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**ENVIRONMENTAL MONITORING HANDBOOK
FOR
COAL CONVERSION FACILITIES**

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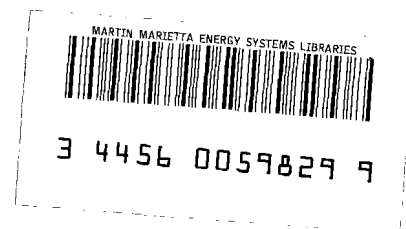
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Abstract

The primary objectives of the Department of Energy's (DOE) coal conversion program are to demonstrate the environmental acceptability, technical feasibility, and economic viability of various technologies for gaseous, liquid, and solid fuels from coal. The *Environmental Monitoring Handbook for Coal Conversion Facilities* will help accomplish the objective of environmental acceptability by guiding the planning and execution of socioeconomic and environmental monitoring programs for demonstration facilities. These programs will provide information adequate to (1) predict, insofar as is possible, the potential impacts of construction and operation of a coal conversion plant, (2) verify the occurrence of these or any other impacts during construction and operation, (3) determine the adequacy of mitigating measures to protect the environment, (4) develop effluent source terms for process discharges, and (5) determine the effectiveness of pollution control equipment. Although useful in a variety of areas, the handbook is intended primarily for contractors who, as industrial partners with DOE, are building coal conversion plants. For the contractor it is a practical guide on (1) the methodology for developing site- and process-specific environmental monitoring programs, (2) state-of-the-art sampling and analytical techniques, and (3) impact analyses.

To correspond to the phases of project activity, the subject matter is divided into four stages of monitoring: (1) a reconnaissance or synoptic survey, (2) preconstruction or baseline, (3) construction, and (4) operation, including process monitoring (prepared by Radian Corp., McLean, Va.). For each stage of monitoring, guidelines are given on socioeconomics, aquatic and terrestrial ecology, air quality and meteorology, surface and groundwater quality, geohydrology and soil survey, and surface water hydrology.

1. Summary of Monitoring Principles and Purpose

1.1 Introduction

The Department of Energy's involvement in the demonstration of coal conversion technology has several objectives. In addition to the traditional objectives of demonstrating technical feasibility and economic viability, there is that of demonstrating environmental acceptability. The emphasis on these three objectives being of equal priority is justified; in a sense, all three are of number-one priority. The current and expected regulatory climates make it mandatory that any new process have the lowest practicable environmental impact. Specific environmental performance standards will be set for coal conversion facilities. In addition, existing ambient standards and guidelines must be met. The demonstration phase of coal conversion technology development offers the first opportunity for determining environmental acceptability and offers a unique opportunity to develop sound information on which to base reasonable and economically achievable standards. The skill and care that go into the planning and execution of the environmental effort should equal that of the technical and economic effort. Although the cost of carrying out an environmental assessment program is typically only a very small fraction of the overall project cost, this cost can be significant and should be thoroughly considered at the proposal stage of budgetary development.

The purpose of this *Environmental Monitoring Handbook for Coal Conversion Facilities* (henceforth called the handbook) is multifaceted. The handbook is intended primarily for contractors who are building demonstration coal conversion plants as industrial partners with the Department of Energy (DOE). The handbook may also be seen as a planning document of particular use to DOE and others in a position of managing or overseeing an environmental monitoring program. The handbook provides guidance in developing environmental and socioeconomic monitoring programs which will provide information adequate to (1) predict the potential impacts of construction and operation of a coal conversion plant at a specific site, (2) verify the occurrence of these or any other impacts during construction and operation, (3) determine the adequacy of mitigating measures to protect the environment, (4) develop effluent source terms for process discharges, and (5) determine the effectiveness of pollution control equipment. In addition, it lays the groundwork for the modeling of those parameters that cannot be adequately monitored.

The handbook provides the contractor with a practical guide on methods for designing an environmental monitoring program (including socioeconomic parameters), state-of-the-art sampling and analytical techniques, and the current body of knowledge regarding impact analyses for coal conversion plants. Because of its basic philosophy, the handbook is not meant to be a static document. The loose-leaf format will facilitate the incorporation of future revisions and updates on developments in sampling and analytical techniques and relevant results from research studies on effluent source terms, toxicology, biota sensitivities, etc.

The handbook is not meant to be used in isolation. Many relevant studies and texts are referenced so that important planning concepts and standard techniques of sampling, analysis, and data storage are at the disposal of the reader. The contractor should consult the references at the end of each section for detailed discussions of many of the recommended methods.

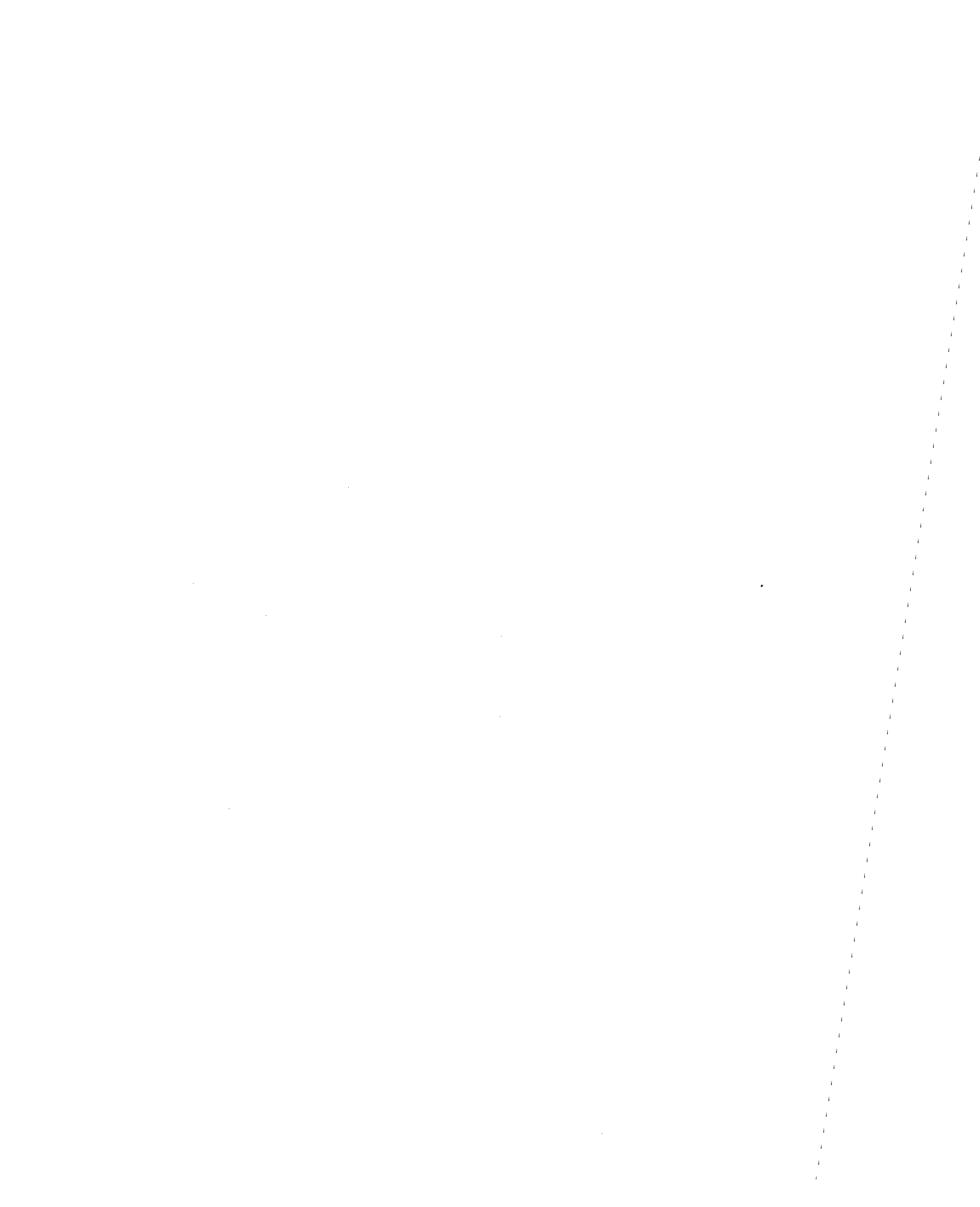
1.2 Demonstration- vs Commercial-Scale Plants

It is a common misconception that demonstration plants, being smaller than commercial plants, deserve a smaller level of environmental monitoring than do commercial plants. There are at least two justifications for thorough monitoring of demonstration plants: (1) Monitoring during the demonstration stage begins the task of establishing a representative data base for the emerging coal conversion industry. (2) Scale-up of effluents and prediction of impacts for commercial-scale operation are likely to be far more realistic when based on data from a demonstration plant than from a pilot plant.

Effluent data from a pilot plant may be of limited value for the following reasons: (1) Some equipment used in the pilot plant will not be used in demonstration- or commercial-scale plants, (2) other demonstration- and commercial-scale equipment (sulfur recovery, for example) generally are not used in pilot plants, (3) pilot plants generally use less sophisticated pollution control technology, (4) some effluent streams may leave the process at such small rates that chemical contaminants may go undetected, and (5) pilot plants typically do not operate for prolonged periods at steady state or under repetitive operating conditions, making effluent data a function of the experimental run. Demonstration plants, on the other hand, normally represent the first module of a future multiunit commercial plant operating with full-scale equipment and plant factors approaching those of the commercial plant. Because the development status has not yet advanced beyond the pilot-plant stage, very few representative data are currently available to estimate effluents or conduct impact assessments for larger scale plants.

The emphasis in this handbook is on demonstration-scale plants to coincide with development of coal conversion technology. Adaptation of the handbook to commercial-scale plants is straightforward and many of the concerns regarding the current shortfall of data may not apply.

It is important to realize that it may not be possible to accurately predict all the potential impacts of commercial-scale plants with data from demonstration plants. Some of the impacts may have significant effects which will not become apparent until the large plants are in operation; because of environmental attenuation others may go through several years of lag time before they are detected. The similarities between demonstration and commercial plants, however, will be much closer than those between pilot and demonstration plants. The major scale-up between demonstration and commercial plants will be in the quantity of effluents, not a difference in types of effluents as might be expected between pilot and demonstration plants. Although it will never be possible to eliminate all the monitoring at any size facility, a thorough monitoring program at the demonstration stage may identify key effluents and environmental impacts, resulting in a more compact and efficient monitoring program for the commercial stage. In the long run, this could be a cost-saving factor as the technology develops to the level of full-scale commercial plants.



1.3 Developing a Monitoring Program

Many monitoring programs are unsuccessful or are not cost-effective due to inadequate planning at the onset. It is strongly suggested that the contractor obtain the services of competent monitoring personnel, including aquatic and terrestrial ecologists, sampling design statisticians, hydrologists, geologists, meteorologists, air and water quality analysts, chemical engineers, process monitoring experts, sociologists, and economists, to ensure an integrated and conceptually sound approach to site-specific monitoring. Close coordination among these specialists is essential to optimize the efficiency and accuracy of the program. (For example, chemical engineers may be able to provide a quantitative characterization of liquid discharges to aquatic ecologists to enable the ecologists to select relevant sampling locations and parameters. Hydrologists and ecologists can coordinate their phases of the program design so that sampling stations can be selected to provide water quality data at a point where aquatic biota is to be monitored.) This handbook is not a "cookbook" that can be applied to all monitoring situations without adaptation. All monitoring programs to a large extent must be derived from site- and process-specific considerations. The environmental assessment needs must be tailored to the particular receiving systems under investigation. This handbook is intended to serve as a conceptual tool or guide to a portion of the site-specific monitoring needs, and the remainder must be supplied by the expertise and judgment of the monitoring personnel.

In general terms, the sequence of activities that goes into developing a monitoring program should proceed as follows:

1. Define the objectives and goals of the monitoring program based on the anticipated environmental impacts of site and plant activity. The monitoring program should provide the data needed to
 - a. detect and assess the impacts of plant construction and operation
 - b. verify the performance of pollution control technology
 - c. verify compliance with environmental regulations.
2. Conduct a synoptic survey based on the existing literature, the site-selection survey, the preliminary plant design, and a site visit to obtain information on
 - a. regional environmental characteristics
 - b. regional socioeconomic conditions
 - c. construction procedures
 - d. plant layout, including storage areas and waste disposal facilities
 - e. process effluents
 - f. potential impacts
 - g. applicable federal, state, and local environmental regulations and permit requirements.

3. Estimate the time and financial resources required.
4. Prepare a tentative description and rationale for the
 - a. parameters to be measured
 - b. level of accuracy needed for each parameter
 - c. location of sampling stations.
5. Add to this program a
 - a. selection of sampling methods
 - b. determination of sampling frequency
 - c. selection of sample-preservation techniques
 - d. selection of analytical procedures
 - e. quality control and data management procedures.
6. Determine the time and financial requirements of the program.
7. Submit the monitoring program to DOE for review.
8. Modify steps 4 and 5 as required to satisfy DOE guidelines.

1.4 Monitoring Program Scope

A monitoring program suitable to all site- and process-specific cases cannot be defined in a generic guide such as this handbook. It is possible, however, to identify the aspects of a case that influence the monitoring program scope (number of parameters to be measured and the frequency of measurement). Stated simply, the scope of the monitoring program is a function of the level of predicted environmental impacts, the degree of confidence placed in those predictions, and the extent of the data collected during the initial reconnaissance or synoptic survey. A broader and more intensive monitoring program may be justified if (1) the level or severity of the expected environmental impacts is high, (2) little scientific information is currently available describing the interaction of plant effluents and the environment, or (3) the locations of liquid discharges, solid waste disposal locations, holding ponds, and the contaminant source terms, etc., are not available prior to designing the program. Here again, the importance of site- and process-specific information and a thorough synoptic survey is emphasized. The cost of the monitoring program is directly related to the scope and will, therefore, be influenced by the same considerations.

In many cases, a relatively broad scope is planned initially with the understanding that dynamic feedback loops exist within a good monitoring program. Often, parameters will be eliminated if initial monitoring data warrant. For example, a chemical compound expected to be released from the process may be monitored prior to operation to determine whether its presence predates the plant. If the compound is not found during the early stages of monitoring, a decision may be made to drop that compound from the baseline monitoring program, and reinstate it once operation begins.

There may be some impacts that will be detectable only through the application of long-term research studies which determine relationships between expected process effluents or other environmental perturbations related to the plant's activities (e.g., construction or socioeconomic impacts) and their environmental effects. Unfortunately, in a developing technology, characterization of effluents expected to be released may not be sufficiently advanced at the baseline monitoring stage to allow adequate impact assessments. This and the limitation of generic research feedback into site-specific monitoring efforts may limit the predictability of environmental impact assessment prior to plant operation to the more common and well-known impact relationships. If process effluents are uncharacterized and their environmental effects are unknown, the baseline monitoring program should involve a broader range of measurements to include all important ecological components or functions of the receiving system that will be in contact with the released effluents. This research effort extends beyond the responsibility of the contractor and additional research may be necessary to enhance the scope of the baseline monitoring program to include specific impact evaluation or prediction that cannot be accomplished in a general monitoring program.

In response to environmental impact assessment needs, DOE, EPA, and others are committed to generic research on the environmental effects of coal conversion effluents. DOE has defined many

research studies that need to be conducted during various phases of their coal conversion demonstration program. These studies will complement the monitoring described in this handbook. For example, an Environmental Development Plan (EDP) for the coal gasification program was released in September 1977. The EDP is intended to be the basic DOE document for environmental research and development planning, management, and review. For each developing technology, the EDP considers all potential areas of environmental, health, and safety programs; determines needed activities for each problem; and identifies applicable ongoing research.

The coal gasification program EDP addresses planning in two basic areas: environmental research and environmental assessment. These include the following:

1. characterization and monitoring of pollutants
2. evaluation and development of control technology and mitigation techniques
3. evaluation of potential ecological effects
4. determination of pollutant transport and transformation phenomena
5. evaluation of socioeconomic effects
6. integrated analyses of the environmental impacts of coal gasification development

1.5 Monitoring Stages

Monitoring is necessary at all steps in the planning, construction, and operation of a new plant. The monitoring program may be divided into four stages: (1) synoptic survey, (2) baseline or preconstruction, (3) construction, and (4) operation. Following this idea, the handbook describes, in Part 2, preconstruction monitoring and includes the synoptic survey. Part 3 describes construction monitoring. Operational monitoring is described in Part 4, which is divided into process monitoring (4a) and environmental monitoring (4b).

1.5.1 SYNOPTIC SURVEY

Although some data collection is involved, the synoptic survey is not a monitoring stage per se, but is the forerunner of the three principal monitoring stages. The purpose of the synoptic survey is to gather information to define the parameters of interest, the nature of the site, historical background data, etc. Through the synoptic survey, site- and process-specific information is gathered in order to plan the remainder of the monitoring program. Generally speaking, the more information available at the planning stage of the monitoring program, the smaller the scope and the more cost-effective the program. A synoptic survey should be conducted for each part of the monitoring program—socioeconomics, aquatic ecology, terrestrial ecology, geohydrology, air quality, and water quality. Typical information generated by the synoptic surveys includes:

1. a detailed plot plan and site layout showing the location of holding ponds, waste lagoons, landfills, coal storage piles, and sources of air emissions and liquid discharges
2. detailed data for all gas, liquid, and solid effluent streams, giving compositions, rates of release, and physical properties
3. solid waste handling and disposal methods and the ultimate disposal locations
4. topographic and geologic data describing watersheds, stratigraphy, groundwater locations and movement, and the location of all surface water bodies
5. detailed construction plans
6. intake location and withdrawal rate for process water
7. location of any pipeline or utility corridors
8. high- and low-flow data for water bodies
9. recorded or potential presence of any endangered species
10. size of the construction and operating labor force, categorized by skill and pay rate
11. location and type of industry in the region which could have an influence on local air and water quality.

This list gives an idea of the type and diversity of information needed prior to developing a monitoring program. The developmental nature of a demonstration plant and the overall timing of the demonstration program may preclude the incorporation into the monitoring program of much of the desired process and site information. This is not, however, an insurmountable problem. The lack of information can be compensated for by increasing the initial scope of monitoring while maintaining flexibility in the program. An example may help to clarify this point. It follows logically that the location of the liquid discharge (assuming one liquid discharge) and its flow rate and composition must be known to identify the receiving body, to select the sampling transect locations, to select the chemical compounds and biological parameters to sample, and to determine the frequency of measurement. If the plant design has not evolved to the stage where this information is available, an acceptable way to proceed would be the following:

1. Broaden the work scope of the water quality and aquatic ecology programs in this specific area with the understanding that inappropriate parts will be eliminated as soon as the actual design is available.
2. Use the design engineer's best estimate and best alternative for the discharge location, flow rate, and composition.
3. Select sampling locations, parameters, and frequencies based on the above estimates.
4. If needed design information is still not available at the scheduled start of the monitoring program, begin monitoring based on number 3 above.
5. When the needed design information is available, eliminate inappropriate sampling locations and parameters and/or add new locations and parameters as appropriate.

Each subsection of the handbook provides a discussion of needed information to be gathered during the synoptic survey. The synoptic survey should also include a site visit by those persons who will be responsible for developing the monitoring program.

1.5.2 PRECONSTRUCTION MONITORING

Preconstruction monitoring establishes existing or baseline conditions through an extended period (a minimum of one year) of analytical or quantitative monitoring. It includes all environmental, social, and economic information collected during the period from the initial site survey to the beginning of construction. During this monitoring phase, site-specific information is collected to

1. enable a characterization of the physical and socioeconomic environment and an assessment of existing levels of environmental disturbance
2. provide data for the preparation of the environmental report and the environmental impact statement (documents that predict potential impacts from construction and operation of the plant and that suggest mitigating measures to avoid these impacts)
3. allow a future comparison of existing site conditions with those that occur during plant construction and operation.

Chemical, physical, and biological monitoring at all stages should be related to the expected effluents from the plant. In particular, during baseline chemical monitoring, an attempt should be made to determine the levels in the receiving environment of those chemicals anticipated to be released during operation. This will allow determination of how much of the chemical loading in the environment during operation is due to the plant and how much predates plant construction and operation. In many cases, it will be necessary to store samples for later analysis so that if previously unsuspected effluents are found to be released from the plant, their background levels can be referenced.

For data to serve as a sound baseline they must be collected relatively close in time to the monitoring data with which they will be compared. For example, if construction activities place several years between the monitoring done during the preconstruction stage and process startup, the preconstruction data may no longer serve as a good baseline with which to assess the environmental changes that occur as a result of operation. In such a case, the preconstruction data would be the baseline data for measuring construction impacts, and additional functional baseline data for measuring the impacts of operation should be taken during the year immediately prior to the scheduled startup (provided that the data are not affected by construction). In conjunction with the preconstruction data, the data taken during construction will begin to reveal annual trends or fluctuations, providing a more sound data base for measuring operational impacts than could be derived from only one year of "baseline" monitoring. (There are some areas of the monitoring program, such as groundwater and surface water monitoring, that are less sensitive to this point than other areas.)

1.5.3 CONSTRUCTION MONITORING

Construction monitoring during site preparation and plant construction provides data for determining construction impacts and additional baseline data for operation. For the data to be meaningful, a high degree of continuity must be maintained with the preconstruction monitoring program. The scopes of the two programs must be nearly identical so that quantitative, statistically valid data comparisons can be made. These data should enable an assessment of expected and unexpected construction impacts and provide additional baseline data for comparison with future operational-phase monitoring data. The program should be timed to permit feedback to plant design and construction engineers for prevention of significant irreversible damage from these impacts.

Many of the potential impacts from construction of a coal conversion demonstration plant will be similar to those from construction of most other industrial plants. Therefore, the monitoring for these impacts will be similar. Potential construction impacts include soil erosion, habitat modification, and boom-town effects due to rapid population increases.

Socioeconomic impacts are expected to be most pronounced during plant construction. Therefore, the construction phase of monitoring should receive more attention socioeconomically than should either preconstruction or operation. Emphasis should be on detecting impacts and evaluating the effectiveness of measures used to mitigate these impacts.

1.5.4 OPERATIONAL MONITORING

Many of the social and economic effects of plant operation will be similar to those of other types of industrial developments. Operational impacts of coal conversion plants on the physical environment may, however, be quite different from those of most other industrial plants. Impacts due to primary effluents from the process and the secondary effluents from ancillary facilities (e.g., coal piles, landfills) may be unique to coal conversion processes, and, although the effluents will be generally similar within a category of process types (e.g., high-Btu gasification), there will be differences among the processes. For example, the solid residuals from the gasifier will vary according to the specific process and the type of coal used. Also, some impacts may be unsuspected initially. Therefore, it is not possible here to specifically detail all the monitoring that will be necessary for all plants. Much of it will be site- and process-specific and will have to be determined in consultation with DOE. The operational monitoring section (Part 4) discusses the effluents that

may be expected from certain types of coal conversion processes. This general information should be supplemented with specific information available from the designer of the demonstration plant, operational pilot plants, and other small-scale facilities.

Monitoring during plant operation should provide sufficient data to assess and document, by comparison with preconstruction and construction data, the environmental impacts of routine and accidental releases of plant effluents. Operational monitoring at the demonstration-plant stage should provide useful information for adapting these technologies to a commercial scale in a timely and cost-effective way. The handbook divides the operational monitoring stage into two distinct, complementary areas—monitoring of the environment and monitoring of the process.

Critical to the environmental assessment of a demonstration coal conversion plant is the accurate measurement of all plant effluents. Process monitoring data from the demonstration plant are vital to the successful development of the industry. This information will form the basis for environmental regulations which may significantly affect the process economics and may prove to be a significant factor in public acceptance. A carefully planned and executed process monitoring program will ensure data reliability and provide a sound basis for effective regulation, control, and environmentally acceptable operation.

Data generated to satisfy the specific objectives of the process monitoring program may be useful for other purposes. Process monitoring data can be used for future biological and health-effects' testing to determine any short- or long-term effects on human health or ecosystem balance. As discussed in Sect. 1.4, DOE has issued an environmental development plan that addresses this type of testing. In this case, the analytical results must be of sufficient qualitative and quantitative accuracy to guide the toxicity testing. The data can also be used to project the impact on air and water quality in the surrounding environment. Direct ambient measurement may not show a sufficiently rapid response, and accurate data for predictions based on dispersion modeling must be available.

Another critical part of environmental assessment is the performance evaluation of pollution control technology. Demonstration plants will be fitted with state-of-the-art control equipment which can be tested at realistic steady-state conditions. A thorough test program can also determine the limits of control under process upset, startup, and shutdown conditions. As feedback loops are established between the demonstration project and commercial planning, increased knowledge of process effluents and environmental interactions may result in more effective and possibly less expensive systems of pollution abatement and impact mitigation.

A well-designed and executed program will also provide engineering data for use in closing mass and energy balances. This may aid in tracing potentially toxic materials through the process units to their exit points and provide information on which to base minor process alterations that could reduce or eliminate problems.

2. Preconstruction Monitoring

2.1 Physical-Chemical Environment

2.1.1 DESCRIPTION OF THE TERRESTRIAL ENVIRONMENT

A baseline description of terrestrial parameters that are likely to change as a function of site activity is required for an environmental monitoring program to detect changes by comparison with construction and operation data. The terrestrial environment will change in several ways: (1) topography, (2) drainage, and (3) soil conditions.

Some features of the environment will not change. Geology and seismicity, for example, will not be affected by construction and operation and, hence, will not be discussed here. They should, however, be treated fully in the environmental report. Groundwater and surface drainage patterns are discussed in Sect. 2.1.2.

A baseline description of various soil units is an important feature in monitoring the potential degradation of the environment caused by construction and operation. The following sections discuss procedures for selection of sample locations, collection and handling of soil samples, and onsite chemical analysis. Laboratory chemical analysis is covered in Sects. 2.1.4, 3.1.2, and 4b.2.2.2.

2.1.1.1 Soil Survey

Construction and operational impacts should be anticipated before construction is actually begun so that the effort required to mitigate these impacts may be minimized. The first step in anticipating impacts to soils due to construction is to obtain an area soil survey. The appropriate soil survey may be identified by contacting the nearest agricultural extension office; the surveys may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Soil surveys do not exist for all areas of the country. If no survey exists for the selected area, it may be necessary to have the site mapped before construction begins. Mapping is done by the Soil Conservation Service of the U.S. Department of Agriculture. Requests for assistance should be directed to the nearest district office.

2.1.1.2 Physical and Chemical Properties

Four physical and chemical properties of soils should be monitored: visual surface disturbance, pH, conductivity, and background levels of toxic materials.

2.1.1.2.1 Visual Surface Disturbance

A low-altitude aerial photograph and appropriate photographs from ground-level vantage points made prior to construction provide the baseline against which future surface disturbance is appraised. Not only does surface disturbance affect drainage (Sect. 2.1.2) and vegetation (Sect.

2.2.1), but it affects soils as well. Soils will be compacted around construction stockpile sites and access routes, or they will be used for loose fill adjacent to excavation sites. Although compaction tests are useful for soils engineering purposes, there are no established criteria for appraising environmental degradation due to compaction. A more pragmatic approach is to rely on visual observation for a qualitative appraisal of the physical disturbance of soil. Aerial photographs can be used to qualitatively assess the gross features of surface disturbance rapidly and conveniently.

2.1.1.2.2 *pH*

Measurement of soil pH is important because pH determines the solubility of toxic and nutrient ions. Therefore, it serves as a predictor of toxic effects and as an indicator of changes in a variety of chemical processes. Soil pH may be modified by such coal conversion effluents as sulfur and lime dust.

Soil samples for pH analysis should be collected from the top 10 cm of soil and analyzed immediately (i.e., either measured on site with a portable meter or taken directly to a laboratory) by Peech's method for pH in water:

To 20 g. of soil in a 50-ml. beaker, add 20 ml. of distilled water, and stir the suspension several times during the next 30 minutes. Let the soil suspension stand for about 1 hour to allow most of the suspended clay to settle out from the suspension. Adjust the position of the electrodes in the clamps of the electrode holder so that, upon lowering the electrodes into the beaker, the glass electrode will be immersed well into the partly settled suspension, and the calomel electrode will be immersed just deep enough into the clear supernatant solution to establish a good electrical contact through the ground-glass joint or the fiber-capillary hole. Then insert the electrodes into the partly settled suspension as indicated above, measure the pH, and report the results as "soil pH measured in water."¹

2.1.1.2.3 *Soluble Salts*²

Alkali soils that are rich in soluble salts are poor agricultural soils. More than 15% exchangeable sodium is ordinarily harmful to the growth of crop plants.

The saturated soil sample used to measure pH can also be used for estimating the concentration of soluble salts. Conductivity is measured by using a portable battery-operated Wheatstone bridge. Conductivity is empirically related to the concentration of total dissolved solids. From these data the salinity hazard may be estimated.

The sodium hazard is based on an empirical relationship between the salinity hazard and sodium-adsorption ratio ($SAR = Na = \sqrt{(Ca + Mg)/2}$).³ The concentrations of sodium, calcium, and magnesium would have to be determined in the laboratory.

2.1.1.2.4 *Toxic Materials*

Samples should be collected to determine the background concentrations of toxic substances that will be emitted by the plant (e.g., combustion products, process products, cooling tower drift, and leachates from stored solid wastes. Samples should be collected as intact soil cores so that subsamples can be obtained from specific locations in the soil horizons as dictated by the specific contaminants. Such samples can be obtained with a core sampler (split spoon or other suitable device) that contains a stainless steel (or other inert) sleeve which acts as a sample container.³ At some locations where rock or vegetation interferes it may be impractical to use a core sampler. If a core sample cannot be obtained, a

hand auger or trowel may be used. In rocky soils the sample should be passed through a 2-mm sieve. The samples, in their containers, should be wrapped securely in aluminum foil after removal from the coring tool. A tag identifying the site and date of collection should be included. Samples to be stored should be sealed in a plastic bag and frozen. A single set of samples is sufficient for the baseline monitoring program.

2.1.1.3 Sample Locations

Because movement of toxicants into and out of soils is tied to vegetation and because changes in soil characteristics are largely of interest due to their effects on vegetation, sampling of soil for determination of changes in chemical characteristics should be carried out at the experimental and control terrestrial-ecology monitoring plots. These plots are described in Sect. 2.2.1.3.1. Sampling locations should be selected randomly within plots, but rare, threatened, or endangered plants should be avoided.

REFERENCES FOR SECTION 2.1.1

1. C. A. Black et al., eds., *Methods of Soil Analysis*, American Society of Agronomy, Inc., Madison, Wis., 1965, pp. 922-23.
2. U.S. Salinity Laboratory Staff, *Diagnosis and Improvement of Saline and Alkali Soils*, U.S. Department of Agriculture Handbook 60, 1954.
3. S. I. Auerbach and D. A. Crossley, Jr., "A Sampling Device for Soil Microarthropods," *Acarologia* **3**, 279-87 (1960).

2.1.2 DESCRIPTION OF THE AQUATIC ENVIRONMENT

2.1.2.1 Purpose and Scope

To develop a complete characterization of the physical and chemical environment of aquatic systems potentially affected by construction and operation of a coal conversion demonstration plant may be one of the most difficult components of the baseline monitoring program. Characterization of the physical and chemical aspects of aquatic systems includes (1) description of the physical structure of the watershed and hydrologic system, (2) monitoring of the hydrology of surface waters and groundwater, and (3) monitoring of water quality. The physical structure of areas surrounding plant sites is relatively stable and relatively easy to characterize. Monitoring of hydrology and water quality, however, requires very careful parameter selection to ensure the collection of baseline data adequate for both predicting and documenting adverse impacts of plant construction and operation.

The baseline monitoring program for description of aquatic systems very probably will be developed before specific plant process effluents have been adequately characterized and before point and nonpoint discharge locations and quantities have been identified. A coal conversion demonstration plant may potentially release a large number of chemical species, both inorganic and organic, and analytical costs for monitoring such parameters can be considerable. Therefore, the selection of physical and chemical parameters to measure in aquatic systems is a crucial phase of design in developing a cost-effective program.

The monitoring program to describe baseline physical and chemical characteristics of aquatic systems developed in this section is assumed to begin one to two years prior to plant construction and to continue, with modification, through plant operation. We therefore address all general aspects of the monitoring program in this Part 2 of the handbook. The first year's monitoring effort will be used to develop the contractor's environmental report which will contribute to an environmental impact statement prepared by the Department of Energy. In the construction and operation sections (Parts 3 and 4) we suggest how the baseline program may be modified to address the specific goals of detection and possible mitigation of adverse environmental impacts.

This section of the handbook will provide guidance for characterization of the physiography of site watersheds and the hydrology and quality of surface water and groundwater. Characterization of watershed physiography will

1. provide information for predicting how the regional landscape affects water flow and water quality.
2. indicate the location of critical habitats requiring sampling and/or protection.
3. guide designers of the plant in making adjustments that will enhance environmental protection and safety.
4. provide the basis for determining if construction or operation of the plant causes alteration of the physical structure of the watershed.

Monitoring directed toward characterizing the hydrology of surface water and groundwater will

1. indicate the major routes of water movement and water flow.
2. provide measurements or estimates of the flow rates and location of groundwater regimes.
3. allow assessment of the adequacy of the water supply for the plant.
4. provide guidance in the location and construction of water intakes, supply wells, pipelines, storage piles, landfills, and waste treatment facilities.
5. provide the basis for determining how construction or operation of the plant alters the site or regional hydrology.

Water quality monitoring efforts are directed toward

1. determination of whether water quality conforms with existing criteria and/or standards.
2. providing information necessary for interpreting the structure and function of biological systems in aquatic habitats.
3. prediction, detection, and potential mitigation of adverse impacts of plant construction and operation on surface waters.

Due to the multipurpose nature of monitoring the physical and chemical characteristics of aquatic environments, there must be close coordination among engineers, hydrologists, water quality managers, and ecologists in the design and execution of the program. For instance, water quality cannot be determined entirely on the basis of physical and chemical parameters. The biota of aquatic ecosystems exert profound, often controlling, influence on water quality. Biological sampling often provides the most accurate indications of water quality, sometimes at lower cost than an exhaustive analysis of chemical constituents. The organization of this handbook suggests an artificial distinction between analysis of water quality and aquatic ecology. In reality, there must be close cooperation between ecologists and water quality personnel: Ecologists will use data on chemical constituents for their analysis, whereas data on structure and functioning of biological communities will complement chemical data for evaluating water quality.

Because of variability in the factors affecting water quality, the general suggestions for monitoring in the section that follows are not applicable to every site. In addition, the guidance provided is based on the following assumptions:

1. Consumptive use of water is expected to range from 2 to 7 cfs. However, the monitoring program described here would be applicable to consumptive use up to 15 cfs. This is based on a demonstration-size plant designed to produce 50 million scfd.
2. Groundwater monitoring will be a substantial component of the overall program. Providing water supply to the plant may substantially alter groundwater levels and flows. Coal storage, effluent handling, disposal of solid wastes, etc., may pose a substantial threat to groundwater quality. Monitoring efforts must be proportional to the potential threat to quantity and quality of groundwater.
3. There will be some aqueous discharge, even if the coal conversion plant is designed for "zero discharge." Such discharges may be indirect, accidental, or low volume, or may occur infrequently (e.g., during periods of heavy rains or flooding). However, these discharges may be important to aquatic biota, due to the possibility of greater concentration of substances in waste "slugs."

The planning and implementation of the monitoring efforts described in this section will be greatly facilitated if the efforts suggested in the checklist below are initiated early in the design of the program.

**Summary checklist for monitoring physical and chemical aspects of
aquatic environments**

1. Define the goals of the aquatic monitoring program.
2. Obtain surveys, reports, and studies used for site selection.

3. Map work:
 - a. Obtain topographical maps, navigational charts, and aerial photographs showing the plant site and surrounding region.
 - b. On a map showing the entire major watershed in which the site is located, outline the watershed's boundaries and identify the plant site.
 - c. Using the site plan and detailed maps, locate the probable sites of water intake, effluent discharge, and wastewater leaching to groundwater. Also, note points of access to be waterways.
4. Review pertinent literature in order to describe the watershed and physiography of the site and region.
5. Consult with USGS and local authorities to locate flow gauging stations. Obtain flow records for the stations within 25 miles of the plant site, including the 7-day, 10-year low flows.
6. Consult with local, state, and regional water resource agencies to obtain any extant inventories of water use and other information about water quality within the watershed. Also, obtain STORET water quality data for the parts of waterways near the plant.
7. From USGS or state geological agency, obtain literature describing groundwaters, aquifers, and regions of groundwater recharge and discharge. If groundwater is to be the water supply, construct a complete water budget for the watershed.
8. If groundwater studies have not been started for siting studies, select the sites for groundwater test wells. Let contracts for construction of test wells three to six months before the start of baseline monitoring so that the wells will be operational at the start of the program.
9. Make a tentative list of the hydrologic and water quality parameters to be monitored, including analytical methods to be used. Tentatively select sampling stations.
10. Make a reconnaissance:
 - a. Conduct dye studies; make aerial observations; determine flow patterns.
 - b. Measure flow rates, approximate physical dimensions of waterways, etc.
 - c. Observe waterways by boat, wading, or walking the banks.
 - d. Note location of various habitats.
 - e. Sample as needed to make final choice of stations, sampling methods, etc. Obtain estimates of the variability of parameters to be sampled.
11. Analyze available background and field data; evaluate any methods applicable to waterways and groundwater; make final choice of sampling stations and analytical methods.
12. Based on knowledge of the aquatic system, make preliminary judgments regarding the limits of detection for monitoring program:
 - a. Estimate how much change in a parameter constitutes an important change that should be measured.
 - b. Use estimates of parameter variability (together with professional judgment) to statistically determine sampling frequency required to observe these changes.
13. Install appropriate monitoring instruments and gauging apparatus; begin monitoring program.

2.1.2.2 Physiographic and Hydrologic Description

This section provides guidance to monitoring personnel in describing the physical structure of the aquatic environment. Such description provides the foundation for monitoring hydrology and water quality.

Descriptions of the physical environment are probably available in plant siting studies or in other regional studies. These descriptions should be evaluated.

2.1.2.2.1 Region and Watershed

The affected region and watershed(s) should be identified. Maps should be obtained on which (1) watershed(s) should be outlined and marked and (2) major channels, basins, and wetlands clearly identified. The underlying geology should be briefly described, including major geological features, strata, geochemistry, and soil types (Sect. 2.1.1). Regional terrain and major drainage patterns should be stressed. Measurements or estimates of the amount of vegetative cover in the watershed(s) should be made, major patterns of erosion should be described, and the erodibility of soils and bedrock should be characterized, especially as related to sediments and water chemistry.

2.1.2.2.2 Surface Waters

Information required to describe channels, basins, and wetlands will come from (1) maps and aerial photographs, (2) previous descriptive reports, (3) observations and measurements made during early reconnaissance, and (4) periodic observations made by personnel later on in the monitoring program.

Stream and river channels

Description of stream and river channels should emphasize the areas likely to receive the greatest impact. The sites of intake structures, effluent channels, site runoff areas, etc., should be described in greatest detail.

Descriptions of stream and river channels should include measurements of stream width, depth, and gradient. Maps should be used to present much information, including depth contours and contour of adjacent terrain. Special attention should be given to describing stream banks and floodplains, including the vegetative cover and stability of both. The size of floodplain areas should be estimated, and the height of stream banks should be noted.

Monitoring personnel should draw or obtain a diagram of the channel gradient. The composition of the streambed should be mapped and qualitatively described. The relative composition of various substrate types should be described. Attention should be given to the stability of the channel and substrate. Shifting-sand bottoms or stabilizing factors such as macrophyte beds should be noted. Hydrologically defined habitats (e.g., pools, riffles, embayments, backwaters, eddies) should be described and mapped, and the percentage of the aquatic environment in each category should be estimated.

Basins

Maps and discussion should characterize the morphology of the basin, including depth, surface area, and volume. Variation of water levels should be noted. Maps should show the shoreline at various water levels and also indicate the contour of the terrain of adjacent land and locations of influent and effluent streams. The stability of the shoreline and the erodibility of nearby land should be described.

Lake-bottom substrate and habitat should be described, including areas of emergent vegetation. A summary of the stratification and overturn patterns of the lake should be presented. Monitoring personnel should determine how often mixing occurs, approximately when, the maximum depth of the thermocline when stratified, and typical variations in the redox potential of hypolimnetic waters.

Wetlands

Wetlands and floodplain areas should be mapped and described, and the extent of such areas should be measured or estimated. The topography of floodplains should be well mapped. Soils, sediments, dominant vegetation types, and habitats should be characterized. Attention should be given to the extent and periodicity of flooding and drying of lowland areas.

2.1.2.3 Hydrological Monitoring of Surface Waters*2.1.2.3.1 Introduction*

The potential impacts of construction and operation of coal conversion plants on surface waters are numerous. Construction activities are likely to alter the landscape and the drainage characteristics of the site area, affecting surface runoff, infiltration, stream flow, erosion, sedimentation, and water levels. Plant operation may consume a critical amount of water, which will affect water availability for other users in the area. An adequate baseline monitoring program must provide sufficient data to assess the potential hydrological effects as well as providing data that will effectively complement the water quality and biological monitoring programs. It is important to stress that in order for the monitoring plan for surface waters to be useful and economically acceptable there must be close cooperation with the personnel preparing the monitoring plans for groundwater, water quality, and aquatic ecology.

The monitoring plan to be outlined is designed for demonstration-size coal conversion plants. These plants are forecast to have total water requirements of 2 to 7 cfs. The monitoring program described here would be applicable to consumptive use as high as 15 cfs and contaminated discharge as high as 5 cfs. The monitoring plan will consider the monitoring of rivers and regulated lakes. Other surface waters are not discussed due to the likelihood that only rivers and regulated lakes will be used by coal conversion plants. The plan includes a synoptic survey which should be performed to provide qualitative data about the surface water. These data can be used to assist in the proper siting of monitoring stations, in the establishment of useful sampling frequencies, and definition of the necessary scope of the monitoring effort. The synoptic survey is not to be construed as a replacement for the baseline monitoring program but as a preliminary survey prior to designing the baseline monitoring program.

The surface-water monitoring program should have as its fundamental features the monitoring of the flow characteristics, temperature characteristics, and erosion and sedimentation characteristics in the site region. Consideration should be given to both near- and far-field characteristics. The baseline monitoring program must provide information on the hydrological characteristics as well as the hydrological parameters required for other segments of the environmental monitoring program.

Monitoring of flow characteristics of surface waters is to be considered important if:

1. The intake flow rate exceeds 1% of the seven-day, once-in-ten-years low flow ($7Q_{10}$).
2. The intake velocity is greater than the annual average velocity of the water source.
3. An aqueous discharge is to be included in the design.
4. Critical aquatic habitats exist in the intake area.
5. Contamination of surface waters is possible.

Monitoring of the temperature characteristics of surface waters is to be considered important if:

1. A thermocline is present.
2. Sensitive aquatic species or habitats are present in the surface waters.
3. A discharge is included in the design.
4. Contamination of surface waters is possible.

The monitoring of erosion and sedimentation is considered important for all sites located near any surface waters.

2.1.2.3.2 Synoptic Survey

The synoptic survey of surface waters is intended to provide extensive and readily obtainable information that will describe the aquatic environment. The data collected can be used to provide qualitative guidelines for defining (1) the extent of the required hydrological monitoring effort, (2) appropriate sampling locations for hydrological monitoring, and (3) temporal variations of the hydrological data. The survey should be performed after reviewing historical information describing the surface waters and after consultation with the other personnel involved in the baseline monitoring program design. Historical records to be consulted regarding surface waters in the site region include STORET data, USGS records, Corps of Engineers reports, environmental impact statements of nearby projects, and local and state records. Federal agencies that maintain useful records are listed in Table 2.1.1. Such data provide information on trends in stream flow, temperature, and sedimentation. The review of historical information should be directed towards establishing the information itemized in Table 2.1.2. If low-flow figures are not available, a low-flow investigation can be made using techniques given in ref. 1.

With a knowledge of the historical trends associated with the surface waters, the synoptic survey can be divided into three study areas, namely, the intake, the site, and the discharge areas. Generally, these study areas will be geographically separate, but individual sites may be designed to allow a combination of the study effort.

The survey of the intake area requires two phases: reconnaissance and data collection. The intake study area should be examined for ephemeral creeks, runoff channels, groundwater seeps, visual characterization of the ambient currents, variations in water depth, quality, and temperature, and vegetative types. Close cooperation with groundwater, water quality, and aquatic ecology personnel can provide additional information for defining the best locations for data collection. Following the reconnaissance, a dye release study of the currents surrounding the intake site should be conducted. Techniques for the performance of a proper dye study are contained in refs. 2 and 3. The most commonly used dye is Rhodamine B. Use of a fluorometer allows determination of ambient currents and turbulent mixing in the surface water. The dye should be released upstream of the intake site, and measurements should be taken until the dye plume has passed the intake site area. A data survey of temperature variations in surface waters in the intake site area should also be performed. A boat survey that records temperature variations with depth allows an accurate portrait of the three-dimensional profile of the surface water. A special attempt should be made to identify any thermocline that might be present. In the boat survey, several locations should be investigated to provide a complete representation of the water transects, which should be chosen to provide a best reflection of the surface water in the study area. The final aspect of the intake synoptic survey should be to examine sediments in the intake site area. This analysis of substrate and suspended material must satisfy the needs of the aquatic ecologist as well as the hydrologist. The hydrologic needs

Table 2.1.1. Checklist of basic hydrologic data collected by the United States federal agencies

	Agricultural Research Service	Bureau of the Census	Coast and Geodetic Survey	Department of Commerce ^a	Corps of Engineers	Fish and Wildlife Service	Forest Service	Geological Survey	Department of the Interior ^b	International Boundary and Water Commission	Mississippi River Commission	Naval Observatory	Public Health Service	Bureau of Reclamation	Smithsonian Institution	Soil Conservation Service	Tennessee Valley Authority	Weather Bureau
Consumptive use	x						x	x						x		x	x	
Density currents					x			x						x		x	x	
Drought								x									x	x
Evaporation	x				x			x		x				x			x	x
Floods					x		x	x		x				x		x	x	x
Groundwater	x				x			x						x			x	
Humidity							x			x							x	x
Ice					x			x										x
Infiltration	x						x							x		x	x	
Interception							x										x	
Lysimeters	x						x									x	x	
Precipitation	x				x		x			x				x		x	x	x
Chemical quality of water								x		x				x	x		x	
River, lake, reservoir stages					x			x		x				x			x	x
Runoff	x				x		x	x									x	
Sedimentation																		
Suspended load	x				x			x		x				x		x		
Reservoir sedimentation	x				x		x	x						x		x	x	
Snow					x		x	x						x		x	x	x
Soil moisture	x															x	x	x
Solar radiation	x											x		x	x		x	x
Storms					x			x						x		x	x	x
Stream flow	x				x		x	x		x	x			x		x	x	
Air temperature							x			x	x						x	x
Soil temperature	x				x		x									x	x	x
Water temperature				x		x		x						x			x	
Tides			x		x			x										x
Water use and waste disposal																		
Drainage		x																
Industrial use		x		x					x				x				x	
Municipal use				x									x					
Sewage and waste disposal													x					
Wind	x				x		x			x							x	x
Experimental watersheds	x				x		x	x									x	

^a Agencies other than the Census Bureau, Coast and Geodetic Survey, and Weather Bureau (very few, special installations).^b Agencies other than the Fish and Wildlife Service, Geological Survey, and Bureau of Reclamation (very few, special installations).By permission from J. W. Dixon, "Water Resources, Part I. Planning and Development," Sect. 26-I in *Handbook of Applied Hydrology*, V. T. Chow, ed., McGraw-Hill, New York, 1964.

Table 2.1.2. Checklist of historic hydrological information

-
1.	Maximum flood stage
2.	Maximum stream discharge of record
3.	Minimum stream discharge of record
4.	Mean stream discharge
5.	Sediment transport-discharge relations
6.	Temperature variations
7.	Stage-discharge relation or reservoir rule curves
8.	Water quality variations
9.	Watershed characteristics
10.	Major water projects and effects on hydrology
11.	Low-flow investigations
-

require at least a description of the sediment discharge with respect to size analysis and quantity of sediment. Techniques for performing this aspect of the synoptic survey are contained in ref. 4. An analysis of the suspended load and the bed load at a representative site should receive the primary emphasis. Distribution of the depositional material surrounding the immediate intake site should also be determined. The sediment survey should be done as closely as possible to the dye study to allow an interpretation of the sediment results with respect to the stream discharge.

The synoptic survey in the plant site area need only include a reconnaissance similar to the one performed at the intake site area. In specific cases, a sedimentation study may be necessary to best identify the nature of the baseline sedimentation monitoring program. Generally, however, this should not be needed. If a sediment survey proves necessary, one similar to the survey performed at the intake site area is recommended.

The synoptic survey in the discharge site area should be similar to the survey in the intake site area. The reconnaissance should be identical to the intake survey. The dye release study, however, should have the dye released at the location of the proposed discharge with measurements made downstream from the discharge site. Special attention should be given to identifying the size of the dye plume as it moves downstream, especially if it comes in contact with the banks or any backwater areas associated with aquatic habitats. Determination of the dispersion of the plume may be accomplished best by the use of aerial photography. Estimates of dye diffusivity should be made from the data obtained. The boat survey of the temperature characteristics and the sediment measurements should be identical to that of the intake study program.

The results of the synoptic survey should be presented in a written report. The presentation should be concise and prepared so that the information gathered can be used in the final design of the baseline monitoring program.

