6VO_4$ (?) | Injection, rat | Lowest: 10 mg/kg | --- | | |
| Sr | Strontium | Strontium-90 | $Sr^{90}$ | As $SrCl_2$, injection, mouse | $LD_{50}$: 148 mg/kg | --- | | |
| S | Sulfur | Elemental sulfur | $S_{(x)}$ | ---------- | ------ | 3 | Irritant | Mucous membranes |
| | | Metal complexes | [M++]S | ---------- | ------ | --- | | |
| | | Sulfur dioxide | $SO_2$ | Air, time-weighted | 5 ppm | None | | Highly irritating gas; pulmonary system |
| | | Sulfur trioxide | $SO_3$ | ---------- | ------ | --- | | |
| | | Sulfur tetroxide | $SO_4$ | ---------- | ------ | --- | | |
| | | Hydrogen sulfide | $H_2S$ | Air | Ceiling: 20 ppm<br>Peak: 50 ppm | None | | Noxious gas |
| | | Sulfuric acid | $H_2SO_4$ | Air, time-weighted | 1 mg/$m^3$ | None | | Affects mouth, lungs; corrosive to skin, membranes |
| | | Carbonyl sulfide | COS | Inhalation, mouse | Lowest: 2900 ppm | None | | Highly toxic; hydrolyzes to $CO_2$ + $H_2S$; respiratory failure |
| | | Carbon disulfide | $CS_2$ | Air, time-weighted | 20 ppm | 3 | Acually between 3 & 4 | |
| | | Metal & non-metal sulfates | $[X^+]_2SO_4$, $[X^{++}]SO_4$ | ---------- | ------ | None | | Purging effects |

## Table IV-30. Inorganic pollutants associated with coal conversion process (cont.).

| | | | | OSHA Toxic Substances List, 1974 | | Toxicity Gosselin et al., 1976 | | |
|---|---|---|---|---|---|---|---|---|
| Symbol | Element | Compound | Chemical Structure | Route | Dose | Rating | Notes | Comments |
| Ta | Tantalum | | | As $TaCl_5$, oral, rat | $LD_{50}$: 1900 mg/kg | --- | | |
| Te | Tellurium | Hydrogen telluride | $H_2Te$ | Dust & fume, time-weighted | 100 ug/$m^3$ | --- | | |
| Tb | Terbium | | | As $TbCl_3$, injection, mouse | $LD_{50}$: 332 mg/kg | --- | | |
| Tl | Thallium | | | Oral, rat | $TD_{10}$: 0.8 mg/kg | 5 | As thallium salts | Neoplastic effects |
| Th | Thorium | | | As $ThO_2$, injection, mouse | 800 mg/kg | --- | | Carcinogenic effects |
| Sn | Tin | | | As SnCl, air, time-weighted | 4 mg/$m^3$ | None | | Variously poisonous as salts |
| Ti | Titanium | Titanium dioxide | $TiO_2$ | Air, time-weighted | 15 mg/$m^3$ | 1 | No known oral effects | |
| W | Tungsten | | | Injection, rat | $LD_{50}$: 5000 mg/kg | 3 | As salts | Diarrhea, respiratory failure--various |
| U | Uranium | | | As $UCl_3$, injection, rat | $LD_{50}$: 500 mg/kg | 3 | By injection (cut) | Nephrotoxicity |
| V | Vanadium | Sodium vanadate | $NaVO_3$ | Injection, rat | Lowest: 10 mg/kg | 5 | Highly toxic | Similar to pentavalent arsenic |
| Yb | Ytterbium | | | Implantation, mouse | Lowest: 25 gm/kg | --- | | Neoplastic effects |
| Zn | Zinc | Zinc oxide | ZnO | Air, time-weighted | 5 mg/$m^3$ | 3 | Impurities | Affinity for lead impurities [see entry for Lead] |
| | | Zinc sulfide | ZnS | ---------- | ------ | 4 | As soluble salts | Similar to copper salts |
| | | Zinc chromate | $ZnCrO_4$ | ---------- | ------ | --- | | |
| Zr | Zirconium | | | As $ZrCl_4$, time-weighted | 5 mg/$m^3$ | --- | | |

Table IV-30. Inorganic pollutants associated with coal conversion process (cont.)

## Sources

Cambell, 1952
Christensen, *et al.*, 1974. Toxic substances list, 1974 ed.
Dull, *et al.*, 1958.
ERDA #84, 89, 2-A, 157, 61, 81, 82.
Finar, 1973.
Gosselin, *et al.*, 1976. Clinical toxicology of commercial products.
Koppenaal, 1976.
Magee, 1975.
Science & Public Policy Program, 1975.
Sorum, 1968.

Toxicity ratings from Gosselin *et al.* as follows:

| Toxicity Rating or Class | Probable Oral LETHAL Dose (Human) | |
|---|---|---|
| | Dose | For 70 kg person (150 lb) |
| 6 Supertoxic | Less than 5 mg/kg | A taste (less than 7 drops) |
| 5 Extremely toxic | 5-50 mg/kg | 7 drops to 1 teaspoonful |
| 4 Very toxic | 50-500 mg/kg | 1 teaspoonful to 1 ounce |
| 3 Moderately toxic | 0.5-5 gm/kg | 1 ounce to 1 pint (or 1 pound) |
| 2 Slightly toxic | 5-15 gm/kg | 1 pint to 1 quart |
| 1 Practically non-toxic | Above 15 gm/kg | More than 1 quart (2.2 lbs.) |

## Abbreviations and Notes

| | |
|---|---|
| ppm | parts per million |
| ppb | parts per billion |
| $ug/m^3$ | micrograms per cubic meter |
| $LC_{50}$ | lethal concentration that kills 50% of test population (gaseous exposure) |
| $LD_{50}$ | lethal dose that kills 50% of test population (oral or injection routes) |

"Injection" pertains to both intraperitoneal and subcutaneous.

"Lowest" refers to lowest published lethal dosage ($LC_{LO}$ or $LD_{LO}$).