2.1.2.3.3 Flow Characteristics

It is necessary to understand the flow characteristics of surface waters in order to determine alterations in circulation due to plant construction and operation, transport of contaminants, transport of suspended material, and heat transfer. Information obtained from the synoptic survey will be instrumental in determining the extent to which monitoring will be necessary at the intake and discharge locations. At the plant site, flow characteristics should be monitored to the extent of being able to determine the dispersion of plant site runoff or of accidental releases that might be introduced into neighboring surface waters. The monitoring program described can be applied to determine the flow characteristics of the intake, plant, or discharge site. It is important to emphasize

that no monitoring plan can be considered complete until site-specific factors that would influence the nature of the monitoring effort have been considered. A partial list of site-specific factors might include irregular stream flows due to human intervention, critical aquatic habitats, regulatory control of stream flow, and interactive effects with other industrial or municipal facilities. These and other factors would all warrant additions to the monitoring program to satisfy site-specific problems. Consultation with all parties concerned and a careful review of the synoptic survey are the most useful means for identifying the site-specific problems that would require additional consideration.

The physical parameters necessary to define the flow characteristics of surface water are velocity, geometry, and density variations in time and space. Determination of these parameters and the extent to which they are monitored depends on the type of water body being considered.

Rivers

Rivers and streams are characterized as being turbulent channels where density effects are not likely to influence the hydrological characteristics, except in cases where there are industrial discharges. Industrial discharges may produce a heated surface layer (power plant discharge) or a sinking plume of high density (chemical plant discharge). The presence of these discharges is regarded as a site-specific problem for the purposes of this discussion.⁵ The monitoring of river flow characteristics in the area of a proposed study location (intake, discharge, plant site) should typify the river currents near the study site and the currents upstream and downstream of the study site (Fig. 2.1.1). An ideal monitoring location would permit the simultaneous determination of the water level and the discharge at an ecological sampling site. The siting of gauging stations, however, often makes this impossible. A good site for the placement of a gauging station should satisfy the following:

1. The channel should be stable so that shifts in the stage-discharge relation are not likely to occur.
2. The stream flow should be naturally controlled or should allow artificial control in order to stabilize the stage-discharge relation.
3. Minimal backwater effects; if no such site is available, additional gauging will be necessary.
4. Access to a cross section for good discharge measurements.
5. Stage gauge properly placed with respect to discharge measurement.
6. Suitability for high discharge measurement.
7. Site accessibility, especially during flooding.

Siting of monitoring stations should be done in consideration of these needs as well as those of the water quality, aquatic ecology, and groundwater programs. Further guidance in site location is provided in refs. 6 through 8. Note that small streams will require less detailed monitoring than rivers.

Once the appropriate monitoring locations have been established, measurements of the water level are best made using a water-stage recorder. If a continuous water-stage recorder with a tape readout is used, it can be interfaced easily with digital data-processing equipment. If the monitoring station is ideally located, the only additional monitoring will be the periodic determination of the discharge. If the monitoring site is lacking in some respects, measurements of the slope, rate of change of stage, and changes in bottom topography, channel width, and sediment load may be necessary.

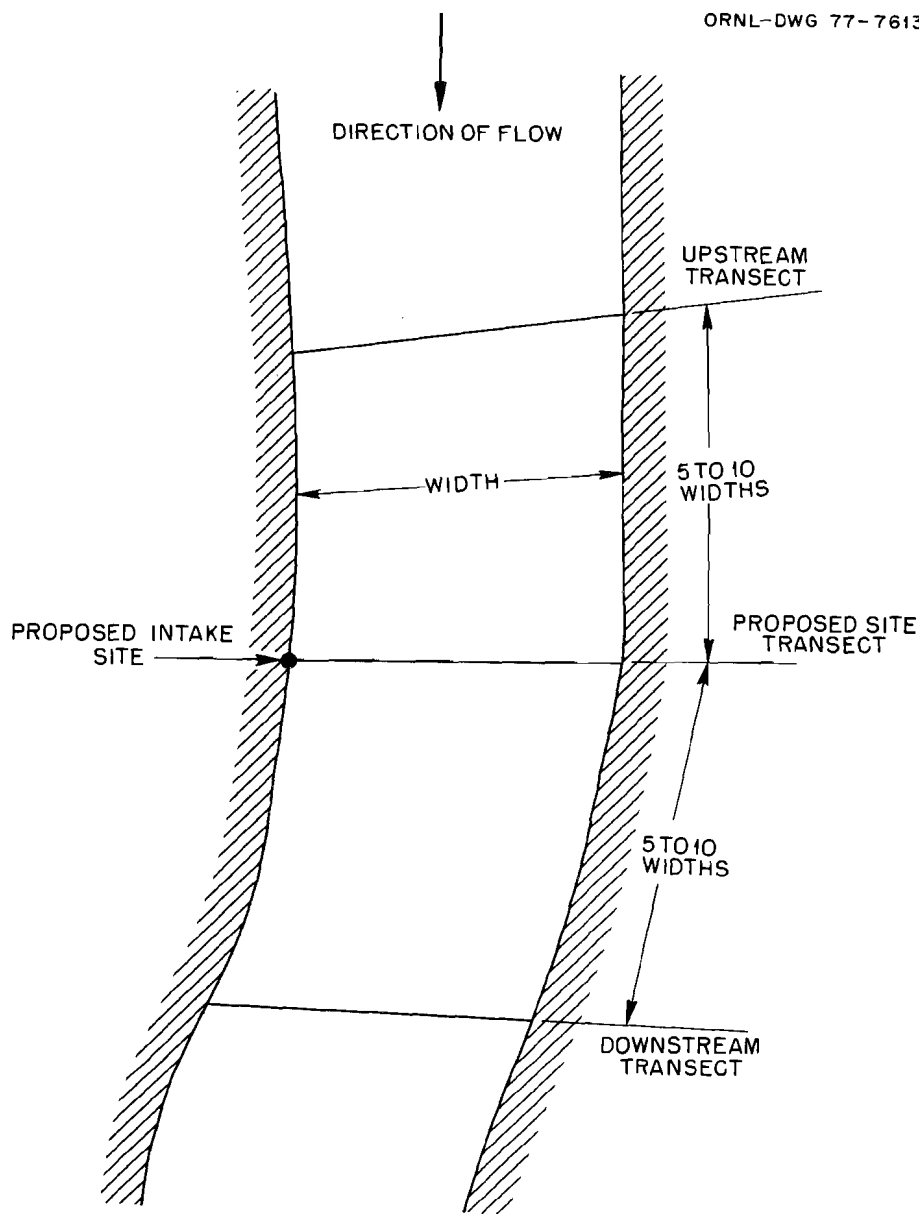


Fig. 2.1.1. Current sampling transects for a river-bank intake.

The proper technique for measurement of discharge is highly dependent on the size of the river. The appropriate method for use at a specific site should be made in consultation with USGS techniques outlined in refs. 6, 8, 9, and 10. In the general case, discharge is determined using a Price current meter to measure the average speed at each vertical sampling location along a transect. The speed is then multiplied by the cross-sectional area of the location's water column. The summation over all the sampling locations of the transect provides the total discharge. The water depths of the transect are measured using a wading rod, cable and weight, or a fathometer. Measurements are made often enough to generate a stage-discharge relation. This relation, once obtained, allows determination of the discharge when only the water stage is known.

Evaluation of stream flow alone does not permit determination of the flushing of backwater areas or becalmed pools. Determination of local circulation patterns in specific regions of a river requires a site-specific investigation to identify the best method for monitoring. Formulation of the discharge site monitoring program will require that the size of the plume from the synoptic survey be carefully considered. The downstream transect should be far enough away from the site to represent the far-field plume characteristics. This transect becomes crucially important when a plant starts operation.

Data obtained during the monitoring program should be used to validate and complement the data obtained during the synoptic survey (Table 2.1.2). Baseline data collected at the intake site should be used to verify that an adequate supply of water is available during low flow. This verification should be based on a flow-duration curve, regulatory restrictions, and water-use requirements downstream of the intake site. Other data analyses that should be performed include stream hydrographs, stage-discharge shifts during the annual water year, and comparison of the monitoring data with nearby USGS station records.

Data collected and analyzed can then be used to simulate plant construction and operational impacts on surface waters. Currently, there are several working computer codes for intake structures,⁵ and research is continuing to make advances in simulation. For accurate results, these simulations require well-specified initial conditions. Thus, the initial conditions supplied by the monitoring program become the essential data for accurate predictions of environmental impacts.

Regulated lakes

Regulated lakes tend to develop circulation patterns and tend to stratify in temperature. The circulation patterns of a typical regulated lake result from a flow that enters from various confluent streams. The flow tends to follow the path that the water followed prior to regulation. The additional embayment water forms calm areas and backwater regions that are flushed by wind-driven currents. The water tends to form a temperature gradient that is reflected in a density gradient. Consequently, much of the circulation in regulated lakes results from wind-driven currents and internal waves. Where intakes or discharges are situated on regulated lakes, circulation may be significantly disturbed by small withdrawal velocities. If the synoptic survey or other parts of the monitoring program require monitoring of lake currents it will be necessary to determine the lake bathymetry, velocities, and directions. For some cases, determination of velocities and directions at various depths may be necessary. Flow characteristics of lakes should be measured radially about the study area under consideration (Fig. 2.1.2). Current studies should be performed often enough to describe the variations in circulation over the year.

Depth measurements can be made using the same methods used for rivers, but measurements of current velocities and directions have to be based on current magnitudes, water depth, and the degree of monitoring required for a specific site. (Some instrumentation used for these purposes is outlined in ref. 5.) The most common current monitoring methods use shrouded propellers or drogues. It should be emphasized that drogue data are useful only if a statistically significant number of drogues are released. Detailed dye or tracer studies may be the best alternative for some sites. In some instances, the use of the moving-boat method developed by USGS¹¹ will provide accurate data and involve less labor. All lake current measurements should include measurements of surface wind speed and direction during the testing period.

In addition to measured monitoring data, data from the lake regulating agency should be obtained. These data should include temporal variations in water level, dam discharge, flow into the lake by confluent streams, reservoir water use, and evaporation estimates.

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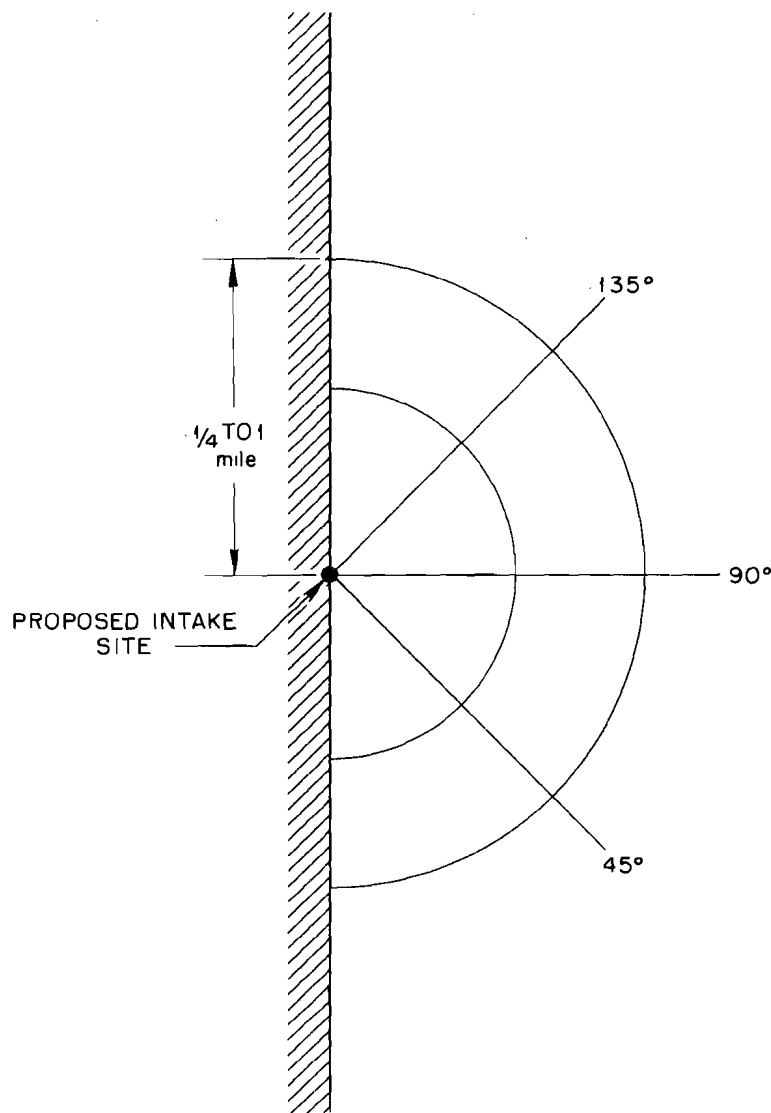


Fig. 2.1.2. Current sampling grid for a regulated lake with a shoreline intake.

Measured data should be used to determine the sensitivity of lake circulation to water levels and wind. Such determinations can be used in lake circulation models to simulate the impact of plant operation on the lake's flow characteristics. Variations in density caused by a thermal gradient will be significant in any lake simulation study. For an accurate analysis, accurate data representing velocities and directions are absolutely necessary.

2.1.2.3.4 Thermal Characteristics

Monitoring of the thermal characteristics of surface water depends on the results of the synoptic survey. If historical or measured data show that a thermocline exists, the monitoring program must be extensive enough to define the motion and formation of the thermocline. In addition to monitoring thermocline motion, the program should strive towards measuring the ambient thermal

characteristics of the surface waters. An accurate baseline monitoring of temperature is necessary to analyze the environmental impacts of the coal conversion plant on water quality, aquatic ecology, and hydrology. The physical and chemical properties that are temperature dependent and the environmental roles they play are described in refs. 12 and 13. As with stream-flow measurement, the techniques used for temperature monitoring of rivers differ from those used for regulated lakes.

Rivers

Rivers are generally turbulent. As a result of turbulence the temperature profile is uniform with depth except for sloughs and backwater areas. Temperatures do vary along any transect. The amount of variation depends on the source of supply (groundwater, snow, precipitation, runoff), the amount of incident radiation, and the energy loss (evaporation, convection, conduction, radiation). A major source of downstream variation in temperature is due to inflow of nearby upstream tributaries.

Temperature measurements in rivers can be made by numerous techniques.^{5,14} The most common technique uses a continuous thermograph with a magnetic tape recorder making hourly readings. These instruments need periodic calibration checks to ensure accuracy.

Selection of the thermal monitoring site should take into consideration the results of the synoptic survey, the needs of other aspects of the monitoring program, and the placement of current monitoring stations. The temperature monitoring transects should be located where the river water has been well mixed by diffusion from upstream influences. Sites should be located upstream and downstream of the study area (Fig. 2.1.3), in addition to one location at the site. Initial data should be taken from the grid points shown in Fig. 2.1.3. Should the data show that there is little variation in temperature along the transect, the number of sampling locations could be reduced. However, one detailed transect should be made during the late summer to ascertain any thermocline that might develop. Vertical profiles do not need to be considered unless a thermocline is noted. In the event of a temperature gradient of more than 3°C, detailed observations along the vertical axis should be made. Additional monitoring locations will be necessary if suitable ones cannot be established. Detailed procedures for sensor placement are contained in ref. 5.

Lakes

Temperature monitoring in lakes is much more difficult than in rivers. Large littoral areas or deep regions will generate large areal and vertical variations in temperature. Withdrawals from and discharges to lakes are, therefore, capable of causing serious impacts to the system. For lakes, surface and depth measurements are needed; the number of required sampling points for depth are determined by the synoptic survey, needs of other aspects of the monitoring program, and the nature of the lake's structure.

Temperature measurements on regulated lakes can be made with the same instrumentation used for rivers. The location of sampling stations, however, is more difficult to determine. A suggested grid for a uniform lake is shown in Fig. 2.1.4. Site-specific conditions (inflow-outflow patterns, unusual bathymetry, inflowing tributaries, large littoral zones) would, of course, modify this grid. When depth measurements are necessary, a sufficient number of monitoring locations should be established in the vertical to portray the thermocline to within 1°C. It is important that the calibration of the thermographs be periodically checked.

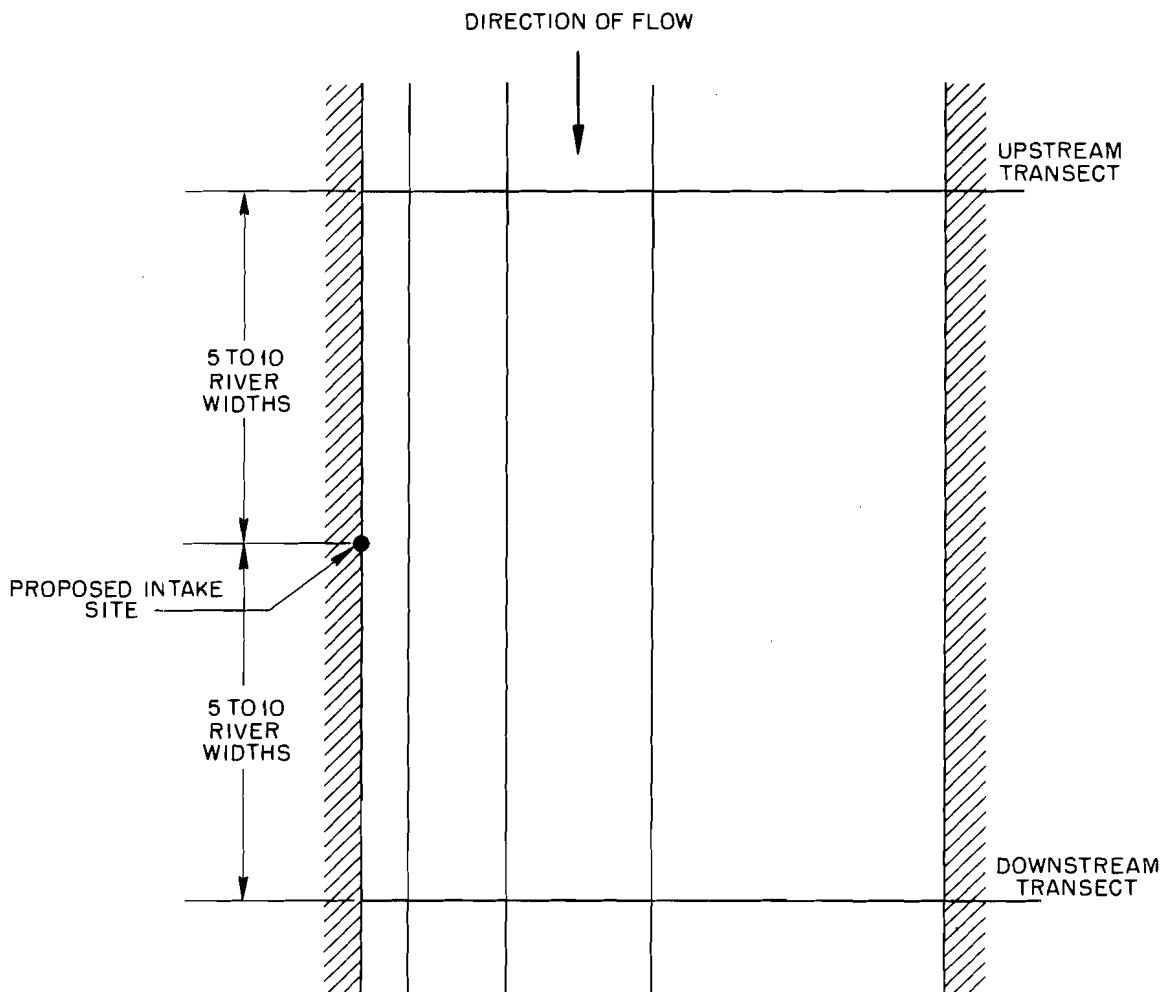


Fig. 2.1.3. Temperature sampling grid for a river-bank intake.

For unevenly heated lakes, it may be necessary to measure the sediment temperature profile. Probes with thermistors attached are used for this purpose. Sediment temperature does not change as quickly as water temperature and so need not be monitored as often.

Measurements of water and air temperature, wind direction and speed, and relative humidity are necessary for proper interpretation of data. In density-stratified lakes, there is always the possibility of sinking effluent plumes and selective withdrawal of water. Special care should be taken in measuring temperature so that adequate information to predict and prevent such undesirable phenomena is provided.

Data analysis

Historical data should be compared with monitoring data to determine the nature and significance of the monitoring year's data. The important historical data are the records of ambient water temperature, from which the maximum, minimum, and mean can be determined.

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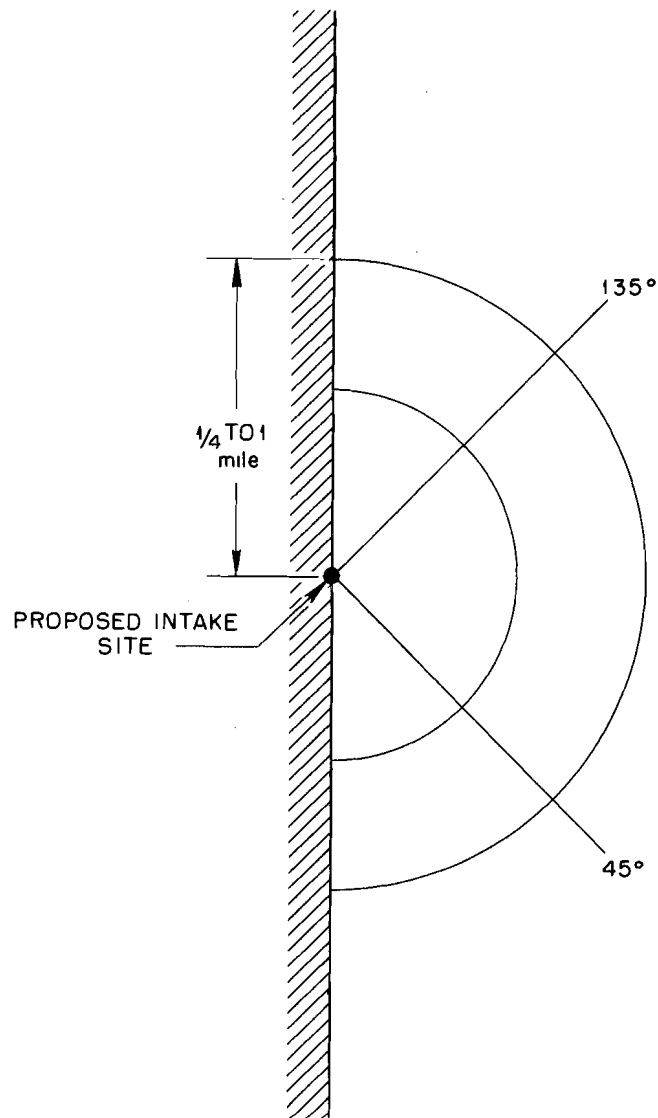


Fig. 2.1.4. Temperature sampling grid for a regulated lake with shoreline intake.

Monitoring data for various depths should be analyzed to determine thermal structure changes in the water. Presentations of the motion and depth of the thermocline should be made. Monitoring data should be compared with available historical data to determine any anomalous conditions.

Modeling

As mentioned previously, a temperature variation in a fluid generates a density variation. Some models for intake analysis include the temperature effects in the density.⁵ There is an intake computer code that can handle this density variation for the case of a submerged offshore intake with axisymmetric flow. The model, which is useful for regulated lakes with offshore intakes, also includes the effects of bottom drag and viscosity. Research is proceeding on the development of a

computer code to handle a shoreline intake. These codes provide a purely numerical solution to the equations of motion and require well-specified boundary conditions. Consequently, the validity of the results depends on the quality of the baseline monitoring data.

The utility of the temperature monitoring data is extended beyond a dynamic physical model. The baseline monitoring data are used to provide baseline information regarding the aquatic environment. For the purposes of an aquatic study, special emphasis is placed on the location and motion of the thermocline.

2.1.2.3.5 Erosion and Sedimentation

Of the many aspects associated with hydrological monitoring, erosion and sedimentation are certain to be of major importance in the design of the surface-water monitoring program. Since erosion and sedimentation have potentially major environmental impacts, a review of these impacts is included with recommendations for the monitoring program design. Sedimentation plays a key role in the aquatic environment, so it is important that the conceptualization and the design of the erosion and sedimentation monitoring program be performed in close consultation with aquatic ecology and water quality personnel.

Erosion and sedimentation can be considered potential problems at coal conversion plants if a reconnaissance of the site area reveals

- sensitive aquatic habitats
- turbid waters
- close proximity to reservoirs or navigation projects
- fine-grained soils
- extensive nearby agriculture
- difficulty in containing runoff

Since this list encompasses nearly every prospective site without the consideration of site-specific problems, the inclusion of a well-designed program for monitoring erosion and sedimentation is necessary. Potential impacts to streams or rivers resulting from erosion and sedimentation are difficult to define completely. Increases in sedimentation threaten existing aquatic habitats and present the possibility of exceeding the carrying capacity of the stream. Should the carrying capacity of the stream be exceeded, the streambed could become unstable. Increased sedimentation can fill navigation channels far downstream or decrease the utility of reservoirs. Reservoirs subjected to increased sediment loads commonly experience aggradation at the head of the reservoir and degradation in the tailwaters, and the reservoir itself is filled with depositional material. With increased sedimentation, some increases in turbidity are certain to occur. The sediment itself presents a medium for the transport and accumulation of contaminants and can seal a stream previously functioning as groundwater recharge. The resultant changes in watershed drainage characteristics often have secondary impacts on aesthetics and water-related recreation. This partial list of potential impacts should underscore the need for a well-designed monitoring plan for erosion and sedimentation.

An effective erosion and sedimentation monitoring program should have as its objective the monitoring of the temporal and spatial variation of suspended sediment, bed material, and erosion. The data needs that should be satisfied are:

1. Evaluation of sediment yield with respect to the different types of land use.
2. Time distribution of sediment concentration and transport rate in streams.

3. Evaluation of erosion and deposition.
4. Characteristics of sediment deposits as related to particle size, flow conditions, and chemical composition.

These data needs are met by the establishment of one of three different types of monitoring stations:

1. Continuous or daily record stations that measure suspended-sediment samples on a daily basis.
2. Partial-record station which only monitors during selected periods (high flows).
3. Periodic sampling station which monitors sediment periodically (once every two weeks or once every month).

For most cases, a partial-record station is appropriate. At a typical partial-record station, sediment sampling is sparse during periods of low flow. During high flows, sampling is regular to intensive. The proper selection of sampling station type depends on the surface water being studied and the historical data that is available. Guidance for the selection of the appropriate station type for a specific application is given in refs. 10 and 15.

A sampling station site should be near a gauging site. This site should be considered first because of the obvious relation between sediment discharge and stream flow. If the gauging site is inappropriate for sediment sampling, due to heavy inflows of sediment nearby, then a second desirable site might be an aquatic ecology sampling area with a water-level gauge added to the sampling plan. The addition of a water-level gauge would permit the necessary interpretation of gauging data from the closest gauging station. Further assistance in locating the sediment sampling site is contained in ref. 16. There should be at least one station upstream and one downstream of the plant site. If the intake possibly could introduce any sediment problems, there should similarly be one upstream and one downstream station added for intake monitoring. For discharges that could introduce sediment increases, upstream and downstream monitoring should be conducted.

Once the site for sampling and the type of station records to be collected have been determined, the data collection equipment, techniques for sample collection, and the extensiveness of monitored data can be specified. For each sampling station, records of the suspended sediment and the bed-load sediment should be determined, along with measurements of water temperature and stage. The number of verticals at which measurements of suspended load and bed load should be made requires a detailed examination of the scope of the monitoring effort. The determination of the number of verticals to sample at each site can be aided by consulting ref. 16. The equipment used for measurement may be (1) point samplers, (2) depth-integrating samplers, or (3) bed-material samplers. Several different models of each type are available for different applications (differences in suspension, weight, maximum sampling depth). A complete discussion of the various types of equipment is available in refs. 16 and 17 or from the Federal Inter-Agency Sedimentation Project.¹⁸ Equipment selection is generally based on water depth and velocity. Specific methods and equipment depend on site-specific information. During sampling, the amount of material to be collected depends on the types of analyses to be performed.¹⁹ Suspended sediment may be collected by the equal discharge increment (EDI) method or the equal transit rate (ETR) method. In the EDI method, in which samples are obtained at the centroids of equal discharge increments, sampling is less expensive and is limited to stable channels where discharge is rather uniform over the water year. The ETR method requires a sample volume proportional to the flow at each sampled vertical. It is important to note that sediment sampling is subject to significant data scatter. Attention to a statistically representative number of samples is required. With less than three samples, the statistical validity of results should be examined. For results that show great deviation, the number of samples must be increased to afford confidence in the results.

Bed-load sampling is performed with the consideration of issues similar to those concerning suspended-sediment sampling. Specific problems are explained in ref. 18. The chemical composition of the bed material should be determined at least once for the parameters listed in Sect. 2.1.2.4, following the recommendations outlined in Sect. 2.2.2. The addition of bed load and suspended load determines total sediment load. For total sediment load to be meaningful, the following data are essential at the same sampling transect:¹⁸

1. Stream width, average depth, mean velocity.
2. Average concentration of suspended sediment from depth-integrated samples.
3. Size analyses of the suspended sediment included in the average concentration.
4. Size analysis of the bed material.
5. Chemical composition of the bed material.
6. Water temperature.

Determination of the sediment characteristics permits the data to be used in predicting erosion, the time variation of sediments, and the anticipated environmental impacts. Determination of erosion can be made directly by comparing upstream and downstream data at the plant site or by predictive methods. Often, both techniques are used. The temporal variation of sediment characteristics is determined from the data using techniques given in ref. 18. Environmental impacts are then assessed by using the combined results of the aquatic ecology, water quality, and sediment monitoring programs.

2.1.2.4 Surface Water Quality Monitoring

2.1.2.4.1 Introduction

Monitoring initiated in the baseline (preconstruction) program is designed to characterize existing conditions in aquatic systems near the plant site with respect to both routine water quality parameters and ambient levels of chemical species potentially related to construction or operation of the plant. The first year's effort in this program will form a part of the contractor's environmental report submitted to DOE. The program should continue during the second year to the initiation of construction activities, and this, together with the first-year effort, can form the baseline water quality characterization upon which impacts of construction and operation can be determined, minimized, and/or mitigated. We emphasize strongly that the surface water quality monitoring effort should be coordinated with monitoring of aquatic ecological systems (Sect. 2.2.2), hydrological monitoring of surface waters (Sect. 2.1.2.3), and hydrological monitoring of groundwater and groundwater quality (Sect. 2.1.2.5).

The baseline (preconstruction) surface water quality monitoring program should be designed largely on the basis of potential impact on aquatic systems. A limited number of routine parameters are necessary inclusions due to their importance in interpreting ecological monitoring information.

Activities at coal conversion plants may affect water quality both directly and indirectly. Table 2.1.3 identifies some of the direct impacts. The indirect impacts result from effects on aquatic biota and changes in the aquatic ecosystems; these are summarized in Fig. 2.1.5 and considered in detail in Sect. 2.2.2.

There are three basic steps in designing a sampling program for water quality: (1) determining which parameters to measure, (2) determining frequency of sampling, and (3) selecting sampling

Table 2.1.3. Potential impacts of coal conversion: water quality implications

Perturbations	Effects on water quality
Construction activities	
Erosion	Increased suspended and dissolved solids
Heavy equipment operation	Releases of oil and grease
Land-use changes	
Clearing land	Runoff will resemble rainwater due to lack of filtration by vegetation and topsoil; runoff will have altered pH, higher concentrations of trace elements
Paving land	More runoff, more rapid runoff; reduced infiltration
Water use	
Drawdown of reservoir	Reduction of surface area; lowering of dissolved oxygen; increased dissolved solids
Reduced flow of river or stream	Reduction of surface area; lowering of dissolved oxygen
Alteration of groundwater flows and levels	Changes in thermal regime; increased dissolved solids
Scouring and silting near intake	Increased suspended solids
Impingement and entrainment of organisms	Increased organic loading (BOD), lowered DO
Chemical discharges ^a	Changes in concentration of various chemicals; various water quality effects

^aSee text.

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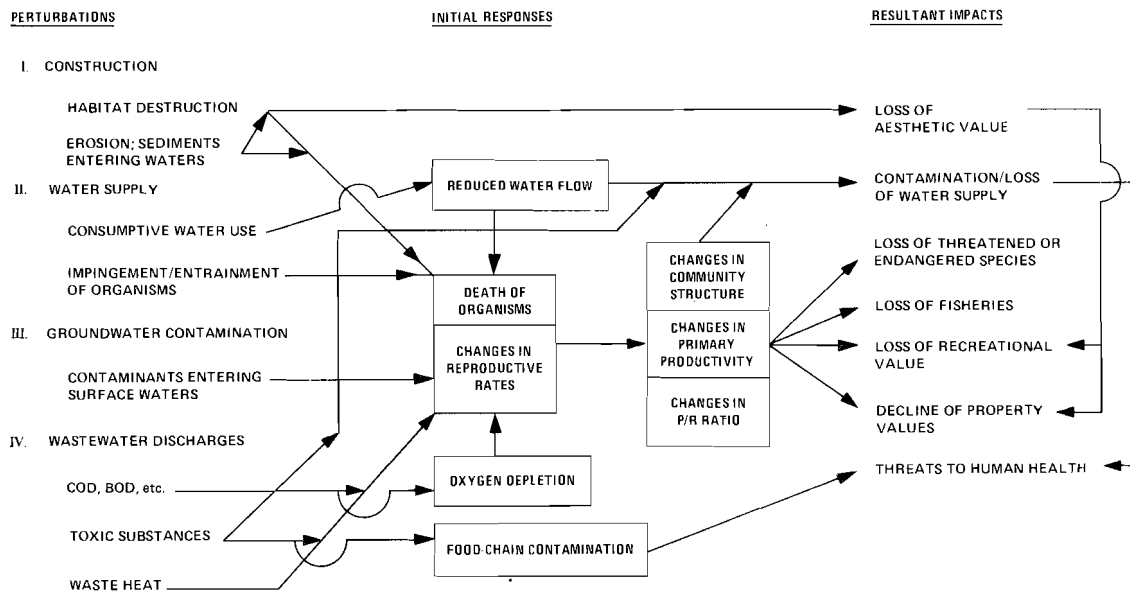


Fig. 2.1.5. Potential impacts on the aquatic environment from coal conversion plants.

locations. The selection of parameters to measure is complicated by incomplete information on the constituents of potential plant effluents. Without this information, we must select parameters that initially represent our best current understanding of effluent characteristics. These parameters should be reevaluated continually as real effluent and plant design characteristics become available.

2.1.2.4.2 Parameter Selection

Thermal components and erosion-sedimentation-related aspects of the baseline program are addressed in Sects. 2.1.2.3.4 and 2.1.2.3.5 respectively. This section addresses all other surface water quality parameters.

Monitoring programs should measure concentrations of any unusual substances in water or substances that exert a controlling influence on background water quality. The geology, hydrology, and biology of the region will influence which water quality constituents are present. In addition, waste loadings from agricultural, industrial, and municipal effluents will affect background water quality.

The designers of a monitoring program should be acquainted with the features of the plant site and region. As indicated in the summary checklist (Sect. 2.1.2.1), monitoring personnel should first review literature on the region and consider the information available from the preliminary site survey. In addition, information regarding water quality and use should be collected. Local authorities and regional water resource agencies should be consulted. An inventory of water uses and waste loadings should be made if it is not already available. (Sect. 2.3.3.4.9).

Some regional and site characteristics that affect the choice of parameters are:

1. In arid zones there is a greater need for data regarding dissolved and suspended solids, especially if irrigation and agricultural use are important.
2. If a facility is located downstream from population centers or industry, monitoring should include background levels of constituents from sewage effluents or industrial wastewater.
3. If the coal conversion plant is near preexisting mining operations, sensitive measurement of pH, sulfate, heavy metals, suspended solids, and other constituents will be required to enable analysts to later distinguish between effects of plant operation and acid mine drainage.²⁰ (If the plant is cosited with a mine, an integrated monitoring program should be designed for both facilities.)

The discussion and recommendations on surface water quality parameters to be measured in the baseline program are separated into inorganic parameters, organic parameters, and related water quality parameters. It is not now possible to specify completely which inorganic and organic parameters it may be necessary to monitor because the selection may vary according to the characteristics of the feed coal, conversion process used, waste treatment efficiencies, and existing site-specific water quality.

Inorganic parameters

Coal may contain measurable quantities of about 50 elements. It is unrealistic to suggest that water quality monitoring address all these elements. However, 30 elements were measured in the filtered aqueous process streams of one coal conversion pilot plant;²¹ these elements, listed in Table 2.1.4, are a first approximation of the number of inorganic elements which may need to be included in the baseline surface water quality monitoring program.

The elements listed in Table 2.1.4, if released in sufficient quantities, may be toxic to aquatic biota or may present a threat to human health if, through the aquatic food chain, the edible

Table 2.1.4. Elements detected in measurable quantities in filtered aqueous process streams from coal conversion plants

Aluminum ^a - C, ^b S ^c	Magnesium ^a - C, S
Arsenic ^a - C, S	Manganese ^a - C, S
Boron ^a - C, S	Molybdenum - C
Barium - C	Nickel ^a - C, S
Beryllium - C	Lead ^a - C, S
Bismuth ^a - C	Rubidium - C
Bromine - C	Antimony - C
Cadmium ^a - C	Selenium ^a - C, S
Cobalt ^a - C	Tin ^a - C
Chromium ^a - C, S	Strontium - S
Copper ^a - C, S	Titanium ^a - C, S
Iron ^a - C, S	Uranium - C
Gallium - S	Vanadium - C, S
Germanium ^a - C, S	Tungsten - C
Mercury ^a - C	Zinc ^a - C, S
Lanthanum - C	Zirconium - C

^aElement estimated to have potentially adverse impact on aquatic systems.

^bElement found in COED effluent.

^cElement found in aqueous effluent from scrubber of 1/2 ton/day Synthoil process development unit.

Sources:

1. S. G. Hildebrand, R. M. Cushman, and J. A. Carter, "The Potential Toxicity and Bioaccumulation in Aquatic Systems of Trace Elements Present in Aqueous Coal Conversion Effluents," pp. 305-13 in *Trace Substances in Environmental Health—X. A Symposium*, D. Hemphill, ed., University of Missouri, Columbia, 1976.

2. R. G. Lett et al., *Screening for Hazardous Elements and Compounds in Process Streams of the 1/2 ton per day Synthoil Process Development Unit*, PERC/R1-77/12, Pittsburgh Energy Research Center, ERDA, October 1977.

organisms are contaminated. It is, therefore, important to determine the ambient levels of these elements in site aquatic systems as an initial step in determining potential impacts on aquatic systems, especially for the preparation of an environmental impact statement. Predictions of potential impacts prior to construction of a plant must take into account both ambient levels of contaminants and levels of anticipated releases. Without specific process effluent information, we recommend that, for any coal conversion plant, these 30 elements be measured in the surface water quality baseline program. However, we emphasize to users of this handbook the desirability of a thorough evaluation of the element list prior to implementation of a site-specific baseline program. It is very probable that the list can be reduced based on information regarding the specific site and process. For instance, the list of trace elements might be modified through knowledge of the trace element content of feed coal or the attenuation capacity of soils at the solid waste disposal site.²²

Organic compounds

Untreated coal conversion aqueous effluents will contain a broad spectrum of organic compounds produced during hydrogenation, gas quenching, and scrubbing²³ which could be accidentally released. Discharged aqueous effluents may still contain traces of organics after treatment. Solid waste and coal handling procedures may also release aqueous contaminants to the environment. The potential number

of organic compounds is extensive. During the baseline program the first level of attack should be aimed at monitoring the major classes of organic compounds to provide an indication of ambient levels in aquatic systems. Table 2.1.5 lists the classes of organic compounds to consider for inclusion in the surface water monitoring program based on an analysis of potential environmental consequences of a release of organic contaminants from aqueous coal conversion effluents.²³ As with the inorganic elements, this list may be incomplete. A limited effort directed toward determining ambient levels of these major classes of organic compounds is necessary during the early phase of baseline monitoring. At the least, monitoring should include determination of total phenols, total PAH, and total thiophenes. If there are substantial loadings of these or other fractions, profiles of molecular weights should be obtained. During the later phase of the baseline program, prior to construction, baseline analyses should be directed to a survey of all organic compounds present and not limited by any prescribed list. Those chemicals known or expected to be released from the plant should be given greater quantitative attention.

Table 2.1.5. Classes of organic compounds to consider in surface water quality monitoring program

Phenols
 Arylamines
 Aliphatic hydrocarbons
 Mono- and polycyclic aromatic hydrocarbons
 Sulfur compounds (thiophenes, mercaptans)
 Chlororganics and chloramines^a

^aIt is desirable to measure these if chlorination is used in treatment of supply water or wastewater for the plant.

Other water quality parameters

In addition to the inorganic and organic parameters mentioned previously, the parameters listed in Table 2.1.6 should also be included in the baseline water quality monitoring program. The frequencies should be adapted to unique site- and process-specific conditions. Cyanides, fluorides, and ammonia are potential constituents of waste streams. Total organic carbon, dissolved organic carbon, chemical oxygen demand, and biological oxygen demand are good gross indicators of water quality which will serve as a crude benchmark for potential contaminants released by plant operation. Measurements of oil and grease and total suspended solids will serve as a baseline for detecting construction-related impacts on aquatic systems. The other parameters listed in Table 2.1.6 provide chemical characterization which may be useful in interpreting structure and function of aquatic biological systems.

The Federal Water Pollution Control Act Amendment of 1972 regulates the discharge of wastewaters from point sources. Point sources include pipes, sewers, storm-water drains, and virtually any conduit that conveys liquids into a body of surface water. Public Law 92-500 establishes a National Pollution Discharge Elimination System (NPDES), effluent limitations, and new source performance standards. The NPDES requires that industries and municipalities secure a permit for each point-source discharge. The NPDES permits define effluent limitations, or restrictions, on the quantities of pollutants that can be released. NPDES permits may also require monitoring of discharges and submission of periodic reports to control agencies.

Table 2.1.6. Recommended parameters and sampling frequencies for surface water quality baseline monitoring

Parameter	Frequency
pH ^a	Monthly and measure over a 24-hr period once quarterly
Total dissolved solids ^a	Monthly and measure over a 24-hr period once quarterly
Dissolved oxygen ^a	Monthly and measure over a 24-hr period once quarterly
Biological oxygen demand	Monthly
Chemical oxygen demand	Monthly
Total organic carbon	Monthly
Dissolved organic carbon	Monthly
Total suspended solids	Monthly
Alkalinity	Monthly
Oil and grease	Monthly
Total phosphorous	Monthly
Total Nitrogen	Monthly
Ammonia	Monthly
Total residual chlorine	Monthly
Flourides	Monthly
Cyanide	Monthly
Inorganic elements ^b	Once during low flow in first year; quarterly in succeeding years to onset of construction
Organic compounds ^c	Once during low flow in first year; quarterly in succeeding years to onset of construction

^aSee text.

^bSee Table 2.1.4 and text.

^cSee Table 2.1.5 and text.

The effluent limitations are based on effluent limitation guidelines or new source performance standards developed by the EPA. Effluent limitation guidelines define how much pollutant discharges can be reduced by application of various levels of technology. New source performance standards define effluent reductions for new facilities and reflect what can be achieved through application of the best available demonstrated control technology.

To date, no new source performance standards have been established for coal conversion plants. Thus it is impossible to state exactly which parameters must be monitored to satisfy regulatory requirements. However, an indication of EPA's approach to coal conversion facilities can be found by examining the effluent limitation guidelines for similar sources such as coal mining, coking, and petroleum refining.

The parameters that the EPA has selected for use in defining effluent limitations for various sources are given in Table 2.1.7.

2.1.2.4.3 Sampling Frequency

Sampling frequency determines the validity and usefulness of data collected in the baseline survey. The potentially high cost of analytical determination of many water quality parameters (especially inorganic elements and organic compounds) makes the determination of sampling frequency a very important task. For all water quality parameters it is desirable to obtain a clear understanding of seasonal variation. For several parameters (dissolved oxygen, pH, total dissolved

Table 2.1.7. Water quality parameters used to monitor effluents from industries similar to coal conversion

Parameters	Coal storage ^a	Coking ^b	Petroleum refining ^c
Ammonia		X	X
Biological oxygen demand			X
Chemical oxygen demand			X
Chromium, total			X
Chromium, hexavalent			X
Cyanide and cyanide A		X	X
Iron, total	X		
Manganese, total	X		
Oil and grease		X	X
pH	X	X	X
Phenols		X	X
Sulfide		X	X
Total organic carbon			X
Total suspended solids	X	X	

^a10 CFR Part 434.20.

^b10 CFR Part 420.

^c10 CFR Part 419.

solids), an indication of variation over a 24-hr period can be valuable in interpreting biological community structure and function. This more intensive sampling can most readily be accomplished using portable or permanently installed instruments.

In an attempt to design a cost-effective sampling frequency and still provide the information necessary to establish baseline water quality conditions, the sampling frequency given in Table 2.1.6 is recommended. Dissolved oxygen, total dissolved solids, and pH should be measured monthly with grab samples. The distribution of dissolved oxygen, total dissolved solids, and pH over a 24-hr period should be determined quarterly. During the first year of the baseline monitoring program, inorganic elements (Table 2.1.4) and organic compounds (or classes of organics) (Table 2.1.5) should be measured at least once during low or base flow conditions. If the list of inorganic elements or organic compounds is reduced on the basis of information concerning plant process effluents, these parameters should be measured twice during the first year to provide an initial understanding of variability. During the second year of the baseline program to the onset of construction, inorganic elements and organic compounds should be measured quarterly. All other parameters in Table 2.1.6 should be measured monthly.

It is possible that the frequencies recommended will not give a true indication of the natural variability of water quality parameters; therefore, they should be evaluated after the first year of monitoring to determine the need for any modification (increase or decrease). If the range of monthly values is small (e.g., $\pm 50\%$ of the mean for parameters such as alkalinity or total dissolved solids), it can be assumed that natural variability has been well characterized. However, if monthly values are widely scattered, without any pattern, this may indicate the need to increase sampling frequency in order to accurately assess natural variability. Additional indications of this are provided by (1) large discrepancies between observed concentrations and those previously reported and (2) wide fluctuations in the size of populations of aquatic organisms.

2.1.2.4.4 Sampling Locations

The locations of surface water quality sampling stations should be coordinated with locations determined in the hydrologic monitoring program (Sect. 2.1.2.3) and in the biological monitoring

program (Sect. 2.2.2.3.1). A problem arises because ecologists need to sample the various habitats, whereas the full battery of chemical analyses can only be run on water from one spot at each station. The ecologist's station, therefore, is a zone, perhaps $\frac{1}{4}$ mile long, that encompasses all the habitats of interest. Samples for chemical analysis should be taken from a representative location within the sampling zone; samples are usually taken at the center of the channel of flow.

The final selection of stations should include all surface water systems potentially affected by plant construction and operation. At least one control station (not influenced by plant construction or operation) should be established on each water body influenced by the plant. A near-field station should be established immediately below the effluent mixing zone from major known point-source effluent release points. A far-field station should be established sufficiently below the near-field station to begin to address the spatial extent of any adverse impacts on water quality.

The number of stations necessary to monitor water quality will be site-specific and should be defined during early synoptic surveys (see summary checklist, Sect. 2.1.2.1).

2.1.2.4.5 Data Collection and Analysis Methods

A comprehensive treatment of methods of data collection and analytical methods for surface water quality parameters is beyond the scope of this handbook. Some detail concerning analytical methodology is given in Sects. 2.1.4.3, 4a.5.1, 4a.5.2, and 4b.2.2.2. There are three primary reference works on analytical methods:

Methods for Chemical Analysis of Water and Waste, U.S. Environmental Protection Agency, Methods Development and Quality Assurance Research Laboratory, National Environmental Research Center, Cincinnati, Ohio, 1974.

Standard Methods for the Examination of Water and Waste Water, 14th ed., American Public Health Association, Washington, D.C., 1976.

Annual Book of Standards, Part 31, Water, American Society for Testing and Materials, Philadelphia, Pa., 1976.

Table 2.1.8 provides a general summary of information related to water quality which is useful in the design and analysis of water quality monitoring.

A choice must be made as to whether to measure a given parameter using portable or permanently installed instruments (if available) or laboratory "wet" methods. Instrumentation for monitoring programs is becoming increasingly sophisticated, and personnel designing the program should consult equipment manufacturers to get the most recent information. Equipment is available not only for determining concentration of certain water quality constituents, but also for collecting samples. Thus, it is possible to obtain composite samples over extended periods. Automated devices can provide sample composition proportional to flow, giving substantially more representative samples than individual grab samples. Information regarding sampling equipment can be found in the EPA *Handbook for Monitoring Industrial Wastewater*²⁴ and can also be obtained from manufacturers.

The containers in which water samples are collected can be important. Table 2.1.9 indicates the approximate size of samples which should be taken and thus the size of containers needed. The sampling containers should have resistance to solution and breakage and should be easy to close and label. Other pertinent factors are size, shape, weight, and cost.