"Ceiling, time-weighted" refers to specific exposure standards as determined by U. S. National Institute of Occupational Safety and Health.

ble IV-31. Carcinogenic, teratogenic, and mutagenic aliphatic substances sssociated with coal conversion.

| Substance | Chemical Formula | Health Effect<br>Carcinogenic | Neoplastic | Teratogenic | Mutagenic |
|---|---|---|---|---|---|
| Chloroform | $CHCl_3$ | 1, 2 | | | |
| Ethyl Sulfide | $(CH_3CH_2)_2S$ | 1 | 2 | 2 | |
| Methyl-N-Nitro-N-Nitrosoguanidine (AS) 1 Methyl-3-Nitro-1-Nitroso-Guanidine | $C_2H_5N_5O_3$ | 1, 2 | 2 | 2 | |

1. NIOSH suspected carcenogen list.

2. Christensen _et al._, demonstrated through laboratory research.

Table IV-32. Carcinogenic monocyclic aromatics (and related bicyclics) associated with coal conversion.

| Substance | Chemical Formula | Health Effect<br>Carcinogenic | Neoplastic |
|---|---|---|---|
| Benzene | $C_6H_6$ | 1,3 | |
| 4-Methyl Amino Azobenzene | $C_{14}H_{15}N_3$ | 1,3 | 3 |
| 1,3,5-tri phenyl benzene | $C_{24}H_{18}$ | 1 | 3 |
| Phenol | $C_6H_5OH$ | 1,3 | |
| 2,5 dimethyl phenol | $C_6H_3OH(CH_3)_2$ | 1,3 | |
| 2,6 dimethyl phenol | $C_6H_3OH(CH_3)_2$ | 1,3 | 3 |
| 3,4 dimethyl phenol | $C_6H_3H(CH_3)_2$ | 1,3 | |
| 3,5 dimethyl phenol | $C_6H_3OH(CH_3)_2$ | 1,3 | |
| 0-Ethyl phenol | $C_6H_5(CH_2CH_3)$ | 1,2 | |
| 0-Cresol | $C_6H_4OH(CH_3)$ | 1,2 | |
| M-Cresol | $C_6H_4OH(CH_3)$ | 1,2 | |
| P-Cresol | $C_6H_4OH(CH_3)$ | 1,2 | |

KEY:

1. NIOSH suspected carcinogen.
2. Carcinogenic with 7,12-dimethyl benz(a)anthracene.
3. Christensen _et al._, demonstrated through laboratory research.

Table IV-33. Carcinogenic, teratogenic and mutagenic polycyclic aromatic compounds associated with coal conversion.

| Substance | Chemical Formula | Health Effect: Carcinogenic | Mutagenic | Teratogenic | Neoplastic |
|---|---|---|---|---|---|
| • Naphthalene | $C_{10}H_8$ | 1 | | | |
| • Acenaphthene | $C_{12}H_{12}$ | | | | 2 |
| • Naphthalamine | $C_{10}H_7NH_2$ | 1,2 | | | |
| • 2-Naphthalamine | $C_{10}H_7NH_2$ | 1,2 | | | |
| • Indole | $C_9H_7N$ | 1 | | | 2 |
| • Anthracene | $C_{14}H_{10}$ | 1 | | | |
| • 9-Methyl Anthracene | $C_{14}H_9(CH_3)$ | 1 | | | 2 |
| • 9,10-Dihydroanthracene | $C_{14}H_8(OH)_2$ | 2 | | | |
| • Benz (a) Anthracene | $C_{14}H_8(C_4H_4)$ | 1 | | | |
| • 1,2 Benz Anthracene | $C_{14}H_8(C_4H_4)$ | 1,2 | | | |
| • Dibenz (a,h) Anthracene | $C_{14}H_6(C_4H_4)_2$ | 1 | | | 2 |
| • 1,2,5,6 Dibenzo Anthracene | $C_{14}H_6(C_4H_4)_2$ | 1,2 | | | 2 |
| • 7,12-Dimethyl Benz(a) Anthracene | $C_{14}H_6(C_4H_4)(CH_3)_2$ | 1,2 | | | 2 |
| • Dibenzo(a,i)Phenanthrene | $C_{14}H_6(C_4H_4)_2$ | | | | 2 |
| • Benzo(a) Phenanthrene | $C_{14}H_8(C_4H_4)$ | 1 | | | |
| • 2-Methyl Chrysene | $C_{18}H_{11}(CH_3)$ | 1 | | | |
| • 3-Methyl Chrysene | $C_{18}H_{11}(CH_3)$ | 1 | | | |
| • 6-Methyl Chrysene | $C_{18}H_{11}(CH_3)$ | 1 | | | 2 |
| • 1,2-Benzo Fluorene | $C_{13}H_7(C_4H_4)$ | 1 | | | |
| • 2-Acetyl Aminofluorene | $C_{13}H_8(CH_2CO_2H)NH_2$ | 2 | | | |
| • Benzo(b)Fluoranthene | $C_{16}H_8(C_4H_4)$ | 1,2 | | | |
| • Benzo(j) Fluoranthene | $C_{16}H_8(C_4H_4)$ | 1 | | | |
| • Benzo(k) Fluroanthene | $C_{16}H_8(C_4H_4)$ | 1 | | | |
| • Pyrene | $C_{16}H_{10}$ | 1 | | | 2 |
| • Benzo(a) Pyrene (1,2) | $C_{16}H_8(C_4H_4)$ | 1,2 | 2 | 2 | 2 |
| • Benzo(e) Pyrene (3,4) | $C_{16}H_8(C_4H_4)$ | 1,2 | | | |
| • o-Phenylene Pyrene | $C_{16}H_6$ | 1,2 | | | |
| • Dibenzo(a,e) Pyrene | $C_{16}H_6(C_4H_4)_2$ | 1,2 | | | |
| • Dibenzo(a,h) Pyrene | $C_{16}H_6(C_4H_4)_2$ | 1,2 | | | |
| • Dibenzo(a,i) Pyrene | $C_{16}H_6(C_4H_4)_2$ | 1,2 | | | |
| • Indeno (1,2,3-cd) Pyrene | $C_{22}H_{12}$ | 1,2 | | | |
| • 3,4,9,10-Dibenzo Pyrene | $C_{16}H_6(C_4H_4)_2$ | 1 | | | 2 |
| • Perylene | $C_{20}H_{12}$ | 1 | | | |
| • Cholanthrene | $C_{20}H_{13}$ | 1,2 | | | |
| • 3-Methyl Cholanthrene | $C_{20}H_{12}(CH_3)$ | 1,2 | | 2 | 2 |
| • 20-Methyl Cholanthrene | $C_{20}H_{12}(CH_3)$ | 1,2 | | | |