Table 2.1.8. Water quality parameters: information for designing sampling programs

Parameter and units	Phase during which parameter should be monitored ^a	Water in which parameter should be monitored ^b	Range of concentration in natural waters ^c	Range of concentration in wastewater from related processes
Ammonia (as N), mg/liter	B,C,O	W,N,G	ND-0.1 ^{d,e}	1800-4300 ^f
Biochemical oxygen demand (BOD ₅), mg/liter	B,C,O	W,N	ND-5	
Chemical oxygen demand (COD), mg/liter	B,C,O	W,N,G		2500-10,000 ^f
Color, platinum cobalt units	B,C,O	W,N,G	0-115 ^g	70 ^h
Cyanide, total, mg/liter	B,C,O	W,N,G	ND	0.01 ^h 10-37 ^f
Dissolved oxygen (DO), mg/liter	B,C,O	W,N,G	0-15	5.8-10.5 ⁱ
Fluoride, mg/liter	B,C,O	W,N,G	ND-1.0 (10) ^j	
Hydrogen ion (pH)	B,C,O	W,N,G	6.2-8.4	8.3-9.1 ^f 2.1-3.0 ^k
Kjeldahl nitrogen (as N), mg/liter	B,C,O	W,N,G		ND-5 ^d
Metals, mg/liter				
Antimony, total	B,O	W,N,G	ND-0.001 ^l	0.07 ⁱ
Arsenic, total	B,O	W,N,G	ND-0.3 ^m	0.06 ⁱ
Beryllium, total	B,O	W,N,G	ND-0.001 ^m	
Boron, total	B,O	W,N,G	ND-5.0 ^m	
Cadmium, total	B,O	W,N,G	ND-0.1 ^m	0.1 ⁱ
Chromium, total	B,O	W,N,G	ND-0.1 ^j	0-15.7 ^k
Copper, total	B,O	W,N,G	ND-0.3 ^m	1.6-3.4 ^k
Iron, total	B,O	W,N,G	ND-0.5 (10) ^g	0.17-93,000 ^k
Lead, total	B,O	W,N,G	ND-0.8 ^m	
Manganese, total	B,O	W,N,G	ND-0.2 ⁿ	0.07 ⁱ
Mercury, total	B,O	W,N,G	ND-0.005 ^o	0.03 ⁱ
Nickel, total	B,O	W,N,G	ND-0.1 ^j	
Selenium, total	B,O	W,N,G	ND-0.02 ⁿ (0.1) ^p	0.1 ⁱ
Vanadium, total	B,O	W,N,G	ND-0.3 ^m	0.04 ⁱ
Zinc, total	B,O	W,N,G	ND-1.0 ⁿ	0.4 ⁱ 1.6-23.0 ^k
Nitrate (as N), mg/liter	B,C,O	W,N,G	ND-5 ^j	3.4-9.0 ⁱ
Nitrite (as N), mg/liter	B,C,O	W,N,G	q (≥5)	
Organics				
Arylamines	B,O	W,N,G		
Aliphatic hydrocarbons	B,O	W,N,G		
Organic carbon, total, mg/liter (TOC)	B,C,O	W,N,G	ND-50 ^d	2100 ^h
Oil and grease, mg/liter	B,C,O	W,N	ND	
Polynuclear aromatic hydrocarbons	B,O	W,N,G		
Phenols, mg/liter	B,O	W,N,G	ND	410-2400 ^f
Phosphorus total (as P), mg/liter	B,C,O	W,N,G	ND-0.5 ^{d,j}	0.1-7.0 ⁱ
Sulfate (as SO ₄), mg/liter	B,O	W,N,G	ND-1000 ^j	9.3-33.0 ⁱ 525-21,920 ^k
Sulfide (as S), mg/liter	B,O	W,N,G	q	0-50 ^f

Table 2.1.8 (continued)

Parameter and units	Phase during which parameter should be monitored ^a	Water in which parameter should be monitored ^b	Range of concentration in natural waters ^c	Range of concentration in wastewater from related processes
Solids				
Dissolved residue, mg/liter	B,C,O	W,N,G	10–761 ^g	720–44,050 ^k
Suspended residue, mg/liter	B,C,O	W,N,G	ND–1000 ^d	
Thiophenes	B,O	W,N,G		
Thiocyanates	B,O	W,N,G	ND	100–1500 ^f
Turbidity, NTU	B,C,O	W,N,G		13–275 ⁱ

^aB, baseline; C, construction; O, operation.

^bW, waste stream(s); N, affected natural water(s); G, groundwater.

^cND – not detectable. First values – surface water; values in parentheses – groundwater.

^dGreater concentrations occur under unusual circumstances.

^eNational Academy of Sciences, *Water Quality Criteria 1972*, EPA-R3/73-003, 1973.

^fE. S. Rubin and F. C. McMichael, "Impact of Regulations on Coal Conversion Plants," *Environ. Sci. Technol.* 9(2), 112–17 (1975).

^gC. N. Durfor and E. Becker, *Geological Survey Water Supply Paper*, U.S. Department of the Interior, 1964.

^hG. R. van Stone, "Treatment of Coke Plant Waste Effluent," *Iron Steel Eng.* 49(4), 63–66 (1972).

ⁱRufus K. Guthrie and Donald S. Cherry, "Pollutant Removal from Coal-Ash Basin Effluent," *Water Resour. Bull.* 12(5), 889–902 (1976).

^jR. G. Bond and C. P. Straub, eds., *Handbook of Environmental Control, Vol. III: Water Supply and Treatment*, CRC Press, Cleveland, Ohio, 1973, Tables 1-13 and 1-14.

^kW. C. Anderson and M. P. Youngstrom, "Coal Pile Leachate – Quantity and Quality Characteristics," *J. Environ. Eng. Div. Am Soc. Civ. Eng.* EE6, 1239–53 (1976).

^lD. P. Kharkar, K. K. Turekian, and K. K. Bertine, "Steam Supply of Dissolved Silver, Molybdenum, Antimony, Selenium, Chromium, Cobalt, Rubidium and Cesium to the Oceans," *Geochim. Cosmochim. Acta* 32, 285–95 (1968).

^mJ. F. Kopp and R. C. Kroner, *Trace Metals in Waters of the United States. A Five Year Summary of Trace Metals in Rivers and Lakes of the United States*, U.S. Department of the Interior, Federal Water Pollution Control Administration, 1967.

ⁿH. J. M. Bowen, *Trace Elements in Biochemistry*, Academic Press, New York, 1966.

^oJ. V. Lagerwerff, "Lead, Mercury, and Cadmium as Environmental Contaminants," pp. 593–636 in *Micronutrients in Agriculture*, J. J. Mortvedt et al., eds., Soil Science Society of America, Inc., Madison, Wis., 1972.

^pW. C. Walton, *Groundwater Resource Evaluation*, McGraw-Hill, New York, 1970.

^qIonic species are unstable in aerated water.

Table 2.1.9. Volume of sample required for determination of the various constituents of industrial water

	Volume of sample ^a (ml)		Volume of sample ^a (ml)
Physical tests		pH, colorimetric	10 to 20
Color and odor ^b	100 to 500	Polyphosphates	100 to 200
Corrosivity ^b	Flowing sample	Silica	50 to 1000
Electrical conductivity ^b	100	Solids, dissolved	100 to 20,000
pH, electrometric ^b	100	Solids, suspended	50 to 1000
Radioactivity	100 to 1000	Tannin and lignin	100 to 200
Specific gravity ^b	100		
Temperature ^b	Flowing sample	Cations	
Toxicity ^b	1000 to 20,000	Aluminum, Al ³⁺	100 to 1000
Turbidity ^b	100 to 1000	Ammonium, NH ₄ ⁺ ^c	500
		Aluminum, Al ³⁺	100 to 1000
		Antimony, Sb ³⁺ to Sb ⁵⁺	100 to 1000
		Arsenic, As ³⁺ to As ⁵⁺	100 to 1000
		Barium, Ba ²⁺	100 to 1000
		Cadmium, Cd ²⁺	100 to 1000
		Calcium, Ca ²⁺	100 to 1000
		Chromium, Cr ³⁺ to Cr ⁶⁺	100 to 1000
		Copper, Cu ²⁺	200 to 4000
		Iron, Fe ²⁺ and Fe ³⁺ ^c	100 to 1000
		Lead, Pb ²⁺	100 to 4000
		Magnesium, Mg ²⁺	100 to 1000
		Manganese, Mn ²⁺ to Mn ⁷⁺	100 to 1000
		Mercury, Hg ⁺ and Hg ²⁺	100 to 1000
		Potassium, K ⁺	100 to 1000
		Nickel, Ni ²⁺	100 to 1000
		Silver, Ag ⁺	100 to 1000
		Sodium, Na ⁺	100 to 1000
		Strontium, Sr ²⁺	100 to 1000
		Tin, Sn ²⁺ and Sn ⁴⁺	100 to 1000
		Zinc, Zn ²⁺	100 to 1000
Chemical tests		Anions	
Dissolved gases		Bicarbonate, HCO ₃ ⁻	100 to 200
Ammonia, NH ₃ ^c	500	Bromide, Br ⁻	100
Carbon dioxide, free CO ₂ ^c	200	Carbonate, CO ₃ ²⁻	100 to 200
Chlorine, free Cl ₂ ^c	200	Chloride, Cl ⁻	25 to 100
Hydrogen, H ₂ ^c	1000	Cyanide, Cn ⁻	25 to 100
Hydrogen sulfide, H ₂ S ^c	500	Fluoride, F ⁻	200
Oxygen, O ₂ ^c	500 to 1000	Hydroxide, OH ⁻	50 to 100
Sulfur dioxide, free SO ₂ ^c	100	Iodide, I ⁻	100
Miscellaneous		Nitrate, NO ₃ ⁻	10 to 100
Acidity and alkalinity	100	Nitrite, NO ₂ ⁻	50 to 100
Bacteria, iron	500	Phosphate, ortho, PO ₄ ³⁻ , HPO ₄ ²⁻ , H ₂ PO ₄ ⁻	50 to 100
Bacteria, sulfate-reducing	100	Sulfate, SO ₄ ²⁻ , HSO ₄ ⁻	100 to 1000
Biochemical oxygen demand	100 to 500	Sulfide, S ²⁻ , HS ⁻	100 to 500
Carbon dioxide, total CO ₂ ^c	200	Sulfite, SO ₃ ²⁻ , HSO ₃ ⁻	50 to 100
(including CO ₃ ²⁻ , HCO ₃ ⁻ , and free)			
Chemical oxygen demand (dichromate)	50 to 100		
Chlorine requirement	2000 to 4000		
Chlorine, total residual Cl ₂ (including OCl ⁻ , HOCl, NH ₂ Cl, NHC ₂ Cl ₂ , and free)	200		
Chloroform-extractable matter	1000		
Detergents	100 to 200		
Hardness	50 to 100		
Hydrazine	50 to 100		
Microorganisms	100 to 200		
Volatile and filming amines	500 to 1000		
Oily matter	3000 to 5000		
Organic nitrogen	500 to 1000		
Phenolic compounds	800 to 4000		

^aVolumes specified in this table should be considered as a guide for the approximate quantity of sample necessary for the particular analysis. The exact quantity used should be consistent with the volume prescribed in the standard method of analysis, whenever the volume is specified.

^bAliquot may be used for other determinations.

^cSamples for unstable constituents must be obtained in separate containers, preserved as prescribed, and completely filled and sealed against all exposure.

Source: U.S. Environmental Protection Agency, *Handbook for Monitoring Industrial Wastewater*, Technology Transfer Program, Washington, D.C., August 1973, pp. 6-6 and 6-7.

Because the critical concentrations for many substances are quite small, attention must be given to all possible sources of contamination. Glass bottles may cause problems in analyses for boron, sodium, and hardness. For dissolved oxygen determination, only glass bottles should be used. Containers should be thoroughly cleaned and rinsed before use. Personnel collecting samples for analyses of heavy metals should avoid using zinc oxide ointment in protecting their noses from sunburn.

Samples from streams or rivers should be taken where water is well mixed, ideally from the center of the channel of flow where velocity is highest and the possibility that solids have settled is minimal. The mouth of the sampling containers should be held slightly below the water surface to avoid collecting excess floating materials. Sampling containers should be rinsed several times with the sample water prior to being filled. Temperature, dissolved oxygen, and pH should be determined at the time of sample collection.

Ideally, samples should be analyzed as soon as possible after collection. This often proves difficult and preservation techniques (identified in Table 2.1.10) must be used. These methods are generally limited to pH control, refrigeration, freezing, poisoning, and other biological inhibition. Such methods can only retard the chemical and biological changes that inevitably continue after a sample is taken in the field. Any preservatives should be added at the time of collection. Samples should be clearly labeled with date, time, location, and an indication of sample type (grab or composite).

Table 2.1.10. Sample preservation

Parameter	Preservative	Maximum holding period
Acidity-alkalinity	Refrigeration at 4°C	24 hours
Biochemical oxygen demand	Refrigeration at 4°C	6 hours
Calcium	None required	7 days
Chemical oxygen demand	2 ml H ₂ SO ₄ per liter	7 days
Chloride	None required	7 days
Color	Refrigeration at 4°C	24 hours
Cyanide	NaOH to pH 10	24 hours
Dissolved oxygen	Determine onsite	No holding
Fluoride	None required	7 days
Hardness	None required	7 days
Metals, total	5 ml HNO ₃ per liter	6 months
Metals, dissolved	Filtrate: 3 ml 1:1 HNO ₃ per liter	6 months
Nitrogen, ammonia	40 mg HgCl ₂ ^a per liter—4°C	7 days
Nitrogen, Kjeldahl	40 mg HgCl ₂ ^a per liter—4°C	Unstable
Nitrogen, nitrate-nitrite	40 mg HgCl ₂ ^a per liter—4°C	7 days
Oil and grease	2 ml H ₂ SO ₄ per liter—4°C	24 days
Organic carbon	2 ml H ₂ SO ₄ per liter (pH 2)	7 days
pH	Determine onsite	No holding
Phenolics	1.0 g CuSO ₄ per liter + H ₃ PO ₄ to pH 4.0—4°C	24 hours
Phosphorus	40 mg HgCl ₂ ^a per liter—4°C	7 days
Solids	None available	7 days
Specific conductance	None required	7 days
Sulfate	Refrigeration at 4°C	7 days
Sulfide	2 ml Zn acetate per liter	7 days
Threshold odor	Refrigeration at 4°C	7 days
Turbidity	None available	7 days

^aDisposal of mercury-containing samples is a recognized problem; research investigations are under way to replace it as a preservative.

Source: U.S. Environmental Protection Agency, *Handbook for Monitoring Industrial Wastewater*, Technology Transfer Program, Washington, D.C., August 1973, p. 6-9.

2.1.2.5 Hydrogeologic Monitoring

2.1.2.5.1 Introduction

Every stage of construction and operation of a coal conversion plant may have an effect on the groundwater regime. During construction, excavation may alter groundwater flow, and dewatering activities may reduce groundwater availability. The consumptive use of groundwater during plant operation further affects groundwater availability and quality. Groundwater quality is of concern because of the possible infiltration of toxic waste streams, fugitive runoff, and leachates from solid materials. Although the transport of contaminants by groundwater is usually slow, the resulting impact is long-lasting and difficult to reverse. Contaminated groundwater can threaten domestic and industrial water supplies, nearby surface waters, and the terrestrial ecology. To provide adequate and cost-effective information for an assessment of these potential impacts, the groundwater monitoring program should also consider the needs of the terrestrial ecology, surface water, water quality, aquatic ecology, and plant process monitoring programs.

The monitoring plan outlined here is for demonstration-size coal conversion plants. Limited information on effluent stream composition prior to developing the monitoring program may necessitate more extensive monitoring of the groundwater regime in the plant vicinity. The monitoring plan assumes that holding ponds and settling ponds will be an important part of waste stream management. Since the plan described makes no assumptions about the nature of the site, many site-specific problems will have to be anticipated. If there is scant information, the complexity of groundwater flow may require a more extensive monitoring effort. It is assumed that little information about the nature of the groundwater regime will be available, but if reliable information is available, the extent of the monitoring effort should be reconsidered.

An essential feature of the monitoring program is a synoptic survey designed to provide information describing the groundwater regime. This preliminary survey is the foundation for the formulation of a good baseline monitoring program. Use of available information on groundwater characteristics can reduce the effort required to complete the baseline monitoring program.

The groundwater monitoring program should be designed to provide useful data concerning groundwater availability, movement, and quality and contaminant transport. Since the impacts on groundwater generally have a long time constant, the conceptual focus of the program should be near the sources of potential contamination.

The complexity of groundwater analysis and the long-term data requirements for the determination of the groundwater regime require that the groundwater monitoring program be designed and implemented by technically trained personnel familiar with groundwater hydrology. The monitoring plan requires an extensive literature search for existing information and a concerted effort in the analysis of that information, which is often incomplete or poorly reported. For the monitoring program to be efficient, every effort should be made to interface with any existing programs performed by other organizations. Such interfacing is necessary even though the monitoring plan must be conceptually focused near the sources of potential impact because proper data interpretation requires that the regional characteristics be as well understood as possible within the practical constraints of the program.

2.1.2.5.2 Synoptic Survey

The synoptic survey of the groundwater regime is intended to provide extensive information for the design of an efficient monitoring program. Information obtained can be used to provide guidance in determining the (1) extent of the required groundwater effort; (2) appropriate locations

for observation wells, piezometers, and other sampling apparatus; and (3) proper frequency for monitoring the groundwater regime. The survey includes an investigation of the existing literature and a data-gathering effort to determine the general characteristics of the groundwater regime. The survey is divided into three parts: (1) characterization of the regional groundwater regime, accomplished primarily by a literature search; (2) identification of the local groundwater regime, potential sources of impact on the hydrogeology, and groundwater conditions in the site area; and (3) defining the aquifer characteristics and hydrogeology from an onsite borehole, which is to be used throughout the monitoring program as a control well.

Results from the three parts of the synoptic survey should be presented in a concise written report. The report should be prepared so that the information can be used in the final design of the baseline monitoring program.

Regional characterization

Regional characterization of the groundwater system consists of two phases: (1) The hydrogeologic environment is investigated for the regional features significant to the evaluation of the groundwater regime and (2) groundwater aquifers are investigated for their uses and characteristics.

In the first part of the synoptic survey (characterization of the regional groundwater regime), accomplished mainly by an extensive literature search, hydrogeologic characteristics are to be identified as precisely and completely as possible (Table 2.1.11). The sources of information include those listed in Table 2.1.1, state geological agencies, state water resource agencies, the scientific literature, local records, site reconnaissance, and local well drillers. The information obtained should be applied towards the regional definition of the geological and hydrological parameters influencing the descriptive material in Sect. 2.1.2.5.3. Historical trends and recent projects affecting the subsurface environment should be determined. Examples are drought cycles, impoundments, mining activities, deforestation, stream or river relocation, and industrial development.

The inventory of the uses of groundwater in Sect. 2.1.2.5.3 should be described regionally to include the locations of wells and springs, depths of wells, status of existing wells, use of withdrawn water, estimated pumpage, and any injection or disposal of wastes into the aquifer. Notations of any wells that have experienced dry periods or water quality problems are especially significant. The user inventory should outline present uses as well as any known future developments that would alter groundwater use patterns.

Table 2.1.11. Regional hydrogeologic characteristics

Lithology
Stratigraphy
Major hydrogeologic units
Relationships between hydrogeologic units
Water-bearing characteristics of each hydrogeologic unit (porosities, specific yields, storage coefficients, hydraulic conductivities, thickness, water chemistry)
Recharge-discharge relationships of the various aquifers (relationships of water levels between individual aquifers, potentiometric surface maps, groundwater flow paths, water budget)
Water quality characteristics of each aquifer
Groundwater use patterns

Groundwater use patterns and hydrogeology should be combined to provide a unified presentation of the regional hydrogeological system. The identification of interaction between aquifers, anisotropic aquifers, deposits of carbonate, shales, basalt, clays, or fractured dense rock is especially important to any future modeling efforts.

Site characterization

Characterization of the groundwater regime in the site area is done in two steps: (1) The hydrogeology is investigated for local features and major variations to the local geology that could be significant to understanding the groundwater regime, and (2) the plant design is examined for features that are important in the development of the monitoring program.

Investigation of the local hydrogeology should focus on identifying features different from the regional ones. Such features might include local disturbances due to present or past mining activity, important geologic features of the site area (carbonate formations, basalt formations, areas of subsidence, fault or shear zones in the bedrock, joint systems, and sinkhole-prone areas), groundwater basin boundaries, recharge areas, and seeps, and gaining or losing reaches of streams. The characterization in the site area should attempt to identify the lithology, stratigraphy, major hydrogeologic units and their connections, water-bearing formations and their areal extents, water quality characteristics, aquifer characteristics, impermeable formations, and the nature of the soils in the vadose zone. Sources of information for this investigation include those used for the regional characterization and site surveys by an experienced hydrogeologist. The site surveys should be concentrated in the proposed waste disposal areas. Areas of concern identified by the plant design investigation should be carefully examined for outcrops, fractures, ephemeral creeks, and drainage patterns. The nature of the surface soils and exposed soil structures should be carefully detailed for depth, color, and composition. It should be emphasized that a complete characterization of the site provides crucial information regarding the extent of the required groundwater monitoring effort.

Examination of the plant design is intended to identify the features of plant operation that might affect the groundwater regime. The features of greatest importance are the waste ponds, storage facilities (both solid and liquid), and disposal areas. Specific plant designs may present other features that should be identified. Each area of the plant should be examined for its proposed location and its probable content. This examination requires a knowledge of the process effluents. Although it may be impossible to identify the effluents at the early stages of design, a complete identification of the effluents and their locations permits a less costly investigation of the groundwater regime. In addition to the locations and the nature of the process effluents, the ultimate fates of the process streams should be assessed. For the purpose of identifying the level of monitoring associated with groundwater availability, the amount of water proposed to be withdrawn from the groundwater storage and any process water that might be reinjected should be detailed as completely as possible. This requires an understanding of the quantities withdrawn and from which water-bearing layer that pumpage or reinjection is to occur. If any process water is to be injected, its quality should be described completely.

Aquifer characterization

The determination of the aquifer characteristics at one location in the site area represents a first investigation of the subsurface environment. The detail of this phase of the synoptic survey in large part depends on the relevant information available from the previously discussed literature searches.

Extensive information regarding the hydrogeology and the aquifer characteristics may allow a reduction in the amount of data that should be collected.

Characterization of the aquifers in the site area is accomplished partially by the drilling of one well. The well should be located up-gradient of the plant site and the waste disposal areas, in an area that will not be disturbed by plant construction or operation. The finished well should be used throughout the monitoring program as a control well for determining any adverse impacts to the groundwater system. The type of drill rig and the drilling fluid used depends on the geology and the depth of the hole. Local drillers should be consulted for the best method. Drill cuttings should be preserved by sampling at 5-ft intervals. In addition to drill cuttings, continuous cores should be preserved for additional information pertaining to the properties of the hydrogeologic units. Split barrel cores are sufficient for deposits that are not water-bearing. In water-bearing formations, undisturbed coring is necessary to determine permeabilities. Techniques for coring are contained in ref. 25. A geologist's log should be kept for the entire drilling process; the log should detail drilling time for short depth intervals, percentage of core recovery, lithology, zones of fluid circulation loss, caving zones, and changes in color of the drilling fluid. The amount of fluid produced should be measured as the hole is drilled. The amount of fluid lost in the borehole should be noted also. Nearby piezometers should record water levels within the aquifer as drilling proceeds. (The number and location of piezometers is discussed later in this section.) The borehole should fully penetrate the aquifer of principal use.

Following drilling, a suite of geophysical logs should be prepared. The logs to be considered are discussed in ref. 26 and should include electric, gamma, caliper, T, fluid resistivity, gamma-gamma, neutron, sonic, and temperature logs. To determine changes in headwater or groundwater movement, a tracer log may be necessary.

After the borehole geophysical logs are studied, the well should be cased, screened, and grouted. If multiple aquifers exist, each aquifer should be cased, screened, and grouted separately to form a nest of wells in the borehole, with the wells sealed from each other. Each well should then be finished and sampled to determine groundwater quality. Well construction techniques are discussed in ref. 27.

The retrieved cores and cuttings should be logged and examined by experienced personnel. Analyses should determine particle size and permeability (horizontal and vertical), porosity, effective porosity, petrology, mineralogy, and moisture content. Methods for soil analysis are given in ref. 28 and Sect. 2.1.1.

Each aquifer should be sampled for water quality. For the purposes of the synoptic survey, the suggested parameters are listed in Table 2.1.12. The principal aquifer should be more completely analyzed than the other aquifers. Parameter selection is further discussed in Sect. 2.1.2.5.4.

Consideration should be given to testing the aquifer by a step-drawdown test. The need for such a test is based on information from the literature search and the results of the borehole geophysical investigation. Methods for performing step-drawdown tests are contained in refs. 29 through 31.

Piezometers placed near the well should be used to observe the water level in each aquifer. If an aquifer test is performed, at least three observation wells should be placed in the aquifer being tested. They should be located so that the well and any two piezometers do not form a straight line. In addition, a sufficient number of piezometers should be placed in the principal aquifer to determine water movement in the site area. Anisotropic aquifers require that more piezometers be used in order to determine groundwater flow. Sufficient water-level measurements should be made to distinguish the mean water level from any short-term fluctuations.

Table 2.1.12. Synoptic survey—water quality parameters

Principal aquifer	Other aquifers
pH	pH
Ammonia (NH ₃)	Ammonia (NH ₃)
Arsenic	Arsenic
Barium	Barium
Boron	Boron
	Cadmium
Total residual chlorine	Total residual chlorine
Chromium (Cr ⁶⁺)	Chromium (Cr ⁶⁺)
Copper	Copper
Cyanide	Cyanide
Fluoride	Fluoride
Hardness	Hardness
Iron	Iron
Lead	Lead
Magnesium	Magnesium
Manganese	Manganese
Total nitrogen	Total nitrogen
Total phosphorous	Total phosphorous
Selenium	Selenium
Silver	Silver
Sulfate	Sulfate
Total dissolved solids	Total dissolved solids
Total organic carbon	Total organic carbon
Zinc	Zinc
Aluminum	
Beryllium	
Bismuth	
Bromine	
Cobalt	
Germanium	
Mercury	
Lanthanum	
Molybdenum	
Nickel	
Rubidium	
Antimony	
Tin	
Titanium	
Uranium	
Vanadium	
Tungsten	
Zirconium	

2.1.2.5.3 Groundwater Hydrology

To determine the availability of groundwater and the possibility of its being contaminated by a coal conversion plant, it is necessary to understand the hydrogeology of the area, especially the unsaturated zone near waste disposal areas and the characteristics of the principal aquifer. The information gathered in the synoptic survey is used to determine the level of hydrogeologic monitoring needed to determine groundwater availability and quality. To satisfy these needs, the purpose of the baseline hydrogeologic monitoring program is to adequately define the subsurface

geology, the chemical and physical characteristics of the soils, and the groundwater hydrology. The monitoring program discussed cannot consider all the related site-specific issues that are involved. Therefore, it must be emphasized that site-specific issues will dictate additional concerns that need to be incorporated into the monitoring program design.

Subsurface geology

Results from the synoptic survey should be evaluated to determine the need for further subsurface studies in the waste disposal and solids' storage areas. The geologic structure and the stratigraphy should be identified to the extent of describing the locations, areal extents, and depths of clay deposits, unconsolidated deposits, aquiclides, aquifers, and perched water bodies. If the geology in the site area is highly variable, further core analysis, cutting analysis, and borehole geophysical investigations may be necessary. The number of subsequent borings can be determined from the synoptic survey and site-specific considerations.

Soil analysis

Determination of the transport of contaminants requires an understanding of transport mechanisms in the unsaturated and saturated zones. The transport of contaminants in the unsaturated zone is influenced by the physical and chemical characteristics of the soils.³² Moisture content is an important physical characteristic because of the obvious relation between it and contaminant transport.

Determination of soil moisture content can be combined with hydraulic conductivity measurements and neutron logging by finding the soil-water characteristic curve. Methods for determining this curve are discussed in ref. 33. The laboratory test requires that representative soil cores from the stratigraphic section be used to determine soil moisture vs pressure. In addition to the laboratory determination, the field measurement of water content should be performed by the application of the $1/3$ -atm technique.²⁸ This technique also can be used to estimate infiltration into the soil. Wet soil samples are cored and analyzed for gravimetric water content.³³ With the soil-water characteristic curve, neutron logging can be used in cased test wells to periodically determine soil moisture and thus soil pressure. For areas that are to be disturbed during construction and operation, periodic determination of soil moisture content should use soil moisture blocks or electric resistance blocks.³³ Soil moisture blocks should be placed at various depths to provide vertical as well as spatial variations in moisture. Soil moisture should be monitored beneath all waste ponds, holding lagoons, and solids' storage areas. Monitoring frequency depends on the type of soil, precipitation, and the specific retention of the soil.

In addition to monitoring soil moisture, the adsorptive properties of the soils need to be determined for the prediction of contaminant transport. For the purposes of modeling, the parameter of greatest interest is the distribution coefficient for each contaminant in the soil core. The distribution coefficient for saturated media (K_d) is defined as:

$$K_d = \frac{\text{quantity of adsorbed material/mass of solid}}{\text{quantity of dissolved material/volume of fluid}}$$

The distribution coefficient for a representative list of chemical materials should be determined according to their potential pollution hazard to potable and nonpotable water and aquatic biota. Table 2.1.13 can be used as a guide. Parameter selection should be based on groundwater use and recharge-discharge characteristics.

Table 2.1.13. Coal-conversion-waste ions of concern in groundwater

	Potable water hazard ^a	Nonpotable water hazard ^a	Aquatic biota hazard ^b
Aluminum	V ^c	V	V
Antimony	L ^d	L	L
Arsenic	H ^e	H	V
Boron	V	L	V
Barium	H	H	V
Beryllium	L	L	L
Cadmium	H	H	V
Cobalt	V	V	V
Chromium	H	H	H
Copper	H	V	V
Iron	H	V	H
Magnesium	V	V	V
Manganese	H	V	H
Mercury	H	V	V
Molybdenum	V	V	L
Nickel	L	V	H
Lead	H	H	V
Selenium	V	V	L
Strontium	H	V	L
Titanium	V	V	V
Thallium	V	V	V
Uranium	V	V	L
Vanadium	V	V	V
Zinc	H	V	H
Zirconium	V	V	V

^aU.S. Environmental Protection Agency, *Quality Criteria for Water*, EPA-440/9-76-023, 1976.

^bRef. 22.

^cV, variable concern or unknown concern.

^dL, low concern.

^eH, high concern.

Understanding the relation between adsorption and contaminant transport requires that soil pH be defined because the solubility of the contaminant species varies with pH.³² The pH near waste disposal sites and solids' storage areas should be measured and monitored quarterly for any temporal changes that might occur. Section 2.1.1 further describes the soil survey.

Groundwater movement

Determination of groundwater movement is the most complex aspect of the groundwater monitoring program. Although difficult, monitoring of groundwater movement in the unsaturated and the saturated zones is necessary to determine contaminant transport and groundwater availability. To detect contaminant transport, the unsaturated zone is the most important region to monitor; to determine groundwater availability, the saturated zone is the most important region to monitor.

Monitoring in the unsaturated zone should determine the transport of water by infiltration and the subsequent dispersion in the vadose zone. Data obtained from the soil moisture studies can be used to determine infiltration. Vertical movement of water can be determined from the moisture

logs. For soils beneath the site, the percentage saturation of water necessary for relative permeability to be greater than zero needs to be identified. A discussion of unsaturated permeability as a function of water content is contained in ref. 34. To analyze the unsaturated zone, records are needed on soil moisture content as a function of time near the waste disposal sites and solids' storage areas. As a minimum, data from moisture blocks or neutron logs should be collected quarterly. For soils with short-term variations in water content, more frequent measurements should be considered.

If perched water exists in the stratigraphy, characteristics such as hydraulic conductivity, porosity, bulk density, and specific retention need to be determined. A slug test with closely spaced piezometers (as discussed in ref. 30) is useful to establish characteristics of the perched water table. Water levels in perched water bodies should be recorded showing monthly variations except in regions with high precipitation recharge. If the perched water body is of large areal extent, movement within the water body should be determined by using a piezometric field.

In the saturated zone, the nature of each aquifer, whether artesian (leaky or nonleaky) or unconfined, should be determined. This requires a knowledge of its areal extent, thickness, composition, size, depth, and type of aquicludes that bound the aquifers.

The extent of monitoring for water movement in the saturated zone is determined from the synoptic survey and the concerns associated with groundwater availability. To determine additional aquifer properties, an aquifer test should be performed near the waste disposal site. Data from a step-drawdown test should be used to determine the transmissivities, storage coefficients, and recharge boundaries of the principal aquifer. The aquifer test should be performed using three observation wells. Confined aquifers could, in addition, be tested using the slug test method with three closely spaced observation wells.

Monitoring of groundwater movement is accomplished by the use of a piezometric field to measure the temporal and spatial variations of groundwater levels. The number of piezometers and the frequency of monitoring are determined from the results of the synoptic survey. Most relevant to this decision are trends in water levels and variations in site geology. It should be noted that although groundwater flow usually approximates the topography, geological variation can alter the course of the flow.

2.1.2.5.4 Groundwater Quality

Characterization of groundwater quality during the baseline monitoring program is the most important aspect of the groundwater monitoring effort. Waste streams and stored solid materials generate leachates that can degrade groundwater quality in the vadose and saturated zones. The monitoring of groundwater quality requires that three major questions be answered: (1) What parameters should be measured? (2) At what frequency should the parameters be measured? and (3) What are the appropriate locations and methods? The answers to these questions are not straightforward or easy. The appropriate answers require close coordination among the plant process, aquatic, surface water, and terrestrial monitoring efforts. The results of the synoptic survey are essential to answering these questions for the site-specific problems that are certain to exist. No discussion of groundwater quality can completely identify all the necessary locations, parameters, frequencies, and methods needed to determine the monitoring program for a specific site due to the wide variations in sites. Thus site-related problems should be carefully considered to provide an effective groundwater quality monitoring program.

Selection of parameters to be monitored can be simplified if the constituents of the waste streams are understood. Since the waste streams are likely to be incompletely defined, the

parameters selected should represent the best understanding available. This understanding is best determined during the synoptic survey; hence, the design of the baseline monitoring program depends heavily on its completeness. Parameters should then be selected to best describe the physical and chemical characteristics of the groundwater.

Temperature is the physical characteristic of groundwater that is of the greatest importance in monitoring. Other parameters such as turbidity, density, color, odor, and taste may need to be monitored in some cases.

The chemical characteristics of groundwater can be separated into organic compounds, trace metals, and other related parameters. General parameters should be selected to typify the overall characteristics of each group (total organic carbon, total dissolved solids, pH, alkalinity), and then the specific parameters to be monitored should be chosen based on results from the synoptic survey and knowledge of the process effluents. The selection of specific parameters should be based on their mobility, potential for hazard, concentration in the effluent streams, and existing standards. Recommendations of parameters to be considered for monitoring from each group are listed in Table 2.1.14. Emphasis must be placed on ensuring that parameter selection satisfies the needs of the aquatic, terrestrial, and surface water quality monitoring programs.

In the selection of parameters, the requirements of agencies regulating groundwater quality must be consulted for current directives regarding coal conversion plant monitoring. Existing programs for surface water are discussed in Sect. 2.1.2.4. Currently, neither federal nor state agencies have issued guidelines or standards for groundwater monitoring of coal conversion plants.

The determination of the proper frequency of monitoring for each parameter depends on the results of the synoptic survey. For the baseline program, the frequency should be sufficient to provide a data base that will separate annual and seasonal variations from short-term fluctuations.

Table 2.1.14. Recommended parameters for groundwater monitoring

Physical	Chemical		Other
	Inorganic	Organic	
Temperature	Aluminum	Selenium	Total coliform
Density	Arsenic	Tin	Fecal coliform
Odor	Boron	Titanium	Uranium
Turbidity	Barium	Vanadium	Thorium
Color	Beryllium	Tungsten	Radium
Taste	Bismuth	Zinc	
	Bromine	Zirconium	
	Cadmium	Silver	
	Cobalt	Total nitrogen	
	Chromium	Nitrate	
	Copper	Alkalinity	
	Iron	Ammonia	
	Germanium	Cyanide	
	Mercury	Fluoride	
	Lanthanum	Phosphate	
	Magnesium	Total dissolved solids	
	Manganese	Total suspended solids	
	Molybdenum	Sulfate	
	Nickel	Chloride	
	Lead	Alkalinity	
	Rubidium	pH	
	Antimony	Hardness, as CaCO ₃	

At a minimum, all parameters selected should be monitored quarterly throughout the monitoring program. Some parameters should be monitored monthly: These should be chosen based on the likelihood that short-term fluctuations will occur. The likelihood of short-term fluctuations can be determined by results from the synoptic survey which will indicate those parameters exceeding existing standards, representing very mobile species, having historical patterns of variability, reflecting existing industrial or municipal activity, or acting as lead indicators of pollution hazards. Parameters such as pH and temperature are more likely to require monthly monitoring than individual trace elements. A final consideration in determining frequency is the location of the monitoring equipment. Samples collected from highly permeable formations or from the vadose zone may require more frequent monitoring to accurately characterize the parameter variation.

Groundwater quality monitoring requires that sampling be performed in the vadose zone and the saturated zones. Each zone requires different methods for the identification of proper sampling locations. The emphasis for sampling should be placed on the vadose zone so that an effective data base will be available for comparison during the construction and operational phases. Surveys of the methods and methodology for sampling are included in refs. 33, 35, and 36.

The baseline monitoring program should focus on identifying the existing groundwater quality in the vadose zone by sampling the unsaturated zone and any existing perched water tables. For unsaturated zone analysis,³³ soil-water samplers are positioned in holes usually drilled by power augers, but some sites may require other techniques. At least three soil-water samplers should be used in each hole to establish quality variations in depth. Each sampler should be separated by the use of group seals in each hole. During the drilling of the holes, core samples should be taken at 2 to 5 ft intervals and preserved for analysis. Logging of the holes should also be included in the drilling procedure. The number of holes to be drilled is determined using the information from the synoptic survey that details the site geology and soils. A sufficient number of holes should be drilled to typify the natural percolates from the waste pond and solids' storage areas. At least three holes for each pond and three holes for each solids' storage area should be sampled. The number of holes required depends on the acreage associated with the waste ponds or the solids' storage areas. Site geological considerations may also affect the number of holes drilled.

Perched water samples can be collected from shallow wells.^{30,33} Each well should be cased and screened but need not fully penetrate the perched water zone. Special attention should be given to perched water bodies that are close to solids' storage areas, waste ponds, or landfill sites. Samples should be collected in accordance with the standard practices outlined in refs. 33 and 37. Water can be retrieved by bailing or by using a submersible pump.

Saturated zone monitoring requires that monitoring wells be drilled and sampled using the techniques outlined in refs. 30 and 33. Each drilled well should be logged, cased, and screened and cuttings should be preserved for analysis as explained in Sect. 2.1.2.5.3 and refs. 33 and 35. Groundwater quality wells should be fully penetrating and each aquifer sampled should be separately sealed. Multiple aquifers can be sampled from the same borehole using nested wells if the aquifers are tightly sealed from each other. The focus of saturated zone monitoring should be on the aquifer of principal use, with special emphasis placed on the down-gradient direction so that any future plant impacts can be accurately assessed. Wells should be located to provide an effective portrayal of the spatial distribution of the existing water quality. Monitoring efforts should make use of existing wells, to the extent feasible.

For the baseline monitoring program, at least one well down-gradient of each waste pond, solids' storage area, and landfill site should be drilled. More wells may be necessary if geological considerations determined during the synoptic survey dictate. Anomalies detected in the data should

be noted. Each well drilled and sampled should be selected so that it will not be disturbed throughout plant construction and operation. This care in well placement is important in efficiently obtaining useful data throughout the baseline monitoring program.

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2.1.3 DESCRIPTION OF ATMOSPHERIC ENVIRONMENT

2.1.3.1 Purpose and Scope

Pollutants in the form of gases, vapors, aerosols, and fine particulate matter can be transported over great distances in the atmosphere. Since it would appear, a priori, that a coal conversion plant is capable of emitting a wide variety of such pollutants, air quality and meteorological monitoring considerations are essential to any environmental program. During the preconstruction phase, the purpose of the atmospheric monitoring program will be to provide a quantitative idea of existing air quality at the proposed site both for commonly occurring pollutants and for those pollutants expected to be emitted from the coal conversion process and which may already be in the ambient environment. The 1977 Amendments to the Clean Air Act defined new facility permit requirements based on the predicted contribution of certain key pollutants resulting from plant operation. EPA monitoring requirements should be incorporated into the monitoring program.

Although many atmospheric contaminants will be in the form of gases, the collection of gaseous samples for analysis in the laboratory is not always a convenient approach to the problem, and actual monitoring and analysis in the field are much to be preferred. For all the gaseous materials dealt with here, in situ analytical techniques are recommended. These various techniques can give readings at very frequent intervals—some of them continuously. In a properly designed system, it is possible to accumulate all these data by means of a convenient data-logging system.

Nearby fossil-fueled power plants could be contributing sulfur dioxide and nitrogen oxides, in addition to particulates containing various trace elements. Industrial complexes, especially those of a petrochemical nature, could be releasing organic compounds. Smaller sources, such as residences heated with fossil fuels, may be individually insignificant, but may be important overall because of their abundance in the area. Efforts should be made to identify all possible sources of pollutants. Such efforts would provide useful information against which to check the adequacy of the monitoring program design.

2.1.3.2 Data-Logging System

The monitoring program described in this section will generate large quantities of data and it is important that these data be collected reliably and in a readily accessible form. By giving some thought to the initial design of a data-logging system, many difficulties can be avoided. The purpose of such a system should be to collect data at frequent intervals in a readily manipulated form (e.g., on magnetic tape) in such a manner that each piece of data will be identifiable at a later date (e.g., there should be no uncertainty as to the time at which a particular datum was obtained, the parameter to which it refers, or the measurement scale, the calibration parameters, zero error adjustments, etc., which may be needed in future analysis procedures).

Generally, most instruments will have analog outputs. The analog signals can be fed to an analog-to-digital converter (ADC), for example, a digital voltmeter, and the digital signal recorded on magnetic tape. This digital signal should be combined with digital information on the channel (recording instrument) involved, the time, and any necessary calibration information. The system should contain a scanner under clock control which will cause the ADC to process signals from the different channels in a prearranged sequence and at prearranged time intervals.

The type of system described is commercially available and very reliable. Such a system is far less expensive than investing in individual strip-chart recorders for each instrument, and it has the advantage of recording the data in computer-compatible format, thus minimizing manual data

reduction and analysis and personnel requirements. For diagnostic purposes, at least one strip-chart recorder and one digital printout must be maintained. By arranging for the logging of every tenth set of measurements, for instance, on a strip chart and in digital printed form, the system can be inspected very easily and malfunctioning instruments, etc., can be identified early.

Examples of typical manufacturers of data-logging equipment are Esterline Angus Instrument Corp.; John Fluke Mfg. Co.; Teledyne Geotech. Inc.; United Systems Corp. (Digitec); Leeds and Northrup Co.; Kaye Instruments, Inc.; Monitor Laboratories, Inc.; Vidar Autodata, Inc.; Doric Scientific Corp.; Hewlett Packard; and Neff Instrument Corp. We do not wish to imply that these are the only manufacturers nor that they are any better than others. These comments will apply equally to all other mentions of specific manufacturers.

2.1.3.3 Air Quality Characterization of the Site

Coal conversion plants will emit a variety of chemical compounds considered pollutants. Sections 4a.3.2 and 4b.3.1.2 discuss these sources generically. The quality of the air at the site should be described in terms of the pollutants for which the EPA has prescribed national ambient air quality standards (NAAQS, the "criteria" pollutants) and those chemical compounds that are considered hazardous to man and also expected to be process emissions (e.g., trace metals on fly-ash particles from a coal-fired utility boiler).

Two classes of criteria pollutants have been influenced by the 1977 Clean Air Act Amendments—sulfur dioxide and particulates. Measuring the ambient concentrations of these pollutants will allow a determination of whether the site is in an attainment area (attaining NAAQS) or a nonattainment area and will enable a selection of which EPA permit requirements apply to the case.

The six criteria pollutants and other compounds described below will have at least one potential source in a coal gasification plant. A carefully planned and implemented preconstruction monitoring program will permit prediction of the impact that the plant will have on the atmospheric environment and will also provide the baseline data with which to measure the actual impacts of operation.

Many textbooks exist that explain in more detail the instrumentation to be discussed in the following sections. Among these are many excellent analytical chemistry books. However, of particular interest from an air monitoring standpoint are an instrumentation handbook published by Lawrence Berkeley Laboratory¹ and a book edited by Stern.²

The instruments described below for the monitoring of gaseous pollutants are capable of sampling repeatedly at intervals of minutes. Some have limitations in that they sample more than one pollutant (e.g., NO and NO₂) and are required to go through a cycle. Others can sample continuously. With the instruments described, it should be possible to take a full set of measurements every 10 min or so by digitizing the measurement of each pollutant and storing the result on tape. As has been indicated earlier, a full measurement and data recording cycle should include the meteorological parameters (see Sect. 2.1.3.4). It is recommended that all in situ measurements of pollutant concentration and measurement of meteorological variables be recorded every 10 min. For diagnostic purposes and to aid in the identification of trends, every sixth set of recorded measurements (i.e., the hourly measurements) should also be printed digitally and displayed on a strip chart. To aid in the identification of a malfunctioning channel, systems can be obtained that will display the first channel for 20 sec and all other channels for 10 sec.

Analytical methods are also described in Sects. 2.1.4.3, 3.1.2, 4b.2.2, 4a.5.1, and 4a.5.2.

2.1.3.3.1 Sulfur Dioxide and Other Sulfur Compounds

The following national ambient air quality standards exist for sulfur dioxide (SO_2): An annual arithmetic mean of $80 \mu\text{g}/\text{m}^3$ (0.03 ppm) is the primary standard and $60 \mu\text{g}/\text{m}^3$ is the secondary standard. (Primary standards are those required to protect public health. Secondary standards are those required to protect public welfare, for example, the protection of crops, materials, and structures from damage.) The 24-hr maximum values are $365 \mu\text{g}/\text{m}^3$ or 0.14 ppm (primary) and $260 \mu\text{g}/\text{m}^3$ or 0.10 ppm (secondary). There is also a 3-hr maximum value of $1300 \mu\text{g}/\text{m}^3$ (0.50 ppm).

A widely accepted method for the measurement of SO_2 levels in the atmosphere is flame photometry. A sample, when burned in a hydrogen flame, emits a characteristic radiation due to the population of an excited level of S_2 .³ Flame photometric detectors (FPDs) are readily available commercially. Stevens et al. have found FPDs to be very reliable in field applications.^{4,5}

Due to plant operation, other reduced sulfur compounds that would be detected by an FPD may be present: for example, H_2S , COS , CS_2 , CH_3SH , and $\text{CH}_3\text{CH}_2\text{SH}$. To discriminate among these compounds and SO_2 , an FPD-gas chromatograph (FPD-GC) should be used. During preconstruction (and construction) monitoring, fewer types of sulfur compounds may exist. Some manufacturers have monitors that detect total sulfur, reduced sulfur, and sulfur oxides by means of an FPD plus various filters. These can do an adequate job in many instances.

An FPD should be capable of measuring SO_2 concentrations quite well over the range of a few parts per billion to about 1 ppm. Sulfur dioxide analyzing systems and/or sulfur analyzers are available from Beckman, Process Instruments Division; Tracor Instruments Inc.; Meloy Laboratories, Inc.; and Monitor Laboratories, Inc.

2.1.3.3.2 Oxides of Nitrogen

The national ambient air quality standard for NO_2 is an annual arithmetic mean of $100 \mu\text{g}/\text{m}^3$ (0.05 ppm). Chemiluminescence can be used to detect nitrogen oxide (NO). The NO reacts with ozone (O_3) to produce NO_2 in an excited state, and this is detected as it decays to the ground state. When the photomultiplier tube is cooled to about -25°C , this technique gives a linear response from 0.001 to 10,000 ppm of NO.³ To detect NO_2 , it must first be converted to NO. Converters using various forms of carbon are generally used. Commercially available units operate in a cyclic mode. The sample gas alternately goes through the converter and a converter bypass. Measurements taken with air which bypasses the converter give information on NO concentration, whereas measurements taken with air which passes through the converter give information on $\text{NO} + \text{NO}_2$ (NO_x) concentrations, and the NO_2 concentration can be obtained by subtraction.

This type of instrumentation is available from Beckman, Process Instruments Division, for example.

2.1.3.3.3 Carbon Monoxide

National ambient air quality standards for carbon monoxide (CO) are: 8-hr maximum, $10 \text{ mg}/\text{m}^3$ (9 ppm); 1-hr maximum, $40 \text{ mg}/\text{m}^3$ (35 ppm).

Although nondispersive infrared techniques are standard for measuring CO concentrations in the 10-ppm range, they are not very sensitive and do not offer sufficient linearity when measuring ambient levels for many practical applications. A commercially available gas chromatographic monitoring instrument detects CO by converting it to methane (CH_4) and can be used successfully in the 0.05 to 10 ppm range. This apparatus separates existing CH_4 from the sample, and then converts the CO to CH_4 . If higher levels of CO are likely to be present (i.e., >10 ppm), commercially available nondispersive infrared techniques should be used.

2.1.3.3.4 *Hydrocarbons*

The national ambient air quality standard applying to hydrocarbons (corrected for methane) is a 3-hr maximum of $160 \mu\text{g}/\text{m}^3$ (0.24 ppm).

Flame ionization detectors are used to measure hydrocarbon concentrations. It should be kept in mind that the technique measures other than just total hydrocarbons—it actually detects C–H bonds. Thus, a flame ionization detector will respond to some oxidized products of hydrocarbons such as aldehydes, ketones, and alcohols. However, the amount of such compounds present in the atmosphere normally will be small in comparison with hydrocarbons.

Commercial instruments are available which will measure both CH_4 and nonmethane hydrocarbons (assuming that other organics are not present). For instance, instruments for hydrocarbon measurement are available from Meloy Laboratories, Inc.

2.1.3.3.5 *Ozone and Oxidants*

National ambient air quality standards exist for photochemical oxidants: A 1-hr concentration of $160 \mu\text{g}/\text{m}^3$ (0.08 ppm) is not to be exceeded more than once per year. Photochemical oxidants consist mostly of O_3 , much of which arises as a result of photochemical reactions involving oxides of nitrogen. Because of the photochemistry involved in the O_3 production, the atmospheric concentration of O_3 is a diurnal variable; consequently, a monitoring program should include frequent enough measurements to deduce the diurnal pattern.

Many O_3 reactions with other chemicals are characterized by chemiluminescence. This property, therefore, can be used to detect O_3 concentrations. Regener^{6,7} developed a technique in which O_3 reacts with rhodamine B. However, Nederbragt, Van der Harst, and Van Fuijn⁸ developed a more commonly used technique in which the chemiluminescent emission from the reaction of O_3 and ethylene is in the 300 to 600 nm range, and its intensity is directly proportional to the O_3 concentration. Typically, a detector of this type has a linear response of 0.003 to 30 ppm O_3 .

Typical manufacturers of O_3 monitoring systems are Beckman, Process Instruments Division; Meloy Laboratories, Inc.; and Monitor Laboratories, Inc.

2.1.3.3.6 *Particulates*

Annual standards (geometric mean) for suspended particulates are $75 \mu\text{g}/\text{m}^3$ (primary) and $60 \mu\text{g}/\text{m}^3$ (secondary). The 24-hr maximum values are $260 \mu\text{g}/\text{m}^3$ (primary) and $150 \mu\text{g}/\text{m}^3$ (secondary). (The reader is referred to Sect. 3.1.2.2 for analysis techniques for airborne particulates.)

Atmospheric loading and size distribution

Particulates can be classified initially into those larger particles that will settle quickly due to gravity and those that will remain in the atmosphere considerably longer. In a dusty area, for example, during construction, the atmosphere may contain a sizable number of the larger particles. In such a situation, these particles should be sampled using gravitational collection. The American Society for Testing and Materials (ASTM) has issued guidelines on such sampling,⁹ and appropriate instruments are available commercially. Basically, such a sampler is a cylinder of glass, plastic, or stainless steel which is firmly mounted so as to remain upright.

For those particles too small to settle quickly, it is necessary to provide a driving force to effect their collection. One method is to pump an air sample through a system containing various sizes of

chambers, orifices, and collection media. The system would also contain some flow-rate-measuring equipment. A technique recommended by the EPA involves a dichotomous sampler which separates particles into two groups—those greater than and those less than $3.5\text{ }\mu\text{m}$ in diameter.¹⁰ Particles smaller than $3.5\text{ }\mu\text{m}$ in diameter are regarded as respirable.

The Anderson cascade impactor performs more detailed size fractionation. For simplicity and ease of analysis, the number of stages can be reduced. High-volume samplers do not perform size fractionation; however, they are quite acceptable for collecting material for elemental and chemical analyses.

Because of analysis requirements, care must be exercised in the choice of a collection filter. Glass filters, for instance, are likely to have impurities which would cause interference in x-ray analysis. Dzubay and Stevens have found Teflon membrane filters with a polyethylene backing to be ideal.¹⁰

Sulfates

Of particular interest will be the amount of sulfate in the atmosphere. Much is expected to be in the form of $(\text{NH}_4)_2\text{SO}_4$, but some of it will be $(\text{NH}_4)\text{HSO}_4$ or H_2SO_4 . Most of this will probably be present as small aerosols and will be evident on analysis of the aerosols collected by the particulate analysis apparatus. (An up-to-date discussion of particulate analysis is contained in Stevens et al.¹¹)

Benzene ring compounds

Certain undesirable benzene ring compounds may be emitted by coal conversion process operations and their presence or absence prior to plant activity should be documented. Their presence can be detected by analyzing samples from the particulate collectors. These compounds are variously referred to as benzene-soluble organics, polyaromatic hydrocarbons, polycyclic aromatics, etc. The compounds of particular interest due to their toxicity are:

- 2-Methyl naphthalene
- Fluoranthene
- 2-Methyl fluoranthene
- Pyrene
- Benzo[*c*]phenanthrene
- Benz[*a*]anthracene
- Chrysene
- 5-Methyl chrysene
- Benzo[*b*]fluoranthene
- Benzo[*j*]fluoranthene
- Benzo[*a*]pyrene
- o*-Phenylene pyrene
- Dibenz[*a,c*]anthracene
- Dibenz[*a,h*]anthracene
- Benzo[*ghi*]perylene

Trace metals

Samples collected on the filters should also be analyzed for trace metals, especially arsenic, beryllium, cadmium, chromium, cobalt, iron, mercury, lead, manganese, nickel, titanium, vanadium, and zinc.

2.1.3.3.7 *Sampling Frequency*

At least one year of analytical monitoring is recommended for a quantitative characterization of the air quality at a given site. It is not necessary to make observations every day, or for a full 24 hours on days of observation. Monitoring every sixth day avoids the systematic bias connected with weekly patterns. This method involves at least one measurement of concentration for each gaseous pollutant in the early afternoon.

In addition to monitoring every sixth day, two 30-day study periods are recommended where sampling is put on a continuous basis, that is, 24 hours per day, with values reported hourly. These study periods are intended to reveal the diurnal character of key pollutants. During these 30-day periods, every sixth particulate sample should be analyzed for particle size distribution and for the concentration of sulfate and nitrates. Every twelfth particulate sample should be analyzed for trace metals and benzene-soluble organics.

The two 30-day periods should be approximately six months apart, with one of the periods scheduled for midsummer. Recommended frequencies for monitoring the above species are given below. These frequencies will provide a good baseline characterization of the atmospheric environment. These guidelines should be adapted to the site under study and reviewed relative to the presence of extant data or ongoing air monitoring programs. For example, an air monitoring station used by the local air quality control region may be located in close proximity to the site. The data collected in such a program may satisfy some of the data requirements of the baseline characterization. DOE should be consulted about the quality and usefulness of such data.

Recommended frequencies for air quality measurement

Every sixth day (noncontinuous basis)

- Carbon monoxide
- Ozone
- Nonmethane hydrocarbons
- Total suspended particulates
- Sulfur dioxide
- Reduced sulfur compounds
- Nitrogen dioxide

During each 30-day study period

Daily (continuous for 24 hours, reported on an hourly basis)

- Carbon monoxide
- Ozone
- Nonmethane hydrocarbons
- Total suspended particulates
- Sulfur dioxide
- Reduced sulfur compounds
- Nitrogen dioxide

Every sixth day

- Analyze a particulate sample for sulfates and nitrates
- Particle size distribution

Every twelfth day

- Analyze a particulate sample for trace metals and benzene-soluble organics

2.1.3.3.8 Location of Air Quality Monitoring Stations

Choosing an air quality sampling site involves the same considerations given to the choice of a meteorological observation site (these considerations are discussed in Sect. 2.1.3.4.1). In fact it may be possible, and even desirable, to locate air quality instrumentation and meteorological instrumentation at the same site.

2.1.3.4 Meteorological Characterization of Site

2.1.3.4.1 Location of Meteorological Observation Station

Meteorological observations at a coal conversion plant site are performed to obtain data to aid in evaluating the fate of pollutants released to the atmosphere and to obtain data which will be needed in other areas of the environmental assessment, for example, data needed by hydrologists and ecologists. Meteorological data may also be urgently needed for dispersion modeling and impact prediction in the event of an accidental release of contaminants to the atmosphere.

A meteorological observation site ideally should be situated on flat, unobstructed terrain. It should be approximately at plant grade level and, ideally, the terrain should be similar to that surrounding the plant. This, in effect, means that the meteorological site should be near the plant site itself but removed some distance (15 to 20 building heights downwind or about 10 building heights upwind) so that it is free from perturbations to the wind field introduced by plant structures. For a plant located on varying terrain, such that there are terrain-induced components in the wind field, it would probably be necessary to have more than one observation site. In case of doubt, a specialist in this type of problem should be consulted.

2.1.3.4.2 Observations To Be Performed

To estimate the atmospheric dispersion of pollutants, data on wind speed and direction and a measure of atmospheric stability are needed. If significant amounts of moisture are likely to be released to the atmosphere, temperature and humidity data are also needed. Meteorological observation techniques to be followed are outlined in reference works such as the World Meteorological Organization *Guide to Meteorological Instrumentation and Observing Practices* and in the National Weather Service's various observer guides.

Atmospheric stability

A standard way to evaluate atmospheric stability is from the temperature gradient. This is less fundamental than methods that account for both the mechanical and thermal components of atmospheric turbulence, such as the evaluation of a Monin-Obukhov length.¹² The purpose of determining stability is to permit estimates of the dispersion of effluents during the prevailing conditions. This is done by means of a dispersion model. One typical and fairly simple example is the Gaussian plume model¹³ which requires estimates of σ_y and σ_z , parameters that are related to the cross-wind and vertical spread of the plume respectively. These parameters depend both on distance from the source and on atmospheric stability. Temperature profile data should probably be used only to deduce the vertical turbulence parameter, σ_z , and horizontal wind direction fluctuations should probably be used to deduce σ_y . Knowledge of wind direction fluctuations is especially important at sites where a lot of meandering occurs at low wind speeds. If such data are not available and a σ_y is deduced from temperature profile measurements only, concentration levels over short time spans (e.g., 1 hr) can be seriously overestimated.

Wind and temperature measurements should be made at several levels, say, 10, 50, and 100 m. For elevated sources, the temperature difference between 50 and 100 m would be appropriate for classifying stability; for sources near the ground, the 10 to 50 m temperature difference should be used. It is strongly recommended that temperature differences be measured directly rather than deduced by subtracting actual temperature measurements. Values of σ_θ (and hence σ_y) should be deduced by locating a direction vane at the 100-m level and feeding its signal to appropriate electronics. It is to be understood that σ_θ is the standard deviation of horizontal wind direction fluctuation for a period of 15 min to 1 hr. Table 2.1.15 shows stability classifications in terms of σ_θ and lapse rate.

Wind measurements should be taken at a height representative of the effective release height of pollutants. Estimation of this height should take buoyancy and momentum of the effluents into account. However, because of the possibility of wind directional shear (particularly at night), it is desirable to have wind direction and wind speed data taken at three levels (e.g., 10, 50, and 100 m) to allow the specification of a wind profile covering most heights of interest.

Table 2.1.15. Atmospheric stability classifications

Stability category	σ_θ (°)	Lapse rate (°C/100 m)
A	25	<-1.9
B	20	-1.9 to -1.7
C	15	-1.7 to -1.5
D	10	-1.5 to -0.5
E	5	-0.5 to 1.5
F	≤ 2.5	≥ 1.5

Radiation

Radiation measurements using an instrument such as a pyranometer should be taken at the meteorological site. However, note that many such instruments require constant attention by qualified personnel. Unless such people are available, a more robust instrument (e.g., the silicon cell type pyranometer manufactured by Lambda Instruments Corporation) should be used. Data at 10-min intervals would be acceptable, and the output should also be integrated daily. Depending on the requirements of hydrological studies, etc., it may be necessary to have two instruments—one for total radiation and one, using a shadow band, for diffuse radiation.

Temperature and humidity

Temperature and humidity measurements should be made at ground level in an aspirated ground-level meteorological shelter. For humidity measurements, it is recommended that a chilled-mirror, dew-point observation instrument be used since it is accurate, reliable, and gives a continuous analog output. Precipitation measurements should be made daily, and precipitation samples should be collected for chemical analysis on an event basis.

2.1.3.4.3 Instrument Accuracy and Reliability

To ensure that data from a monitoring program are of high enough quality to be of practical use in environmental studies of a plant site, certain accuracy and reliability criteria must be met.

Wind speed should be measured to an accuracy of 0.25 m/sec, and the anemometer starting speed should be <0.5 m/sec. Accuracy for time-averaged temperature values should be $\pm 0.5^{\circ}\text{C}$. Temperature difference accuracy should be $\pm 0.1^{\circ}\text{C}$. As already pointed out, temperature difference should be measured directly and not by the subtraction of one temperature reading from another.

Servicing and maintenance schedules should ensure 90% data recovery. This will require that backup instruments be available in many cases. All instruments should be given a cursory check (by strip-chart inspection) at least once a day. The various electronic calibration checks (i.e., "zero" and "full-scale") should be performed at least weekly—daily would be better—to ensure good data recovery. A full electronic checkout should be performed at least four times a year. Complete calibration should be done at least once a year.

Lightning damage is a continuing possibility. Surge suppressors should be installed on all power and signal lines. Typical communications industry practices for lightning rods, grounding systems, cable shielding, etc., should be followed.

2.1.3.4.4 Instrument Mounting

Wind and temperature instruments on towers should be mounted so that the towers themselves do not cause interference. Wind sensors should be mounted on booms at least one tower-width away from a tower having an open latticed structure and at least two tower-widths away from a closed tower. Temperature sensors should also be mounted on booms, which need not be as long as the ones for the wind sensors. However, temperature sensors must not be affected by thermal radiation from the tower itself. It would be appropriate, therefore, to paint the tower a light color. All booms should be mounted so that they are perpendicular to the prevailing wind direction. Temperature and temperature difference sensors should be housed in fan-aspirated enclosures to minimize solar-heat-induced errors.

2.1.3.5 Atmospheric Impact Assessment

In the preconstruction phase, existing atmospheric loading should be measured as completely as possible. The need for estimation of atmospheric impacts due to the plant will arise in later stages of the project. Of course, monitoring for exposure to atmospheric pollutants will continue. Nevertheless, it will be necessary to anticipate the impact of certain pollutants before such impacts occur, and, for these purposes, there must exist the capability to perform atmospheric transport and diffusion analyses. The meteorological data obtained during the preconstruction and construction phases of the plant, as well as the continuing program of meteorological observations during operation, will be vital to the calculations needed to perform such analyses. The purpose of this section, therefore, is to explain the types of calculations to be performed with the meteorological data.

Data needed to estimate dispersal of atmospheric effluents are primarily meteorological in nature. However, certain information on emission sources is needed. Obviously, the output rate of the source (source strength) is needed for each pollutant. Such data are usually available as time averages and, since many calculations are performed using time-averaged atmospheric data, such emissions data are appropriate. However, if emissions have a definite pattern, such as a diurnal cycle, it might not be appropriate to use time-averaged meteorological data. The height of the source of emissions is also of importance, particularly within the first 10 to 20 km of the source. The maximum ground-level concentration and its location under any given set of meteorological conditions is very dependent on the height of the source. If the emissions containing a pollutant of

interest are buoyant, the effective height of the source will be greater than the physical height. Sufficient information about the effluent's exit temperature and exit momentum is needed to estimate the effective source height.¹⁴

For particulate emissions, those of larger diameter ($>20\ \mu\text{m}$) will have a settling velocity important to their atmospheric drift characteristics. To deal effectively with such a situation, information on particle size distribution is needed. Similarly, information on particle size is needed for resuspension sources (e.g., mine tailings).

In the actual modeling of atmospheric dispersion in a time-averaged sense (e.g., in calculating average ground-level concentrations for, say, a month), information on wind speed and direction and atmospheric stability is necessary. The Gaussian plume technique has proved reliable for estimating ground-level concentrations of gaseous effluents from point sources and, by extension, from area and line sources. In the Gaussian plume technique, wind speed and direction are used to calculate pollutant advection, and atmospheric stability data are used to calculate dispersion. Very frequently, a climatological calculation is performed whereby a joint probability distribution for wind speed class, wind direction, and atmospheric stability class is used. In such calculations, wind direction may be known only to within a compass sector, that is, 22.5° . Thus, the lateral dispersion of the plume is not calculated. The plume is assumed to be evenly distributed laterally over the 22.5° of the relevant sector, and atmospheric stability information is used merely to calculate vertical dispersion. This procedure is convenient and reliable for climatological calculations.

In estimating concentrations associated with particular meteorological episodes, however, a precise wind direction may be specified, and, hence, it would be appropriate to include the lateral dispersion also. In most cases, lateral and horizontal dispersion will be determined as functions of atmospheric stability class, which is often derived from the temperature lapse rate. However, as mentioned previously, under light wind conditions there may be significant horizontal meandering of the wind vector which will cause the effective horizontal dispersion to be much greater than that suggested from a measurement of temperature lapse rate alone. This is often the case for stable conditions. For this reason, a measurement of σ_θ ought to be taken as part of the normal set of meteorological observations. A recent review of turbulent diffusion typing can be found in ref. 15. Hosker summarizes recently available parameterizations of vertical and horizontal diffusion.¹⁶

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15. F. A. Gifford, "Turbulent Diffusion-Typing Schemes: A Review," *Nucl. Saf.* **17**(1), 68 (1976).
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2.1.4 DESCRIPTION OF CHEMICAL ANALYSIS

Knowledge of coal-conversion-related materials is the key to evaluating possible environmental impacts. Unfortunately, not only are few definitive data available on which to base analytical programs, but indications are that, when available, analyses may involve a virtual galaxy of chemical species, physical states, and matrices (Table 2.1.16). Sections 4a.3.2 and 4b.3.2 describe the coal-derived substances of interest and relate them to the unit operations of streams in which they are generated.

2.1.4.1 Purpose and Scope

This section describes acceptable analytical methods for identifying and quantifying in the environment those effluents that are potential environmental and health hazards. First, the known background levels of anticipated chemicals in each of the environmental media—air, water, soil—and in biota are detailed in Sect. 2.1.4.2. Analytical techniques, centered around EPA standard methods whenever possible, reporting that agency's desired limits of detection, precision, accuracy, and elimination of interferences, are then described in Sect. 2.1.4.3.

Table 2.1.16. Some gasification product and by-product species of interest

Component	Class	Item or property of interest
Gases	Inorganic	H ₂ , CO, O ₂ , N ₂ , Ar, NH ₃ , H ₂ O
	Acid gases	H ₂ S, CO ₂ , SO _x , NO _x , HF, HCl, HCN
	Organic	CH ₄ , C ₂ H ₆ , C ₂ H ₄ , C ₃ H ₈ , C ₃ H ₆ , C ₄ H ₁₀ , C ₄ H ₈
	Sulfurous	COS, CS ₂ , CH ₃ SH, C ₂ H ₅ SH
Organic liquids and solids	Hydrocarbons	C ₅ –C ₁₂ hydrocarbons, benzene, toluene, xylene, indenes, naphthalenes
	Polynuclear aromatic compounds	Pyrenes, fluoranthenes, phenanthrenes, fluorenes, acenaphthenes, benzopyrenes, chrysenes, coronene
	Nitrogen compounds	Pyridine, picolines, lutidines, quinoline, iso-quinoline, quinaldine, indole, carbazole, acridine
	Phenols	Phenol, cresols, xlenols, naphthols
	Sulfur compounds	Mercaptans (thioalcohols), thiophenol, thiocresol, benzothiophene
Trace elements	Nonvolatile	Ba, Be, Ca, Cr, Cu, Mn, Mo, Ni, Sr, V, Zn
	Volatile	As, B, Cd, F, Hg, Pb, Sb, Se, Sn
Coal, ash, and particulate	Ultimate	C, H, N, S, Cl, O
	Proximate	Moisture, heat content, ash, volatiles, fixed carbon
	Sulfur forms	Total, pyritic, sulfate, sulfide
	Ash (particulate)	SiO ₂ , Al ₂ O ₃ , Fe ₂ O ₃ , TiO ₂ , P ₂ O ₅ , CuO, CaO, MgO, Na ₂ O, K ₂ O, F, SO ₄ ²⁻ , trace elements
Water	Dissolved gases	See items listed above
	Organics	
	Trace elements	
	Ions	S ²⁻ , SO ₄ ²⁻ , NO ₃ ⁻ , F ⁻ , Cl ⁻ , Br ⁻ , CN ⁻ , PO ₄ ³⁻ , CO ₃ ²⁻ , HCO ₃ ⁻ , SCN ⁻ , H ⁺
	Gross characteristics	BOD, COD, TOC, suspended solids, oil and grease, specific conductance

Source: J. A. Dorsey, "Sampling Strategies," in *Sampling Strategy and Characterization of Potential Emissions from Synfuel Production, Symposium Proceedings, Austin, Tex., June 8–10, 1976*, ERDA CONF-760602, 1976, p. 50.

2.1.4.2 Background Levels

Knowledge of normal ambient or background concentrations of environmental pollutants is helpful not only in determining safe levels of exposure but also for indicating the resolution needed for environmental analysis. Many substances once thought to be absent from the environment are found to exist naturally at levels near or below an analytical detection limit. Thus, as measurement techniques improve, the number of “natural” pollutants increases.

Information on background levels of possible coal conversion effluents varies greatly with the particular compound. For example, some common air pollutants, such as SO₂, have been monitored extensively,¹ whereas others, such as COS and CS₂, have been largely neglected.² Likewise, sources of data are widely dispersed, ranging from comprehensive EPA and USGS reports to scientific journal articles.

2.1.4.2.1 Organic Compounds

Ross surveys the environmental interactions of polycyclic aromatic hydrocarbons and reports their concentrations at a wide variety of sites and in most environmental media.³ Concentrations of a large number of other organic pollutants are reported by Sawicki.⁴

2.1.4.2.2 Trace Elements

Levels in air of 11 trace metals which had been monitored from 1970 to 1974 by the National Air Surveillance Network are reported by Akland.⁵ Concentrations in all the environmental media—air, water, soil, and rocks—and in plants and animals are tabulated for 66 elements by Ross.³ Recently compiled background concentrations and potential environmental and health effects of 14 trace elements associated with coal conversion solid wastes can be found in ref. 6.

2.1.4.2.3 Air Pollutants

Concentrations of the air pollutants sulfur dioxide, carbon monoxide, nitrogen dioxide, suspended particulates, and ozone are listed in ref. 1. Average and maximum air concentrations of ammonia, nitrogen oxides, and nitric acid in a midwestern city are reported by Spicer et al.⁷ Data on three nonmetallic inorganic ions—ammonium, nitrate, and sulfate—in air are reported by Akland.⁸ Sections 2.1.3.3 and 3.1.2 also address air pollutant analysis.

2.1.4.2.4 Other Pollutants

Although ambient concentrations are not given, a large number of inorganic, organic, and metallic pollutants, including hydrogen sulfide, fluorides, and ammonia, are discussed by Britt and Hushon in terms of the concentrations that give rise to health, environmental, and aquatic effects.⁹ (Ambient concentrations for hydrogen sulfide, fluoride, and ammonia are given in refs. 10 through 12 respectively.) In the absence of other data, these threshold limit values provide a rough estimate of upper limits for monitoring environmental concentrations.

2.1.4.3 Chemical and Instrumental Methods of Analysis

2.1.4.3.1 PAH and Other Organic Compounds

The search for traces of certain organic compounds in the environment has become a serious matter. More than two million organic compounds have been identified, many of which are hazardous and which can reach the environment via industrial accidents or pollution. Polycyclic aromatic hydrocarbons (PAH) are proven carcinogens and thus are of particular importance when present in the environment.

The best documented and most frequently used analytical procedures for removing organics from water involve charcoal adsorption and solvent extraction. Samplers using charcoal adsorption are usually labeled CAM (Carbon Adsorption Method) samplers. Three types of charcoal units have been used by the EPA and others in sampling waters.^{13,14} A Mega sampler consisting of four 12 by 30 in. polyvinyl chloride (PVC) columns and two sand prefilters was built as a trailer-mounted unit by the EPA. Each carbon column was layered with activated carbon: A 5-in. strata at the bottom was composed of a coarse-grade carbon, such as type F-300 of the Pittsburgh Carbon Company; a 12-in. middle strata was composed of a fine-grade carbon, such as Nuchar C 190 $\times$ 30 mesh; and a 5-in.-thick top layer was of the same coarse-grade carbon as used for the bottom layer. Each unit weighs about 22 lb, and the units can be connected in series if necessary.¹³ The sand prefilters are used when the water body to be sampled is turbid or has sediment.

Typical CAM samplers (high- and low-flow) are used by the EPA for collection of samples such as ten- and one-year equivalents; the high-flow CAM is used mainly for drinking waters and the low-flow CAM for raw waters. The high-flow CAM sampler (CAM_{hf}), shown in Fig. 2.1.6, is made from a 3 by 18 in. Pyrex pipe with brass and stainless steel fittings. Two grades of activated carbon are layered in: a 4.5-in.-thick bottom layer of 4 $\times$ 10 mesh carbon, a 9-in.-thick middle layer of 30-mesh carbon, and a top layer of 4 $\times$ 10 mesh carbon which fills the pipe (about 4.5 in.). The CAM_{hf} unit should be attached to an apparatus (Fig. 2.1.7) that will regulate the flow rate to 0.25 gpm and provide a pressure of 40 psi. The normal sample volume for this unit is 5000 gal. The low-flow CAM (CAM_{lf}) sampler is usually used for raw-water sampling, which is most efficient at low-flow rates and throughput volumes. The carbon cartridge is the same as that in the CAM_{hf} but is filled with 30-mesh carbon only and is attached as part of the CAM_{lf} apparatus (Fig. 2.1.8). The flow rate should be about 120 ml/min, which, in one week, should produce a 1200-liter sample. A metering pump on the downstream end of the carbon column regulates the flow rate and volumetrically measures the water in 1-liter increments which register on a counter. The CAM_{lf}, as shown in Fig. 2.1.8, has been widely used by many state and federal agencies.¹⁵ A major drawback is the 115-V, single-phase, 60-cycle electric supply that is required.

A miniature CAM (CAM_m) sampler has been developed for application to drinking water, groundwater, and surface water. The CAM_m is used primarily for monitoring general organic concentrations, not as a collector of organics for further identification.¹⁴ The CAM_m carbon column is shown in Fig. 2.1.9; the column contains 70 g of 14 $\times$ 40 mesh activated carbon and is attached to the sampler as shown in Fig. 2.1.10. The sampler operates at 20 ml/min for 48 hr with a low constant head of water (less than 1 m). The water to be sampled is supplied by gravity from a low constant-head tank. Sample size after 48 hr is about 60 liters of water.¹⁴ The sampler automatically flushes the charcoal column for 7 to 8 sec every 30 min to wash out particles and air which would impede water flow. The pump and flushing-cycle timers require 115 V electric power.

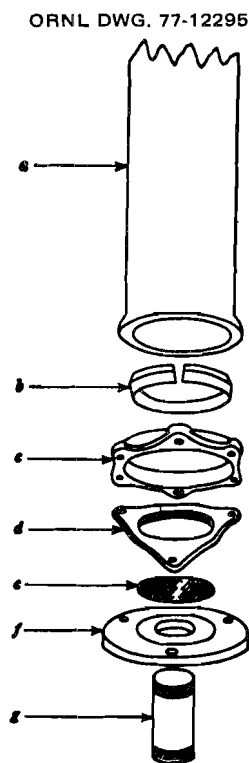


Fig. 2.1.6. End assembly of carbon adsorption unit. *a*, Pyrex pipe, 3-in. diam, 18-in. length. *b*, Asbestos inserts (two), for 3-in. pipe. *c*, Flange sets (two), for 3-in. pipe. *d*, Neoprene gaskets (two), $\frac{1}{4}$ -in. thickness, with 3-in. hole slotted to $\frac{3}{8}$ -in. depth to take screen. Drill 3 holes, $\frac{5}{16}$ -in. diam, to match flange. *e*, Stainless steel screens (two), 40-mesh, $3\frac{3}{4}$ -in. diam. *f*, Brass plates (two), $\frac{1}{16}$ -in. thickness $\times$ $6\frac{1}{4}$ -in. diam. Tap hole in center for $\frac{3}{4}$ -in. nipple. Score a circular groove ($\frac{1}{16}$ -in. depth $\times$ $\frac{1}{16}$ -in. width and $3\frac{3}{8}$ -in. diam) into the plate to prevent leakage. Drill 3 holes, $\frac{5}{16}$ -in. diam, to coincide with the flange. *g*, Galvanized nipples (two), $\frac{3}{4}$ in. $\times$ 3 in. Thread nipple into brass plate and weld in place. *h*, Aluminum bolts and nuts (six), $\frac{5}{16}$ in. $\times$ 2 in., for holding assembly together. Source: American Public Health Association, *Standard Methods for the Examination of Water and Wastewater*, 13th ed., Washington, D.C., 1971, Fig. 22, p. 261.

All the carbon filters described here require solvent extraction of collected organics from the carbon. Sampler carbon (Mega, CAM, or miniature) preferably should be removed in a room designed to reduce contamination potential and placed in a drying tray. The carbon can be dried by a forced-air draft of a temperature normally between 35° and 40°C. The dried carbon should then be transferred to Soxhlet extractors and extracted with chloroform for 48 hr. Concentration of the sample may be preferable after extraction, especially since the Mega sampler requires 40 gal of chloroform; this can be accomplished by distillation of excess solvent until the desired volume is reached.

Inadequacies of carbon adsorption sampling of water are that some organic compounds may not adsorb onto the carbon, or that adsorbed organics may not be recovered by the solvent used. These problems contribute to negative errors. Activated carbon may adsorb inorganic substances which would contribute to the weight of the extract obtained and produce a positive error.¹⁴

Macroreticular resins have been used for sampling water to recover trace organic contaminants.¹⁴ Junk et al. used a porous polymer resin (Rohm and Haas Amberlite XAD-2) to isolate organics by sorption in a small column.¹⁶ The resin was commercially purchased and the fines were removed by slurrying in methanol and decanting. The remaining beads, 20–60 mesh, were purified by sequential Soxhlet extractions with methanol, acetonitrile, and diethyl ether for 8 hr per

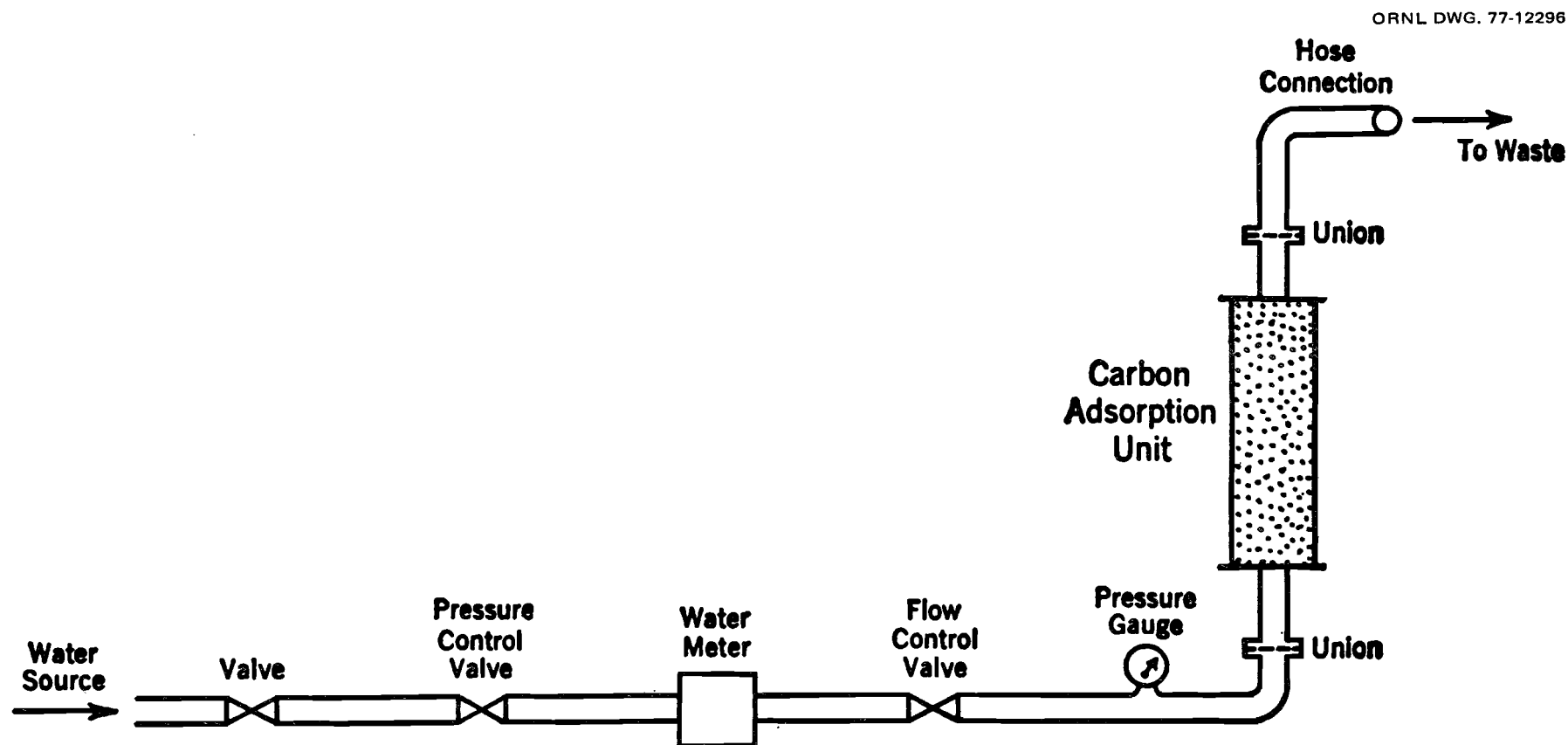


Fig. 2.1.7. Installation of carbon adsorption unit (0.25-gpm flow rate; 40-psi pressure). Source: American Public Health Association, *Standard Methods for the Examination of Water and Wastewater*, 13th ed., Washington, D.C., 1971, Fig. 21, p. 261.

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- Legend**
- A—3/8-in. globe valve
 - B—1-gpm flow control valve
 - C—Bypass tee
 - D—Pressure gauge (0-60 psi)
 - E—"All fine" carbon column
 - F—Constant-head tank
 - G—Metering pump
 - H—Volumetric measurement tank
 - I—Solenoid valve
 - J—Liquid level control relay
 - K—Disconnect switch
 - L—Convenience outlet
 - M—Digital counter

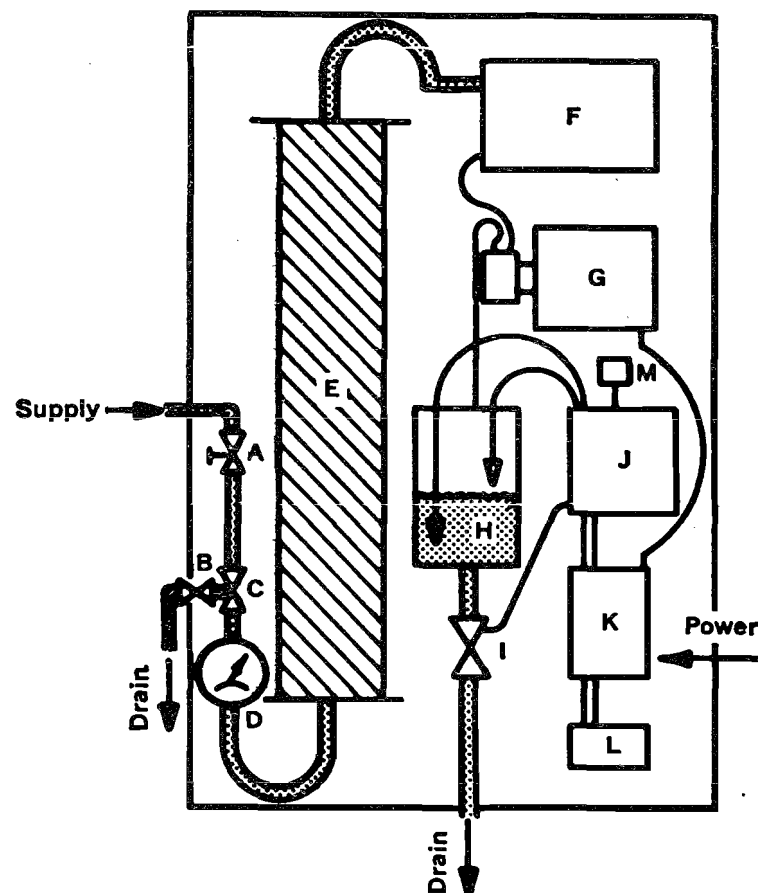


Fig. 2.1.8. Low-flow CAM sampler mounted on a panel 30 by 36 in., which can be stored in an 8-in.-deep crate. Approximate weight of the complete unit is 75 lb. Source: American Public Health Association, *Standard Methods for the Examination of Water and Wastewater*, 13th ed., Washington, D.C., 1971, Fig. 23, p. 265.

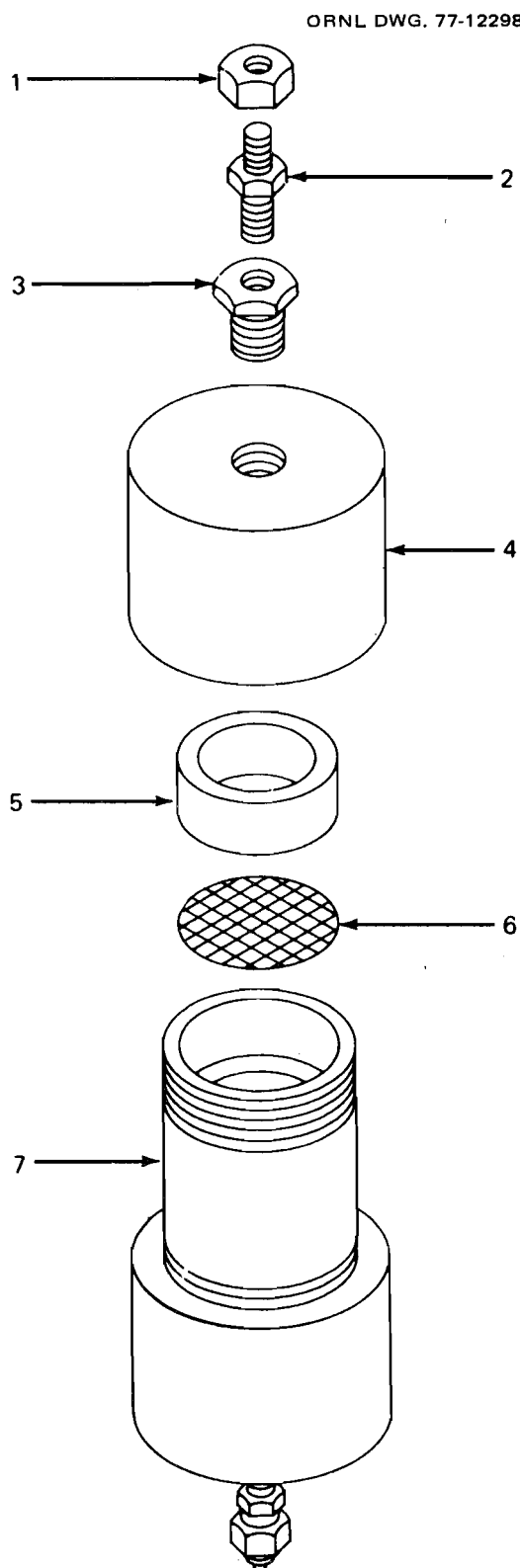


Fig. 2.1.9. Miniature CAM sample column assembly. 1—fitting cap; 2—adapter, $\frac{1}{4}$ -in. pipe to $\frac{1}{4}$ -in.-OD tubing; 3—bushing, pipe, brass, $\frac{1}{2} \times \frac{1}{4}$ in.; 4—PVC end cap, pipe thread, PVC schedule 80; 5—spacer-screen support, $1\frac{1}{2}$ in., PVC schedule 80, $\frac{5}{8}$ in. high; 6—screen, $2\frac{1}{4}$ -in.-diam stainless steel wire cloth 40×40 mesh, wire 0.012-in. diam; 7—nipple, pipe, PVC schedule 80, 2-in. pipe threaded, 3 in. long (note: both ends are identical). Source: American Public Health Association, American Water Works Association, and Water Pollution Control Federation, *Standard Methods for the Examination of Water and Wastewater*, 14th ed., Washington, D.C., 1975, Fig. 506:2, p. 539.

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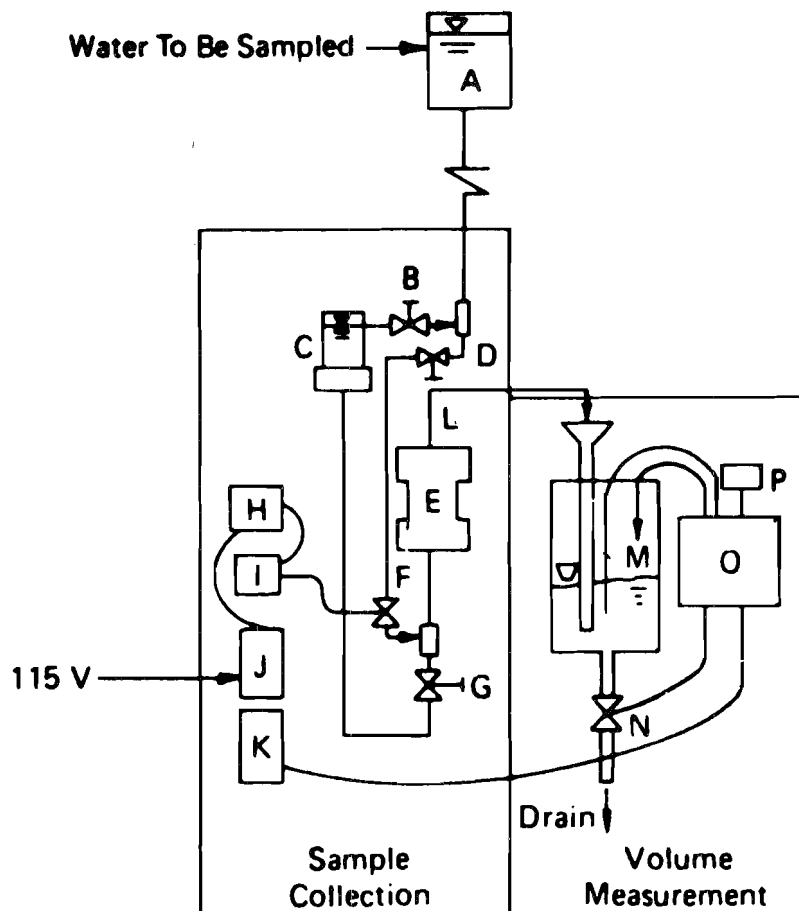


Fig. 2.1.10. Schematic of miniature CAM sampler, model A. Model B does not have parts M-P and replaces them with a calibrated collection vessel. A—constant head main tank, B—sample column feed-tank valve, C—sample column feed tank, D—flushing valve, E—sample column, F—flushing solenoid valve, G—sample column flow-regulating valve, H—30-min timer, I—delay timer set for 7-8 sec, J—power on-off switch, K—duplex outlet, L—sample column outlet tube, M—volume-measuring tank, N—volume-measuring solenoid valve, O—volume-measurement control, P—digital-counter volume recorder. Source: American Public Health Association, American Water Works Association, and Water Pollution Control Federation, *Standard Methods for the Examination of Water and Wastewater*, 14th ed., Washington, D.C., 1975, Fig. 506:1, p. 538.

solvent and then added as a methanol slurry into a glass column (0.6 cm ID, 10 cm long) with a clean silanized glass wool plug above and below the beads. The EPA used the column and noncontaminating connections for direct sampling from plumbing fixtures.¹³ Flow rate was obtained by collecting a measured volume in a known period of time. Redistilled diethyl ether was the solvent used for organic removal. The column was filled with 20 ml ether, capped, and allowed to stand for 10 min before being drained into a test tube. A second washing with 5 ml diethyl ether should be added to the column and allowed to flow into the test tube. The column should be immediately regenerated with methanol.

The XAD-2 diethyl ether sample may be freed of residual water by placing the test tube in liquid nitrogen for two 10-sec intervals to freeze the water; the diethyl ether then can be decanted into a concentration vessel. Sample concentration may be accomplished by distillation.¹⁶

Airborne PAH samples entrained on particulates can be collected with commercial high-volume samplers that have been fitted with glass-fiber filters. Each filter is preweighed and has air (about 1500 m³ total) pulled through it by the sampler. After collection, the filter is allowed to equilibrate, is weighed, and portions are extracted in a Soxhlet extractor with cyclohexane for 24 hr.¹⁷ The extract should be put through a Rosen separation, which uses adsorption chromatography, to isolate the PAH fraction from the aliphatic and heterocyclic compounds.¹⁸

Analysis of organic compounds

Computerized gas chromatography-mass spectrometry (GC-MS) is the lone significant example of a workable "survey"-type analytical method. A survey analytical method must (1) separate complex mixtures (by chromatography), (2) use a detector able to produce information of sufficient quality to permit reliable qualitative analysis, and (3) have a continuous detection system to acquire information on each mixture component as it emerges from the chromatograph. Voluminous data require some form of automated data acquisition and reduction. Other methods such as GC-infrared spectrometry are not as sensitive, and infrared spectra are not as useful as mass spectra for unequivocal identifications. GC-MS analysis may be preceded by GC analysis of the sample to find optimum separation conditions; this will minimize wasteful use of the MS instrument.

The EPA made a major commitment in 1971 to the use of computerized GC-MS equipment for analysis of organic pollutants.¹⁹ A typical EPA GC-MS configuration is shown in Fig. 2.1.11. Most systems are composed of quadrupole mass spectrometers [Finnigan-controlled by PDP-9 minicomputers (Digital Equipment Corp.)], although a few systems use Varian and Hewlett-Packard spectrometers with Varian 620 and Hewlett-Packard H-P 2100 minicomputers.¹⁹

Keith divides the organic compounds found in any type water into three crude categories (Fig. 2.1.12).²⁰ Those compounds listed in the left-hand box range in vapor pressure from gases at room temperature and pressure (STP) to the volatility of some common solvents such as chloroform. This class of compounds is ideally suited for GC-MS, and a sample preparation procedure developed by Bellar and Lichtenberg defines many of these compounds.²¹ The detection limit of this method is about 1.0 µg/liter for many compounds.²¹ The method may be used to analyze organic compounds that are 2% soluble in water and boil below 200°C. Compounds that boil above 200°C show significant qualitative enhancement if the sample is heated. The method is useful from 1 to 2500 µg/liter (0.001 to 2.5 ppm) with most gas chromatographs. The procedure begins with 5 ml of a water sample injected into a purging device (Fig. 2.1.13a). The purging device, using nitrogen as the purge gas, is constructed of glass tubing with a glass frit at the base of the reservoir to pass finely divided gas bubbles through while retaining the aqueous sample above. Design of the purging device allows for maximum bubble contact time (11 min is optimum) and efficient mixing. Volatile materials are transported directly from the device to a trap (Fig. 2.1.13b) by the purge gas. The trap is a short section of stainless steel packed with an adsorptive material such as silica gel or gas-chromatographic-grade porous polymers. The properties of the adsorptive material are chosen to meet the needs of the particular analysis since the retained compounds must not be irreversibly sorbed by the trap, as happens between silica gel and some aromatic compounds above C₉.²¹ The sorptive material must also be thermally stable.

Trap contents are transferred from the trap to almost any septum-type liquid-inlet GC column by the use of a desorber. The desorber (Fig. 2.1.13c) uses an auxiliary carrier flow-control system which elevates the trap temperature and backflushes it with nitrogen directly into the GC septum. The desorber is attached by piercing the GC liquid-inlet septum with the needle. A GC-MS system composed of a gas chromatograph (Varian Aerograph Series 1400) with a 2-mm-ID glass column

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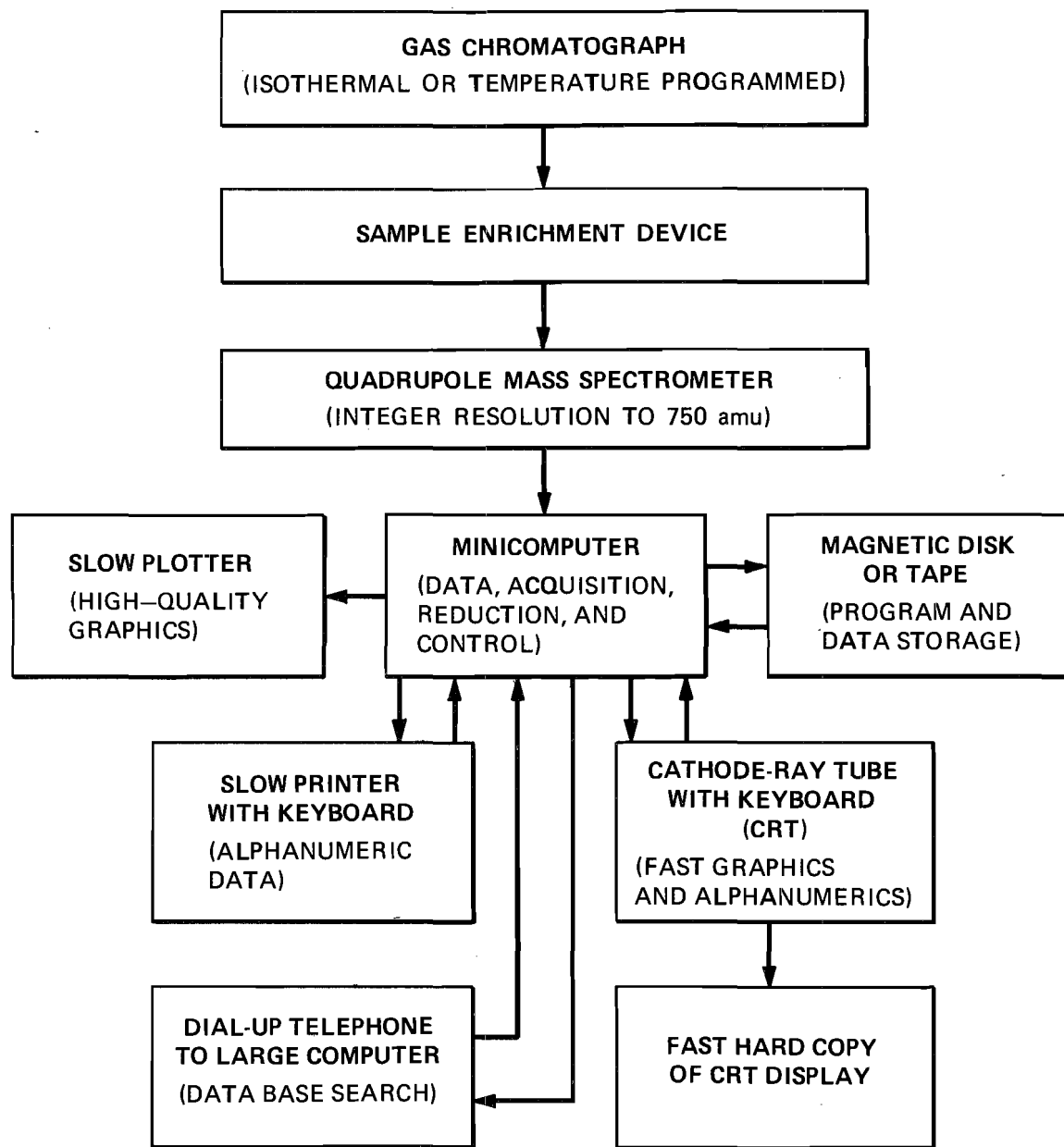


Fig. 2.1.11. Typical computerized GC-MS system. By permission from S. R. Heller, J. M. McGuire, and W. L. Budde, "Trace Organics by GC/MS," *Environmental Science and Technology*, American Chemical Society, Washington, D.C., 1975.