1. NIOSH suspected carcinogen
2. Christensen, et al. demonstrated through laboratory research.

Table IV-34. Carcinogenic heterocyclic compounds associated with coal conversion.

| Substance | Chemical Formula | Health Effect: Carcinogenic | Neoplastic |
|---|---|---|---|
| • Indole | $C_9H_7N$ | 1 | 2 |
| • 4-Nitro Quinoline-N-Oxide | $C_9H_9N(NO_3)$ | 1,2 | 2 |
| • 11 H-Benzo(a) Carbazole | $C_{12}H_7N{:}NC_4H_4$ | 1 | |
| • Benz(c)Acridine | $C_{13}H_7N(C_4H_4)$ | 1,2 | |
| • Dibenz(a,h) Acridine | $C_{13}H_5N(C_4H_4)_2$ | 1,2 | |

1. NIOSH suspected carcinogen.
2. Christensen et al. demonstrated through laboratory Research.

## C. TRANSPORT AND DISPERSION OF COAL PLANT EFFLUENTS IN THE ENVIRONMENT.

### 1. Atmospheric Transport and Dispersion.

A basic understanding of atmospheric transport and dilution is necessary for the proper design of ambient air pollution monitoring programs. Pollution is emitted into the atmosphere from a large variety of sources which can be classified into four groups:

1. Isolated tall stack sources
2. Short and low velocity stacks, where emissions may be subject to aerodynamic downwash due to the atmospheric flow patterns around nearby buildings, hills, and the stack itself.
3. Fugitive emission sources (sources that do not have stacks, such as dust blowing off a coal pile, or hydrocarbons emitted from a settling pond in a coal gasification plant).
4. Non-stationary sources such as trucks, trains, airplanes, and automobiles.

Once emitted into the atmosphere, many factors influence the concentrations of ambient air pollution. Emissions from isolated tall stacks are carried upward in the air by the kinetic energy and buoyancy of the plume. The stack diameter effluent temperature, density, specific heat capacity, and volume rate of flow, along with the wind velocity and ambient temperature, determine the height of the plume from the stack. For short stacks or stacks with low exit velocities, the air flow pattern around the stack or nearby buildings can cause a phenomenon known as aerodynamic downwash. This can lower the effective height of an emission source, or even bring the plume down to ground level before atmospheric entrainment, turbulence, and diffusion have an opportunity to dilate the plume to safe levels. The distinction between elevated point sources and those sources subject to significant aerodynamic downwash is important because it influences where air pollution monitors should be located to measure the maximum impact of a source.

If a plume is above the influence of ground-level phenomena and has reached its equilibrium height above the ground, atmospheric turbulent diffusion takes over; the resulting ground level concentration is determined by the wind direction and velocity, along with the degree of turbulence in the air. Air turbulence is determined by solar elevation, cloud cover, wind velocity, and atmospheric temperature as a function of height above the ground. Any discontinuities in the general atmospheric flow pattern, such as those found in air circulation cells around large bodies of water, can also influence the resulting ground-level concentration. Other factors include ground elevation, atmospheric humidity, precipitation, clouds of condensed water (both natural and man-made, such as cooling tower plumes), settling of particulates, chemical reactions of the pollutant with other chemicals in the air or on surfaces, and the effects of sunlight on the rate of such reactions. The "heat island" effect of large urban centers and the amount of ground surface roughness can also influence the ground-level concentration resulting from elevated and isolated sources. The maximum concentration due to such isolated sources often occurs far downwind.

If the source is not isolated, or if the stack exit velocity is too low, then the plume can become completely or partially trapped in the turbulent wake of nearby structures or the stack itself. Such trapping greatly increases ground concentrations in the immediate vicinity downwind of the source. The resulting ground level concentration can then be dominated by aerodynamic factors associated with the exact geometry of nearby buildings and stacks, or hills, surface roughness, and the wind velocity and direction. If the plume is trapped in the turbulent downwash of a building and is brought down to ground level as a result of this downwash the resulting maximum ground-level concentration will occur very near the building, within two or three building heights or widths (whichever is smaller) downwind of the building.

Fugitive emissions can occur within the turbulent wake of buildings or refuse piles. If the ground-level fugitive source is not in the turbulent wake of a building or other obstruction, then the dimensions of the source, instead of that of nearby structures, along with the factors discussed for sources from short stacks, will apply.

For mobile sources, the size of the source, along with its velocity and the factors discussed for sources of fugitive emissions, will determine the resulting ground-level concenration. For multiple mobile sources, such as vehicles on a heavily used highway, the source can be approximated as a continuous line source where the emissions are initially mixed uniformly into the tubulence caused by the vehicles on the highway, and are then diluted by the same forces that affect ground-level sources.

### 2. Surface Water Transport and Dispersion.

Knowledge of the mechanisms of pollutant transport and diffusion in streams and water bodies is well developed but by no means complete. Consideration of these mechanisms together with knowledge of likely environmental contaminants released by the coal plant, is necessary in determining the spatial and temporal dimensions of an ambient monitoring program.

In general, transport and dispersion factors in water involve hydrological, chemical, and biological actions and interactions. Waste constituents are classified as "conservative" and "non-conservative." The former class includes those parameters, primarily dissolved solids such as sodium, calcium, magnesium, chloride, and sulfate, whose transportation and dispersion are mostly dependent upon hydrologic factors. For these, understanding of the flow of water in a stream, the turnover of water in a lake, or the exchange of water in an estuarine system is sufficient to predict their behavior in a particular aquatic environment. This category represents an assumption of chemical and biological inertness which is appropriate only for certain circumstances, e.g. equilibrium concentration of the dissolved substance; a negligibly small precipitation rate constant; or a large concentration relative to biological utilization rate.

In contrast, non-conservative constituents are highly subject to changes in their aquatic concentration, due to exchange with various sources and sinks. This is a more realistic model of the behavior of most pollutants, but characterization and quantification of the exchange mechanisms are not well understood for most pollutants.