240 cm long and packed with Chromosorb-101 (50–60 mesh) was used for qualitative identifications. The carrier gas was helium at a flow rate of 30 ml/min, and the oven temperatures were initially 125°C for 3 min, followed by a 4°C/min increase up to 220°C. The mass spectrometer (Finnigan 1015C Quadrupole) was controlled by a Systems Industries 150 data-acquisition system.²¹ Quantitative analysis can be accomplished by modifying the desorber to attach directly onto a GC liquid-inlet system. The GC was fitted with a microcoulometric detector.

An alternative method for analysis of the compounds in the left-hand box in Fig. 2.1.12 is direct-aqueous-injection GC-MS using a cross-linked polystyrene-type column.²⁰

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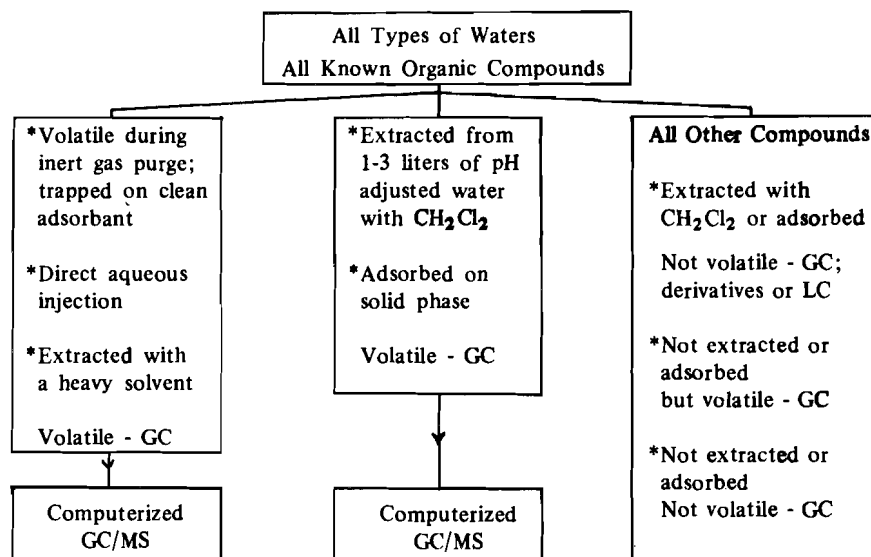


Fig. 2.1.12. Classification of organic compounds according to analytical behavior with survey methods. By permission from L. H. Keith, *Identification and Analysis of Organic Pollutants in Water*, Ann Arbor Science Publishers Inc., Ann Arbor, Mich., 1976.

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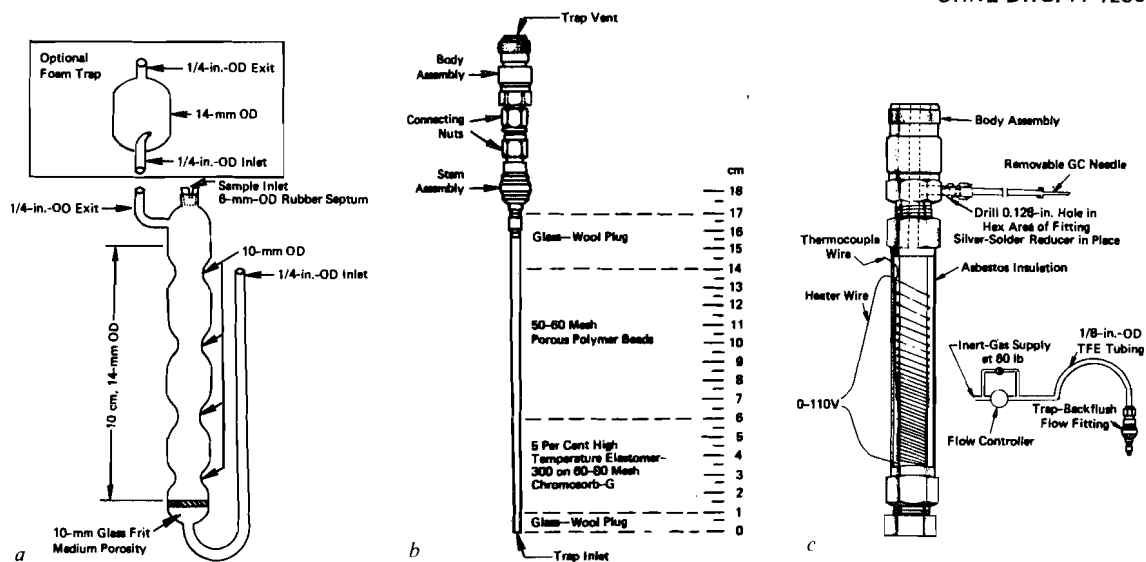


Fig. 2.1.13. The Beller and Lichtenberg organic sample preparation device. (a) depicts the purging device, (b) shows the trapping device, and (c) shows the desorber. By permission from T. A. Bellar and J. J. Lichtenberg, "Determining Volatile Organics at Microgram-per-Liter Levels by Gas Chromatography," *Journal of the American Water Works Association*, American Water Works Association, New York, 1974.

May et al. developed a dynamic head-space sampling procedure for volatile and nonvolatile hydrocarbons, including benzene, toluene, or xylene in water or sediment.²² The sensitivity of this system for single components is at the $\mu\text{g/kg}$ (ppb) level. Collected samples are quick-frozen in the field to minimize loss of low-concentration hydrocarbons. An internal standard consisting of an aromatic hydrocarbon solution of known concentration (about $2 \mu\text{g}/\mu\text{l}$ for each hydrocarbon present) is added to each water sample just prior to freezing. Frozen samples are thawed overnight in the laboratory in a laminar flow hood at a temperature of 4°C (Fig. 2.1.14). Thawed samples (internal standard should now be added to sediment samples) are transferred to 2-liter tared flasks in the amount of 750 ml water or 100 g sediment. About 600 ml of hydrocarbon-free water should be added to each sediment sample.

A 2-liter flask was used as part of the head-space sampling apparatus (Fig. 2.1.15) and was connected to a supply of scrubbed nitrogen gas. The exit of the flask was connected to an 0.6-cm-OD stainless steel column 6.5 cm long, packed with Tenax-GC which had been heated to 350°C for 30 min to remove contaminants. The gas flow through the flask was at a rate of 150 ml/min and a temperature of about 15°C . The head-space was sampled at room temperature for 2 hr; then the flask was heated to 70°C and sampling continued for another 2 hr. Water trapped in the column was removed at the end of the 4 hr by connecting the column directly to the nitrogen line (flow rate = 150 ml/min).

Water remaining in the flask after head-space sampling was subjected to liquid chromatography (LC) as shown in Fig. 2.1.14. The water was first pumped (10 ml/min) through an LC precolumn of 0.6-cm-OD stainless steel (6.5 cm long) which was packed with 37- to $50\text{-}\mu\text{m}$ pellicular (superficially porous) support with a bonded C_{18} -stationary phase. After the head-space-sampled water was pumped through the LC precolumn, the precolumn was attached to an LC capable of gradient elution (Fig. 2.1.16). The column was 0.6-cm-OD stainless steel 30 cm long, packed with $10\text{-}\mu\text{m}$ microparticulate (totally porous) support with a bonded C_{18} -stationary phase. Ten milliliters of hydrocarbon-free water was pumped through the column to remove trapped air, and then elution of compounds was accomplished with a 30:70 (vol/vol) methanol-water mobile phase (3 mg/min rate).

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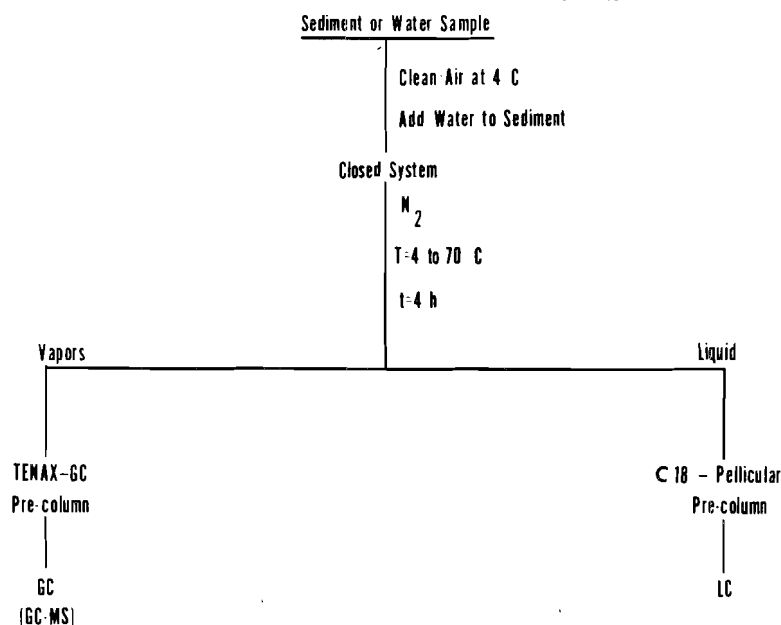


Fig. 2.1.14. Scheme for analysis of hydrocarbons in marine sediments and water. By permission from W. E. May et al., "Chromatographic Analysis of Hydrocarbons in Marine Sediments and Seawater," *Journal of Chromatographic Science*, Elsevier, Amsterdam, 1975.

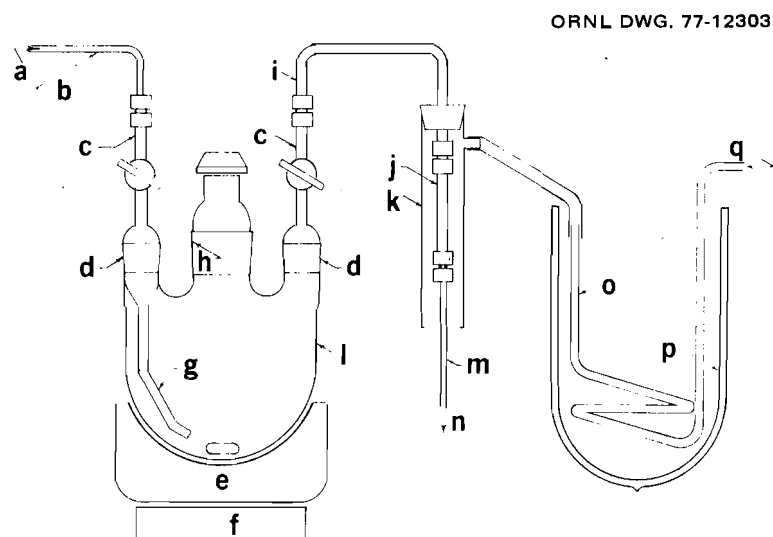


Fig. 2.1.15. Head-space sampling vessel. (a) N₂ gas inlet, (b) copper tubing ($\frac{1}{8}$ in.), (c) glass tubing ($\frac{1}{4}$ in.), (d) tapered joint 24/40, (e) heating mantle, (f) magnetic stirrer, (g) dispersion tube with coarse frit, (h) tapered joint 45/50, (i) glass transfer line ($\frac{1}{4}$ in.), (j) TENAX trap, (k) glass cooling jacket maintained at 15°C with air, (l) 2-liter round-bottom flask, (m) Teflon tubing ($\frac{1}{8}$ in.), (n) to rotometer, (o) copper coil, (p) ice bath, and (q) compressed-air inlet. By permission from W. E. May et al., "Chromatographic Analysis of Hydrocarbons in Marine Sediments and Seawater," *Journal of Chromatographic Science*, Elsevier, Amsterdam, 1975.

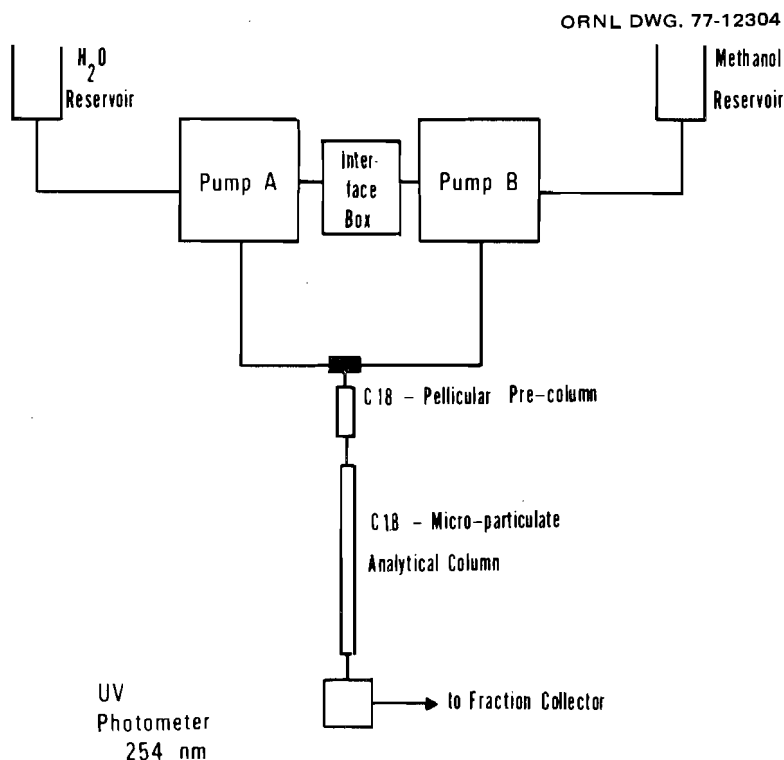


Fig. 2.1.16. Analysis scheme for nonvolatile hydrocarbons by coupled-column liquid chromatography. By permission from W. E. May et al., "Chromatographic Analysis of Hydrocarbons in Marine Sediments and Seawater," *Journal of Chromatographic Science*, Elsevier, Amsterdam, 1975.

The percentage of methanol in the mobile phase was programmed to reach 100% in 40 min. A uv photometer was used as a detector.

The Tenax-GC precolumn was inserted between an unheated GC injection port and a coiled, glass, SE-30-coated, SCOT (surface-coated open tubular) analytical column 100 m long, having an 0.65-mm ID (Fig. 2.1.17). The Tenax-GC precolumn was covered with a heater that was heated to 375°C for 8 min as helium was pumped through the system at 20 ml/min. As the precolumn was heated, the first eight coils of the SCOT column were separated and cooled by spraying with liquid nitrogen to provide thermal focusing of compounds released by the heated precolumn. After the first 8 min, the carrier gas flow was reduced to 6 ml/min, cooling of the SCOT column was stopped, and the GC oven temperature was raised to 50°C and maintained for 8 min. The GC oven temperature was allowed to rise 6°C/min after the 8 min at 50°C until a temperature of 275°C was reached and maintained. Detection was by a flame ionization detector (FID).

The second box in Fig. 2.1.12 represents compounds whose volatility and stability make them especially amenable to GC. These compounds include the chlorinated hydrocarbon pesticides, the PAH, polychlorinated biphenyls (PCB), and others.

Bailey et al. used GC-MS to analyze water samples thought to contain chlorinated hydrocarbon pesticides.²³ Water samples were collected, extracted with chloroform, concentrated, and analyzed by GC for optimum GC-MS conditions.²⁴

Lao, Thomas, and Monkman applied a computerized GC-MS system to the rapid quantitative analysis of PAH in environmental samples.¹⁷ The system collects mass spectra, total ion current, and GC data and performs data reduction—all under complete computer control. The method consists of three steps: (1) preliminary separation of PAH by solvent extraction and/or column chromatography; (2) identification of PAH by a combination of GC with quadrupole mass spectrometry and computer; and (3) measurement of PAH by GC with an FID and a data processor for measuring relative retention times and calculating response factors. Table 2.1.17 summarizes the GC operating conditions.

A quadrupole mass spectrometer has several advantages over the magnetic scanning equipment used in an earlier study by Lao et al.:²⁵ for example, relatively low initial cost yet reasonable resolution; simple design and low volume, permitting high pumping speeds and straightforward maintenance and repair; and extremely high speed mass scans, which are linear with mass and which greatly simplify system control, data logging, and spectra interpretation.²⁶ The principal disadvantages are low resolution and sensitivity at higher masses, which may be largely overcome by using computerized data-processing methods.

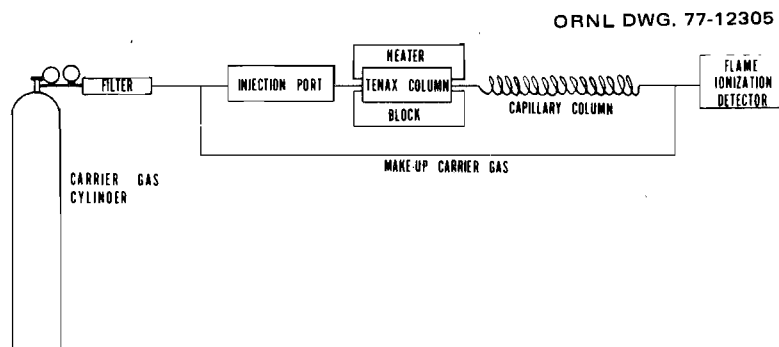


Fig. 2.1.17. Schematic of gas chromatographic flow system showing location of TENAX-GC precolumn. By permission from W. E. May et al., "Chromatographic Analysis of Hydrocarbons in Marine Sediments and Seawater," *Journal of Chromatographic Science*, Elsevier, Amsterdam, 1975.

Table 2.1.17. Chromatographic operating conditions

	Packed column	SCOT column
Detector	FID	FID
Detector temperature, °C	300	300
Liquid sample volume, μ l	0.5	0.2
Sample injector temperature, °C	325	325
Column	12 ft long, 0.125-in. diam, stainless steel, packed with 6% Dexsil 300, 400, or 410 on 80-100 mesh Chromosorb W (HP)	35 ft long, 0.02-in. diam, stainless steel coated with 2% Dexsil 300
Carrier gas (helium) flow, ml/min	40	4
GC-MS split ratio	9:1	1:1
Initial temperature, °C	165, held for 2 min	165, held for 2 min
Programmed temperature, °C/min	4	4
Final temperature, °C	295, held for 50 min	295, held for 80 min
Recorder attenuation	160 and 640	160
GC-MS interface temperature, °C	325	325

By permission from R. C. Lao et al., "Application of a Gas Chromatograph-Mass Spectrometer-Data Processor Combination to the Analysis of the Polycyclic Aromatic Hydrocarbon Content of the Airborne Pollutants," *Analytical Chemistry*, American Chemical Society, Washington, D.C., 1973.

The mass spectrometer was calibrated with perfluorobutylamine (GC-43). Once the spectrometer was properly calibrated, the instrument response for mass range did not change over the experimental period. Instrument sensitivity was checked daily with a sample of decafluorotriphenylphosphine. This compound has a base peak of m/e 198 and key fragments of m/e 275, 442, and 443 in its spectrum; therefore, it is convenient to use for an ion abundance calibration of the high-mass region, where the PAH have their molecular and fragmentation ions.

A computerized data-processing system is necessary for acquiring and storing the great quantity of data produced by the MS. The computer controls the MS scan and, in addition to reducing the burden of analyzing the data, produces final results much more quickly and accurately than would be possible by manual data handling.

Lao, Thomas, and Monkman collected air particulate samples and separated the PAH fraction by the method described earlier in this work.¹⁷ The concentrated PAH fraction was injected into the above-described GC-MS system, and mass spectra were obtained for each eluted GC peak. These spectra were compared with spectra obtained from over 40 primary PAH standards of known purity. The standard or reference solutions were prepared by combining known amounts of pure PAH. These synthetic mixtures were run on the GC-MS system to obtain GC retention times and response factors and MS spectra. Table 2.1.18 lists the GC parameters for the synthetic mixture of PAH on a Dexsil-300 packed column.

Fluoranthene, which has been found in all air samples and is eluted from the GC column as a pure isolated compound, was selected as the internal reference for both relative retention times and response factors.

Gas chromatographic parameters were obtained on both packed (Dexsil-300) and SCOT columns. The columns were preconditioned for 24 hr at 350°C. There was no apparent column bleeding during the TC runs. The final temperature of 295°C was maintained for 50 min to ensure the complete elution of the seven-ring compounds. Concentrations of PAH in the air sample were

Table 2.1.18. Retention time and response factor data of primary PAH standards on Dexsil-300 packed column

Compound name	Relative retention time ^a	Response factor ^a
Biphenyl	0.211	0.751
1,2,3,4,5,6,7,8-Octahydro-anthracene	0.250	0.776
Benzoindene	0.388	0.810
Fluorene	0.412	0.864
9,10-Dihydro-phenanthrene	0.473	0.827
9,10-Dihydro-anthracene	0.499	0.803
2-Methyl-fluorene	0.546	0.916
1-Methyl-fluorene	0.555	0.916
9-Methyl-fluorene	0.603	0.916
Phenanthrene	0.648	0.920
Anthracene	0.664	0.880
Benzoquinoline	0.688	0.926
Acridine	0.708	0.918
2-Fluorene carbonitrile	0.733	0.926
3-Methyl-phenanthrene	0.790	1.042
2-Methyl-phenanthrene	0.795	1.042
2-Methyl-anthracene	0.806	0.998
Dihydro-pyrene	0.962	0.962
Fluoranthene	1.000	1.000
Pyrene	1.064	1.067
Benzo[a]fluorene or 1,2-benzofluorene	1.153	1.137
Benzo[b]fluorene or 2,3-benzofluorene	1.172	1.137
Benzo[c]fluorene or 3,4-benzofluorene	1.777	1.137
2-Methyl-fluoranthene	1.193	1.070
4-Methyl-pyrene	1.196	1.144
3-Methyl-pyrene	1.235	1.142
1-Methyl-pyrene	1.233	1.138
Benzo[c]phenanthrene	1.342	1.238
Benzo[ghi]fluoranthene	1.406	1.250
Benzo[a]anthracene	1.418	1.245
Chrysene	1.428	1.239
Triphenylene	1.432	1.242
4-Methyl-benzo[a]anthracene	1.545	1.328
1-Methyl-chrysene	1.553	1.334
6-Methyl-chrysene	1.565	1.321
β,β' -Binaphthyl	1.582	1.267
7,12-Dimethyl-benzo[a]anthracene	1.636	1.424
9,10-Dimethyl-benzo[a]anthracene	1.631	1.436
Benzo[j]fluoranthene	1.698	1.293
Benzo[k]fluoranthene	1.743	1.426
Benzo[b]fluoranthene	1.748	1.330
Benzo[a]pyrene	1.853	1.322
Benzo[e]pyrene	1.851	1.331
Perylene	1.892	1.332
3-Methyl-cholanthrene	1.985	1.337
1,2,3,4-Dibenzanthracene	2.295	1.342
2,3,6,7-Dibenzanthracene	2.304	1.342
Benzo[b]chrysene	2.440	1.348
<i>o</i> -Phenylenepyrene or 2,3-phenylenepyrene	2.418	1.354
Picene	2.457	1.354
Benzo[c]tetraphene	2.499	1.351
Benzo[ghi]perylene	2.595	1.356
Anthanthrene	2.574	1.350
Coronene	3.523	1.483
1,2,3,4-Dibenzpyrene	3.592	1.485
1,2,4,5-Dibenzpyrene	3.592	1.481

^aRelative to fluoranthene.

By permission from R. C. Lao et al., "Application of a Gas Chromatograph-Mass Spectrometer-Data Processor Combination to the Analysis of the Polycyclic Aromatic Hydrocarbon Content of the Airborne Pollutants," *Analytical Chemistry*, American Chemical Society, Washington, D.C., 1973.

calculated by using the response factors relative to fluoranthene obtained from the GC of the standard PAH. The Dexsil-300 packed column chromatogram is shown in Fig. 2.1.18. Results of the analysis of this particulate air sample on the Dexsil-300 packed column and the SCOT column are shown in Table 2.1.19.

The packed column yielded better GC results than did the SCOT column; coronene, the highest-molecular-weight PAH generally found in air, was completely eluted only on the packed column at the final temperature of 295°C. No further compounds were detected, even with a 60-min extended final temperature program. Calculations of relative percentages were based on the assumption that all components had been eluted. Since coronene was not eluted from the SCOT column, the total integrated area of the chromatogram was less than that of the packed column. The percentage composition of the individual components thus had a calculated difference.

One of the problems inherent in gas-liquid chromatography schemes for separating four- and five-ring PAH is bleeding of the liquid stationary phase from the column packing (support) at elevated temperatures. Janini, Muschik, and Zielinski have synthesized a high-temperature nematogenic crystal, *N,N'*-bis(*p*-butoxybenzylidene)-*a,a'*-bis-*p*-toluidine (BBBT), which greatly reduces the problem of bleeding.²⁷ An 8% loss of liquid phase was reported from a BBBT column operated at a column temperature of 285°C for 100 hr. The resolution and separation factor of chrysene-benz[*a*]anthracene on BBBT remained constant within 2% over a continuous 146-hr operation.

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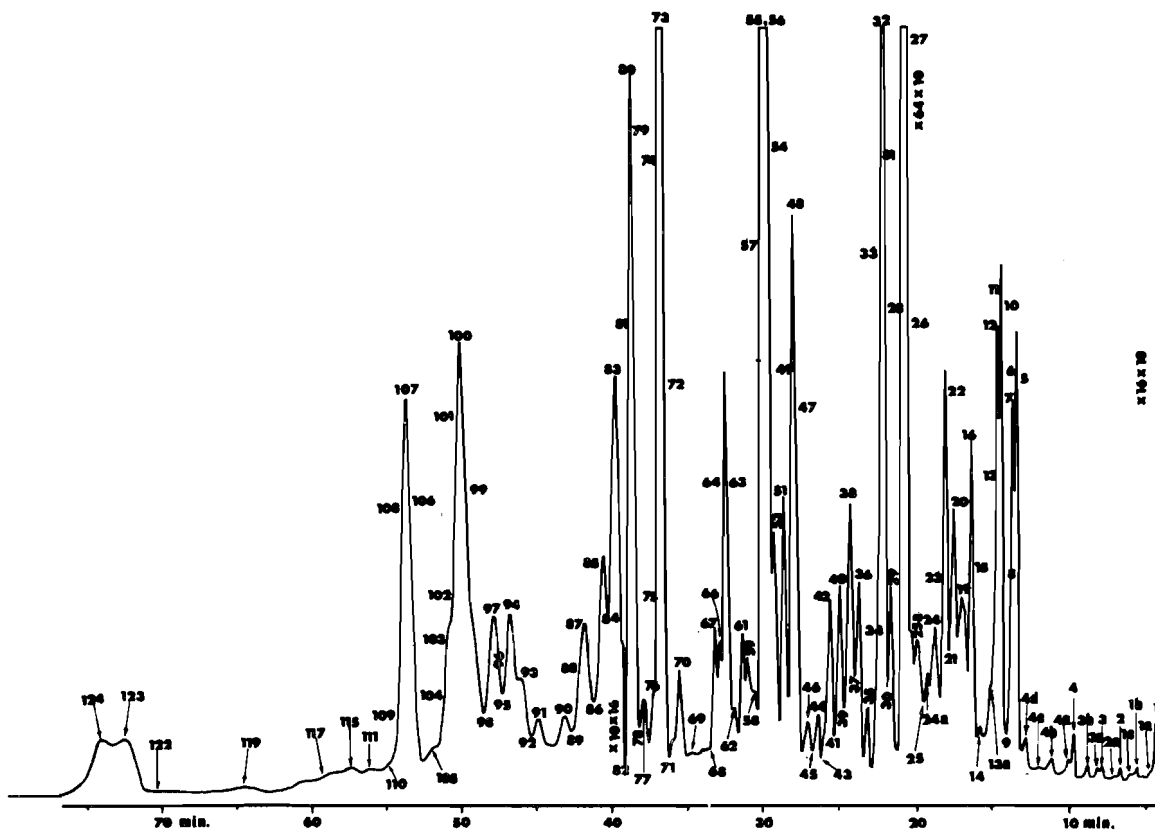


Fig. 2.1.18. Gas chromatogram of air sample on Dexsil-300 packed column. By permission from R. C. Lao et al., "Application of a Gas Chromatograph-Mass Spectrometer-Data Processor Combination to the Analysis of the Polycyclic Aromatic Hydrocarbon Content of the Airborne Pollutants," *Analytical Chemistry*, American Chemical Society, Washington, D.C., 1973.

Table 2.1.19. PAH concentrations in airborne particulate sample

Compound	Dexsil-300 packed column		Dexsil-300 SCOT column	
	Peak number	Concentration ^a (μg)	Peak number	Concentration ^a (μg)
Acridine ^b	12	0.6745	12	0.1907
Anthanthrene ^b	107		107	
Anthracene ^b	7	0.5252	7	0.1058
Benzindene ^b	3	0.0131	3	0.0011
	3a	0.0147	3a	0.0262
Benzo[<i>a</i>]anthracene ^b	55	44.6912	55	13.1333
Benzo[<i>b</i>]chrysene ^b	100	6.5796	100	1.9482
Benzo[<i>b</i>]fluoranthene ^b	72		72	
Benzo[<i>ghi</i>]fluoranthene ^b	51	3.7276	51	0.8372
Benzo[<i>j</i>]fluoranthene ^b	70	1.9437	70	0.4158
Benzo[<i>k</i>]fluoranthene ^b	72	32.8984	72	11.5132
Benzo[<i>a</i>]fluorene ^b	36	2.5566	36	0.5937
Benzo[<i>b</i>]fluorene ^b	38	4.5780	38	1.3954
Benzo[<i>c</i>]fluorene ^b	38		38	
Benzo[<i>ghi</i>]perylene ^b	107	3.8119	107	1.1328
Benzo[<i>c</i>]phenanthrene ^b	48	9.7808	48	3.1300
Benzo[<i>a</i>]pyrene ^b	80	14.9268	80	5.1223
Benzo[<i>e</i>]pyrene ^b	80		80	
Benzoquinoline ^b	11	0.6899	11	0.0609
			11a	0.0159
Benzo[<i>c</i>]tetraphene ^b	105			
β,β'-Binaphthyl ^b	66	1.1838	66	0.7974
Biphenyl ^b	1	0.0941	1	0.0013
Chrysene ^c	55, 58		55, 58	
Coronene ^b	123	1.2522		Not eluted
1,2,3,4-Dibenzanthracene ^b	94	1.3348	94	0.4477
2,3,6,7-Dibenzanthracene ^b	97	1.4697	97	0.3397
Dibenzpyrene ^b	124	1.3621		Not eluted
Dihydro-anthracene ^{b,c}	4a	0.0305	4a	0.0023
Dihydro-benzo[<i>a</i>]anthracene ^c	53	2.4037	53	0.2029
			53a	0.3694
Dihydro-benzo[<i>a</i>]fluorene ^c	29	2.3624	29	0.5384
Dihydro-benzo[<i>b</i>]fluorene ^c	29		29	
Dihydro-benzo[<i>c</i>]fluorene ^c	35	0.5813	35	0.4057
			35a	0.0332
Dihydro-benzo[<i>c</i>]phenanthrene ^c	46	0.5166	46	0.0138
			46a	0.0508
Dihydro-chrysene ^c	53		53, 53a	
Dihydro-fluoranthene ^c	25	0.1826	25	0.0394
Dihydro-fluorene ^c	1b	0.0330	1b	0.0046
Dihydro-fluorene ^c	1c	0.0171	1c	0.0003
Dihydro-methyl-benzo[<i>k&b</i>]fluoranthenes ^c	67	1.6251	67	0.5141
Dihydro-methyl-benzo[<i>ghi</i>]fluoranthene ^c	59	1.0593	59	0.2162
Dihydro-methyl-benzo[<i>a&e</i>]pyrenes ^c	67		67	
Dihydro-phenanthrene ^{b,c}	4	0.0556	4	0.0102
Dihydro-pyrene ^{b,c}	25a	0.1168	25a	0.0633
Dihydro-triphenylene ^c	53		53, 53a	
Dimethyl-anthracene ^c	22		22	
Dimethyl-benzo[<i>a</i>]anthracene ^{b,c}	68a	0.0966	68a	0.979
Dimethyl-benzo[<i>b</i>]fluoranthene ^c	91		91, 93	
Dimethyl-benzo[<i>k</i>]fluoranthene ^c	91	0.3264	91, 93	0.1409
Dimethyl-benzo[<i>a</i>]pyrene ^c	93	0.6661	91, 93	
Dimethyl-benzo[<i>e</i>]pyrene ^c	93		91, 93	
Dimethyl-chrysene ^c	69	0.1136	69	0.0423
Dimethyl-phenanthrene ^c	20		20	0.1424
Ethyl-anthracene ^c	22	1.0451	22, 20a	0.1272
Ethyl-phenanthrene ^c	20	0.8691	20a, 20	0.0199

Table 2.1.19 (continued)

Compound	Dexsil-300 packed column		Dexsil-300 SCOT column	
	Peak number	Concentration ^a (μg)	Peak number	Concentration ^a (μg)
Fluoranthene ^b	27	15.7200	27	4.9620
Fluorene ^b	3b	0.0242	3b	0.0044
Fluorene carbonitrile ^{b,c}	13a	0.1082	13a, 14	0.0297
Fluorene carbonitrile ^{b,c}	14	0.0270		
Hexahydro-chrysene ^c	48		48	
Methyl-anthanthrene ^c	119		119	
Methyl-anthracene ^b	19	0.5985	19	0.1048
Methyl-benzo[<i>a</i>]anthracene ^b	61	1.4318	61	0.0253
Methyl-benzo[<i>b</i>]fluoranthene	77		77	
Methyl-benzo[<i>k</i>]fluoranthene	77	1.7520	77	0.4858
Methyl-benzo[<i>b</i>]chrysene ^c	117	0.0791	117	0.0207
Methyl-benzo[<i>ghi</i>]perylene ^c	122	0.1748		Not eluted
Methyl-benzo[<i>a</i>]pyrene	87	0.8756	87	0.1155
Methyl-benzo[<i>e</i>]pyrene	87		87	
Methyl-benzo[<i>c</i>]tetraphene ^c	117		117	
Methyl-β,β'-binaphthyl ^c	68	0.9169	68	0.1600
Methyl-biphenyl	2	0.0245	2	0.0008
Methyl-biphenyl	2a	0.0098	2a	0.0088
3-Methyl-cholanthrene ^b	85	0.8912	85	0.1072
Methyl-chrysene ^b	64	6.1948	64	1.4590
Methyl-dibenzanthracene ^c	115	0.1587		
Methyl-fluoranthene ^b	40	2.1762	40	0.5211
1-Methyl-fluorene ^b	4c	0.0136	4c	0.0005
2-Methyl-fluorene ^b	4b	0.0405	4b	0.0027
9-Methyl-fluorene ^b	4d	0.0576	4d	0.0070
Methyl-phenanthrene ^c	16	0.5825	16	0.2065
Methyl- <i>o</i> -phenylene-fluoranthene ^c	111	0.0415		
Methyl- <i>o</i> -phenylene-pyrene ^c	119	0.1270	119	0.0111
Methyl-picene ^c	119			
Methyl-pyrene ^b	42	2.6224	42	0.5634
			43	0.0308
Methyl-triphenylene	62	0.3963	62	0.3446
Octahydro-anthracene ^{b,c}	1a		1a	
Octahydro-fluoranthene ^c	24	0.2949	24	0.0385
Octahydro-phenanthrene ^c	1a	0.0163	1a	0.0018
Octahydro-pyrene ^c	24a	0.0832	24a	0.0299
Perylene ^b	83	2.1666	83	0.6619
Phenanthrene ^b	5	0.6102	5	0.2199
<i>o</i> -Phenylene-fluoranthene	90	0.1566	90	0.0092
<i>o</i> -Phenylenepyrene ^b	100		100	
Picene ^b	105	0.0984		
Pyrene ^b	32	16.8904	32	4.8121
Tetrahydro-methyl-benzo[<i>a</i>]anthracene ^c	58	0.9814	58	0.0988
Trimethyl-fluoranthene ^c	44	0.6456	44	0.0628
Trimethyl-pyrene ^{b,c}			44a	0.0258
Triphenylene ^{b,c}	55, 58, 68a		55, 58, 68a	

^aCalibrated with fluoranthene with the specific response 0.3455 μg/unit area.^bDetermined by comparison with a primary standard compound of known purity with respect to relative retention time and mass spectrum.^cCompounds found in the air sample which have not been previously reported.By permission from R. C. Lao et al., "Application of a Gas Chromatograph-Mass Spectrometer-Data Processor Combination to the Analysis of the Polycyclic Aromatic Hydrocarbon Content of the Airborne Pollutants," *Analytical Chemistry*, American Chemical Society, Washington, D.C., 1973.

A differential scanning calorimetry (DSC) scan of BBBT showed phase transition temperatures of 159°C (solid-smectic), 188°C (smectic-nematic), and 303°C (nematic-isotropic). Plots of the retention times of anthracene and phenanthrene on BBBT vs reciprocal absolute temperature show that the retention times decrease with increasing column temperature until the smectic-nematic transition is approached. After the transition temperature is passed, the retention times again increase with temperature increase until the solute volatility overrides the increasing temperature-raising retention effect.

Chromatograms of pentacyclic aromatic hydrocarbons indicate that benzo[*a*]pyrene (BaP) can be separated from benzo[*e*]pyrene as well as from other members of the benzopyrene fraction. In addition, a fairly complex mixture of three- to five-ring PAH isomers can be separated using BBBT. Chromatograms of programmed-temperature gas-liquid chromatographic analyses of a synthetic mixture containing 13 PAH show the retention profiles and elution orders of these compounds. The PAH in this synthetic mixture, in order of increasing retention time, are phenanthrene, anthracene, fluoranthene, pyrene, benzo[*mno*]fluoranthene, triphenylene, benz[*a*]anthracene, chrysene, naphthacene, benzo[*k*]fluoranthene, benzo[*e*]pyrene, perylene, and BaP.²⁷ Liquid crystals having nematic-isotropic transition temperatures above 200°C that have been used as high-temperature gas-liquid chromatographic liquid phases are listed in Table 2.1.20.

Finnigan and Knight (as cited in ref. 20) described a GC-MS method for determination of PAH compounds in oil samples. It is suspected that PAH compounds become concentrated in the refining process and could reach dangerous levels. This method uses a high-resolution glass capillary column GC in combination with electron ionization (EI) MS for PAH instead of chemical ionization (CI) because PAH compounds lend themselves to EI interpretation.²⁰ Operating conditions for the GC-EI-MS are shown in Table 2.1.21. The 1-sec scan rate by the quadrupole MS is a necessity for

Table 2.1.20. Liquid crystals having nematic-isotropic transition temperatures above 200°C

Code	Structure	Molecular weight	Smectic (°C)	Nematic (°C)	$\Delta T_{\text{nematic}}$
I		358		239–265	26
II		372		200–320	120
III		394		189–356	167
IV		420		266–390	>124
V		446		274–340	>66
BMBT		448		181–320	139
VI		489		154–344"	190
BBBT		532	159–188	188–303	115
VII		538	171–184	184–358"	174
VIII		546	83–125	125–206	81
IX		622	150–211	211–316	105

"Decomposes.

By permission from G. M. Janini, G. M. Muschik, and W. L. Zielinski, "N,N-Bis(p-butoxybenzylidene)-α,α'-bis-p-toluidine: Thermally Stable Liquid Crystal for Unique Gas-Liquid Chromatography Separations of Polycyclic Aromatic Hydrocarbons," *Analytical Chemistry*, American Chemical Society, Washington, D.C., 1976.

Table 2.1.21. Conditions used for PAH analysis
of oil sample by glass capillary GC-EI-MS

Column:	20 m × 0.02-in. ID SE-30 glass capillary
Column temperature:	Ambient to 250°C at 4°C/min
Carrier gas:	Helium at 2 cm ³ /min flow
Injector temperature:	250°C
Sample size:	0.2 µl (splitless injection)
Mass range scanned:	40–350 amu
Scan time:	1.227 sec

By permission from L. H. Keith, *Identification and Analysis of Organic Pollutants in Water*, Ann Arbor Science Publishers Inc., Ann Arbor, Mich., 1976.

capillary GC-MS analysis since slower scans cause serious degradation of GC resolution. The difference between a 1-sec scan and a 3-sec scan is shown in Fig. 2.1.19. The m/e value searches in this method are specific for PAH compounds. PAH compounds with a molecular weight at about m/e 252 are those that are the most carcinogenic.²⁰

When analyzing organic mixtures of normal paraffins that contain isomers, the use of a high-resolution glass capillary column GC with CI-MS is recommended. EI-MS can fail to show significant mass spectral differences in isomers present, but CI-MS indicates that isomer differentiation and identification are possible. Finnigan and Knight (as cited in ref. 20) used a sterane sample to test GC-CI-MS effectiveness in isomer separation. Steranes and titerpanes are some of the most complex compounds found in petroleum and rock samples. This particular example involves CI-MS examination of a rock sample which can first be isolated into hydrocarbon classes by either column or thin-layer chromatography. The glass capillary GC column was operated

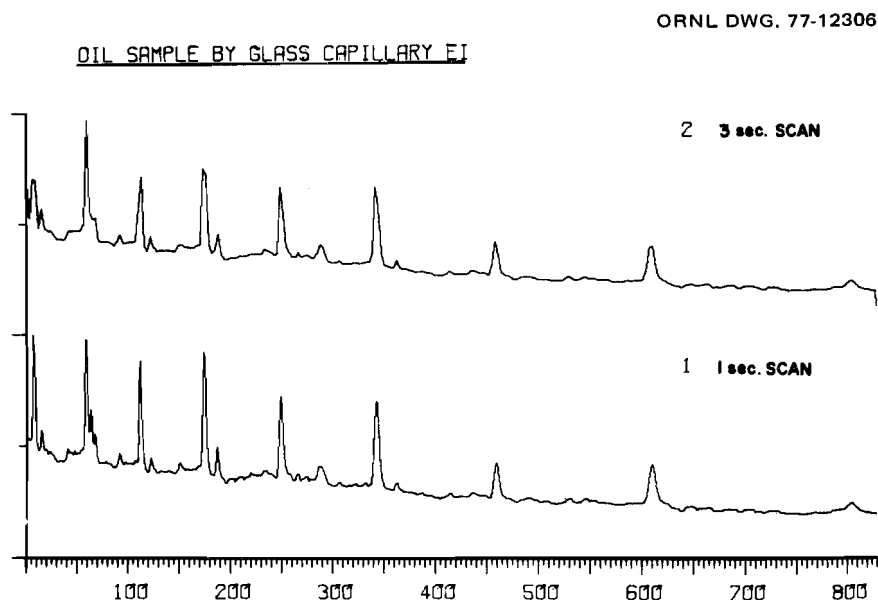


Fig. 2.1.19. Total ion chromatograms of oil sample by glass capillary GC and EI-MS, when scanning at 1-sec mass scan and 3-sec mass scan. By permission from L. H. Keith, *Identification and Analysis of Organic Pollutants in Water*, Ann Arbor Science Publishers Inc., Ann Arbor, Mich., 1976.

under conditions shown in Table 2.1.22. Results of a total-ion scan show sterane isomers (Fig. 2.1.20) in the shaded portion of the chromatogram. CI-MS scans (Figs. 2.1.21 and 2.1.22) show the compounds with the same apparent molecular weight but different m/e ratios in the 390–450 region.²⁰ The CI-MS scans provided differentiation for further study of the compound structure so that its identity can be determined.

The far-right box in Fig. 2.1.12 includes all organic compounds not falling into the parameters previously discussed. These compounds are those that cannot be traced under survey methods such as GC. These compounds—for example, carbamate pesticides—require numerous and specific “analyze-for” methods. The approach having the most promise for analysis of these compounds is high-pressure liquid chromatography (HPLC) with interfacing of a mass spectrometer.²⁰ This method may extend the range of compounds amenable to MS, but since volatility is required for MS, other methods should be developed.

Table 2.1.22. Conditions used for geological sample^a
analysis by glass capillary GC-CI-MS

Column:	50 m × 0.02-in. ID OV-1 glass capillary
Column temperature:	Ambient to 280°C at 4°C/min
Carrier gas:	Helium at a flow of 2 cm ³ /min
Sample size:	2 µg (total) in hexane
Injector split ratio:	10:1
CI reactant gas:	Methane
Source pressure:	1 torr
Mass range:	100–650
Scan time:	3 sec

^aExtract of a several-million-year-old rock.

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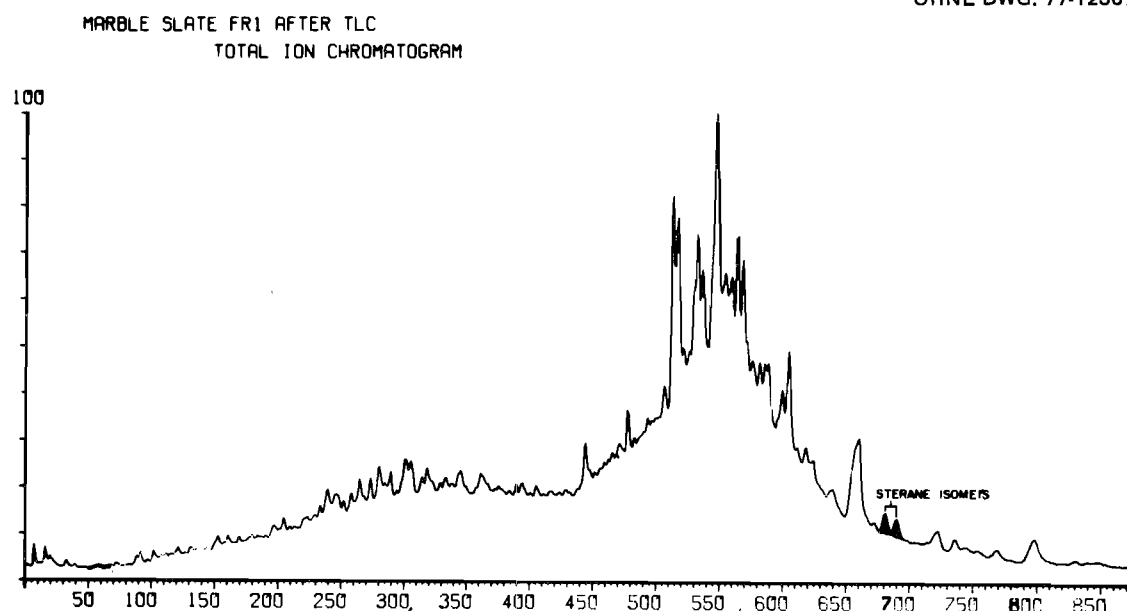


Fig. 2.1.20. Total ion chromatogram of marble slate fraction after separation by thin-layer chromatography. Shaded portion represents sterane isomers. By permission from L. H. Keith, *Identification and Analysis of Organic Pollutants in Water*, Ann Arbor Science Publishers Inc., Ann Arbor, Mich., 1976.

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MARBLE SLATE FR1 AFTER TLC
* 662 -653

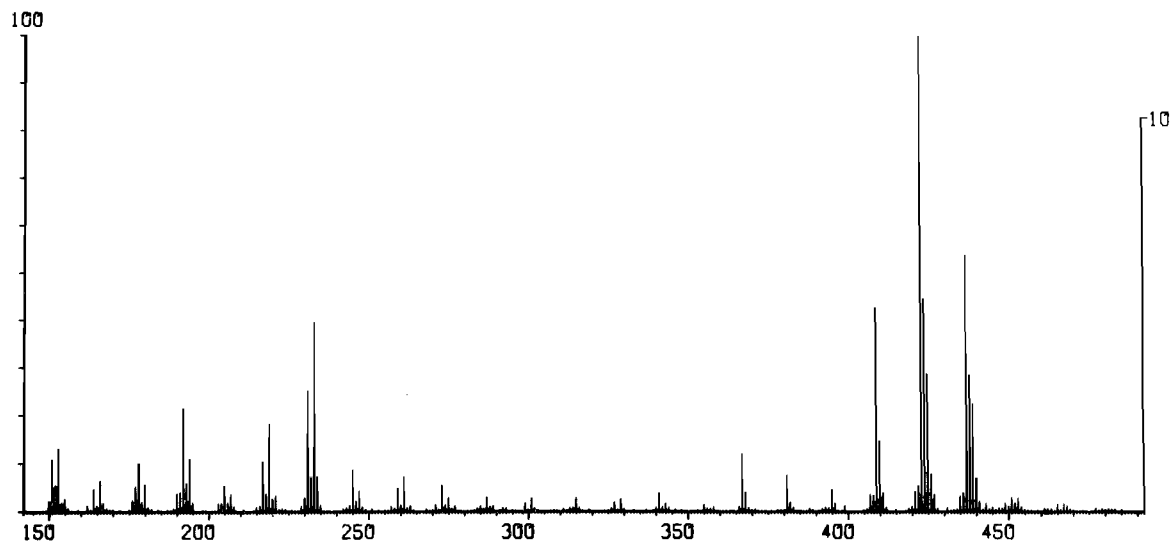


Fig. 2.1.21. Mass spectrum by CI of scan 662 with background subtracted (scan 653). By permission from L. H. Keith, *Identification and Analysis of Organic Pollutants in Water*, Ann Arbor Science Publishers Inc., Ann Arbor, Mich., 1976.

ORNL DWG. 77-12362

MARBLE SLATE FR1 AFTER TLC
* 681 -678

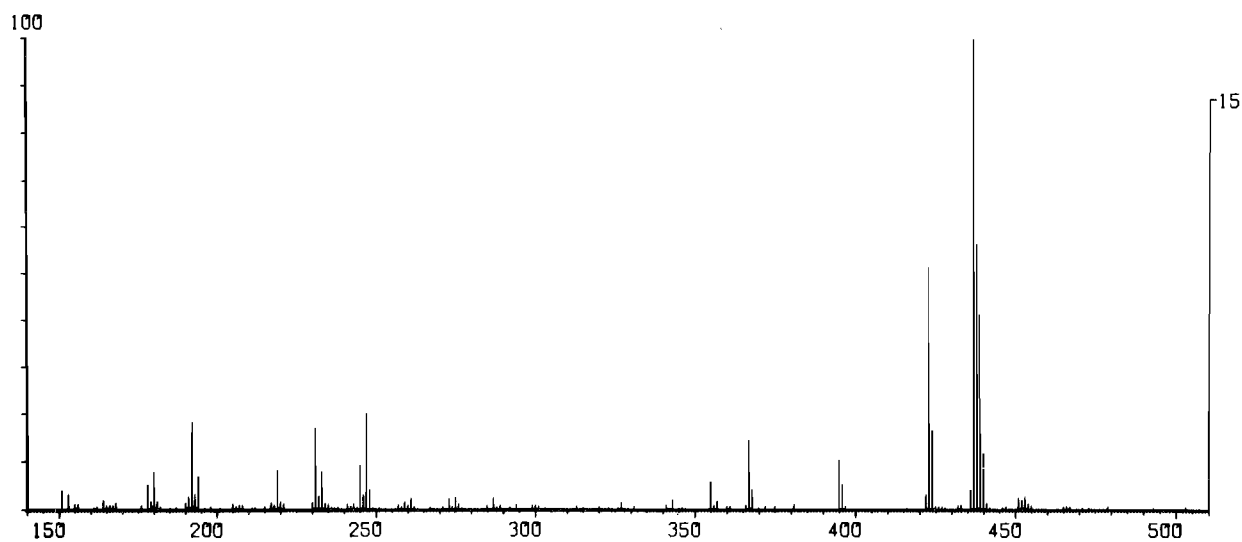


Fig. 2.1.22. Mass spectrum by CI of scan 681 with background subtracted (scan 678). By permission from L. H. Keith, *Identification and Analysis of Organic Pollutants in Water*, Ann Arbor Science Publishers Inc., Ann Arbor, Mich., 1976.

2.1.4.3.2 Trace Elements

Trace elements and other noncombustible components of coal typically constitute 10% to 20% of the total mass. The trace elements occur as an integral portion of the organic coal structure and are not released until the coal is destroyed, as by combustion or conversion.²⁸ The rise in public awareness of trace elements in the environment resulting from coal and other sources has placed a greater emphasis on analytical methods that are economical, efficient, and quick. Analytical methods that are reliable in the fractional parts-per-million range of contaminant in the condensed phase or micrograms per cubic meter of air are necessary for reliable results.²⁹ Trace elements released by coal conversion processes may be identified by a variety of methods.

Analytical techniques

Spectrophotometric techniques have been the basis of many coal analysis methods.³⁰ Spectrophotometry is based on measuring light absorbance by a particular sample as a function of wavelength. Analysis by these techniques normally involves the reaction of a coloring reagent with the element of interest, the addition of needed masking or buffering agents, and measurement of absorbents by the element-reagent complex in a spectrophotometer. For example, an absolute sensitivity of 0.5 to 20 μg has been reported for spectrophotometric measurements of arsenic in biological and environmental samples with complexes of silver diethyldithiocarbamate, ammonium molybdate, and 8-mercaptoquinoline.³¹ A widespread method for cadmium determination is the extraction of cadmium with dithiazone followed by spectrophotometric reading. This method has a sensitivity of 50 $\mu\text{g/liter}$.³²

One of the most widely used techniques for analysis of trace elements is atomic absorption spectrometry (AAS) (Tables 2.1.23 and 2.1.24), in which samples and standards are aspirated into an AAS flame. A hollow cathode lamp provides a source of radiation characteristic of the element of interest. The adsorption of characteristic energy by atoms of the metal in the flame can be related to the metal concentration in the aspirated sample. Sensitivity is adequate for all metals collected in air samples, but not satisfactory for beryllium, cadmium, calcium, chromium, manganese, molybdenum, nickel, or tin in biological samples.³³ The relative standard deviation of AAS measurements is about 3% in the ranges listed in Table 2.1.23.

Interferences occur less often with AAS than with many other methods.³⁴ Potential interferences include (1) background or nonspecific absorption from particles produced in the flame, (2) spectral interferences caused by the adsorption of radiation by atoms other than those of the element being measured, (3) ionization interferences, (4) chemical interferences, and (5) physical interferences due to changes in viscosity or surface tension of the sample. Corrections for many of the interferences are given in Table 2.1.24.

In some instances, increased sensitivity can be obtained by replacing the AAS flame with a graphite-, carbon-, or tantalum-ribbon furnace in which the sample is heated to incandescence (flameless spectrometry). Talmi and Morrison³⁵ and Talmi³⁶ describe a radiofrequency induction furnace in which an induction-heated graphite crucible produces vaporization and atomization of the sample (Fig. 2.1.23). Flameless AAS may be used on all types of samples, but it works best on direct analyses of solid biological and environmental samples without previous processing.³² Absolute sensitivities with the radiofrequency induction furnace are generally inferior to other nonflame systems, but matrix interferences are substantially lower.³⁷ The relative sensitivity of the method is 10^{-4} to $10^{-6}\%$ for zinc, silver, lead, cadmium, indium, and magnesium, with an average standard deviation of 8%. Talmi and Crosmun report detection limits of 5 pg for lead and copper.³⁷

Table 2.1.23. Sensitivity, detection limit, and optimum working range for elements

Element	Sensitivity ($\mu\text{g}/\text{ml}$)	Range ($\mu\text{g}/\text{ml}$)	Detection limits		Minimum threshold limit value ($\mu\text{g}/\text{m}^3$)
			$\mu\text{g}/\text{ml}$	$\mu\text{g}/\text{m}^3$	
Ag	0.036	0.5–5.0	0.003	0.1	10 (metal and soluble compounds)
Al	0.76	5–50	0.04	2	NL ^a
Ba	0.20	1–10	0.01	0.4	500 (soluble compounds)
Be	0.017	0.1–1.0	0.002	0.08	2
Bi	0.22	1–10	0.06	3	NL
Ca	0.021	0.1–1.0	0.0005	0.02	5,000 (CaO)
Cd	0.011	0.1–1.0	0.0006	0.03	200 (metal dust and soluble salts)
					100 (cadmium oxide fume)
Co	0.066	0.5–5.0	0.007	0.3	100 (metal fume and dust)
Cr	0.055	0.5–5.0	0.005	0.2	100 (chromic acid and chromates, as CrO_3)
					500 (soluble chromic, chromous salts)
					1,000 (metal and insoluble salts)
Cu	0.040	0.5–5.0	0.003	0.1	100 (fume)
					1,000 (dusts and mists)
Fe	0.062	0.5–5.0	0.005	0.2	10,000 (iron oxide fume, as iron oxide)
					1,000 (soluble compounds)
In	0.38	5–50	0.05	2	100 (metal and compounds)
K	0.010	0.1–1.0	0.003	0.1	NL
Li	0.017	0.1–1.0	0.002	0.08	25 (as lithium hydride)
Mg	0.003	0.05–0.50	0.0003	0.01	10,000 (as magnesium oxide fume)
Mn	0.026	0.5–5.0	0.003	0.1	5,000 (metal and compounds)
Na	0.003	0.05–0.50	0.0003	0.01	2,000 (as sodium hydroxide)
Ni	0.066	0.5–5.0	0.008	0.3	1,000 (metal and soluble compounds)
Pb	0.11	1–10	0.02	0.8	150 (inorganic compounds, fumes, and dusts)
Rb	0.042	0.5–5.0	0.003	0.1	NL
Sr	0.044	0.5–5.0	0.004	0.2	NL
Tl	0.28	5–50	0.02	0.8	100 (soluble compounds)
V	0.88	10–100	0.1	4	500 (V_2O_5 dust)
					100 (V_2O_5 fume)
Zn	0.009	0.1–1.0	0.002	0.08	1,000 (ZnCl_2 fume)
					5,000 (ZnO fume)

^aNL signifies no limit expressed for the element or its compounds.

By permission from T. J. Kneip et al., "General Atomic Absorption Procedure for Trace Metals in Airborne Material Collected on Membrane Filters," *Health Laboratory Science*, American Public Health Association, Inc., Washington, D.C., 1975.

Interferences may result from smoke or salt particles produced during heating which cause light scattering.³² Flameless techniques usually produce an absorbance peak of shorter duration than do flame techniques.

A major disadvantage of AAS is that at least 1 to 2 ml of solution is needed for determination of each element. Thus, for small samples, the necessary dilution will increase sensitivity requirements.

Spark-source mass spectrometry (SSMS) involves high-energy excitation of solid samples by a radiofrequency spark, followed by spectrometric separation of the ionic fragments from the sample.³⁸ Detection limits for this method are given in Table 2.1.25. Generally, SSMS is capable of extremely high sensitivity and is applicable to about 70 elements.³⁸ Accuracy is usually 20% to 30%, but Carter et al. report that SSMS with isotope dilution is capable of trace element determination with a precision of 10%.³⁹ Limitations of this method are its high cost, limited general accuracy, and the fact that most samples must be in solid form.

Microwave plasma emission spectrometry has been used to analyze organomercury compounds,⁴⁰ alkyl-arsenic acids,³¹ and selenium.⁴¹ An intense argon or helium discharge, powered

Table 2.1.24. Flame and operating conditions for elements

Element	Type of flame	Analytical wavelength (nm)	Interferences ^a	Remedy ^a
Ag	Air-C ₂ H ₂ (oxidizing)	328.1	IO ₃ ⁻ , WO ₄ ²⁻ , MnO ₄ ²⁻	<i>b</i>
Al ^c	N ₂ O-C ₂ H ₂ (reducing)	309.3	Ionization, SO ₄ ²⁻ , V	<i>b, d, e</i>
Ba	N ₂ O-C ₂ H ₂ (reducing)	553.6	Ionization, large concentration of Ca	<i>d, f</i>
Be ^c	N ₂ O-C ₂ H ₂ (reducing)	234.9	Al, Si, Mn	<i>b</i>
Bi	Air-C ₂ H ₂ (oxidizing)	223.1	None known	
Ca	Air-C ₂ H ₂ (reducing)	422.7	Ionization and chemical	<i>d, e</i>
	N ₂ O-C ₂ H ₂			
Cd	Air-C ₂ H ₂ (oxidizing)	228.8	None known	
Co ^c	Air-C ₂ H ₂ (oxidizing)	240.7	None known	
Cr ^c	Air-C ₂ H ₂ (oxidizing)	357.9	Fe, Ni	<i>b</i>
Cu	Air-C ₂ H ₂ (oxidizing)	324.8	None known	
Fe	Air-C ₂ H ₂ (oxidizing)	248.3	High Ni concentration, Si	<i>b</i>
In	Air-C ₂ H ₂ (oxidizing)	303.9	Al, Mg, Cu, Zn, H ₂ PO ₄ ³⁻	<i>b</i>
K	Air-C ₂ H ₂ (oxidizing)	766.5	Ionization	<i>d</i>
Li	Air-C ₂ H ₂ (oxidizing)	670.8	Ionization	<i>d</i>
Mg	Air-C ₂ H ₂ (oxidizing)	285.2	Ionization and chemical	<i>d, e</i>
	N ₂ O-C ₂ H ₂ (oxidizing)			
Mn	Air-C ₂ H ₂ (oxidizing)	279.5	None known	
Na	Air-C ₂ H ₂ (oxidizing)	589.6	Ionization	<i>e</i>
Ni	Air-C ₂ H ₂ (oxidizing)	232.0	None known	
Pb	Air-C ₂ H ₂ (oxidizing)	217.0	Ca, high concentration SO ₄ ²⁻	<i>b</i>
		283.3		
Rb	Air-C ₂ H ₂ (oxidizing)	780.0	Ionization	<i>d</i>
Sr	Air-C ₂ H ₂ (reducing)	460.7	Ionization and chemical	<i>d, e</i>
	N ₂ O-C ₂ H ₂ (reducing)			
Tl	Air-C ₂ H ₂ (oxidizing)	276.8	None known	
V ^c	N ₂ O-C ₂ H ₂ (reducing)	318.4	None known in N ₂ O-C ₂ H ₂ flame	
Zn	Air-C ₂ H ₂ (oxidizing)	213.9	None known	

^aHigh concentrations of Si in the sample can cause an interference for many of the elements in this table and may cause aspiration problems. No matter what elements are being measured, if large amounts of silica are extracted from the samples, the samples should be allowed to stand for several hours and should be centrifuged or filtered to remove the silica.

^bSamples are periodically analyzed by the method of additions to check for chemical interferences. If interferences are encountered, determinations must be made by the standard additions method, or, if the interferent is identified, it may be added to the standards.

^cSome compounds of these elements will not be dissolved by the procedure described here. When determining these elements, one should verify that the types of compounds suspected in the sample will dissolve if using this procedure.

^dIonization interferences are controlled by bringing all solutions to 1000 ppm Cs (samples and standards).

^e1000 ppm solution of La as a releasing agent is added to all samples and standards.

^fIn the presence of very large Ca concentrations (greater than 0.1%), a molecular absorption from Ca(OH)₂ may be observed. This interference may be overcome by using a background correction when analyzing for Ba.

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by a microwave generator, is produced in a capillary tube, and the sample (previously separated by GC) is placed inside. The sample is instantly fragmented into molecular species and free atoms. The plasma is an efficient spectroscopic excitation source and produces a characteristic spectrum which can be monitored. The detection limits are 20 and 40 pg for arsenic and selenium, respectively, and 0.002 to 0.0005 ng for mercury.

X-ray fluorescence (XRF) is a cheap and rapid quantitative analysis tool, requiring no time-consuming chemical concentration or alteration steps.⁴² With XRF, *K* or *L* orbital electrons are ejected from atoms of the element when the sample is irradiated by an x-ray source. A series of x-ray lines are emitted when the ejected electrons are replaced by those from outer orbits; the x-ray spectrum given off is then read by a detector.³²

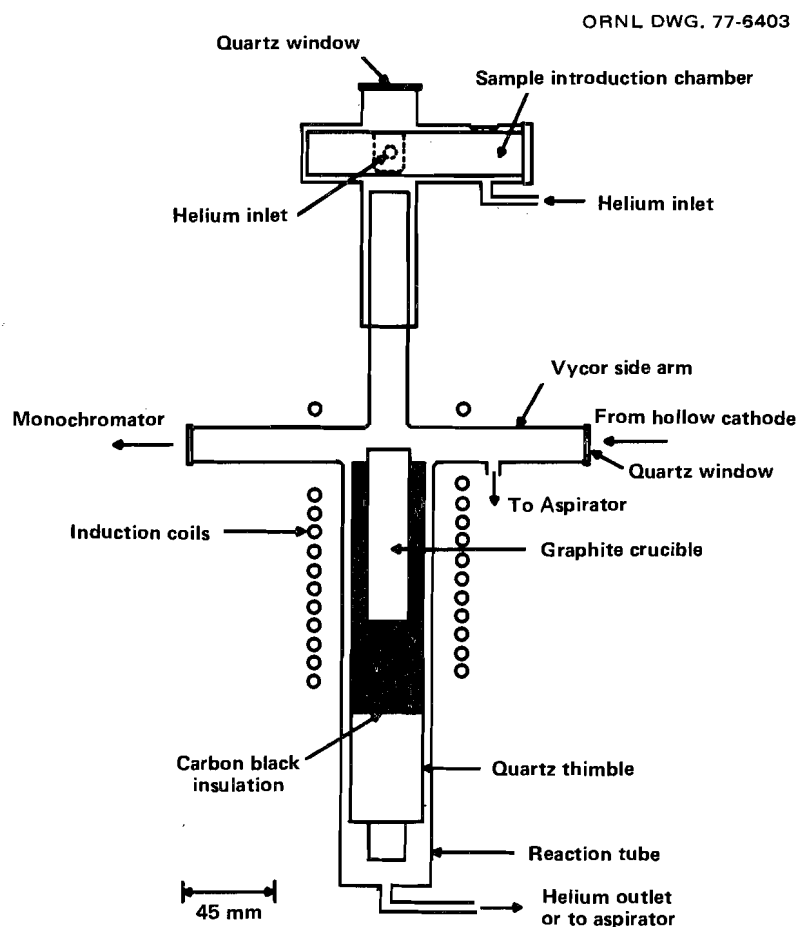


Fig. 2.1.23. Radiofrequency source chamber. By permission from Y. Talmi and F. H. Morrison, "Induction Furnace Method in Atomic Spectrometry," *Analytical Chemistry*, American Chemical Society, Washington, D.C., 1972.

Table 2.1.25. Detection limits (ng) for elements
by spark-source mass spectrometry

Ag, 0.2	Er, 0.5	Mn, 0.05	Sm, 0.5
Al, 0.02	Eu, 0.2	Mo, 0.3	Sn, 0.3
As, 0.06	Fe, 0.05	Na, 0.02	Sr, 0.09
Au, 0.2	Ga, 0.09	Nb, 0.08	Ta, 0.2
Ba, 0.2	Gd, 0.5	Nd, 0.4	Tb, 0.1
Be, 0.008	Hg, 0.6	Os, 0.4	Th, 0.2
Bi, 0.2	Ho, 0.1	Pb, 0.3	Ti, 0.05
Ca, 0.03	In, 0.1	Pd, 0.3	Tl, 0.2
Cd, 0.3	Ir, 0.3	Pr, 0.1	Tm, 0.1
Ce, 0.1	K, 0.03	Pt, 0.5	V, 0.04
Co, 0.05	La, 0.1	Re, 0.2	W, 0.5
Cr, 0.05	Li, 0.0006	Rh, 0.09	Yb, 0.5
Cs, 0.1	Lu, 0.1	Ru, 0.03	Zn, 0.1
Cu, 0.08	Mg, 0.03	Sc, 0.04	Zr, 0.1
Dy, 0.5			

By permission from J. J. Dulka and T. H. Risby, "Ultratrace Metals in Some Environmental and Biological Systems," *Analytical Chemistry*, American Chemical Society, Washington, D.C., 1976.

Major limitations of the method are lack of sensitivity, dependence on sample thickness, and application restricted to the heavier elements.³⁸ Detection limits for several elements are given in Table 2.1.26. Sparks et al. describe a system that uses a monochromatic x-ray diffractor and a solid-state-detector energy-analyzing system (Fig. 2.1.24).⁴² The monochromatization by diffraction improves detectability as compared with systems using white radiation or transmission target x-ray tubes. This system is capable of detection limits below 1 ppm by weight for heavy elements to 10 ppm for lighter elements in a variety of samples. The accuracy of the monochromatic method compares favorably with NBS standard reference materials for many elements (Table 2.1.27).

Neutron activation analysis (NAA) is a highly sensitive (Table 2.1.28), nondestructive method for analysis of many elements.⁴³ Basically, the method consists of irradiation of samples in a nuclear reactor, which produces radioisotopes of the element of interest. Appropriate measurement of daughter activities affords a means for calculating the parent isotope (element) concentrations.³²

Table 2.1.26. Detection limits (μg) for elements by x-ray fluorescence spectrometry^a

Ag, 1.2	Cs, 0.15	Nd, 0.30	Sr, 0.00007
Al, 5.0	Cu, 0.00002	Ni, 0.06	Tb, 159/ml
As, 0.11	Eu, 0.66	P, 0.001	Te, 0.12
Au, 0.001/cm ²	Fe, 0.0085	Pb, 0.0003	Th, 6.5/ml
Ba, 0.12	Ga, 0.01	Rb, 0.0075	Ti, 0.001
Bi, 0.61	Hg, 0.24	Rh, 103/ml	U (as UO ₂), 0.72
Ca, 0.100	In, 1.1	Sc, 0.38	U, 0.00002
Cd, 0.40	K, 0.52	Se, 0.020/cm ²	Y, 0.22
Ce, 0.17	La, 0.12	Si, 170 ppm	Yb, 6.8/ml
Co, 0.05	Mn, 0.00015	Sm, 4.1/ml	Zn, 0.00004
Cr, 0.00006	Mo, 0.072	Sn, 3.9 ppm	Zr, 0.00002

^aElements not available: Be, Dy, Er, Gd, Ge, Hf, Ir, Li, Lu, Mg, Na, Nb, Np, Os, Pa, Pd, Pr, Pu, Re, Sb, Ta, Tm, and W.

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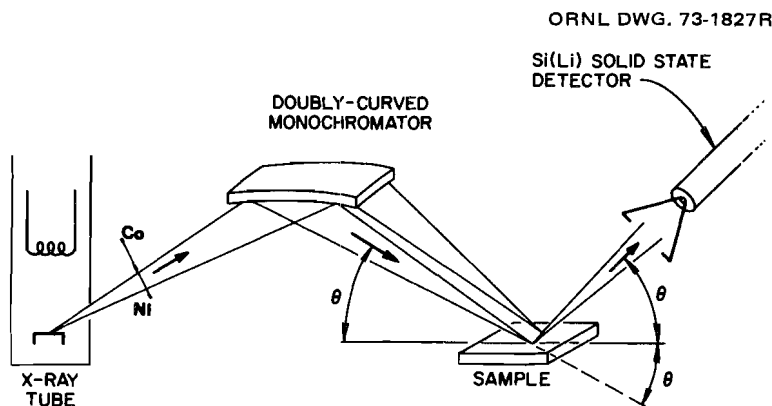


Fig. 2.1.24. Arrangement using a primary beam monochromator to select a monoenergetic x-ray source to excite characteristic x rays for fluorescent analysis. Solid-state detector provides the energy resolution for identifying the fluorescent energies from the sample. By permission from C. J. Sparks, Jr., et al., "Simple, Quantitative X-Ray Fluorescent Analysis for Trace Elements," pp. 361-68 in *Trace Substances in Environmental Health. VII*, University of Missouri, Columbia, Mo., June 12-14, 1974, University of Missouri, 1974.

Table 2.1.27. Comparison of concentrations determined by XRF with NBS standard reference materials

Element	Orchard leaves		Coal	
	NBS 1571 reference standard (ppm)	XRF (ppm)	NBS 1632 reference standard (ppm)	XRF (ppm)
Fe	300 ± 20	301 ± 2.5	(8600)	7150 ± 800
Cu	12 ± 1	9.6 ± 1.7	18 ± 2	22.6 ± 3
Zn	25.3 ± 3	25 ± 1.6	37 ± 4	36.6 ± 1.4
As	14 ± 2	15.3 ± 0.5	5.9 ± 0.4	3 ± 2
Se			2.8 ± 0.2	5.5 ± 0.5
Br	(10)	6.6 ± 0.4		23.7 ± 3.2
Rb	12 ± 1	11.2 ± 0.4		28.6 ± 3.2
Sr	(37)	34.3 ± 0.5		155 ± 15
Pb	45 ± 3	40 ± 2	30 ± 9	23 ± 0.9

By permission from C. J. Sparks, Jr., et al., "Simple, Quantitative X-Ray Fluorescent Analysis for Trace Elements," pp. 361-68 in *Trace Substances in Environmental Health. VII, University of Missouri, Columbia, Mo., June 12-14, 1974*, University of Missouri, 1974, Table I, p. 365.

Table 2.1.28. Sensitivities^a for elements by neutron activation analysis^b

Sensitivity (g)	Elements
10^{-13} – 10^{-12}	Dy, Eu
10^{-12} – 10^{-11}	Au, In, Mn
10^{-11} – 10^{-10}	Hf, Ho, Ir, La, Re, Rh, Sm, V
10^{-10} – 10^{-9}	Ag, Al, As, Ba, Co, Cu, Er, Ga, Hg, Lu, Na, Pd, Pr, Sb, Sc, U, W, Yb
10^{-9} – 10^{-8}	Cd, Ce, Cs, Gd, Ge, Mo, Nd, Os, Pt, Ru, Sr, Ta, Tb, Th, Tm
10^{-8} – 10^{-7}	Bi, Ca, Cr, Mg, Ni, Rb, Se, Te, Ti, Tl, Zn, Zr
10^{-7} – 10^{-6}	Pb
10^{-6} – 10^{-5}	Fe

^aSensitivity based on irradiation period of $0.5t_{1/2}$ or 10 hr, whichever is less at a flux of 10^{13} neutrons $\text{cm}^{-2} \text{sec}^{-1}$. Activity measured by NaI(Tl) gamma spectrometry.

^bSensitivities for activation analysis are dependent on the thermal neutron fluxes at the irradiation facility, time of irradiation, and half-lives of the radioisotopes measured, among other factors. Hence, the numbers quoted here are only representative of the high sensitivities that can be obtained by neutron activation analysis.

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Disadvantages of this method are the expense of facilities and the slowness of analysis, especially for elements yielding nuclei having long half-lives.³⁸ As a result, NAA usually is used only in multielement analysis, where cost and time are not of great importance.

Quantification of trace elements in coal is a first step in appraising the potential for trace element catalysis of coal conversion reactions and the possible environmental impact of a conversion process. Trace elements have been determined by many techniques, some of which were discussed in more detail earlier in this section. Pollock used dry ashing and acid dissolution followed by conventional AAS to determine lithium, beryllium, vanadium, chromium, manganese, cobalt, nickel, copper, zinc, silver, cadmium, and lead.⁴⁴ Flameless AAS determinations of bismuth, selenium, tin, tellurium, beryllium, lead, arsenic, cadmium, chromium, antimony, and germanium were made with the aid of a graphite furnace accessory. Mercury can be determined by this technique after oxygen bomb combustion.

Dreher and Schleicher discuss optical emission spectroscopic techniques used to analyze 16 trace elements in coal ash produced at high temperatures.⁴⁵ Coal samples are ashed in a high-temperature muffle furnace, which mainly produces oxides of the elements measured in this method. Two kinds of instruments for emission spectrometric measurements are discussed: (1) a direct-reading spectrometer, used to analyze tin, boron, lead, copper, cobalt, nickel, beryllium, chromium, vanadium, molybdenum, and germanium; and (2) a photographic-plate recording spectrograph for determination of boron, manganese, chromium, lead, beryllium, vanadium, silver, copper, zinc, zirconium, cobalt, and nickel. Standard operating conditions for both instruments are shown in Table 2.1.29. Major drawbacks in the use of emission techniques include the great care that must be exercised in the ashing procedure to guard against contamination or loss of certain elements and the sample inhomogeneities that cause variations in emission intensities.

Sharkey, Kessler, and Friedel used SSMS to determine trace elements in respirable-range mine dusts and prepared coal dusts.⁴⁶ A commercial Mattauch-Herzog mass spectrometer equipped with photographic and electrical detection systems and a radiofrequency spark source was used; instrument resolution is 1 part in 5000. Electrodes are prepared by mixing the samples with equal parts of pure graphite plus 50 ppm indium to ensure homogeneous mixing and to determine plate sensitivity. This mixture, one for each sample, is pressed into electrodes in polyethylene slugs in a commercial isostatic die. Samples are analyzed by making graded photoplate exposures ranging from 1×10^{-12} to 3×10^{-7} .

Muter and Nice used AAS to analyze coal samples for major and minor constituents in siliceous materials.⁴⁷ A lithium tetraborate fusion-acid dissolution technique was applied to coal ash to determine silicon, aluminum, iron, titanium, calcium, magnesium, sodium, potassium, manganese, nickel, barium, silver, gold, chromium, copper, gallium, indium, molybdenum, antimony, and zinc. The technique used high-temperature ashing to produce samples for analysis. Standards for ash analyses are prepared in aqueous solution from commercially available pure salts, with appropriate acid additions, where necessary, to match acid concentrations in the samples and to hold materials in solution. The lithium tetraborate fusion technique makes determinations of mercury, and possibly lead and tin, questionable because of the volatility of the elements. Relative error values for the elements ranged from 0 to a high of 18%, with most values being 5% or less. The 18% error was for indium and was attributed to the low concentration of the element.

Kuhn, Harfst, and Shimp used XRF for the analysis of whole coal.⁴⁸ High- and low-temperature ashes were analyzed prior to whole-coal samples. The first phase of the work was to prepare calibration curves by independent methods and use the curves as standards. The accuracy of the XRF method depends on the accuracy of the methods used to prepare the calibrating standards.

Table 2.1.29. Standard operating conditions

	Spectrometric	Spectrographic
Instrument	Jarrell-Ash Model 750 Atomcounter	Jarrell-Ash 3.4-m Ebert with 3-lens collimating system
Arc current, A	15 (short circuit)	11 (true)
Arc voltage, V, dc		250
Electrode gap, mm	6	4
Exposure time, sec	65	Completion + 10 (usually about 150)
Electrodes		
Sample	National L-3979	National L-3903 (ASTM C-13)
Counter	National L-4036 (ASTM C-1)	National L-4037 (ASTM C-1 with radial tip)
Electrode atmosphere	80% argon, 20% oxygen at 10 scfh	80% argon, 20% oxygen at 14 scfh
Sample charge, mg	15	20
Attenuation ^a		Neutral density filter, 6% transmittance
Step sector		1:1.585, 8 steps
Entrance slit width, μm	10	25
Exit slit width, μm	50	
Development		3.0 min in Eastman D-19, 30 sec in 2.4% acetic acid, 4.0 min in Eastman fixer

^aBecause the concentrations of most trace elements in the ash were too high to be recorded on a total energy ignition, it was necessary to insert a neutral density filter in the light path after the second lens of the three-lens collimating system.

By permission from G. B. Dreher and J. A. Schleicher, "Trace Elements in Coal by Optical Emission Spectroscopy," pp. 35-47 in *Trace Elements in Fuel*, S. P. Babu, ed., Advances in Chemistry Series 141, American Chemical Society, Washington, D.C., 1975.

The comparative accuracy and detection limits of this method are shown in Table 2.1.30. Coal samples are ground with a binder and pressed into a 1 $\frac{1}{8}$ -in.-diam disc under 40,000 psi pressure. Samples showed the greatest precision when ground to -325 mesh and failed to yield acceptable results when left as large as -60 mesh. This method yields reasonably accurate analyses of whole coals with a simplicity and speed that makes it important in large-scale surveys of coal resources.⁴⁸

Carter, Walker, and Sites used SSMS and thermal emission mass spectrometry (TEMS) to determine trace elements in coal.⁴⁹ Conducting electrodes for general scan analysis are prepared by mixing the pulverized coal or ash sample with an equal amount of pure silver powder (99.999% silver). The mixture is then pressed into polyethylene slugs in an isostatic electrode die at 25,000 psi for 1 min.

Table 2.1.30. Comparative accuracy for whole coal and limits of detection based on 50 samples

Element	Accuracy (%)	Limit of detection (%)
Al	±0.08	0.012
Si	±0.10	0.016
S	±0.04	0.003
Cl	±0.01	0.0015
K	±0.02	0.003
Ca	±0.04	0.0005
Mg	±0.010	0.015
Fe	±0.10	0.005
	(ppm)	(ppm)
Ti	±6.3	7.5
V	±3.1	2.5
Ni	±1.9	3.5
Cu	±2.5	1.0
Zn	±23.0	2.0
As	±4.3	3.2
Pb	±7.7	1.8
Br	±1.0	0.5
P	±15.0	15.0
Co	±1.3	2.5
Mn	±3.4	4.5
Cr	±2.1	1.5
Mo	±5.2	5.0

By permission from J. K. Kuhn, W. F. Harfst, and N. F. Shimp, "X-Ray Fluorescence Analysis of Whole Coal," pp. 66-73 in *Trace Elements in Fuel*, S. P. Babu, ed., Advances in Chemistry Series 141, American Chemical Society, Washington, D.C., 1975.

Thermal emission mass spectrometry has been used to determine lead and uranium in coal and fly ash. A three-stage thermal emission mass spectrometer is used in this work. Lead analyses are conducted by thermally producing lead ions at rhenium filament temperatures of 1100° to 1300°C and producing uranium ions at rhenium filament temperatures of 1700° to 1825°C.⁵⁰ Small quantities of uranium (10 to 100 ng) in the form of uranium nitrate are loaded onto rhenium V-type canoe filaments, which produce ions for analysis. Pulse counting is used for ion detection. The loaded filaments are placed in the instrument, and the source region is pumped down to a pressure of 1×10^{-5} torr. The filaments were carburized in situ, with benzene vapor introduced through a Granville-Phillips variable leak. The resulting carburized filaments reduce the UO_2^+ ion signals to near zero and enhance the U^+ signal. The precision of an isotope dilution analysis, when using this technique in which reagent blank contributions are kept insignificant, is usually within $\pm 1\%$.⁴⁹

Frost et al. used NAA for the determination of antimony, arsenic, bromine, cadmium, cesium, gallium, mercury, rubidium, selenium, uranium, and zinc.⁵¹ The technique involves irradiating the coal sample with thermal neutrons and determining the elements with an NaI(Tl) detector and a

400-channel pulse-height analyzer. The use of a solid-state Ge(Li) detector and a 1000- to 4000-channel analyzer can extend instrumental NAA to as many as 43 major, minor, and trace elements. The range and scope of the NAA method make it a good procedure for rapidly monitoring the composition of many coal samples.

2.1.4.3.3 Other Pollutants

Phenols

Phenols, the hydroxy derivatives of benzene and its condensed nuclei, are normally analyzed by one of three 4-aminoantipyrene colorimetric methods. The methods determine phenol and ortho-, meta-, and parasubstituted phenols (the substitution is a carboxyl, halogen, methoxyl, or sulfonic acid group) under proper pH conditions.¹⁴ The 4-aminoantipyrene colorimetric method used for extreme sensitivity is method B. Samples must be protected from interferences such as phenol-decomposing bacteria, oxidizing and reducing substances, and alkaline pH values. CuSO₄ added to a sample can inhibit bacterial action, and the addition of H₃PO₄ acidifies the sample and can eliminate chemical changes caused by an alkaline pH. Oxidizing agents can be removed by lowering the pH to less than 4.0 with the H₃PO₄ and aerating by stirring before adding the CuSO₄.

Method B is used when the phenol concentration is less than 1 mg/liter. The sample purification principle is that phenols distill at about a constant rate from nonvolatile impurities and that the rate of volatilization is gradual so that the volume of the distillate must equal the volume of the sample being distilled. A 500-ml sample at pH 4.0 (achieved by adding the H₃PO₄) which contains 5 ml of CuSO₄ should be distilled until 450 ml is in the receiving flask; distillation should then be stopped and 50 ml of phenol-free water added to the distilling flask. Distillation should be continued until 500 ml of purified sample has been collected. The 500-ml pure sample should be placed in a 1-liter bottle; 10 ml of NH₄Cl should be added and the pH should be adjusted to 10.0 ± 0.2 with concentrated NH₄OH. The mixture should next be placed in a 1-liter separatory funnel and 3.0 ml of aminoantipyrene solution (2.0 g of aminoantipyrene per 100 ml of H₂O) added. Let the color develop for 3 min and extract immediately with chloroform. The amount of chloroform used for extraction depends on the size of absorption cells used with the photometric equipment (1- to 5-cm cells require 25 ml chloroform and 10-cm cells require 50 ml chloroform). The chloroform extract should be filtered and dried. The extracts should be examined in either a spectrophotometer or a filter photometer set to 460 nm. The amount of phenol in the unknown can be determined by:

$$\mu\text{g/liter phenol} = \frac{CD}{E} \frac{1000}{B}, \quad (1)$$

where C = micrograms of known phenol solution, D = absorbance reading of unknown sample, E = absorbance of known sample, and B = milliliters of original sample.

Method C is used when the phenol concentration is greater than 1 mg/liter and less sensitivity is acceptable (minimum detectable quantity is 0.1 mg of phenol when a 5-cm absorbance cell and a 100-ml distillate are used). The method is simply to take 100 ml of sample distillate plus a known sample and a blank, add 2.0 ml of NH₄Cl, adjust the pH to 10.0 ± 0.2 with NH₄OH, add 2.0 ml of aminoantipyrene solution and mix well, add 2 ml of potassium ferricyanide solution and mix well, wait 15 min and transfer to absorbance cells. The samples (unknown, known, and blank) are measured at 510 nm and the unknown phenol concentration is calculated by Eq. (1).

The results of work by Junk et al. with macroreticular resins (Sect. 2.1.4.3.1) can also be applied to phenols.¹⁶ Sampling was by the same method reported earlier. Elution of the resin column was accomplished by washing with 25 ml of diethyl ether. Residual water was removed from the diethyl ether by immersing the receiver in liquid nitrogen for two 10-sec intervals. The ether was decanted into a concentration vessel, a boiling chip was added, and a Snyder column was attached. The ether was boiled over a hot plate with a solvent evaporation rate of 0.5 to 2.0 ml/min until 1.00 ml remained in the concentration vessel. Compounds in the ether were subjected to GC and detected with an FID. The column was stainless steel (6 ft $\times$ $\frac{1}{8}$ -in. OD) packed with 80–100 mesh acid-washed DMCS-treated Chromosorb W coated with 5 wt % OV-1 liquid phase. A du Pont 21-490-1 combination gas chromatograph-mass spectrometer was used to identify organics eluted from the XAD resins.

Ammonia

Ammonia occurs naturally in nature and nitrogen in this form is of great interest in waters and wastewaters. Ammonia concentrations can vary from 50 mg of nitrogen per liter in wastewaters to less than 10 mg of nitrogen per liter in other waters.¹⁶ Two colorimetric methods normally are used for ammonia determinations: the nesslerization method which is sensitive to 20 μ g of nitrogen per liter under optimum conditions and can be used for concentrations up to 5 mg of nitrogen per liter and the phenate method which has a sensitivity of 10 μ g of nitrogen per liter and is useful for concentrations of ammonia nitrogen up to 500 μ g/liter. Ammonia concentrations of above 5 mg of nitrogen per liter can best be determined by a titration procedure preceded by distillation of the sample. Best results by any method are obtained with fresh samples which have had chlorine (which would react with ammonia) removed by the addition of 0.8 ml of concentrated H_2SO_4 per liter. The acidity should be neutralized immediately before determination by addition of NaOH or KOH. The sample should be buffered to pH 9.5 with a borate buffer and distilled into either a boric acid solution (nesslerization) or in sulfuric acid (phenate method).¹⁶

The nesslerization procedure begins with formation of the Nessler reagent. One hundred grams of HgI_2 and 70 g KI are dissolved in a small quantity of water and this mixture is slowly added, with stirring, to a cool solution of 160 g NaOH in 500 ml water. The resulting solution should be diluted to 1 liter and stored in a sealed glass bottle out of sunlight. Two milliliters of the Nessler reagent can be added to the distilled sample to neutralize the boric acid and raise the pH to 10.5. The sample should be mixed with the Nessler reagent by capping the sample container and inverting it several times (at least six). Let the sample stand for 10 min after mixing to allow the reaction to proceed, after which time it should produce a color from yellow to brown. The yellow color is characteristic of low amounts of ammonia nitrogen (20 to 250 μ g/50 ml) and can best be measured by a spectrophotometer set to 400 to 425 nm with a 1-cm light path. A 5-cm light path allows measurements of 5 to 60 μ g.¹⁴ Higher concentrations of ammonia nitrogen (up to 500 μ g), indicated by the darker color, can be measured in the wavelength region of 450 to 500 nm. Calibration curves should be determined under conditions identical to the samples. Temporary standards can be prepared by adding to separate vials either 0, 0.2, 0.4, 0.7, 1.0, 1.4, 1.7, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, or 6.0 ml of standard NH_4Cl and diluting the vial to 50 ml with ammonia-free water, then adding 1.0 ml of Nessler reagent.

The phenate method involves the formation of indophenol, which has an intense blue color, from the reaction of ammonia, hypochlorite, and phenol catalyzed by a manganous salt. Formation of the phenate reagent is achieved by dissolving 2.5 g of NaOH and 10 g of phenol in 100 ml of

ammonia-free water. The phenate reagent is added a drop at a time, to a total volume of 0.6 ml, to a 10.0-ml distilled sample in a 50-ml beaker that has been treated with 1 drop (0.05 ml) of MnSO_4 and 0.5 ml of hypochlorous acid solution (this solution should be added with stirring). For each batch of unknowns, a blank and a known standard should also be treated. The standards should be in an ammonia nitrogen range of 0.1 to 5 μg and should be used to determine the calibration curve for the spectrophotometer. Treated samples should be tested on a spectrophotometer with a setting from 600 to 660 nm. The blue color produced by the reaction has its greatest absorbance at 630 nm.

Calculations for determination of ammonia nitrogen differ for the two test methods. The formula for the Nessler method is:

$$\text{mg/liter ammonia N} = \frac{A}{\text{ml of sample}} \frac{B}{C}, \quad (2)$$

where the amount of nitrogen in the ammonia-free water used for dilution is deducted, as is the reagent blank for the volume of the borate buffer and NaOH (6 *N*) used in the sample.¹⁴ In the equation, *A* = micrograms of nitrogen found colorimetrically, *B* = total distillate collected, including the acid absorbent, and *C* = milliliters of distillate taken for nesslerization. The formula for ammonia concentration determination by the phenate method is:

$$\text{gm/liter ammonia N} = \frac{AB}{CS} \frac{D}{E}, \quad (3)$$

where *A* = absorbance of the sample, *B* = micrograms of ammonia nitrogen in the standard taken, *C* = absorbance of the standard, *S* = milliliters of unknown water sample used, *D* = total distillate collected, including the acid absorbent, and *E* = distillate used for color development.

Sulfate

The EPA describes two methods for the analysis of suspended sulfate—the turbidimetric (sulfaver) method and the methylthymol blue method.⁵² Both methods use the same sample collection and extraction procedure, which involves the collection of suspended sulfate from ambient particulate matter by a standard high-volume sampler with glass-fiber or other filter media. After a 24-hr sampling period, the exposed filter is equilibrated and weighed; a 2 by 20 cm strip of filter is placed in an Erlenmeyer flask, 25 ml of distilled water is added, and the mixture is refluxed for 30 min. When the solution cools, it is filtered through acid-washed Whatman No. 42 filter paper and diluted to 50 ml with distilled water.

The turbidimetric method of analysis uses barium chloride to treat an aqueous extract of the sample in the presence of sulfaver, a proprietary stabilizing agent, forming barium sulfate crystals of uniform size. The absorbance of the barium sulfate suspension is measured by a spectrophotometer, with the sulfate ion concentration being determined by comparison with a previously determined standard. Provided that a uniformly good technique is used and that interferences are absent, sulfate ion concentrations are reproducible within $\pm 5.8\%$ at a 95% confidence level.

Analysis is automated in the methylthymol blue method. The EPA indicates that this method has replaced the turbidimetric method because it makes possible a higher rate of analysis and reduces the chance for operator error:

The filter extract sample is first passed through a cation-exchange column to remove interferences. The sample containing sulfate is then reacted with barium chloride at a pH of 2.5 to 3.0 to form barium sulfate. Excess barium reacts with methyl-thymol blue to form a blue-colored chelate at a pH of 12.5 to 13.0. The uncomplexed methylthymol blue color is gray; if it is all chelated with barium, the color is blue. Initially, the barium chloride and methylthymol blue are equimolar and equivalent to the highest concentration of sulfate ion expected; thus the amount of uncomplexed methylthymol blue, measured at 460 nm, is equal to the sulfate present.⁵²

The methylthymol blue method has a 95% confidence level at 200 ppm and a detection limit of 10 ppm.

2.1.4.3.4 *Particulates*

One of the most dangerous forms of pollution is airborne particulate matter. Particle size and the element or compound mobilized are determining factors in toxicity.^{53,54} Trace elements such as beryllium, cadmium, arsenic, selenium, lead, antimony, mercury, thallium, and vanadium are especially toxic in particulates since most living organisms have little or no tolerance for them. Particulate samples can also routinely contain polycyclic organic matter (POM). Trace element and POM-containing particulates are routinely found in areas where fossil-fuel combustion takes place.

Airborne particulates are normally collected by high-volume filtration of the air. The high-volume sampler is the same type as that described in Sect. 2.4.3.1 of this work and used by Lao, Thomas, and Monkman.¹⁷ Air flow rates are normally 1.2 to 1.7 m³/min for 24 to 48 hr. Filters are usually flash-fired fiberglass, are 99.9% efficient, and have a low resistance to air flow.⁵⁵

POM particulate analysis begins with the above sampling procedure using filters washed in pentane. Analytical samples for POM materials are extracted from the filters with benzene. The quantity of benzene-extractable material from an average high-volume sample is usually about 25 mg. A quantity of 50 to 150 mg of benzene-soluble material is usually needed for analysis, so it is necessary to pool organic fractions from several individual samples collected at the same site. The organic fractions should be stored in a dark refrigerator in clean glass bottles.⁵⁵ Analysis of POM samples can be accomplished by GC-MS. Separation of all common POM sufficient for identification by MS was accomplished using packed columns of 1.5% Drexsil-300 on 60-80 mesh Chromosorb W-AW. The temperature program involved an initial 2-min isothermal period at 165°C followed by a progression of 4°C/min up to 325°C (Natusch as cited in Thurston, Skogerboe, and Russo⁵⁶). MS analysis often requires reconstructing individual mass chromatograms for unique identification of compounds. The ability of this procedure to separate two components of a GC peak is shown in Fig. 2.1.25.

Trace element determination in particulates is accomplished by sampling with the high-volume sampler. Particulates are analyzed directly by SSMS or XRF spectrometry.⁵³ The analytical methods are discussed fully in Sect. 2.1.4.3.2.

Particulate sulfur samples are collected with the same high-volume sampler, using glass-fiber filters. Particulates are extracted in 0.25 to 1 ml of double-distilled, deionized water at 25°C. The most promising technique for accurate determination of submicrogram quantities of particulate sulfur—sulfur compounds on particles—is the thermal decomposition of particulate sulfur

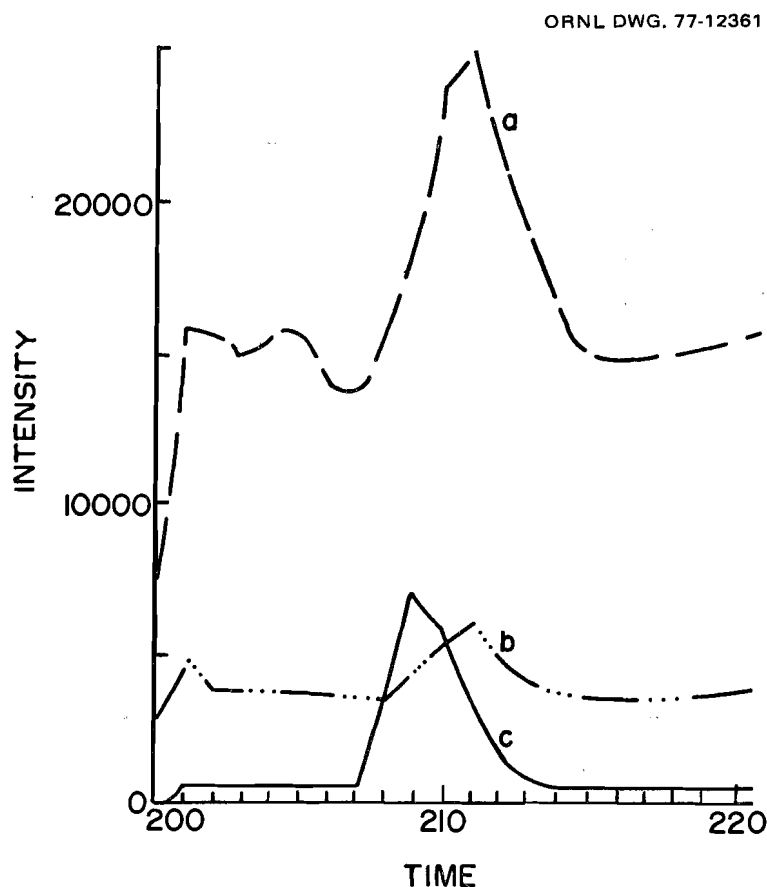


Fig. 2.1.25. Total ion current mass chromatographic peak (a) and reconstructed mass chromatograms for $m/e = 99$ (b) and $m/e = 149$ (c). Source: R. V. Thurston, R. K. Skogerboe, and R. C. Russo, *Toxic Effects on the Aquatic Biota from Coal and Oil Shale Development: Progress Report-- Year 1*, Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, 1976, Fig. 3, p. 205.

compounds to gaseous products and subsequent detection by a flame photometric detector (Fig. 2.1.26).⁵⁷ Sample extracts and solutions are transferred to a tungsten boat and heated at 60°C for 30 sec until dry. The residue is then vaporized by capacitor discharge. Vaporized gaseous decomposition products of the sulfur compounds are carried to the flame photometric detector by a stream of clean charcoal-filtered air. The lower detection limit of this method is controlled by the purity of the distilled water; a 5- μ l sample of distilled water gives a signal equivalent to 0.3 ± 0.05 ng of sulfur, which corresponds to a solution concentration of 0.06 μ g/ml.

The precision inferred from three consecutive analyses performed at concentrations of 0.6, 1.6, 3.2, and 6.4 μ g/ml of sulfur as sulfuric acid is about 2.5%, excluding extraction errors. When the extraction step is included, precision is about half as good. Table 2.1.31 shows that the percentage of sample recovery is between 88% (sample 40077B) and 10% (sample 40076F).

Ten samples of size-classified ambient aerosol were analyzed first by XRF and then by the vaporization-flame photometric detector technique. Comparison indicates that the sulfur concentrations obtained by XRF are, on the average, 23% higher than those obtained by vaporization-flame photometric detection.