Sediments can be considered a major source and sink in aqueous systems for many waste constituents. Exchange mechanisms include sedimentation of particulate matter, adsorption on the surface of particulates or existing sediment, precipitation, and dissolution. Biological factors comprise a complex second source and sink. Exchange may be with the aqueous system directly (e.g. dissolved nutrient uptake by algae) or indirectly through sediments (e.g. release of nutrients from organic sediments). These mechanisms are closely tied to biological transport and dispersion pathways. Exchange rates for most of these mechanisms are functions of such environmental characteristics as temperature, pH, oxidation-reduction potential, and solar insolation, further complicating understanding of pollutant transport and dispersion.

QUAL-II, a mathematical model developed for EPA, incorporates state-of-the-art understanding of internal sources and sinks and exchange kinetics for dissolved oxygen, biochemical oxygen demand, organic nitrogen, ammonia, nitrite, nitrate, phosphorus; coliforms; water temperature, and chlorophyll-a. (Provision is made in the model for considering other parameters as non-conservative constituents.) Table IV-35 indicates the data requirements for the simulation of water quality constituents in streams by QUAL-II. Although the climatological parameters can be computed on a watershed basis, other parameters must be determined for upstream areas and point sources, tributaries, and incremental flows at, and downstream of, the point of interest. Models for lake and estuarine pollutant transport and disposal have also been developed with similar data requirements (Penumalli *et al.*, 1976).

TABLE IV-35. QUAL-II data requirements for modeling of water quality constituents.*

| | | |
|---|---|---|
| Hydrologic | | |
| | Flow | Channel Characteristics |
| Water Quality | | |
| | Dissolved Oxygen | Phosphorus |
| | Carbonaceous BOD | Coliforms |
| | Nitrogenous BOD | Phytoplankton |
| | Ammonia | Periphyton |
| | Nitrite | Total Nitrogen |
| | Nitrate | Total Dissolved Solids, |
| | Water Temperature | Benthic Composition |
| Climatological | | |
| | Wind Speed | Evaporation Coefficient |
| | Barometric Pressure | Dust Attenuation Coefficient |
| | Cloudiness | |
| | Dry Bulb Temperature | Altitude |
| | Wet Bulb Temperature | |

* Source: Willis, R., D. R. Anderson, and J. A. Dracup, 1976. Transient water quality modeling in streams, *Water. Res. Bull.* *12*: 157-174.

It is possible to use these models to predict the fate of pollutants in an ambient aquatic environment. However, as suggested above, the data requirements necessary for model calibration and verification can be considerable. Because experience with some of the potential ERDA coal plant pollutants is limited, relevant models are not well developed. Data for model verification and calibration could well amount to an ambient monitoring system itself. Model assumptions which are valid for general applications may not be appropriate for the kinds and quantities of pollutants expected from ERDA coal plants. For example, dissolved trace metals are generally considered to be conservative water constituents. However, an ambient monitoring program for coal-ash basin effluent has demonstrated that sediment, benthos, and aquatic plants and animals serve as significant sinks for trace metals. An ERDA monitoring program with comprehensive ambient monitoring elements may add to state-of-the-art knowledge of aquatic transport and dispersion and lead to the development of predictive models for future impact analysis.

### 3. Transport And Dispersion By Or In Soil.

Pollutants can be dispersed by soil, clay minerals in particular. If the pollutant becomes adsorbed on, or dispersed within, a clay mineral, it may subsequently be transported to a new area by soil erosion. The pollutant may then become available for deleterious reactions through elutriation or through uptake by plant roots.

Transport of coal plant effluents by soils can take several routes (Figure IV-1). The movement of chemical species through these pathways is dependent on the specific chemical and its interaction with various parts of the ecosystem. The principal physical characteristic which governs the behavior of soil with respect to coal plant effluents is particle size. Pollutants adsorb most efficiently on smaller particles (clays). Generally, the larger particles will remain at the surface while small particles are sorted vertically in the natural soil matrix. However, there are numerous exceptions to the general depositional pattern which are related to local sedimentation events. The long-term exposure of land areas lacking vegetation cover to aeolian (wind blown) processes which occur in periglacial areas near large continental or alpine glaciers, can alter the general pattern. Analogous conditions may occur near large fly ash or gob pile disposal areas which have little or no vegetation for long periods of time. In such cases, fine materials may be deposited above coarse particles, creating a less permeable zone at the surface; this leads to localized wet areas during storms.

The surface structure of these clays varies by general type of clay. However, a significant feature of clays is their ability to adsorb on their surfaces cations which exhibit an excessive negative charge. Studies of ionic reactions with clay minerals such as smectite have shown that cation-exchange capacities using relatively small organic molecules (benzidine; p-aminodimethyaniline; p-phenylenediamine; α-Napthylamine; 2, 7-diaminofluorene; piperidine) are nearly the same as the displacement of the adhering hydrogen ion by barium (Grim, 1968). However, some ortho- and meta-nitroanilines do not form salts with montmorillonite. As a general rule, the small ions are adsorbed up to the cation-exchange capacity, whereas the larger ions may be adsorbed in excess.

The water-adsorbing properties of clays are reduced as the surfaces are coated with organic ions. This changes the