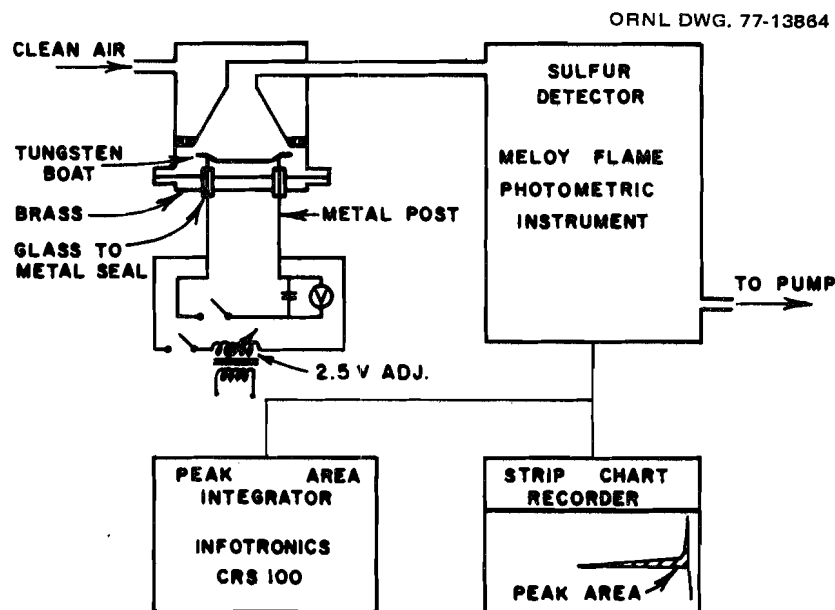


Fig. 2.1.26. Schematic of the sulfur detection system consisting of the flash vaporizer, Meloy SA-160 flame photometric detector, strip-chart recorder, and the peak area integrator. By permission from J. D. Husar, R. B. Husar, and P. K. Stubits, "Determination of Submicrogram Amounts of Atmospheric Particulate Sulfur," *Analytical Chemistry*, American Chemical Society, Washington, D.C., 1975.

Table 2.1.31. Recovery of known amounts of sulfur as $(\text{NH}_4)_2\text{SO}_4$ added to samples^a

Sample No.	Sulfur ($\mu\text{g}/\text{ml}$)				Recovered sulfur (%)
	Sample	Added	Total	Recovered	
40075F	4.06	3.09 ± 0.07	7.04	2.98	96.3
40075B	4.00	3.09 ± 0.07	6.84	2.84	91.9
40076F	3.38	3.09 ± 0.07	6.77	3.39	109.7
40076B	3.23	3.09 ± 0.07	6.59	3.36	108.7
40077F	3.94	3.09 ± 0.07	6.96	3.02	97.7
40077B	3.22	3.07 ± 0.07	5.95	2.73	88.3

^aRecovered sulfur mean is 3.05 ± 0.27 , with percentage standard deviation from the mean 8.8%.

By permission from J. D. Husar, R. B. Husar, and P. K. Stubits, "Determination of Submicrogram Amounts of Atmospheric Particulate Sulfur," *Analytical Chemistry*, American Chemical Society, Washington, D.C., 1975.

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2.2 Biota

2.2.1 TERRESTRIAL ECOLOGY

2.2.1.1 Purpose and Scope

The purpose of terrestrial environmental monitoring for coal conversion facilities is twofold: (1) the description of the plant site and its immediate environs to provide data for prediction of environmental impact in NEPA documents, which is fulfilled by a site survey; and (2) the determination of the actual impacts of the plant, which is fulfilled by a more intensive analytical program.

Although this section is intended as a guide to the design of a monitoring program, the great diversity of the North American terrestrial biota and the great variety of habitats in which they occur preclude its use as a "cookbook." The expertise of the terrestrial ecologist who designs and executes the monitoring program will have to be relied on to fulfill the purpose of these guidelines. The design and execution of most ecological monitoring programs can be improved by consultation with a biometrician; this is highly recommended.

Also, all appropriate state and federal laws should be consulted prior to the development of any sampling program.^{1,2}

2.2.1.2 Synoptic Survey

The aim of the synoptic survey is to gather both new and existing information to characterize the plant site and vicinity. The results of this survey will be used in the selection of sites for the analytical monitoring program. Information that should be provided includes a map of plant communities occupying the site and vicinity (the area within 3 km of the site), a determination of the area occupied by each community, and a description of the major floral and faunal components of each community.

Vegetation mapping is most readily performed by using aerial photographs. Aerial photographs are available for most of the United States (Table 2.2.1), but these vary widely in scale, resolution, and recentness. In many cases, existing (out-of-date) photographs should be supplemented by current imagery. It is recommended that these new photographs include, in addition to conventional black-and-white photographs, color infrared images taken from conventional low-flying aircraft. The color separation provided by these images will not only facilitate mapping but will provide an indication of the general level of vegetation stress existing at the site during the baseline period. This use of infrared imagery has been extensively documented.³⁻⁵ The scale of photographs used will depend on the complexity of the vegetation distribution. A scale of 12.5 cm per kilometer (8 in. per mile or 1:8000) is needed for areas with numerous community types. Otherwise, a scale of 5 cm per

Table 2.2.1. Published information useful for vegetation studies

Information aid	Where obtained	Information available
Aerial photographs to LANDSAT imagery	East of the Mississippi River: U.S. Geological Survey, Distribution Center, 1200 South Eads St., Arlington, VA 22202 West of the Mississippi River: U.S. Geological Survey, Federal Center Bldg. 41, Denver, CO 80225 Local air services U.S. Soil Conservation Service (SCS) U.S. Forest Service Agricultural Stabilization and Conservation Service NASA EROS Data Center, Sioux Falls, SD	1. Drainage networks 2. Land forms 3. Extent of colluvium, alluvium, and other 4. Vegetative patterns (infrared) 5. Fracturing and jointing patterns 6. Slope gradients 7. Location of mass movements 8. Land cover characteristics
Vegetative maps	U.S. Department of Agriculture, Independence Ave. between 12th and 14th Sts., S.W., Washington, D.C. U.S. Forest Service State forestry division State agriculture division Local universities Infrared and other aerial photographs	1. Types and extent of vegetative cover 2. Density of cover

Source: U.S. Environmental Protection Agency, Technology Transfer, *Erosion and Sediment Control: Surface Mining in the Eastern U.S.*, EPA-625/3-76-006, October 1976.

kilometer (3.2 in. per mile or 1:20,000) is satisfactory. Care should be taken in determining the scale of aerial photographs, including those obtained from outside sources. The contractor should not assume that he must bear the total cost of this or subsequent remote-sensing programs, because the benefits to foresters, agriculturalists, and land-use, water-use, and recreation planners are potentially great. When initial contacts with local and regional agencies are made, such possible cooperative arrangements should be discussed.

Existing vegetation maps are available from a variety of sources (Table 2.2.1). These may serve as aids both in the establishment of boundaries and in the selection of suitable classifications and designations of plant communities and wildlife habitats. Although several systems of classification exist which would be applicable to the entire United States,⁶⁻⁸ none provides the level of resolution required for assessment of a specific site. State or regional surveys may be available.

The area occupied by each plant community can be determined by use of a compensating polar planimeter, dot grid, or electronic area calculator.

Confirmation of the community types identified from aerial photographs should form the first stage in the field survey. A series of walking surveys by field biologists can accomplish this. Observations of conspicuous components of the biotic communities can complement local literature to provide a preliminary description of the terrestrial environment. Special consideration should be given potential habitats for endangered, threatened, or otherwise important species.

Meteorological data and dispersion models (Sect. 2.1.3.4) should be obtained as early as possible to ensure that the synoptic survey will encompass potential permanent plot sites that may be necessary for study of operational impacts (Sect. 2.2.1.3.1).

2.2.1.2.1 *Floral and Faunal Census*

The biotic survey should be continued beyond the synoptic phase to provide a characterization of the site and vicinity for the purposes of impact assessment. The goal of this continued survey is to determine the

abundance, spatial distribution, and habitat requirements ... for species which are important for one of the following reasons:

1. the species is commercially or recreationally valuable;
2. the species is listed as threatened or endangered by the federal government or the state in which the project is located (these should be tabulated separately with their habitat requirements and reasons for decline);
3. the species is known to affect the well-being of some important species within criteria (1) or (2) above;
4. the species is a dominant component of the ecological system;
5. the species will be used as an indicator species—i.e., those species which can provide important information on the bioaccumulation of toxic substances within or near the proposed project site.⁹

The survey should describe the communities that will be destroyed by construction and waste disposal. This will provide information necessary for impact assessment and for planning revegetation programs and determining their success.

Because a large variety of organisms in a large variety of habitat types could be affected by development of coal conversion facilities, no complete, authoritative description of all methods to be used for floral and faunal surveys can be presented. However, considerable attention has been devoted to this problem and several useful, annotated compendiums of ecological survey methods exist. A useful document for this purpose is the terrestrial ecology section of ref. 10. The methods presented are intended for use in biotic surveys of nuclear power plant sites for the fulfillment of requirements similar to those described above. Other works that deal with vegetation sampling methodology include refs. 11–15. Works that deal with faunal sampling include refs. 16–20.

Tilled agricultural land can be characterized in terms of crop species, yield, and amount of irrigation and fertilization. Pasture and logged forest lands should be treated in the same manner as natural communities.

The use of a particular sampling technique assumes a certain sensitivity and requires the selection of an appropriate sample size for statistical analysis. Most commonly used sampling methods have had some statistical treatment of the errors associated with their use, and consideration of these statistics is an important prerequisite to project design and implementation. Description and discussion of these biostatistics are found in refs. 19, 21, and 22. Sampling for this survey should be stratified by the community types identified in the synoptic survey.

Special emphasis should be placed on threatened and endangered species. Current lists of endangered species are available in the *Federal Register*. Information on habitat requirements, ranges, and other ecological parameters for sensitive wildlife is available through a user-accessed computer information system at the U.S. Army Engineer Waterways Experiment Station.²³ In addition, many states and geographic regions have lists of rare and endangered species,^{24–27} and the National Audubon Society issues an annual “Blue List” of birds that are declining in numbers. If individuals of a threatened or endangered species are believed to occupy or regularly visit the vicinity of the site, an effort should be made to locate and, as far as possible and prudent, census the population.

2.2.1.2.2 *Collection of Biotic Materials*

During the floral and faunal censuses it may be beneficial to collect and store specimens of various terrestrial organisms for later reference. These specimens can be used to verify species

identifications, as a record of species distribution and composition within the habitats sampled, and as a source for tissue and organ analysis. As the list of threatened, rare, and endangered species changes, it is increasingly important to establish records of the geographic occurrence of species and their habitat specificity and to document any changes resulting from the construction and operation of energy-related facilities. Reference materials should therefore be collected and preserved correctly if they are to serve these purposes. State and federal laws should be consulted and appropriate permits obtained before any organisms are collected.

Voucher specimens should be collected if identification is or could be questionable. Questions of identification may arise if a species is rare, near the edge of its range, a member of a group with unsettled taxonomy, or simply similar to other species. Voucher specimens should be representative individuals of the species which are free of physical abnormalities and which have been carefully preserved. It is imperative that these specimens be properly and completely labeled. Individual tags and records should include an identification number, collector's name, date, exact location where collected, sex, general size measurements (for vertebrates and woody plants), Latin binomial, and any other pertinent data such as reproductive condition, stomach contents, and habitat. Methods of collection vary with the species group and are generally described in refs. 28–31. Repositories for voucher specimens and aid in identification can be obtained from the Association of Systematics Collections, Museum of Natural History, University of Kansas, Lawrence, Kansas 66045.

Tissue samples should be regularly collected from indicator species as part of the analytical monitoring, and additional baseline samples from a wider variety of species should be preserved to allow future analysis of unforeseen impacts and to aid the search for indicator species. Tissue samples should be preserved for all “important” species except those that are threatened or endangered. Voucher specimens may also serve as sources of tissue samples. When possible, these samples should be obtained from specimens collected at the permanent study plots (Sect. 2.2.1.3.1); otherwise, the location should be specified as exactly as possible, with other information to be provided as described for voucher specimens.

A wide variety of tissues should be contained in this survey collection. Based on previous studies,^{10,32–36} samples of animal tissues taken for chemical analysis might include feathers, hair, bone, blood, muscle, liver, lung, spleen, kidney, gut, brain, adipose tissue, gonads, oviducts, feces, and the whole organism if it is small (e.g., insects or small mammals). Plant samples should contain the whole plant or samples of leaf, stem, root, and flowers or fruits, if available.

Samples for long-term storage should be freeze-dried.

2.2.1.3 Analytical Monitoring

One purpose of the analytical monitoring program is to provide a means of detecting the effects of plant operation on terrestrial ecosystems. These effects can take two forms: changes in community composition and changes in ecosystem function. These changes can be explained and, to some extent, predicted by monitoring the accumulation of toxic substances in biotic materials. A second purpose of the analytical monitoring program is to determine the level of contamination of human food due to coal conversion facility operation.

2.2.1.3.1 Selection of Permanent Monitoring Plots

To produce useful results, permanent experimental and control monitoring plots (henceforth, simply “plots”) should be established and monitoring begun as early as possible. At least one year of

data collection—preferably two—should precede construction. Baseline monitoring will establish preconstruction levels of environmental parameters, extent and pattern of variance, and correlation between experimental and control plots.

Locations of plots should be based on plant community mapping and models of dispersal and deposition which include meteorological and topographic factors. Experimental plots should be located in the areas of maximum deposition or ground-level concentration of contaminants within each major terrestrial community type. Where wind directions are seasonally variable, emphasis should be placed on growing-season meteorology. If release of contaminants occurs by a variety of distinct pathways, plot location should be fitted to the distribution of deposition. For example, coal dust and gases leaked from the plant will have their greatest concentrations immediately downwind of the plant, whereas fly ash and gases released from stacks may have their greatest concentration several miles downwind and maximum deposition of cooling-tower drift may occur at an intermediate distance. The establishment of sets of experimental plots in multiple areas of maximum deposition will provide monitoring of areas of intermediate deposition for each group of pollutants. If all identified pollutants achieve their maximum deposition rate at the plant site, an additional set of plots should be established to monitor the pollution concentrations characteristic of a larger area. These plots should be established if concentrations of the major gaseous pollutants are expected to average more than twice the average background concentrations in an area of at least 750 ha.

Plots should be established in those community types that occupy more than 10% of the land area within 3 km of the plant. In deserts, riparian woodlands should be included even when they are a minor community in terms of area because their more reliable source of water greatly reduces the large fluctuations in productivity which are characteristic of true desert vegetation and which could mask pollution effects. Other small but important natural communities should be included when recognized. Where present, tilled land should be classified by cropping system (e.g., dry land vs irrigated). Additional permanent plots should be established to include any population of threatened or endangered plants or relatively sessile animals that may be affected by the plant but are not found in other plots.

Because of the temporal variation in the structure and function of biotic communities which results from succession, weather, and other physical and biological processes, baseline data from experimental plots cannot adequately serve as the control for analysis of operational data. Therefore, control plots must also be established. A full set of baseline data should be obtained from these plots to establish their similarity to the experimental plots and to determine the relative magnitude of seasonal and other variability.

Control plots should also be located in each major community type and should, as far as possible, include sessile, threatened, and endangered biota. Control plots should be as similar as possible to the corresponding experimental plots in terms of species composition, successional state, and history of disturbance (e.g., grazing or logging). Agricultural control plots should match the crop and cultivation system of the experimental plots.

If no other major sources of air pollutants affect the area, control plots should, as far as possible, be placed in the quadrant centered on the least frequent wind direction, or in other areas of minimal impact. Where one or a few discrete sources exist or are planned in the area, models and monitoring data should be combined to determine areas of minimal total contamination. Where major sources of atmospheric contamination are numerous or diffuse, they should be treated as background, and control plots should be located as if the plant existed in isolation. Predicted concentrations of gases and deposition rates of particulates at the control plots should be less than 10% of the predicted maximum concentration at the experimental plots. To satisfy the requirements of

similarity to experimental plots and low contamination, control plots may be located several miles from the plant. Neither control nor experimental plots should be located within 30 m of a road. Plots should be located adjacent to air, soil, and groundwater monitoring stations.

Plots should be of sufficient size to allow a characterization of the vegetation and to permit completion of all of the monitoring activities described in subsequent sections without disturbance of census subplots for low vegetation. Oosting¹¹ suggested that a 100-m² plot is sufficient for the characterization of forest vegetation, but a larger plot (0.1 ha) is necessary in diverse forests with large trees. This plot size would also supply sufficient space for monitoring activities. A 25-m² plot should be sufficient for grasslands and croplands. In shrub lands and savannas, plot size should be related to plant spacing.

Where heavy grazing or major anthropogenic disturbance of the plots are anticipated, fencing should be constructed to protect the plots. Matching experimental and control plots should be treated similarly in this regard.

2.2.1.3.2 Changes in Community Composition

Outside the areas where vegetation is destroyed by construction and waste disposal, changes in community composition generally are expected to be less significant and less readily detected than changes in ecosystem function. In addition, signs of stress should be detectable before a significant loss of species occurs. Therefore, regular estimation of population size should be limited to threatened and endangered species. Methods for population size estimation will be selected as part of the survey program (Sect. 2.2.1.2.1).

2.2.1.3.3 Measures of Stress

Concentrations of toxic materials that do not result in immediate mortality can result in decreased productivity, reduced reproduction, and reduced resistance to predation and parasitism. These effects can result in increased mortality and decreased population size or biomass. Whereas symptoms of stress in animals are detected by autopsy or the examination of blood chemistry and other physiological indicators, stress in plants is much more readily monitored. Because intraspecific variability in air pollution sensitivity is high in many plants, within-site replication is important.

Leaf condition

Stress imposed on vascular plants is often reflected in the condition of the leaves. Signs of stress resulting directly from exposure to atmospheric contaminants include chlorotic and necrotic lesions, curling, and incomplete expansion. Other indicators of stress include extent of disease, insect, and weather damage.

Leaves should be collected for examination as near the end of the growing season as possible but before the onset of seasonal leaf death. Leaves should be collected randomly. In forests with closed or nearly closed canopies, leaves should be collected above the level of canopy closure. This can be done by shooting down twigs with a shotgun. If trees do not form a canopy, leaves should be collected from the outside of the trees at a standard height, at least 3 m above the ground. The dominant and codominant species should be sampled. In unforested systems, leaves should be sampled at a standard height from the tallest common species.

Damage to leaves should be described in terms of the type of damage and the percentage of leaf surface so damaged. The distribution of the damage (e.g., marginal, terminal, or intercostal) should

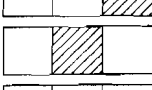
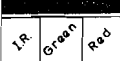
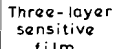
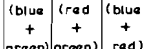
be noted, except for that caused by herbivores. Finally, the total area of the leaf should be determined. For correct interpretation, leaves from experimental and control areas should be carefully compared and the damage related to meteorological and air quality information. Lacasse and Moroy provide a guide to the interpretation of leaf damage.³⁷

Premature leaf dropping is another symptom of plant stress. Collection of leaf fall is discussed in the following section (2.2.1.3.4).

Remote sensing

Healthy foliage records red on infrared color film, whereas vegetation under stress records in other distinctive colors (Fig. 2.2.1). This change may often be noted before symptoms are detectable from the ground. All plots should be aerially photographed seasonally, using infrared color film. A scale of 1:2000 has been found to be suitable for this purpose.³⁶

ORN-L-DWG 77-7884

Colour of original	Black parts after first development	Positive after reverse development	Positive as seen on light table
GREEN			Blue Blueish-purple Dark purple
RED			Greenish-blue Green
YELLOW			Cyan
BLACK			Black Grey
INFRARED			Red
GREEN + I.R.			Bright red Magenta Pink Purple-Brown
RED + I.R.			Yellow
YELLOW + I.R.			White
I.R. Green Red Three-layer sensitive film		Cyan Yellow Magenta (blue + green) (red + green) (blue + red)	

EXAMPLES OF VEGETATION TYPES
Healthy conifers
Healthy conifers
Conifers
Diseased or deficient foliage
Dead needles of conifers which no longer reflect I.R. or green
Yellowing and dead leaves of vegetation under stress
Dead trees devoid of leaves or needles
Partly diseased foliage-causes response in all 3 layers-no dye formed
Young grass
Healthy broadleaves in Spring and Summer
Healthy deciduous green foliage
Healthy conifers and broadleaves
Vegetation without chlorophyll, or damaged vegetation
Conifers under stress
Partly damaged leaves and needles
Vegetation under stress
Red autumn leaves, do not reflect green, only red and I.R.
Yellow autumn leaves

Fig. 2.2.1. Key for detecting vegetation stress by Kodak Ektachrome Infrared Aero film (false color). By permission from J. L. van Genderen, "Remote Sensing of Pollution on Teesside," *Environmental Pollution*, Applied Science Publishers, England, 1974.

Lichens

Lichens have been recognized for some time as sensitive indicators of air pollution in general and of sulfur dioxide in particular.^{38,39} Their advantage over instruments as air pollution indicators lies in their relative nonspecificity; their selective (and therefore more realistic) mode of uptake, that is, through cell walls; and their ability to integrate the effects of a variety of stress sources. If possible, specimens of at least two species of lichens should be found in the plots, marked for future reference,

and photographed on color film along with an appropriate scale. The lichens should be wetted thoroughly $\frac{1}{2}$ hr before being photographed to ensure a standard condition. Parameters monitored should include thallus form, coloration, and growth rate. Variation in color rendition can be minimized by using fresh rolls of professional transparency film, exposed with standard illumination (a ring flash works well) and developed immediately, using fresh solutions.

2.2.1.3.4 *Measures of Ecosystem Function*

The primary functional processes of ecosystems are energy fixation and transfer and the associated cycling of materials between the biotic and abiotic components of the system. The two dominant components of ecosystem function are primary production and decomposition. Changes in the rates of these processes are highly significant, are often due to air pollution, and may occur in the absence of overt macroscopic stress symptoms.

Primary production of tree-dominated ecosystems can be estimated by litter fall. Litter should be collected in 0.25-m² trays 10 cm high.⁴⁰ Litter so collected should be retrieved weekly in autumn and monthly during the rest of the year. Leaves and seeds should be sorted by species, dried in a 70°C oven, and weighed. Productivity of grassy or herbaceous vegetation should be estimated by harvesting aboveground parts at intervals.⁴¹⁻⁴³ Wiegert's method of determining optimum quadrat size is recommended.⁴¹ Harvested material should be dried at 70°C to constant weight and the weight recorded. Productivity of arid-land shrubs is highly variable and not easily estimated. Effects of air pollutants on desert plants are only likely to be detected by greenhouse fumigation experiments.

Productivity of agricultural crops should be estimated by hand harvesting usable portions from the plots at the normal harvesting period. If fields are small relative to the distribution of atmospheric contaminants, conventional methods of harvesting and measuring yield from an entire field may be substituted; that is, let the farmer gather data by harvesting and marketing his crop.

Although these methods do not produce a precise determination of primary production, because not all tissues are included and herbivory is not excluded, they accurately reflect the process, and little additional information concerning pollution effects would be gained by additional sampling effort.

Decomposition rate can be estimated by the use of litter bags. Litter should be obtained at the time of maximum leaf fall or dieback by harvesting or from litter trays. Dry, weighed, random samples of litter should be placed in bags of approximately 5-mm-mesh nylon or other inert fabric. Depth of litter in the bags should approximate the accumulated depth of a year's natural litter fall. A sufficient number of bags should be pinned to the soil surface to allow collection of a statistically valid sample after one year in grasslands and after one, two, and three years in forests. This technique is not suitable for deserts. When bags are collected after exposure, living plant material that has grown into the bag and macroinvertebrates should be removed, the remaining litter dried to constant weight, and the final weight recorded.

2.2.1.3.5 *Sampling for Chemical Analysis*

Chemical analysis of biological materials serves a variety of functions. It provides an indication of where and at what rate toxic substances are being accumulated. It indicates possible pathways of movement of toxic materials into human populations. It provides an explanation in terms of specific toxicants of symptoms of environmental stress detected by other means. It can provide an early warning of future symptomatic environmental stress. Four groups of organisms should be sampled

for chemical analysis: (1) plants, because they are the prime entry point for pollutants into terrestrial biotic communities; (2) detritivorous macroinvertebrates, because of their association with the soil which is the major terrestrial sink of pollutant materials; (3) carnivores, because of the possibility of magnification in food chains; and (4) those agricultural and game species that are consumed by humans. Plant tissue sampling will be limited to vascular plant leaves. Although other tissues (notably feeder roots) may contain higher concentrations of toxicants, trends in leaf concentrations should reflect trends in other tissues. Leaves should be collected seasonally as described in Sect. 2.2.1.3.3. Leaves from conifers and other evergreens should be separated into age classes. Emphasis should be placed on known accumulator and sensitive species.⁴⁴ In addition, where the viability of the population would not be affected and the proper permits are available, leaves of rare or threatened plant species should be collected when damage appears, in order to determine what compounds are involved.

Drying of leaves should be prevented between collection and preparation by immersion of stems or roots in water or placement in a tightly closed container. Particulates and soluble substances on the leaf surface should be removed by washing the leaf twice for 20 min each time in doubly distilled water in a reciprocating shaker. The wash water should be filtered and both the water and filtrate saved for analysis. The leaf should then be dried to constant weight in a 70°C oven and refrigerated in a tightly stoppered bottle containing information on species, date collected, collection site, weight, and a sample number to associate it with the surface contaminant samples. If volatile compounds are to be analyzed, the fresh samples should be frozen and stored in a closed container.

Where present in sufficient numbers, lumbricid worms provide ideal agents for monitoring the biological availability of toxic substances in the organic horizons of the soil. Lumbricids can be collected from moist soil without disturbing vegetation. The simple technique involves driving a wooden stake into the ground and rubbing another wooden stake across the top. The low-frequency sounds produced drive lumbricids to the surface. Alternatively, lumbricids may be driven to the surface by passing an electric current between two metal rods driven into the ground⁴⁵ or simply collected from the surface on a wet night. Where lumbricids are scarce due to soil acidity or other factors, diplopods or isopods may be substituted. These animals may be collected in pitfalls, metal cans buried with their tops flush with the soil surface. In desert communities, tenebrionid beetles may be substituted. Detritivores should be collected twice a year during periods when the surface soil is moist. Animals should be held in moist paper until the gut is evacuated and then frozen and stored in glass or inert-plastic containers with proper identification.

The choice of carnivores collected for tissue analysis will depend on their availability. Lizards have small home ranges and are abundant in most warm ecosystems. They can be easily collected with noose poles or .22-caliber bird shot. Shrews are common in colder climates and are equally suitable. They can be collected in hamburger-baited traps or, if small species are present which will not spring traps, in tin-can pitfalls. Nestling passerine birds are also potentially useful but are only available during a limited period. Other carnivores are generally less suitable because they are not sufficiently common (e.g., snakes and mustelids) or because they range over large areas (e.g., adult birds). Stomach contents should be recorded to aid in determining routes of toxicant transfer. Whole animals should be frozen for storage. Animals should be collected monthly during their active period.

Pathways to man include game animals, livestock, dairy products, honey, and crops. Game species that are hunted in the area of the plant should be collected by shooting during the legal season, or samples may be obtained from hunters. Migratory species which only pass through the area should be ignored. Tissues sampled should include edible flesh (muscle, fat, liver). Samples of

milk or edible flesh should be obtained from livestock that graze in pastures or are fed onsite from hay fields which contain or adjoin plots. If commercial beehives exist in the area, honey samples should be analyzed annually. Crops should be sampled as described in Sect. 2.2.1.3.4 and a subsample of edible portions retained for analysis. All food samples should be frozen for storage in glass or other inert containers.

Additional information concerning nutrient and toxicant retention by terrestrial ecosystems may be obtained from water chemistry data. Nutrient loss in surface water or groundwater may be a sensitive indicator of ecosystem stress.⁴⁶

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2.2.2 AQUATIC ECOLOGY

2.2.2.1 Purpose and Scope

2.2.2.1.1 *Food-Web Approach to Monitoring*

Aquatic ecosystems, like their terrestrial counterparts, are driven by energy inputs from the sun (photosynthesis) or by indirect energy sources in the form of incoming reduced organic carbon compounds (allochthonous detrital carbon). Kinetic energy in the form of moving water (currents or waves) serves to disperse food and create habitats out of substrate material. These energy inputs are captured or used in various ways to create or process aquatic biomass in a series of dynamic interactions referred to as the aquatic food web. The concept of a food web, where matter and energy flow from one consumer or producer to another, is a useful tool for the analysis of aquatic ecological processes, especially for investigating structural and functional properties. Use of a food-web approach in monitoring programs is justified by its pragmatic utility in resource management which should operate on a systems basis to be effective. Reference to a conceptual food-web model will allow integration of the baseline monitoring effort among the essential biological components and habitat features of the aquatic receiving system.

The baseline monitoring program should include a series of biological components in the important habitats under investigation. Given that for any parameter, a measurement uncertainty and hence an interpretive judgment may exist, a multicomponent biological monitoring program is necessary to define the nature and scale of impacts, especially in a developing technology. The multicomponent approach (in a food-web format) will give parallel lines of evidence for resulting environmental impacts of new energy developments.

2.2.2.1.2 *Scale of Expected Impacts on Aquatic Biota*

Aqueous effluents released from coal conversion plants may contain a mixture of organic and inorganic contaminants. Runoff from coal storage piles, leaching from effluent evaporation or settling ponds, and leaching from solid waste landfills may all contribute aqueous effluents to surface-water receiving systems (Sects. 2.1.2.3 and 2.1.2.4). Point-source discharges of plant effluents, if they exist, will also contribute aqueous effluents. Increased sediment loading, siltation, and physical removal of habitats may also occur from plant-related activities—for instance, along rights-of-way. These and other additions or disturbances to receiving waters must be evaluated for their potential impact on the receiving aquatic ecosystem and any potential health hazard to man.

Potential effluents from coal conversion processes may affect aquatic biota in a variety of ways, from acute reactions (e.g., death) to chronic effects (e.g., reproductive impairment, or lowering of biotic production). Energy flow patterns among the aquatic biota may also be disrupted by long-term chronic impact. Many of the potential effluents have unknown or poorly described environmental impacts and DOE has research efforts under way for their appraisal and control (Sect. 1.4).

Spatial considerations in the baseline monitoring effort should be defined. These usually depend on the toxicity and the amount of effluents released and their dispersion characteristics in the receiving waters. Dispersion or transport of effluents should be addressed in the monitoring program for adequate environmental impact analysis (Sect. 2.1.2.3). Near- and far-field areas of the receiving system, relative to effluent sources, should be simultaneously monitored to provide a comparison of subacute vs chronic effects (if any) and to delimit the spatial range of environmental impacts.

Physical habitat disturbance or modification may cause displacement of functional communities of organisms, increased mortality of particularly sensitive organisms, or loss of critical reproductive or nursery habitat. Conversely, habitat disturbance may be minor and easily absorbed by the receiving system with little apparent effect. The baseline monitoring program should be designed to provide estimates of the probable spatial extent and significance of these potential impacts.

Included in the spatial sampling limits is a representative selection of upstream or nonimpacted (control) habitats in close association with the downstream or disturbed areas. The upstream or undisturbed sites chosen should allow for adequate comparison between affected and unaffected areas. Since natural systems normally exhibit marked seasonal and year-to-year variation, only a number of sequential yearly estimates of biotic parameters will yield enough useful comparative data between the undisturbed (control) and the impacted (experimental) areas to assess the extent and possible long-term consequences of impacts.

As data from research information and characterization and testing of process effluents become available, some functional studies on ecosystem processes may be necessary for site-specific impact evaluation. This is a case where DOE research will complement the monitoring suggested in the handbook. The evolution of aquatic baseline studies to include functional process rate measurement during a time period immediately preoperational is essential to adequate impact evaluation on an ecosystem level (Sect. 2.2.2.3.3). For instance, community respiration of the benthic species assemblage of a receiving system, which reflects the rate of turnover of biomass in the system, may be an important indicator of environmental change resulting from effluent releases.

An important element in the monitoring sequence from baseline through operational-phase monitoring is the time scale of biotic responses to those disturbances (chemical and physical) resulting from coal conversion plant construction and operation. The baseline ecological monitoring program is the initial time reference for analysis of environmental impacts, some of which (e.g., chronic effects) may not be evident until a substantial lag time has occurred (possibly a number of years). The use of baseline data for future impact assessment and verification makes the retrieval of adequate and accurate information on the preoperational receiving system particularly important for the success of long-term environmental impact analysis.

2.2.2.1.3 Focus of Baseline Monitoring Program

Much of the monitoring for environmental impacts should focus on the potentially impacted habitats that contribute the bulk of the net yearly production for the different biotic components in the receiving aquatic ecosystem. For instance, areas of high biotic productivity, high biota concentration, or critical habitat, such as spawning or nursery habitat, are biologically important and should be emphasized in the monitoring effort. Unique or rare habitats protected by statute or regulation should also be considered if present in the study area. Much time and effort can be wasted by evaluating the biotic composition of relatively unimportant or unproductive portions of receiving waters.

The baseline monitoring program should include all important aquatic environments that will be affected by plant construction and operation. It is not likely that only a single aquatic environment type will be disturbed by the proposed plant. For instance, many large rivers are dammed into a series of locks and pools where sections are characterized more by reservoir fauna and flora than by large-river biota. Different habitat types should be dealt with separately. It is also important to interface monitoring in different aquatic systems which are biologically linked if they both will suffer impacts. For instance, feeder streams may serve as seasonal spawning habitat for

reservoir fish, or backwater areas of large rivers may be essential for the biological productivity of the main water body. The baseline monitoring program design should reflect site-specific spatial consideration both for habitat type and functional relationships between different areas.

The objective of the baseline aquatic ecology monitoring program, using a food-web analysis and the above considerations, is to characterize (under time and money constraints) (1) the ecological structure of the aquatic receiving system, (2) the qualitative (or quantitative, if necessary) relationships among the important components of the system, (3) natural spatial and temporal changes in the important system components, (4) existing toxic substance body burdens in those system components which may lead to toxic substance ingestion by man, (5) any existing perturbations to the system which should be separated from those of the proposed plant, and (6) the rates of important functional processes in the aquatic communities which reflect the effects of stress imposed by coal conversion effluents. Predictions of the level and mode of the biotic responses to plant-related disturbances will be based on this information and any known relationships or special study (causal monitoring) results describing biological responses to coal conversion effluents. Any changes in important ecosystem processes or spatial and temporal species composition which occur during construction and operation of the proposed plant can then be quantified or described during later monitoring programs.

2.2.2.1.4 Critical Period Sampling

The evaluation of ecological processes is inherently complex and time-consuming. The effort needed to acquire data for adequate assessment readily translates into the consumption of large sums of money and other valuable resources. Therefore, to obtain the greatest return per unit of effort, it is desirable to sample only as much as needed during the appropriate period of the day, season, or year to define the process or impact in question within the necessary precision limits. One of the most effective ways of achieving this goal is to do an assessment prior to formulating the monitoring program so that causal relationships are implicit in the monitoring scheme. Monitoring should be considered as a procedural step in a system of scientific inquiry involving prediction, monitoring, and assessment. The monitoring program should be designed with the aid of a competent statistician working in conjunction with ecologists so that the dual consideration of sampling effort at the appropriate time can be effectively established. This should allow the most cost-effective sampling program to be developed.

It is the intention of this section to spell out as much as possible, without site-specific considerations, the appropriate time of year or day for taking samples and the desirable precision of the parameter estimate. It is then assumed that the contractor will use this information, along with the site-specific data gathered on the initial synoptic survey (Sect. 2.2.2.2), to prepare the site-specific monitoring program.

2.2.2.2 Synoptic Survey

The synoptic survey is intended to retrieve limited field data and to compile existing information to initially characterize the receiving aquatic environs on which the proposed plant will be located. This initial characterization will allow formulation of the baseline monitoring program along rational lines based on possible impacts to the existing receiving system. The synoptic survey should attempt to (1) identify the approximate distribution of important habitats for maintenance and production of aquatic communities; (2) obtain a rough idea of the species assemblage present in these habitats; (3) approximate food-web relationships among the important components of the

receiving aquatic system, using general ecological considerations; and (4) provide a rational basis for sampling area selection. This will allow formulation of an initial, conceptual food-web model for the dominant components of the receiving aquatic ecosystem, especially in those habitats that contribute the greatest biotic productivity. The synoptic survey should cover areas above and below the proposed effluent outfall or area to be disturbed by plant construction and operation to allow selection of appropriate comparison areas for baseline monitoring. This will promote the monitoring program (1) to be sensitive to those populations most important to the aquatic ecosystem, (2) to be responsive to the important habitats most likely to suffer impact, and (3) to emphasize the aquatic ecosystem as an entity rather than as a given area below the effluent outfall. The synoptic survey should aid in developing cost-effectiveness in the baseline monitoring program. The survey should be planned in coordination with other parts of the monitoring program so that important supporting data will be available. Water quality, hydrological, and process monitoring programs should be consulted (see Sect. 1.3).

Extensiveness and rapid information turnaround are stressed in the synoptic survey rather than intensiveness and quantitative sampling. However, samples collected during the survey should be eventually integrated into a detailed analysis of the receiving system. For an efficient survey, all extant data on the physical, chemical, and biotic character of the aquatic environs to be sampled should be collected, synthesized, and evaluated prior to starting the survey. The field collecting program should be carefully planned from existing information to cover all possible habitats that are deemed important, including various water depths, and to sample for the majority of species suspected to be present (unless rare, endangered, or threatened). Data requirements, methods and intensity of sampling, and data presentation for the synoptic survey are described in the following sections.

2.2.2.2.1 Existing Biological, Habitat, and Hydrological Information

Maps of existing biological, habitat, and hydrological data should be collected or, if necessary, synthesized from available information to aid in preparing the synoptic survey (see, also, Sect. 2.1.2). Information on seasonal flow regimes, substrate character and stability, location of emergent or submergent macrophyte beds, and the location of spawning beds should be sought. Aerial photographs, U.S. Army Corps of Engineers maps, and habitat maps prepared by local or state natural history surveys or any other sources should be pursued for use in designing the survey. State and federal government reports, local colleges and universities, and local residents should be consulted to assist in planning. This information should be used to guide the following survey efforts.

2.2.2.2.2 Transect Analysis for Substrate Composition and Benthic Macroinvertebrates

Substrate type and distribution is a dominant factor in determining the presence and approximate population size of aquatic macroinvertebrates. Consequently, the synoptic survey should include information on the types of substrate present, their distribution, and the approximate macroinvertebrate communities associated with each type. This will aid in selecting the appropriate sampling sites in impacted and comparison areas for the baseline monitoring program. The following discussion is given to aid in the development of a substrate and macroinvertebrate sampling scheme, considering both general needs and varying levels of existing information.

Those habitats described in part A of "Important Elements of the Synoptic Fish Survey" (Sect. 2.2.2.2.3) should also be sampled for their macroinvertebrate community structure. If the contractor has

identified additional important habitats for benthic macroinvertebrates, either through site reconnaissance or through reference to extant data sources (e.g., Corps of Engineers maps, aerial photographs, reports), these habitats should also be sampled.

Sediment and macroinvertebrate sampling transects should be perpendicular to the shoreline. The distance downstream, the fraction of the total cross-river width, or the portion of a lake or reservoir covered by the sampling will depend on the available information on probable dispersion characteristics (based on dye-release studies, mathematical models, etc.) of the effluent plume in the receiving water. The sample nearest the shoreline should be taken as close to the shore as possible and no further than 10 m away. Samples (2 replicates per site) of invertebrates and surface sediment (upper 5 cm) should be taken at intervals of 10 m along each transect. If the macroinvertebrate association with a sediment type is known to be fairly constant, only a percentage of the total sediment samples need be processed for their macroinvertebrate content.

In areas that may receive nonpoint-source pollutants from the proposed plant, the transects should be randomly located along the shoreline to ensure an equal representation of all sediment and macroinvertebrate community types that may exist in the study area. If existing information suggests that relatively nonproductive habitats (such as shifting sands or channelized river beds) are commonplace and easily recognizable within the study area, a stratified random placement of transects in biologically productive areas will ensure that useful information is collected.

In rivers for which there is no prior knowledge of the dispersion pattern of the effluent plume, transects should be taken close to the proposed outfall location and then at increasingly greater distances downstream until it is judged that dispersion should reasonably have occurred. For instance, transects may be at distances of 50, 100, 200, and 500 m upstream from the effluent source point and 25, 50, 75, 100, 150, 250, 450, 850, and 1500 m downstream from the effluent source point. The number of transects should be adequate to explore the sediment and macroinvertebrate characteristics in the effluent plume dispersion area and in comparison areas. The general relationship of placing transects at approximately twice the distance from the point-source outfall should be maintained unless modified by known environmental heterogeneity.

If prior knowledge exists on the probable cross-river extent of an effluent plume, the proportion of the total river width sampled for each transect may vary as needed to allow the sampling to be concentrated in areas of probable impact. Likewise, if prior information exists on the downstream or far-field dispersion of effluent plumes, transects should emphasize the higher pollutant concentration areas near outfall or inflow locations but include far-field sampling to develop spatial continuity in the baseline monitoring program.

In lakes and reservoirs, the benthic transect survey for sediment distributions and macroinvertebrate associations may be planned similar to that given above whenever applicable. Deep-water areas expected to receive only minor impacts may be ignored initially. Sampling efforts should be concentrated in the shallow littoral-zone areas in close association with probable release sites of effluents (either point- or nonpoint-source releases). Some chemical plumes demonstrate a sinking behavior owing to their density. This should be considered when selecting sampling depths.

The sampling schemes outlined above should provide initial information on the majority of macroinvertebrate species present in the study area. The samples should be processed rapidly and a catch curve estimated. The catch-curve concept is as follows.¹ The number of species taken (accumulated in the sampling) is plotted on the vertical axis and the sampling effort on the horizontal axis. Sampling effort should be defined as accumulative area sampled. As illustrated in Fig. 2.2.2, when the plotted points are joined with a smooth curve, the curve at first rises abruptly, because many species occur in the first samples. Progressively fewer new species are added as sampling continues.

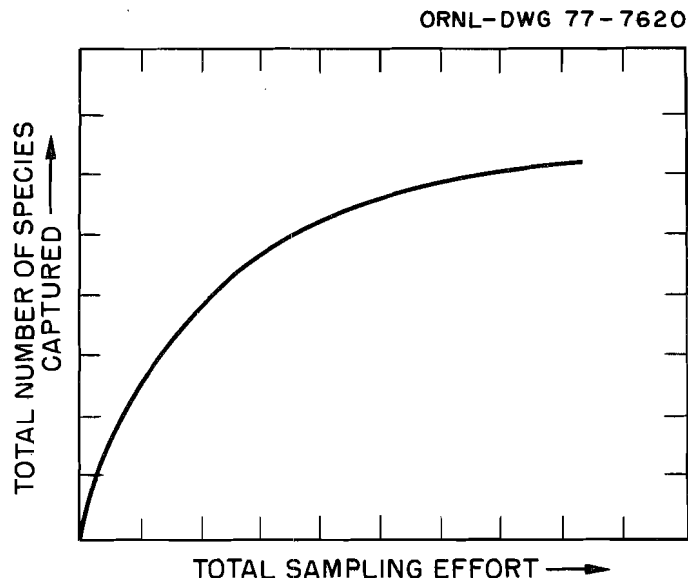


Fig. 2.2.2. Typical catch curve.

A sufficient number of stream or lake-shore macroinvertebrate transect samples should be taken to ensure that an additional 10% sampling effort would yield less than a 10% increase in the number of species taken. Additional transects, if required to satisfy the catch-curve criteria, should be randomly located in biologically productive habitat near effluent discharge points. This should allow a thorough description of the macroinvertebrate assemblage while avoiding an arbitrarily determined sampling effort.

Data requirements

For each replicate data set in each transect, the following information should be obtained.

Benthos

Species (if possible)

Densities (number per unit area)

Biomass (ash-free dry weight per unit area per species)

Sediment

Particle size distribution (for instance, less than 53, 250, or 1680 μm ; greater than 1680 μm), percentage ash-free dry weight (AFDW) for each particle size fraction (corrected for carbonate content)

Data presentation

Sediment characterization and distribution and benthic macroinvertebrate assemblages should be condensed into a series of maps and tables as illustrated in Fig. 2.2.3. On each map the following information should be included.

North

Scale

ORNL-DWG 77-7619

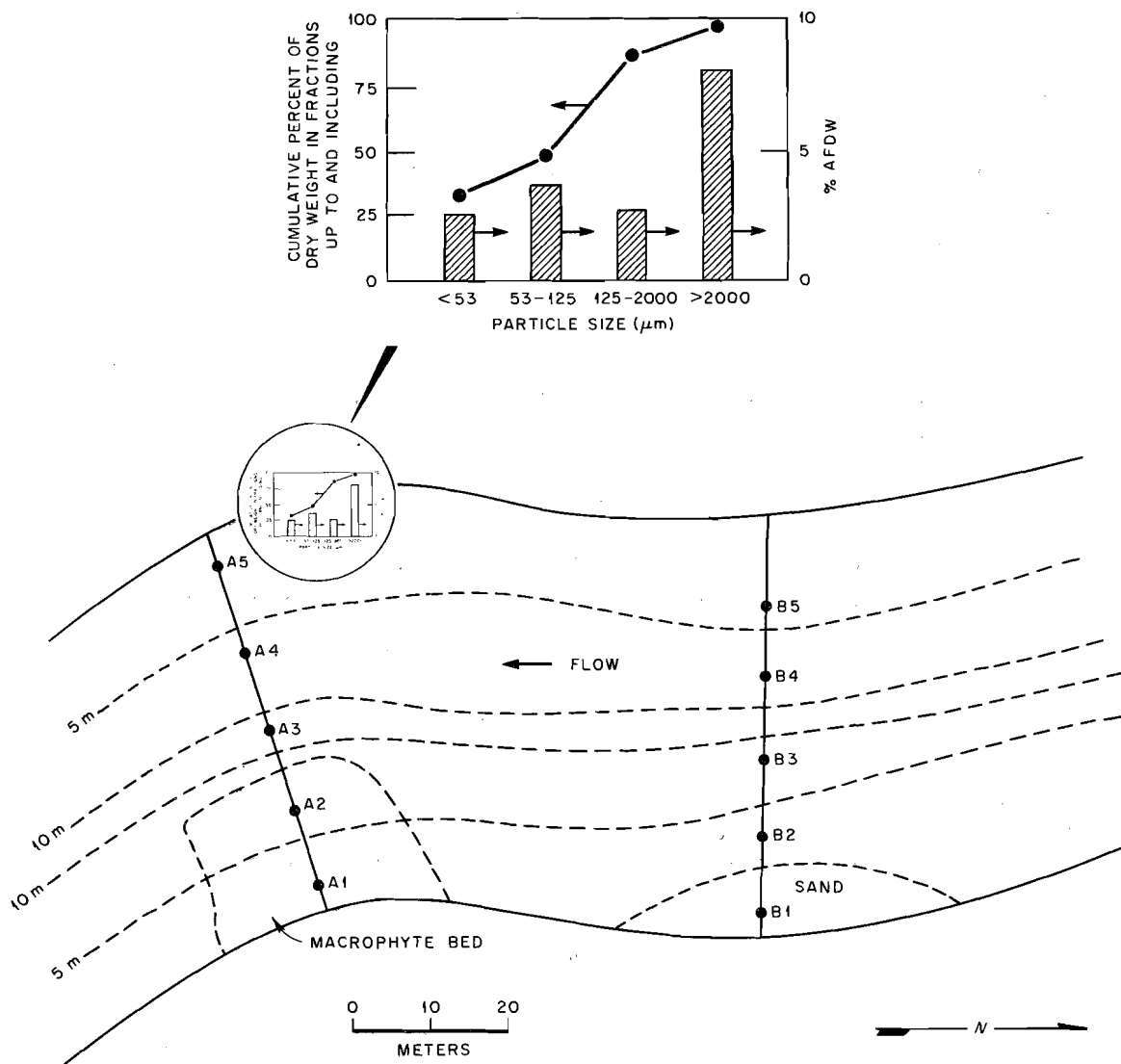


Fig. 2.2.3. Important features of map reporting.

Direction of water flow, including lake currents if known

River

Depth contours

Transect locations

Sampling locations

Superimpose habitats where known (macrophyte beds, substrate types, pools, backwaters, spawning sites, etc.)

At each sampling site:

Identification code number

Graph of particle size distribution, % AFDW

Water depth

Each table of benthic macroinvertebrate data should be referenced to the identification code number of its sampling location. Authorities and references should be cited for:

Methodologies and techniques (field, laboratory), specifying and describing differences between what is cited in the literature and what was actually done by contractor [International Biological Program (IBP) manuals, Battelle's source book on monitoring methods]

Species identifications (Pennak,² Ward and Whipple,³ Usinger et al.,⁴ Illinois Natural History bulletins, etc.)

Prior site description data (Corps of Engineers, USGS, etc.)

2.2.2.2.3 Fish Survey

The synoptic fish survey should be designed to initially determine the species composition, the size-class distribution of the important species, the habitats in which they are found, and the approximate distribution of habitats within the study area.

Important elements of the synoptic fish survey

A. Sampling should be done in all important fish habitats determined from existing hydrological and biotic data or from initial work during the synoptic survey. Habitat types are differentiated by:

1. Current speed: erosional or depositional
2. Depth: adequate or inadequate water depth for fish cover
3. Presence of macrophytes
4. Presence of large objects creating shelter or pools
5. Presence of inflowing water such as springs and streams
6. Backwater areas that will be affected by land disturbance or effluent runoff or discharge
7. Special habitats such as spawning and nursery grounds

Specific habitats of interest that should be emphasized in the sampling program are:

1. Pools with water depth greater than 2 ft, with a silt-clay substrate, and, especially, supporting abundant macrophyte and attached algal communities. Pools with shifting sand, bedrock, or hard-pan bottoms may be sparingly sampled during the synoptic survey unless they are the only habitat present.
2. Pools with large drift accumulation affording preferred habitat for fish, including artificial constructions in stream improvement programs (such as trees, brush, or artificially placed rubble) which provide fish shelter.
3. Backwater areas considered good fish habitat which may suffer impact from plant construction or effluent dispersion. Omission of these areas from the synoptic survey should be justified by the site maps showing the extent of land disturbance or a preliminary evaluation of the effluent plume dispersion area based on hydrological considerations or dye dispersion studies.