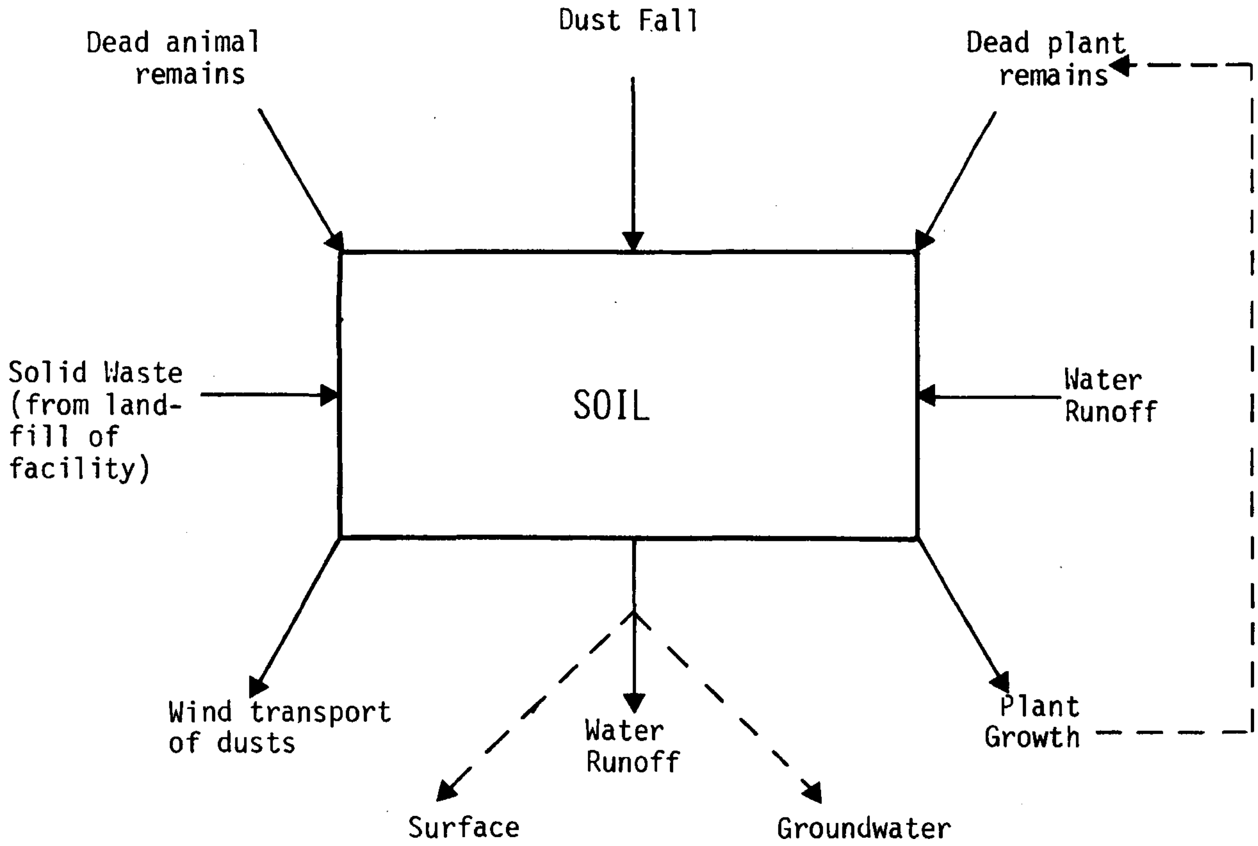

Figure IV-1. Simplified diagram of effluent flow through soil matrix.

swelling-shrinking characteristics of the clays and could impede further movement of dissolved materials through the clay matrix.

The adsorption of neutral molecules on clay mineral structures, both non-ionic and organic molecules, reflects their dipole nature and lack of electron symmetry within individual molecules. This concept of the dipolar nature of many neutral molecules is significant when compared with the polar nature of clay mineral structure. The results of a large number of tests with organic components indicate that the adsorption mechanism is hydrogen-bonding, rather than cation or anion bonding, to the clay mineral. This results in the space between the clay mineral sheets changing as a function of the neutral molecule size rather than as a function of charges present on adjacent sheets of the clay mineral. Other biological assays of adsorption of protein, enzymes, and other complex organic molecules indicate a similar pattern.

An important property of clays is the amount of water (or other liquid) they can hold at saturation, the amount being called gel volume. As the gel volume of a clay is approached, it tends to become more erosible and to lose engineering stability. Several organic compounds have the ability to disperse in clay minerals. Table IV-36 lists gel volumes of bentonite for a number of compounds whose principal differences in gel behavior are believed to be due to the organophilic properties of the clay. These appear to be negligible until an amine chain of at least 10 carbon atoms is present. In addition, these data suggest that the swelling is low in non-polar liquids like aliphatic and aromatic hydrocarbons, and that gel volume tends to increase as the dielectric constant of the organic compound increases.

Some general conclusions about the adsorbing ability of montmorillonite and kaolinite clays indicate that the montmorillonite system restricts adsorption because of its capillary dimensions, while kaolinite clays present a relatively unrestricted surface for adsorption.

Once adsorption has taken place, dissociation occurs very slowly or not at all in some clays, while in others it occurs rather easily. The key predictive character appears to be that basic units, as in montmorillonite, are necessary to retard chemical change. Breakdown of certain carbohydrate compounds in soil by microorganism is retarded by montmorillonite and attapulgite, while illite and kaolinitic clays show very little of this effect.

Table IV-36. Gel volume of 2-g samples of dodecylammonium-benthonite in various liquids.

| Liquid | Gel volume, ml | Liquid | Gel volume ml |
|---|---|---|---|
| Water(untreated bentonite) | 31 | Butyl carbitol | 12.5 |
| Water(dodecylammonium-bentonite) | 2.0 | *n*-Butyl phthalate | 12.5 |
| Petroleum oil, Gulfpride SAE 10 | 2.5 | Isophorone | 12.5 |
| Petroleum oil, Gulfpride SAE 40 | 2.5 | Benzyl alcohol | 13.0 |
| Dow Corning Fluid 200 | 2.5 | Bromoform | 13.0 |
| Petroleum ether | 3.0 | Ethyl acetate | 13.0 |
| Piperidine | 3.0 | Tricresyl phosphate | 13.0 |
| Naphtha | 3.5 | Acetone | 13.5 |
| Carbon disulfide | 4.0 | Ethanol (95%) | 13.5 |
| Carbon tetrachloride | 4.0 | Nitroethane | 13.5 |
| Dibutylamine | 4.0 | Acetonitrile | 14.0 |
| Glycerol | 4.5 | Isoamyl acetate | 14.0 |
| Tributylamine | 4.5 | Castor Oil | 14.0 |
| Amyl nitrate | 6.0 | Linseed oil | 14.0 |
| α-Butylene bromide | 6.0 | Oleic acid | 14.5 |
| Eucalyptol | 6.5 | *n*-Butylaldehyde | 15.0 |
| Styrene | 6.5 | Cyclohexanone | 15.0 |
| Toluene | 6.5 | Dodecylamine | 15.5 |
| Bromobenzene | 7.0 | Ethyl bromide | 15.5 |
| Linoleic acid | 7.0 | *n*-Butyl tartrate | 16.5 |
| Cymene | 7.5 | *n*-Heptaldehyde | 18.0 |
| Aniline | 8.0 | Methyl iodide | 18.0 |
| Cyclohexanol | 8.0 | γ-Picoline | 18.0 |
| Ethylene dichloride | 8.0 | Acetophenone | 19.0 |
| Benzene | 9.0 | Tetraethyl ortho-silicate | 19.0 |
| Paraldehyde | 9.0 | Coconut Oil | 20.0 |
| Acetic anhydride | 10.0 | Dodecyl alcohol | 20.0 |
| Chloroform | 10.0 | Methyl ethyl ketone | 20.0 |
| *o*-Cresol | 10.0 | Diethyl ketone | 21.0 |
| Ethyl malonate | 10.0 | Hexadienal | 21.0 |
| Formamide | 10.0 | Pyridine | 28.0 |
| Furfuryl alcohol | 10.0 | Benzaldehyde | 31.0 |
| Toluidine | 10.0 | Benzoyl chloride | 33.0 |
| Phenol | 10.5 | Crotonaldehyde | 34.0 |
| Butyl stearate | 11.0 | Ethyl ether | 35.0 |
| 2-Nitropropane | 11.0 | Furfural | 35.0 |
| Acetic acid, glacial | 12.0 | Benzonitrile | 50.0 |
| Isoamyl alcohol | 12.0 | Nitrobenzene | 88.0 |
| 1-Nitropropane | 12.0 | | |

Source: Grim, 1968.

This brief summary of the general behavior of compounds in the presence of clay minerals is useful for an understanding of the behavior of fugitive compounds which fall off-site and begin the interactions described in Figure IV-1. These concepts are also valuable for predicting the behavior of landfill material with the existing subsurface clay minerals so that the finite limits of adsorption may be estimated.

## 4. Biological Systems.

a. Introduction: The movement of materials from coal plants into biological systems can be traced through three major pathways: (1) ingestion of food materials, (2) respiration (for terrestrial organisms), and (3) immersion in the diluting medium (aquatic organisms, soil organisms).

The behavior of exotic materials with respect to living systems has been extensively studied during the past twenty-five years, primarily to better understand the dispersion of pesticides and radioisotopes in ecosystems. These data have led to almost universal observations that:

1) many non-essential compounds and elements are taken up by organisms randomly;

2) once materials are taken into the nutrient cycle, they tend to remain in the organic material (either alive or dead);

3) because many exotic materials have no associated metabolic pathway developed in an organism for biological decay, these materials retain their physical half-life characteristics (often reflecting great stability over long periods of time);

4) concentrations of exotic materials vary greatly throughout "life-space" but occur ubiquitously;

5) many exotic compounds tend to accumulate in living organisms at concentrations for greater than those found in the surrounding environment;

6) many exotic compound have deleterious physiological effects on organisms in which they become concentrated.

These observations have led to genuine concern about the introduction of any exotic material into the environment.

Potential pathways for the dispersion of these materials into the air, water, and soil are not difficult to imagine. Perhaps the largest pathway will be episodic excursion from normal plant operation, as during start-up and decommission.

Another pathway could be the accidental introduction of surface runoff or process water into surface or ground waters. Finally, the many possibilities for fugitive atmospheric emissions suggest potential entry into biological systems through breathing, surface contact, or fallout into aquatic and terrestrial habitats. Biological systems can interact with the exotic material emitted from a coal conversion plant in several ways.

b. Bioamplification: Bioamplification is the process which allows materials in limited supply to become concentrated in living organisms, above their normal amounts in the ambient environment, to levels of biological significance. Many elements and compounds are biologically amplified. However, the items of greatest concern are those amplified elements or compounds for which there is no biological "escape route" or metabolic pathway. An example of bioamplification occurred with the element strontium. Strontium, which is normally found in very small amounts, behaves biologically much like calcium. Large-scale production of radioactive daughter species began (A-bomb explosions, reactor developments, solid waste storage), and $Sr^{90}$, one of the radioactive isotopes, was observed replacing calcium in bone, blood-forming tissues, and milk of vertebrates. The presence of radioactive atoms near the important blood-forming organs has apparently modified the cancer rate for these organs in several mammals, including man.

Documentation of pesticide bioamplification is well established. Persistent chlorinated pesticides have appeared in the biological systems of birds at high altitudes, thousands of miles from the nearest point of pesticide application. Man, never an intentional target organism, carries a persistent burden of pesticides in his fatty tissue, as the result of the ingestion of food which has been protected from pest attack by persistent pesticides. These same processes of bioamplification apparently occur with a wide variety of substances; the release of even small amounts of material can, over time, represent a significant hazard to an individual or a population.

Guthrie and Cherry (1976) have shown that concentrations of most chemical constituents in a drainage system for an ash basin at a coal-fired power station were greatest in the sediments (75 percent) and least in the water (> 1 percent), indicating that the major removal of material was due to sedimentation. Eight elements (Br, Ca, Cl, Cd, Na, Sb, Se, and Zn) were more highly concentrated in one or more biotic forms than in the sediments. Chromium was the only metal more highly concentrated in plants than in animals. Midges concentrated Fe, Cu, Cr, Hg, Co, Sb, and As best among all organisms. Active metals (Ca, Na, and K) were more concentrated in crayfish and mosquito fish (Gambusia affinis) than in the sediments. Primary producers concentrated material least, while the consumer-level organisms bioamplified elements consistently.

## D. POTENTIAL ECOSYSTEM EFFECTS.

### 1. Effects on Individual Species.

a. Introduction: Studies of the effects of exotic substances on individual organisms have followed several major lines of research. These include: (1) studies required to determine effectiveness of a particular insecticide, herbicide, drug, or other material which has a planned use; (2) studies which explain the etiology of an observed effect on some non-target organism; (3) studies which examine the metabolic behavior of introduced materials into living systems. While these investigations may overlap and involve generally similar techniques, the application of results will vary. Too often, the results of one class of studies are so compartmentalized that effects on unexpected organisms have been overlooked or reduced in importance. Against this general background, the unexpected effects or consequences of the introduction of exotic materials into the environment have been emphasized.

b. Examples of Effects on Individual Species: The effect of a material on an organism may be positive, neutral or negative. A positive effect may be a fertilizer for plants or a vitamin for an animal; a neutral effect could be flavorings added to food which have little direct effect but serve to enhance the desirability of a particular food; a negative effect may be the release of a chemical such as lead or mercury which, when ingested, changes behavior.

c. Flowering Plants: Studies with crop species (corn, soybeans, wheat, barley, clover, and others) have been conducted to determine dosage rates which produce visible injury symptoms. Visible injury from airborne gases such as $SO_2$ include necrosis, chlorosis, or abnormal pigmentation of foliage or floral parts. Less dramatic but no less important are subtle effects and physiological effects without visible injury such as reduced photosynthesis, changes in stomatal behavior, or reduction in yield and growth. Jones, Weber, and Balsillie (1976) point out that short-term, high-concentration episodes can cause significant vegetation damage, yet such episodes may have no effect on the annual average concentration of $SO_2$.

Interaction between two or more atmospheric pollutants may produce more pronounced effects than either pollutant alone. Sulfur dioxide and ozone form one such combination.

d. Non-flowering Plants: Most data available for non-flowering plants deal with the impoverishment of lichen and bryophte flora near industrial centers. Many studies have related this reduction in species present to the average annual concentration of $SO_2$ without consideration of the short periods of high concentrations which undoubtedly occurred. These small plants provide habitat, food, and shelter for many small animals and serve as the basis for community systems which are poorly understood at present.

Impacts of air pollutants on algae have been examined in several countries. At a recent symposium (Dochinger and Seliga, 1975) depauperate algae populations were reported apparently due to acid precipitation. Spring runoff is generally more acid at the beginning of the year, and rapid invasions of Sphagnum moss mats have been observed after such events in lakes of the northeastern U.S. and Scandinavia.

e. Metals in Plants: Trace elements such as Ca, Mg, K, S, B, Cu, Zn, Fe, and Mn are required for plant growth. Many of these elements are chelated or integral parts of complex organic molecules such as enzymes or co-enzymes. Magnesium, for example, is an integral part of the chlorophyll molecule.

Many metals are required by plants in small amounts to avoid classic deficiency symptoms of chlorosis, lodging, or leaf wilting; however, excess amounts of metal ions or large shifts of soil pH which may cause interference with metal uptake also can result in plant damage or death. Studies with sewage-amended soils (Dudas and Pawluk, 1975) indicate that mineral uptake by plants is directly proportional to the soil concentration. Only lead and mercury content in lettuce was not significantly increased by the application of sewage waste. Cadmium, on the other hand, appears to be concentrated by the plants used by Dudas and Pawluk (1975), which resulted in a caution due to the reported deleterious effects of cadmium on humans (Fasset, 1972).

f. Metals in Animals: The effects of metals in animals have been well documented for man and several common laboratory mammals (Lee, 1972). However, effects on aquatic animals have not been studied as intensively. One study of the effects of zinc on minnows (Bengtsson, 1974) showed early behavioral responses of fright and tetanic coma followed by increased muscle tone which interfered with swimming. Following this, the fish seemed passive and flabby when handled. Frequent caudal hemorrhages occurred and appeared to be associated with fractures of the vertebral column. These symptoms appeared within ten days at concentration levels above 0.20 ppm zinc. Bengtsson also comments on the close symptomatic similarity of zinc poisoning to pesticide poisoning in fish.

Davies, et al. (1976) present information on chronic toxicity of lead in rainbow trout. The lead-affected fish (at levels below acute toxicity) showed major abnormalities, including blacktail, caudal atrophy, caudal fin erosion, and lordoscoliosis (dorsal-ventral and bilateral spinal flexures). In severe cases, paralysis and muscular atrophy of the flexed portion of the fish occurred.

In laboratory studies of bluegills, Benoit (1975) found that copper at concentrations of 166 ug/liter significantly affected reproduction and survival. The gills and liver were the principal sites of copper concentration. These studies on bluegills are similar to results with brook trout and brown bullhead. Projections of survival data by Benoit indicated that the 96-hr TL50 is approximately 1100 ug Cu/liter, which is consistent with reported data for fathead minnows.

Another study involving fish is the monitoring of flesh-tainting substances which result in "off-flavor" flesh to a test panel of fish tasters (Thomas, 1973). Thomas lists 49 substances or classes of substances which are known to cause off-flavor to fish flesh. Nineteen of these compounds are found in coal gasification plant effluents, suggesting that this effect may be an excellent monitoring index as well as a potential environmental impact.

A study of metals in fish-eating birds showed that the concentration of mercury varies by tissue in the bird (Hoffman and Curnow, 1973). The only reference to behavior by Hoffman and Curnow concerned two black-crowned night herons which were caught by hand on the ground. These birds had an average of 11.53 ppm mercury in the primary wing feathers. Other investigators have reported mercury levels in the carcasses of great blue herons found in Lake St. Clair of up to 175 ppm in the liver.

Studies of heavy metal concentrations in invertebrates deal with the bioaccumulation in hard skeletal (or shell) parts rather than with the behavioral or toxic effects on the intact organism. A study to monitor lead in a tributary of the Cumberland River (Harpeth River, Tennessee, USA; Clarke, *et al.*, 1976) through the lead content of several species of fresh-water mussels showed that lead concentrations in shells of asiatic clam (*Corbicula manillensis*) are reliable indicators of environmental lead levels. Since these data were developed from shells of dead animals, no information on behavioral changes or the soft tissue pathology of the mollusks is available.

*g. Metals in Humans*: The inhalation, ingestion, or skin exposure to metal vapors, dusts, or compounds cause or are implicated in a wide variety of human disorders (Table IV-37). Central nervous system deterioration due to plumbism is a well-known effect of chronic exposure to lead either through

Table IV-37. Effects of metals in humans.

| Metal | Inhalation | Ingestion | Symptoms/Remarks |
|---|---|---|---|
| Mercury | | | |
| Metallic (acute)<br>Metallic (chronic) | Acute chemical penumonitis. | | Chills, fever, cough, tight feeling in chest, tremor, erethism, gingivitis. |
| Mercury bichloride | | Corrosion of digestive tract, kidney damage. | Bloody diarrhea, uremic death. |
| Alkyl Mercury | | Progressive poisoning. | Congenital defects--cerebral palsy, mental retardation. |
| Lead | | Gastro-intestinal tract absorption, blood effects, encephalopathy, peripheral neuropathy, anemia, renal tubular dysfunction, and reproductive dysfunction. | Patients show apathy, drowsiness, and stupor, alternating with hyper-irritable intervals. |
| Cadmium | CdS trapped in lungs for periods in excess of a 5-day biological half-life; concentrates in kidneys and lungs. | Concentrates in kidneys & lungs after ingestion with drinking water. | A series of doubtful symptoms, including hypertension, fetal placenta destruction, renal necrosis in animals, sarcomas in animals (rats), Itai-Itai disease in older women. |
| Beryllium* | Granulomatous chronic chest disease resembling tuberculosis. | | Acute: acute beryllium pneumonitis, inflammation of upper respiratory tract. Chronic: progressive pulmonary disease, associated cardiac disease, dyspnea. |
| Chromium | Respiratory system damage due to inhalation of acid mists. | | Perforation and ulceration of nasal septum; dermatitis from chromate dusts in portland cement industry. |
| Manganese | Manganese pneumonia. | | High temperature & dyspnea which do not respond to antibiotics. |
| | | Manganese poisoning. | Central nervous system effects: sleepiness, mask-like facial expression, twitching or tremor in hands & legs; emotional disturbances. |
| Nickel** | Nickel carbonyl may be important in cigarette smoke. | | This is the most toxic gas for which Threshold Limit Values have been established. |
| Vanadium*** | Urban air. | | Regression against diseases of the heart, bronchitis in males, and pneumonia in males & females. |
| | Inhaled $V_2O_5$ implicated in pulmonary irritation. | | Cough, nasal catarrh, dyspnea. |
| Arsenic | May be inhaled. | | Although compounds of arsenic cause death or illness, this element does not appear to be an environmental threat. |
| Fluoride | | Water intake. | Osteoporosis. |

NOTES:

* Beryllium may be detected in air of communities using coal as a fuel, but it is of no known hygienic consequence. Primarily causes disease in the workroom setting. [See also Table III-30.]

** Coal ash may contain between 3 and 10,000 ppm of nickel. Coal combustion represents a substantial source of this metal. [See also Table III-30.]

*** United States coals contain 16 to 176 ppm vanadium with coal ash enriched up to 1,000 ppm. [See also Table III-30.]

SOURCE: Lee, D.H.K., ed. 1972. Metallic contaminants and human health. New York: Academic Press.

inhalation or pica. Other metals have similar chronic effects or result in epithelium ulceration when exposure occurs as an acid mist or reactive oxidizing agent (chromium, vanadium). The liver, as the major detoxifying organ for the circulatory system, is often the site of elevated metal concentrations in an exposed individual. The renal tubules of the kidney also are the sites of degenerative pathology in the cuboidal epithelium in many types of chronic metal exposure.

Most exposures to highly toxic, acute, or chronic doses of metals have occurred in an industrial setting (lead is an exception to this); the best information on the pathology and toxicology comes from this experience. Ambient or background conditions appear to be implicated as pathogenic in several cases of general exposure of populations near large industrial plants.

A potential apparently exists for a background vanadium increase near areas where large coal-fired plants operate. At the present time vanadium is a measurable component of the atmosphere over large cities, although its health impact cannot be assessed at its present low level of concentration. Other elements may increase in the atmosphere in the future, but at present industrial hygiene and increasingly stringent effluent requirements are reducing the effect of these elements on the general population.

### 2. Effects on Biological Community Structure.

A biological community is the entire assemblage of organisms (plants, animals, bacteria, etc.) which occur within a given ecological system. It is generally recognized that community structure changes on a cyclic, short-term basis in response to seasonal changes. Permanent changes in structure can occur on a long-term basis (geological time) due to such factors as climatic changes and the evolution of new species or extinction of previously existing species from a variety of causes. On a shorter time scale, community structure can change as a result of short-lived natural events such as floods, earthquakes, or weather events close to the climatological extremes for the region. The other short-lived (or chronic) influence on community structure is the effect of human activities, including pollution from coal plants.

In many respects, changes in community structure can be very sensitive indicators of pollution (or other humanly produced disturbances) because the organisms are essentially a continuous monitor of the various environmental stressors that are working on them.

The simplest measure of community structure is the species list, but changes in the membership of such lists are only a crude indicator of environmental disturbance. The extinction or extirpation of a species, especially if it is valued by society or has a critical role in ecosystem function, is considered a major environmental impact. (So is the addition of an "exotic" species, but this seems highly unlikely to result from ERDA coal plant activities.) It should be recognized that extinction of one species can result in wholesale changes in community structure because other species may depend on the extinct member, in whole or in part, for some vital requirement.

Somewhat more sensitive indicators of change in community structure are changes in the density (individuals per unit area or unit volume) of individual species. It is not always easy to distinguish the effect of normal seasonal changes or of other short-term stressors from those caused by pollution, of course.

One of the fundamental generalizations of ecology is that a new or increased environmental stressor tends to reduce the diversity of a biotic community. An unstressed community tends to have a large number of species, but no one species is very numerous. When such a community is stressed, the number of species present is reduced (often drastically) and a few species become extremely abundant. Presumably, the more sensitive species are extirpated and the more resistant ones expand to utilize the available resources. The problem with communities of low diversity is that they generally seem to be vulnerable to catastrophic changes when confronted with further environmental stress. Diversity is measured by a variety of indices which combine measures of variety (number of species) with density of individual species, resulting in a single numerical descriptor. These indices will be discussed in Chapter V.

In recent years, ecologists have developed mathematical techniques to describe changes in community structure over time or space; these calculations, known as multivariate analysis, allow precise description of such changes and accurate correlation of these changes with physical and chemical factors in the environment. These techniques can indicate environmental stress and identify the particular stressor or stressors which are responsible. As such, they will be described in the section of this report dealing with state-of-the-art in environmental monitoring.

*U.S.GOVERNEMNT PRINTING OFFICE: 1977 -740- 062/ 98 REGION NO. 4