Night sampling should be done in those important habitats that may not contain fish during daylight periods but which may be important feeding grounds during evening, night, and early morning. These are usually shallow areas with macroinvertebrate food resources which do not provide adequate fish shelter during daylight hours.

B. Sampling should be designed to collect individuals of the most common species and representatives of their various size classes. The possible presence of these species and size classes should be initially determined from existing information (e.g., natural history surveys, fishery management data for the study area, or local fishermen). This includes all pelagic and benthic fish thought to be present unless rare, threatened, or endangered. The latter groups of species should only be observed as present or absent and not destructively sampled.

C. Visual observations should be made along the shoreline within the effluent dispersion area or land disturbance area (whichever is greater) for spawning activity and the presence of fry or fingerlings of game fish to identify spawning and nursery areas. Observations should be gathered qualitatively as present or absent and, if present, whether sparse or abundant. Criteria for use of these relative terms should be set up a priori for use in the field and should be given in the data presentation section (see "Data Presentation").

D. If the synoptic fish survey is undertaken during the period of spring spawning (usually April through June), then samples of ichthyoplankton abundance along transects out from the shoreline must be taken (can be integrated with the macroinvertebrate survey). This information should be presented as numbers of each species found per unit water volume and referenced to the sample location given on an appropriate map.

Preparation of the synoptic fish survey

Important existing information on the physical, chemical, and biotic characteristics of the receiving aquatic environs, including those "undisturbed" sites near the effluent outfall which will be used for comparison, should be obtained and evaluated before the synoptic survey is undertaken. The important elements of an efficient sampling program are given below (see, also, ref. 5).

A. Know the hydrological characteristics of the study area, both upstream and downstream of the effluent outfall or in both potentially impacted and comparison areas. Habitats of interest should be determined from flow data, depth profiles, or biotic features, if available in the form of recent maps or aerial photographs. As previously described, areas of silt deposition should be given particular attention, as should areas providing fish shelter (see, also, Sect. 2.1.2).

B. Know the fish species present. Sampling for fish is dependent on the probable distribution of each species by habitat, life history stages, season, and time of day. The field survey design should be adjusted to maximize gear efficiency relative to the species of fish present (i.e., habits of the fish, their size, location, and response to the fishing gear) and the needs of the sampling program. Field taxonomy procedures for all species suspected to be present should be known before conducting the study. Of special interest is the recognition of any rare, endangered, or threatened species thought to be present in the study area.

C. Know the fishing methods to be used. There are usually a number of different ways to capture fish in any given habitat (Sect. 2.2.2.3.2.). The proper implementation of the sampling technique is necessary to ensure that representatives of most species and their size classes are collected.

D. Know the selectivity of the sampling gear. Selectivity is inherent in fish sampling and therefore the catch from any one method will not give adequate species representation and size distribution. More than one type of gear normally will be needed to get an adequate representation of the common species present in any given habitat and their size classes.

E. Know the appropriate methods of subsampling. Methods for subsampling the total collected individuals in any given species or size class should be determined prior to the actual field work.

Techniques necessary to ensure freedom from systematic bias due to procedure should be clarified prior to field collection.⁶

F. Field data sheets should be prepared before conducting the survey. The raw data should be appended to the synoptic survey report, so care should be taken to present it in a readable and interpretable form. All sample preservation and identification equipment and techniques should also be determined according to standard methods before the survey is undertaken and should be described in the synoptic report.

Data requirements of the synoptic fish survey

The synoptic fish survey is designed to initially determine the species composition within important fish habitats, the size class distribution of the common species, and the approximate food-web relationships among the most important fish and other aquatic biota in the study area. (Food-web relationships will be inferred from the data collected and knowledge of the general ecology of the organisms present.) Therefore, each important habitat type should be effectively sampled with a sufficient number of sampling techniques to provide this information. Special emphasis should be placed on those habitats in the area to be disturbed by plant operation which are believed to support the most fish biomass and to contribute significantly to fish productivity, including spawning areas, nursery areas, or areas used by migrant species. Endangered or threatened species should be given special attention only if they are discovered in the study area during the survey, if direct observation has been made prior to the survey, or if regional distribution of any such species strongly suggests that they may inhabit the study area.

Each fish caught in the field should be identified, weighed, and measured unless subsampling is appropriate. The time, date, place of capture, river stage, and type of gear used should be recorded. Chemical and physical parameters desired for boat surveys should be taken simultaneously with the biotic samples (Sect. 2.1.2.4). Each species should be sorted in the field by size class for subsequent analysis. Fish of the same species and size class, captured in similar habitats, may be pooled for a composite sample to be taken (differences between habitats of similar character are not the aim of the survey). Size-class separation criteria (i.e., size-class intervals, total length, forklength, etc.) and accuracy of length and weight measurements for each species should be determined by accepted fishery methods. Reference sources used should be given in the data presentation.

Data presentation

Sampling locations for the fish survey should be shown on a detailed map of the aquatic system under study. Each sampling location should be given an identification code for reference in the data tables or diagrams. Data on all fish captured at each sampling location should be presented in the form of tables of species collected, length-frequency diagrams for each species, and weights per size class for each species. All data should be clearly related to type of sampling gear used.

Spawning and nursery habitats as indicated by presence of fry or spawning fish found during the survey should be presented as approximate-area drawings. If the environmental mosaic is too detailed to draw, descriptive statements of the general locations of these habitats may be substituted.

2.2.2.3 Characterization of Biological Communities

The purpose of this section is to present the general considerations of receiving aquatic ecosystems which should be addressed in developing a baseline biological characterization

monitoring program. Since environmental impact assessment in a variety of receiving system types may be necessary for a proposed facility, it is important to point out how ecological considerations may differ among system types. It is also important to recognize habitat differences within any receiving system, especially those areas where natural (or man-influenced) biological, physical, or chemical features cause biota to concentrate in specific habitats. Spatial placement of sampling stations relative to effluent discharge areas and the necessary breadth of biological component sampling, including critical period sampling, are discussed below. The following section should be used in conjunction with results presented in the synoptic report and with any available information on probable spatial distributions of effluents and their probable environmental impacts to develop this section of the baseline monitoring program. A summary of this section is provided in Table 2.2.2. In general, the data collected in this program will provide the major input to the site-specific environmental impact statement (EIS).

2.2.2.3.1 Sampling Station Placement

One of the needs of the baseline monitoring program is to define the spatial distribution and species utilization of biologically important habitats relative to effluent plume dispersion areas. Although the final number and placement of sampling stations are site-specific and subject to DOE review, some general considerations should be expounded.

Biological sampling should include those important habitats observed in the synoptic survey. Sampling station placement within these habitats should be chosen to represent the range (diversity) of important habitats found in the receiving system to detect near- and far-field effects relative to control areas and should be integrated with water quality monitoring (Sect. 2.1.2.4).

Since near-field impacts are expected to be greater than far-field impacts, sampling stations generally should be more numerous near the zones of maximal disturbance. One method for addressing the transport of effluents and identifying near- and far-field areas is to follow the dispersion of a conservative parameter in the effluent plume until it reaches analytical or ambient background levels. The parameter chosen should have low reactivity (i.e., low particle adsorption, decomposition, or atmospheric dispersion) to allow a maximum estimate of hydrologic dispersion. If possible, it should mimic general transport phenomena of potentially toxic substances in the plume. The area encompassed by the travel of the effluent plume before it is diluted to ambient level should be the boundary of the downstream (rivers) or far-field (lakes) sampling area. Dye experiments should be conducted in the receiving system to approximate this area for the baseline monitoring program (Sect. 2.1.2.3.2). However, other background limits which will affect spatial considerations in the monitoring effort may be set by regulatory agencies.

The appropriate distance and number of far-field stations relative to near-field stations is, again, a site-specific consideration. Far-field stations should be located, as much as possible, outside the zone of influence of other effluents not derived from the proposed coal conversion facility. Nutrient loading or toxic chemical discharge from feeder streams entering the main receiving system are examples of spurious inputs that should be avoided in sampling station placement.

In some cases, the distinction between near- and far-field effects may be somewhat academic, and modifications to the above considerations may be appropriate. An example is the diffuse inflow of contaminated groundwater from land disposal sites where near- and far-field stations may not be readily discernible due to rapid mixing. Other potential nonpoint-source inflows of contaminants derived from the proposed facility may also fit in this category.

Table 2.2.2. Summary of aquatic ecology monitoring requirements

System component	Measurement of interest	Critical period sampling	Sampling frequency ^a
Phytoplankton	Cells/ml	Early spring bloom to fall senescence	Biweekly
	Dominant species (genus) composition		
	Primary production (if required)	Same samples	Weekly
Zooplankton	Dominant species composition densities/vol	Late winter to late fall	Biweekly
Benthic algae	Relative densities and dominant species composition	Late summer biomass maximum period	Once a year
Macrophytes	Densities (dry weight/unit area), spatial distribution, species composition	Late summer, early fall biomass maximum; plus spring distribution (May to June) during height of fish spawning	Biweekly intervals one month before and one month after predicted biomass maximum plus once in spring
	Toxic pollutant contamination chemistry	During seasonal occurrence of edible parts and during biomass maximum	Once or twice a year
Benthic macroinvertebrates	Biomass (dry weight/species), major species composition, spatial distribution	Entire year	Bimonthly
	Toxic pollutant contamination chemistry	Spring preemergent instar biomass maximum plus summer low water period	Twice a year
Ichthyoplankton	Densities/vol species composition	April to October (depends on presence of late spawners)	According to system, either
			Day Day-Night
			April Weekly Biweekly
			May to June 4 days Weekly
Young-of-the-year fish	Species composition, spatial distribution	Before spawning; at population height (July); early fall	July to Oct. Weekly Biweekly
Adult fish	Species composition, size-class distribution, spatial distribution	Spring spawning period plus mid-summer and fall (winter if necessary)	Three times a year (plus winter if necessary)
	Toxic pollutant contamination chemistry (selected species)	Spring spawning period, fall	Twice a year
	Stomach analysis		Three times a year
	Fecundity	Spawning period for each species	Short-interval time series once a year
Anadromous fish species	Species present plus habitat utilization	Spawning or migration periods	Whenever necessary
Endangered or threatened species	Critical habitat type plus spatial distribution of habitat	Whenever critical periods exist, especially reproduction periods	Whenever necessary (annually)

^aFrequencies may be modified by site-specific considerations.

The selection of control stations should also reflect the diversity of important habitat present in the receiving system which may suffer impact from the proposed development. Control areas should (1) not be close to the effluent outfall or near those areas that will be disturbed (spatial consideration); (2) have similar substrate, current, turbidity, temperature, or other important physical and chemical characteristics that allow comparison with areas that will suffer impacts; (3) have similar communities of aquatic organisms (species composition and density should be closely related); and (4) not receive any impact from plant construction, groundwater contamination, effluent discharge, or possible airborne contaminants. The sites most closely fulfilling these criteria should be included in all aspects of the baseline monitoring program. The before-after or upstream-downstream ratio method of comparison used in this monitoring assumes equal natural year-to-year variability in the control and affected areas. Although not rigorously validated with data from one year's baseline effort, this assumption will more likely be realized if the control and affected communities are as similar as possible, reflecting similar past environmental histories.

The sampling program should be designed so that area differences are compared, instead of individual stations or points. That is, the habitat or sampling location of interest should be considered an area of interest which is randomly sampled after its boundaries have been described. This is opposed to repeated sampling occurring at a fixed point in the receiving system. Sampling designs should, therefore, be some form of stratified random sampling where the receiving environment is partitioned into different habitat types (areas) with random sampling within each type.

The concept of sampling on a large area basis as opposed to sampling various fixed stations scattered throughout the aquatic system is a more realistic sampling policy. This approach allows for a better evaluation of the effect that the proposed plant may have on the total aquatic system. Due to the complexity and interaction of the spatial and temporal distribution patterns of the organisms in the aquatic environment with the physical and chemical complexities of the system, analysis and evaluation of potential plant impacts based on fixed-station measurements may be meaningless. Fixed points or stations may not, for example, be characteristic of the aquatic system as a whole and repeated sampling may lead to biased conclusions.

A further comment on sampling station location is important. Generally, the utility of a sampling station depends on its representation of an important biotic community or habitat relative to the needs of the monitoring program. However, the spatial extent of the sampling area depends on the spatial scale of environmental heterogeneity found at the site of interest. If destructive sampling is to be repeatedly done in a particular habitat type, it may be important to select those areas that allow destructive sampling on a spatially random basis (to minimize sampling bias) yet afford enough sampling area to minimize the effect of sampling disturbance. In many instances, this consideration is unnecessary, but where a destructive sampling event will remove or modify a significant portion of the biotic community or habitat being sampled, the contractor should consider alternative sites, which may lessen the sampling effect on the remaining biotic community. In some circumstances, destructive sampling may not be advisable due to spatial limitations of a particularly important habitat. In this case, nondestructive sampling techniques such as visual observation or aerial photography may be implemented to provide the necessary baseline data.

2.2.2.3.2 Sampling Strategies for Biological Communities

Phytoplankton

Habitat considerations

Phytoplankton in lakes and reservoirs are well known as important energy sources for secondary consumers and are important contributors to the biotic productivity of standing-water systems. Thus it is important to assess impacts on their productivity in these receiving systems.

In large rivers, phytoplankton usually exist as products of washout from protected bays and inlets, from feeder streams originating from lakes or impounded water bodies, or from benthic algae displaced from the river bottom. The greatest concentration of phytoplankton is usually found near the mouth of a river rather than near the headwaters. The contribution of the phytoplankton to the biotic productivity of a large river system, however, is highly variable. Phytoplankton productivity varies from river to river, between different reaches of the same river, and from season to season or year to year for the same location in a given river.

Unfortunately, the role of phytoplankton in the total yearly energy budget of large-river ecosystems is essentially unknown. In only a few cases can definite relationships about the possible importance of river phytoplankton production be assessed.^{7,8} Given the current status of river phytoplankton ecology, sampling in rivers should be done only periodically to estimate algal biomass and dominant species composition as an indication of environmental quality. If species identification is difficult, genus determination may be substituted. Natural spatial and temporal variations in phytoplankton abundance should be evaluated in the baseline monitoring program.

Lakes, reservoirs, or protected bays, inlets, or backwaters for river systems which have high biological productivity and which may experience impacts from activities related to the proposed plant should be assessed for their level of phytoplankton primary production. This is especially important if these areas supply large amounts of suspended organic carbon or plankton to a main river system by periodic washout phenomenon or if they are prime fish habitat and support a rich fauna and flora. Primary production measurements may be necessary to characterize the importance of this energy input to the receiving system biota or to clarify the distinction between reservoir and river habitat. For instance, it may be necessary to monitor potentially impacted backwater areas serving as nursery grounds for fish that are supported by primary production via zooplankton growth or to distinguish navigation pool sequence rivers that may function more as reservoirs than typical rivers having a washout flora. In some circumstances, it may be sufficient to characterize the receiving system according to its level of primary production during the baseline study and have these measurements deleted from later monitoring programs.

Critical period sampling

Phytoplankton productivity in most standing fresh-water systems is typically maximal in the spring before substantial grazing by herbivores begins, suffers a decline during summer stagnation, and resurges somewhat in late summer or fall. The sampling program for dominant species composition and concentration should begin in early spring at the onset of the algal bloom period. This date may vary from February to late spring, depending on the particular system under investigation. For instance, if present, ice cover will usually delay the onset of spring growth. If the onset of the algal bloom period is unknown, information from a similar system in the same general geographic zone may be used to approximate this period. Sampling should continue until late fall when phytoplankton senescence and population decline occurs. If periodic and noticeable blooms

occur during specific seasonal periods in backwater areas or in the main receiving water system, the extent and duration of these phenomena should be recorded, and species composition and the number of cells per milliliter should be measured.

If primary production in lakes, reservoirs, or backwater areas is to be measured, the sampling period should cover the early spring bloom to fall senescence period unless foreshortened by natural events such as water drawdown and desiccation. Where necessary, depth and time integral productivity measurements should be made biweekly to estimate primary productivity per unit of water surface area per day.

Biweekly sampling may not adequately measure the amount of yearly or seasonal production (low accuracy) but may serve to indicate the relative importance of primary production in the receiving system.

Zooplankton

Habitat considerations

Zooplankton in lakes and reservoirs are important consumers of phytoplankton and detritus, and they constitute an essential food resource for pelagic fish. In shallow-water areas of protected shoreline nursery habitats, they may also serve as important food for the young-of-the-year fish. For standing-water systems, therefore, it is important to evaluate the seasonal population densities, species composition, and spatial distributions in those areas of receiving systems that may suffer impact, especially those areas that are also important habitat for fish. Although there are operational problems in separating zooplankton from simultaneously collected particulate detritus (e.g., rotifers in rivers), separation and counts per unit volume for the zooplankters should be done where possible.

Zooplankton in river systems should be monitored in those habitats where they are an important food resource for higher trophic levels, especially in areas of juvenile fish concentrations. Although zooplankton are not expected to be especially abundant in large warm-water rivers, some will be present in all river systems. Their significance in any river under investigation should be initially estimated from an evaluation of the habitat types and distributions where zooplankton are generally considered to have high productivity and where the feeding habits (size class differentiated) of the dominant fish species found in these habitats include consumption of zooplankton.

Critical period sampling

Sampling for zooplankton concentrations and species composition will usually be done from late winter to late fall. Marked seasonal variation in the zooplankton populations and in species composition will usually be evident in fresh-water systems. For instance, in late winter period, only a few zooplankton species may be present due to many species being in resting stages; overwintering adult populations can be evaluated in the later winter sampling period. If the zooplankton are to be monitored extensively during an annual cycle of production, the entire growth period from late winter to late fall should be regularly sampled. It may also be important at the beginning of the zooplankton sampling effort to consider the time lag of zooplankton population increases behind those of phytoplankton.

Day-night sampling for changes in vertical distribution or addition of nocturnal predators to the water column, such as *Charoborus* larvae, should be conducted at least once during the baseline monitoring effort to determine if such sampling is necessary for the purposes of the study (e.g., vertical distribution of a pollutant plume).

*Benthic algae**Habitat considerations*

Benthic algae are associated with littoral zones where light penetration is sufficient for net positive benthic primary production to occur. In some systems, the shallow littoral zones may be the dominant areas for primary production which may support much of the remaining biological system. Although benthic algal primary production, as evidenced by the seasonal buildup of benthic algal biomass, may be important for the biotic productivity of the receiving system, field sampling problems such as separation of algae from detritus or primary productivity measurements are too difficult and time consuming to be cost-effective in the monitoring program. However, if effluent releases tend to stay in shallow productive habitat before dispersion occurs, such as along river shorelines or in shallow bays or inlets, these areas should be characterized by a description of relative amounts and dominant species composition of the benthic algae present. Such descriptions will be used to estimate the possible biotic effect of effluent dispersion patterns and the presence of baseline conditions such as scouring, water nutrient levels, or the presence of phytotoxic agents.

Critical period sampling

Benthic algae normally commence growth in late spring after the high turbidity and scouring action of spring runoff diminishes. The standing crop may then increase to a late summer or early fall maximum or have a number of seasonal peaks, depending on temperature relationships of the benthic algae and their responses to environmental variables. Generally, if known for the receiving waters or a similar system, the estimated period of the maximum standing crop should be used for the descriptive analysis given above.

*Macrophytes**Habitat considerations*

An aquatic macrophyte is defined in this handbook as any large macroscopic plant maintaining itself in standing or flowing waters. Macrophytes may be large, rooted algae such as *Nitella* and *Chara* species or higher plants such as *Potamogeton*. They may be floating in quiet eddies or trapped among large detrital accumulations. Since macrophyte beds are usually the site of the most intense production of benthic macroinvertebrates and, hence, are important for other members of the aquatic food web, their presence and distribution should be thoroughly assessed for the possible effect of effluent release or other disturbances from plant construction and operations.

Since the utilization of macrophyte biomass as food occurs principally in the fall of the year or during the winter kill period (dieback) when the macrophyte biomass enters the detrital food web, net daily primary production is usually not as important as is the standing crop during the fall or late-summer period. In addition, the contribution of epiphytes (on macrophytes) to primary production will only be qualitatively assessed from their known associations with the various species of macrophytes present in the study area, the macrophyte density, and the macrophyte distribution.

The macrophyte communities should be evaluated with respect to their species composition, distribution, and density within the aquatic environs of the proposed coal conversion facility. If, however, there are extensive macrophyte beds (such as *Chara* or *Nitella*) in depositional areas which support a rich epiphytic algal community, it may be necessary to measure the primary production per square meter of the aggregate benthic plant community to allow a more thorough assessment of the effect of effluents on energy flow through the benthic community. Primary production in relation to

plant biomass (turnover rate) may be high in this situation, and standing-crop measurements will not be adequate to assess the potential loss of primary production to the aquatic food web if the macrophyte beds are affected or removed by man-induced disturbances.

An important function of macrophyte beds is their influence on the water velocity or flow regime near the sediment-water interface. When water passes over macrophyte beds, it tends to slow down and, therefore, allows suspended particulate material to deposit. This process increases the available food supply for the invertebrate communities inhabiting these areas. Therefore, macrophyte removal does more than just remove a source of primary production from the river system. It can markedly affect the depositional environment and hence the suitability of the area for benthic invertebrate growth. Macrophyte beds also serve as refuges and feeding areas for larval fish.

Since macrophytes are good integrators of pollution levels, tissue accumulation of toxic substances that may be released by the proposed plant should be evaluated for baseline values. If certain edible parts are used as a food resource by water fowl, mammals, or other grazers, they should be separately sampled from the main macrophyte biomass.

Critical period sampling

The seasonal biomass peak for macrophyte species usually occurs just before flowering and seed production or toward the end of the summer growth period. The exact period of maximum biomass depends on the species, weather, and hydrological conditions. Since macrophyte communities are typically an unstable complex of species in a mosaic pattern which may vary from season to season or between different areas of the same fresh-water system, the appropriate sampling period may initially be uncertain. Usually, the recognition of groups of plants with common growth forms (emergent, floating-leaved, free-floating, or submerged) is an important element of the macrophyte monitoring effort, and this community consideration should be used to approximate the sampling dates if possible. It may be necessary to sample over the range of seasonal biomass peaks for the macrophyte communities present in the study area. If applicable, the seasonal maximum biomass for the entire community may be used as the appropriate sampling period.

To operationally define the biomass peak requires that sampling be done at two-week intervals, one month before and one month after the suspected period of maximal accumulation. When field sampling shows that this event has occurred, sampling may be discontinued.

In addition to the biomass peak, sampling should also be done in the spring, during the May to June fish spawning period, to describe the spatial distributions of macrophyte communities that may be important to other biota.

Baseline toxic chemical accumulation sampling should be done for all macrophyte species during the maximum biomass period. In addition, those species used as a food resource by grazers should be sampled for their edible component tissue quality during the appropriate season. If they are continually grazed, once-a-year tissue sampling is sufficient.

Benthic macroinvertebrates

Habitat considerations

Benthic macroinvertebrates are the dominant food resource for many species of fish and other vertebrates in aquatic systems. They may also form an important link between dissolved and particulate contaminants in the water and organisms higher in trophic status.

The relative importance of benthic macroinvertebrates in the aquatic food web and their general susceptibility to ingestion of contaminants adsorbed or incorporated into suspended particulate matter or recently sedimented material necessitates careful monitoring of their population size and distribution in receiving waters during the baseline monitoring program. Monitoring should be done in all aquatic receiving systems that might be affected by the proposed plant. Specific habitats known to be especially productive for benthic macroinvertebrates should be emphasized. For instance, macrophyte beds, depositional areas of rivers, shallow arms of lakes and reservoirs, and near-shore littoral plains with abundant benthic algae are more productive than shifting sands, hard-pan, or bedrock areas. Deep-water sediments should also be sampled unless they are anaerobic throughout the year or will not be affected by effluent releases.

Where dominant benthic macroinvertebrate food species are present, their baseline levels of toxic substances to be released should be determined. If dominant species do not exist in the receiving system, an aggregate sample of the macroinvertebrate community may be substituted and the sample content defined.

Critical period sampling

Sampling for benthic macroinvertebrates should be done bimonthly throughout the year. The bimonthly sampling interval will allow estimation of any seasonal changes in habitat preference resulting from varying hydrological parameters, especially low-water stresses such as increased temperature, decreased dissolved oxygen, or possible increased concentration of released effluents.

Baseline toxic substance accumulation levels should be monitored twice a year: during the spring biomass maximum and during late summer.

Ichthyoplankton

Habitat considerations

The ichthyoplankton life stage for many fish species represents the critical period in their life history and consequently for the fish resources of the receiving aquatic ecosystem. Ichthyoplankton, consisting of drifting eggs and weakly swimming, newly hatched fish, are affected by currents and wave action to a greater extent than are adult fish. Many species reported from large rivers, such as shad and white perch, have planktonic eggs, and drifting larvae are characteristic of many other species, including some with demersal eggs. The ichthyoplankton, compared with later life stages, are especially susceptible to environmental hazards such as toxicants in effluent plumes or impingement or entrainment at water intake structures. Mortality of eggs and young fish may affect both general food-web processes (ichthyoplankton serve as an important food resource to predators) and, in time, the adult fishery populations. The extent and significance of these effects will, however, depend greatly on compensatory mechanisms in the fish populations (such as intraspecific competition for food and space) and in the aquatic ecosystem as a whole (such as predator switching to more abundant food resources).⁹

All potentially impacted areas of the aquatic receiving system where spawning is expected to occur should be sampled for their ichthyoplankton concentrations during the baseline monitoring program. In flowing-water systems, spawning areas frequently include shorelines, with appropriate substrata and cover (e.g., plant debris, macrophytes), and may also include areas inundated during periods of high water. Particular monitoring attention is, therefore, warranted for those shoreline, backwater, or protected inlet areas where spawning habitat is found and where plant-related

disturbances are most likely to occur. Since backwater areas constitute the main spawning habitat in large river systems, they should be thoroughly sampled where they may suffer impact from plant-related activities. These areas are in addition to the main receiving water mass where ichthyoplankton will drift by effluent discharge points (or nonpoint-source areas) or areas of other potential disturbances (such as siltation or scouring). Special attention should be given to proposed water intake areas in all receiving systems which may cause impingement and entrainment mortality on the ichthyoplankton populations.

For standing-water systems, near-shore littoral zones and shallow embayments should be emphasized in the ichthyoplankton sampling program. If pelagic spawners do not occur in the receiving system (refer to synoptic survey results), pelagic waters may be sampled less intensively for ichthyoplankton drift in effluent plume dispersion areas.

Critical period sampling

The greatest concentrations of ichthyoplankton usually occur in temperate fresh-water systems between the months of April and September, with May and June representing the height of their concentrations. However, each water system will vary according to species of fish present and the hydrological conditions that affect breeding behavior and spawning. Knowledge of the fishery present in the receiving water is, therefore, important in determining the length of the ichthyoplankton sampling period. For instance, some fish, such as catfish species, may spawn two or more times during a given year and may continue spawning until late summer or early fall. Ichthyoplankton sampling should begin in April and continue through September or October as necessary, with the majority of the sampling done in the spring. Anadromous fish may modify the above considerations and possibly require winter sampling. For winter sampling, ichthyoplankton should be collected when conditions permit; water intake and effluent discharge points should be emphasized.

Day-night variability and short time pulses of some ichthyoplankton species (e.g., Clupeids) make sampling schedules somewhat complex in order to adequately estimate seasonal ichthyoplankton flow in a given system. Day-night and depth distribution studies should be conducted on each receiving water system under investigation to determine if these variables will markedly affect the sampling error. Although replication of ichthyoplankton tows may not be great, given the usual patchy distribution of ichthyoplankton, these added variables should be taken into consideration to eliminate as much error from the approximation as is possible for a standardized sampling effort. Relevant results from these studies should be incorporated as rapidly as possible into the sampling regime. Generally, it may be expected that nonflowing water systems will have vertically stratified ichthyoplankton and that rapidly flowing and turbulent systems will not. If site-specific day-night or depth distribution variability in ichthyoplankton concentrations is significant, the sampling program should be adjusted accordingly. For instance, night sampling should be emphasized if daytime concentrations are much lower. Or, turbulent rivers with low variability in ichthyoplankton distributions by depth may be sampled by replicate midwater tows which may not be appropriate for slow-moving navigation pools requiring surface, midwater, and bottom tows for adequate sampling. Oblique tows at a standardized angle or boat speed, from bottom to water surface, may also be used if appropriate.

*Young-of-the-year fish**Habitat considerations*

The suitability of the study area for maintaining young-of-the-year fish populations is usually essential for maintaining the fishery resources of the aquatic receiving system. It is necessary, therefore, to evaluate the species composition, spatial distribution, and habitat utilization of young-of-the-year fish during the baseline monitoring program to allow prediction of possible changes during plant construction and operation. For those areas expected to receive impact from plant-related activities, the nursery habitat areas should be mapped and evaluated for their young-of-the-year fish populations.

In some aquatic receiving systems, spawning and nursery habitat will be similar although not entirely overlapping. In flowing-water systems, nursery habitat is found mainly in backwater or still-water areas. Emergent macrophyte areas near shorelines or any shallow and relatively still water created by accumulations of large drift near shorelines (logs, brush, etc.) may serve as young-of-the-year fish habitat. For standing-water systems, the shallow bays and inlets are the most likely nursery habitats. Pelagic water, especially with much current or wave action, is not suitable for most fish fry and, therefore, may not be included in the young-of-the-year sampling program unless a pelagic fish is present in the system (coordinate with synoptic survey results or any initial results from the adult-fish monitoring program). Possible impingement and entrainment mortality at proposed intake structures should be considered in the sampling program.

Critical period sampling

To evaluate the temporal species composition and habitat utilization of potentially impacted areas of the receiving system by young-of-the-year fish, their populations should be sampled before spawning occurs in the spring, at their population height (usually July), and during early fall in conjunction with the adult fish sampling program described in the next section. However, if small or concentrated populations existing in headwater streams will be significantly affected by destructive sampling techniques, nondestructive methods should be used.

For evaluation of the baseline toxic substance body burden concentrations in young-of-the-year fish, samples for chemical analysis should be collected during the seasonal population peak in midsummer.

*Adult fish**Habitat considerations*

Habitat utilization by adult fish, and their possible interactions with effluent plumes, should be evaluated during the baseline monitoring program. All important fish habitat that may be disturbed during construction and operation of the proposed plant and control areas should be sampled for adult fish by the appropriate means. Since different fish species will be found in different habitat types, sampling gear should be selected to capture those adult fish suspected to be present in any given sampling location. Information gathered in the synoptic survey should be used to design the adult fishery monitoring program, both for where to sample and what gear to use.

Bottom areas in flowing-water systems, especially where food resources (e.g., drift or benthic macroinvertebrates) are high, and in all backwater areas with suitable water depth and cover (e.g., logs, large rocks, low water visibility) should be emphasized in the sampling program. Depositional

areas containing abundant benthic macroinvertebrates and having suitable depth should also be sampled for adult fish. Spawning beds should be included where appropriate.

In standing-water systems, bottom dwellers and near-shore species of adult fish should be sampled. Since most adult fish will reside in protected bays and inlets or in littoral zones with abundant food (e.g., macrophyte beds, areas with abundant benthic algae, depositional areas with abundant benthic macroinvertebrates, and areas with high zooplankton populations), the near-shore areas should be emphasized in the sampling program. If pelagic species are present in the receiving system, the open-water areas where they are found and which will receive effluents or disturbances from plant-related activities should also be sampled.

If, from the synoptic survey and existing information on an extant fishery, certain forage and piscivorous species are determined to play an important role in regulating energy flow through the aquatic food web or are commercially or recreationally important, their size-class distribution, fecundity, food-web relationships (stomach analysis), and tissue quality (toxic pollutant accumulation) should be assessed during the baseline monitoring program. Although the diversity of forage species, especially members of Cyprinidae or Percidae, may be fairly large, it is not the intention of this section to recommend a size-class distribution or tissue quality survey of all members of a diverse community. Rather, the dominant members of functional groups should be separated on the basis of the synoptic survey and existing information and should be studied more intensely than a general survey would allow. It is, therefore, recommended that the contractor make a distinction between the less important species and the relatively dominant members of the fish community. These distinctions should be based on evidence from the synoptic survey, existing fishery information, and from the conceptual food-web model of the receiving system.

Critical period sampling

Adult fish populations should be intensively sampled during the spring and early summer spawning period. This will enable an estimate to be made of the adult spawner populations and the spatial distribution of spawning habitats. Species composition, size-class distribution, and spatial distribution within the study area should be emphasized. As for young-of-the-year fish, if small adult fish populations are present in headwater streams, then destructive sampling should be avoided as much as possible if significant impacts to their population dynamics may result.

Similar to benthic macroinvertebrates, spatial distribution patterns of adult fish adjust to seasonal changes in hydrological parameters. Adequate monitoring of the seasonal use of potentially impacted areas by the fishery present therefore requires additional sampling during the summer and fall. Summer sampling should be done during high-temperature, low-dissolved-oxygen conditions (if they exist) and should emphasize the spatial limitations of adult fish distributions during this period. Fall sampling should be done to distinguish the resident fish populations from more seasonally resident species (e.g., spawning runs from reservoirs or lakes into potentially impacted streams) and to characterize fall adult fish spatial distributions. The three sampling periods will allow description of seasonal shifts in habitat utilization to selected areas such as feeder streams or groundwater inflow areas due to their modifying effect on environmental conditions. Those backwater areas that become unsuitable for many fish species or some fish life stages after summer drawdown or development of toxic conditions should be noted in the sampling effort.

Stomach analyses of those important food-web species identified in Sect. 2.2.2.2.3 should be done once during the spring, summer, and fall to confirm food-chain relationships. The number of samples taken during each of these periods should be sufficient to separate size-class differences in

food resources and provide an adequate cross section of the food types used during the sampling period (diurnal sampling may be necessary).

Fecundity estimates for spawning adults should be done by species and size class (percentage of body weight) during the height of the spawning season. Close attention should be paid to the exact sampling period to allow an accurate estimate. It is usually important to monitor water temperature during the spawning period. To ensure an accurate fecundity estimate, samples should be taken at two- to three-day intervals around the peak of the spawning period for any given species. Due to higher individual variability, highly fecund species (e.g., Clupeids) may have to be sampled more intensively than the more uniformly fecund species (e.g., salmonids).

Baseline concentrations of toxic substances accumulated in adult fish tissue should be evaluated during the spring spawning period when interaction with reproductive events is most important and during the fall sampling period. Samples from adult fish which are commercially or recreationally valuable should include liver, gall bladder, and muscle tissue samples. Liver and gall bladder samples will be used to assess detoxification and internal organ storage of toxic substances released by the proposed facility. To assess ingestion of the adult fish by man, tissue samples should be taken on those portions (e.g., axial muscle) of the fish that are normally eaten. Head, viscera, and skin usually should not be included. Fatty areas along bones, if normally part of the edible or prepared portion of the fish, should be included in the sample. Other adult fish should have axial muscle tissue samples taken for chemical analysis.

If thermal discharges are expected or if fish-attractive substances are present in the effluent releases, winter sampling for the species composition and spatial distribution of adult fish populations in effluent dispersion areas should also be done.

Anadromous fish

Habitat considerations

Utilization of the aquatic receiving system by anadromous fish should be evaluated during the baseline monitoring program. If such species are present in the study area during a specific time of the year, their habitat utilization within potentially impacted areas, either as a migratory route or for spawning, should be studied.

If a major fishery of an anadromous species exists in the aquatic receiving system, the utilization of potentially impacted areas for spawning or the migration (numbers) of anadromous fish expected to pass through the impacted areas should be initially evaluated from existing literature. The synoptic survey results may not reflect the temporal presence and habitat utilization of these species, so fishery management or resource evaluation institutions should be consulted for the necessary information. If the study area is used as a spawning ground, the spatial utilization of the receiving system for the species in question should be evaluated in the field during the appropriate seasonal period. If the study area is used only as a migratory route, the passage of anadromous fish past effluent discharge points, effluent concentration areas (effluent plume dispersion path), or water intake structures should be evaluated. Much of the necessary information for potential impact evaluation may be available from regional fishery resource data. Only those specific uses of potentially impacted habitats by anadromous fish which are important for their population maintenance should be considered during field investigation.

If an anadromous fishery exists in the study area, the anadromous ichthyoplankton, young-of-the-year, and adult fish population should be included where applicable in the monitoring programs previously discussed, including stomach analysis and baseline toxic chemical body burden determinations of adults.

Critical period sampling

If anadromous fish utilize potentially impacted areas, sampling for spawning habitat distribution, migratory routes through effluent dispersion areas, and approximate population size should be done whenever appropriate. Baseline values for body accumulations of toxic substances to be released by the proposed plant should be determined from those samples collected. Stomach analysis should also be done on the collected individuals (size-class differentiated) if feeding within the study area is considered important (from regional fishery resource information) for population maintenance of the anadromous species. Fecundity estimates should follow the previously described program.

*Threatened or endangered species**Habitat considerations*

If threatened or endangered species are found in the aquatic receiving system during the synoptic survey or are thought to be present (by the availability of suitable habitat and the known distribution of the species in question), the study area should be evaluated for the presence of these species. In any areas expected to receive impacts from plant-related activities, critical habitat for preservation of the species or for maintenance of their populations should be evaluated.

Destructive sampling generally is not considered appropriate for evaluation of the presence and habitat utilization of these species, so much of the sampling effort should be expended on characterization of the receiving system habitat for maintenance of these populations. Some live capture and release of these species may, however, be necessary to confirm their presence in selected habitats. Spatial distribution of these species should be evaluated with respect to effluent plume dispersion and any other habitat change or impact that may result from plant construction and operation.

Critical period sampling

The seasonal utilization of potentially impacted habitat by a threatened or endangered species should be used to determine the sampling period (live capture and release) for these species. If possible, these seasonal periods should be approximated from the known biology of the species in question. If the species is not well-studied, approximation of these periods using information from closely related species should be attempted with the help of authorities familiar with the species under investigation.

Any environmental parameter that is known to limit the distribution or population density of the species being considered should be described and evaluated in the appropriate habitat during the limiting season or period of occurrence.

2.2.2.3.3 Analytical Monitoring

The biological characterization program (Sect. 2.2.2.3) will be used to initially describe the ecology of the receiving system and to prepare an EIS for the proposed coal conversion facility. After the EIS and before operation of the facility, an analytical monitoring program designed to measure sensitive functional response variables of the extant biological communities in the receiving system should be conducted. This program should constitute a year's study immediately preoperational, coinciding with the latter stages of construction when major impacts have subsided.

Construction activities or construction-related impacts may present some difficulties in designing the continued baseline monitoring program for functional process data. If possible, the environmental contractor should initiate his field studies as given below after the recovery of receiving system aquatic communities from construction impacts. This is necessary to ensure baseline functional process rate measurements that reflect the correct order of magnitude values for an undisturbed (preexisting) system. Although "recovery" is difficult to quantitatively define, the environmental contractor should review construction-period monitoring data on biological community composition or, if necessary, perform a field survey to determine if the return to preconstruction community composition has occurred.

Further, the contractor should attempt to maintain sampling stations in the same area used for the characterization program (Sect. 2.2.2.3.1) or in nearby similar areas if construction impacts warrant such a change. The criteria for maintaining the same sampling stations are difficult to quantify and relocation should be considered according to the following: (1) The extant biological communities should be reasonably similar to those of preconstruction. (2) The environmental heterogeneity should be about the same as during preconstruction. That is, if siltation or some other physical modification has eliminated much of the previous existing diversity in habitats, then either the new habitats should be monitored (if they are stable) as given below or the sampling stations should be moved to monitor the previously observed ecosystem components. Maintaining the original baseline sampling locations is preferred, but the final decision should be based on site-specific considerations. (3) Near- and far-field sampling stations should be included in the program design as discussed below and in Sect. 2.2.2.3.1. In general, the environmental contractor will find that the above criteria will be applied more to near-field sampling stations; far-field stations used in the characterization program probably will be disturbed less by construction activities.

The timing of the baseline analytical monitoring program is important both to avoid the above-mentioned construction disturbances and to provide a continuous time sequence of data with the beginning of the operational monitoring program (Sect. 4b.3.2). The environmental contractor should coordinate the commencement of this program with DOE to ensure the utility of the data collected for operational impact assessment.

Sampling station placement

Generally, all considerations given in Sect. 2.2.2.3.2 should also be included here. Near- and far-field and control stations should be included in the functional process measurement program. Of particular importance to sampling station placement are the locations of effluent outfall points, onsite storage ponds for waste products or coal, and surface and subsurface drainage that will enter offsite surface water systems. The exact number of sampling stations is site-specific.

Sampling effort

In addition to the functional process measurements, analytical aquatic studies should include sampling for community composition and spatial distribution. The biological communities for which functional response variables are measured should also be sampled for species composition and density at the same frequency as given in Table 2.2.2. Both structural and functional aspects of the receiving system are important indicators of environmental stress and response to perturbation. Although a structural (biological component) analysis gives indications of the environmental quality of the receiving system, it can only approximate functional relationships and functional process rates should be considered separately. Additional biological community composition and spatial

distribution analysis may be necessary according to the assessment and recommendations provided in the site-specific EIS. Therefore, the complete analytical monitoring program should consist of (1) community composition and spatial distribution monitoring to provide corollary information to that gathered from functional process monitoring, (2) toxic chemical body burden monitoring as discussed in the previous section, (3) functional process monitoring as presented below, and (4) additional considerations based on the significant environmental impacts identified in the site-specific EIS. This is the same set of considerations used to develop the operational monitoring program (Sect. 4b.3.2) which is generally an extension of the program developed here.

Functional process measurements

The following functional parameters are being considered for their utility in determining ecosystem performance under stresses that may be imposed by coal conversion effluents. Ecosystem performance measures are currently being developed by DOE, so further additions and clarifications of this program will be forthcoming, especially as modes of ecosystem stress from potential coal conversion effluents become better known. These functional response variables will be used to detect the existence of ecological impacts and to provide the basis to relate these changes to potential alterations in ecosystem performance and possible health hazards to man.

Given natural variation, a single functional process measurement is not adequate for impact evaluation in a complex system. Therefore, the following parameters are considered a minimal complementary set of measurements for site-specific evaluation of ecosystem stress, including estimates of possible health hazards to man.

Benthic community indicators

Special studies of benthic macroinvertebrate populations in particularly important habitats that may be affected by plant-related activities may be warranted on the basis of their potential for bioaccumulation of potentially toxic materials. Many benthic macroinvertebrates feed by filtering water (e.g., hydropsychid caddisfly larvae, clams) or by collecting detrital materials (e.g., chironomid midge larvae, burrowing mayfly nymphs). They collect small organisms and organic and inorganic particles which may contain contaminants such as adsorbed trace metals. Ingestion of this material may allow bioaccumulation processes to occur in benthic macroinvertebrate populations and suggests that secondary production rates may be readily susceptible to pollutant loading. Toxic pollutants may adversely affect benthic production by reducing growth rates, production rates, or survival, thereby reducing the energy and nutrient input to consumers. For instance, an immediate impact of an effluent with a specific gravity greater than that of the receiving water may well occur on the benthic macroinvertebrates if the effluent sinks to and hugs the bottom prior to mixing and dilution. The habitat where benthic macroinvertebrates live and feed may also have redox conditions conducive to solubilization of some adsorbed or precipitated elements which would remain insoluble or chemically bound in more oxidizing environments. Benthic macroinvertebrates are also usually resident rather than migratory and so provide a good index of aggregate seasonal disturbances in a given area which more mobile species may not display.

Benthic community respiration, which is related to the rate of turnover of benthic biomass, is an indicator of community performance. Changes in benthic community respiration resulting from chronic-level releases of pollutants may be less evident (through routine field sampling) than changes in community species composition or spatial distribution resulting from pollutant releases. For instance, the effects of bioaccumulation or uptake of toxic substances on community respiration has

a time lag shorter than changes in species composition. Also, the effects of toxic pollutants on patterns or rates of energy flow through a biological community are usually more predictable than the population dynamics of the individual species of that community. Although community composition and diversity can be extremely sensitive to environmental change (all pollutants do not affect all species equally), physiological processes such as community respiration should be important and sensitive indicators of community performance and therefore should be monitored.

Macroinvertebrate growth rates on artificial substrate such as rubble-filled basket samplers may also be a useful indicator of community functioning. Although burrowing forms will not be represented, where this is not the dominant biomass type the uniformity of artificial substrate sampling may allow better comparison among different locations than will sampling of natural substrates.

Microbial respiration of particulate organic matter

Biodegradation rates of particulate organic matter (detritus) reflect the aggregate environmental physical-chemical conditions and recent past biological histories during the period measurements are taken. Since microbial processing of released pollutants and the supply of microbial biomass to higher trophic levels are fundamental to both adequate environmental protection and the flow of energy through the aquatic food web, microbial processing rates should be measured.

Since microbial processes control the cycling of nutrients in most natural systems, their responses to environmental changes represent an important parameter for measuring ecosystem stress. Some indication of nutrient cycling may also be obtained from the free nutrient concentration measurements described in Sect. 2.1.2. Biodegradation rates and hence the mobility and spatial dispersion of toxic substances in potential coal conversion effluents may be site-specific. To allow calculation and prediction of the long-range (time) and far-field (space) effects of toxic substances that may be released, special studies by others (see Sect. 1.3) may be necessary to answer important questions on transport and microbial transformation rates in the receiving system (see, also, Sect. 2.1.2.3). Generally, measurements of microbial process rates are important because microbiota (1) consume organic substances many of which are not utilized by other organisms; (2) mineralize pollutants; and (3) form the base of the aquatic food web in predominantly heterotrophic receiving systems such as small headwater streams or turbid rivers.

Functional variables in fish

Fish fecundity and egg viability are sensitive parameters for site-specific consideration of the toxicity of potential coal conversion effluents. It is well known, for instance, that the concentration of a toxic substance that will directly limit fish growth is well above the concentration level that will significantly affect reproduction of the same species. Therefore, if potentially impacted areas contain important spawning habitat, site-specific toxicity effects on reproductive physiology are useful sensitive indicators of stress to fish populations.

Survival of larval fish stages is also a sensitive indicator of environmental conditions. Although it may be difficult to catch enough young-of-the-year fish to allow a realistic estimate of their role in energy and mass transport, their survival has an important effect on fish community dynamics.

Certain physiological responses of fish to potential coal conversion effluents may provide important complementary information on reproductive impairment. Relative population measurements (e.g., catch per unit effort) in highly mobile species like fish will not yield as much useful information as will comparisons of physiological measurements on fish caught in affected areas to those

caught in unperturbed areas. This will be especially true for resident fish caught from midsummer to fall. For instance, fish blood parameters have rapid response times to ambient conditions so that residency requirements for fish caught in a given area are not so stringent. Therefore, in dealing with the problem of fish residency in a given sampling area, individual physiological responses such as enzyme levels in the blood may provide sensitive indicators of environmental stress.

Behavioral modification in fish may be associated with contact with effluent plumes. If concomitant population studies indicate significant biological events related to behavioral modification, special studies on fish behavior may be necessary. Time exposure of mobile and sessile organisms in seasonally migrating effluent plumes in large lakes or rivers may also have to be evaluated (as is true for benthic macroinvertebrate communities).

2.2.2.3.4 Field Methodology

Sampling methodologies for the aquatic system components discussed in Sects. 2.2.2.3.2 and 2.2.2.3.3 are not given in the handbook. Rather, the contractor is directed to acknowledge source books that have adequate descriptions of field techniques for retrieval of the data desired in the aquatic baseline monitoring program. Generally, the contractor will find that the monitoring methods described in Battelle's *Source Book of Monitoring Methods*, cited below, are adequate for most data collection needs. However, supplementary or necessary additional information may be found in the other references given below. The contractor should provide or cite adequate published literature on the applicability of the desired technique for the context in which it is to be used. These source books are:

- Environmental Impact Monitoring of Nuclear Power Plants, Source Book of Monitoring Methods*, vol. 2, Battelle Pacific Northwest Laboratories, 1975.
- Methods for Assessment of Fish Production in Fresh Waters*, W. E. Ricker, ed., 2d ed., IBP Handbook No. 3., Blackwell Scientific Publications, Oxford, 1971.
- A Manual on Methods for Measuring Primary Production in Aquatic Environments*, R. A. Vollenweider, ed., IBP Handbook No. 12, F. A. Davis Company, Philadelphia, Pa., 1969.
- Methods for the Study of Marine Benthos*, N. A. Holme and A. D. McIntyre, eds., IBP Handbook No. 16, Blackwell Scientific Publications, Oxford, 1971.
- A Manual on Methods for the Assessment of Secondary Productivity in Fresh Waters*, W. T. Edmondson and G. G. Winberg, eds., IBP Handbook No. 17, Blackwell Scientific Publications, Oxford, 1971.
- Techniques for the Assessment of Microbial Production and Decomposition in Fresh Waters*, Y. I. Sorokin and H. Kadota, IBP Handbook No. 23, Blackwell Scientific Publications, Oxford, 1972.
- Standard Methods for the Examination of Water and Wastewater*, 13th ed., American Public Health Association, Washington, D.C., 1971.
- University of California, Lawrence Berkeley Laboratory, Environmental Instrumentation Group, *Instrumentation for Environmental Monitoring. Volume 2: Water*, LBL-1, 1973.
- K. V. Slack et al., *Techniques of Water-Resources Investigations of the United States Geological Survey*, Book 5, Chap. A4, 1973.
- J. E. McKee and H. W. Wolf, eds., *Water Quality Criteria*, 2d ed., Publication No. 3-A, California State Water Resources Control Board, 1963.

Water Quality Criteria 1972, EPA R3-73-033, Committee on Water Quality Criteria, National Academy of Sciences, National Academy of Engineering, 1972.

Biological Methods for the Assessment of Water Quality, American Society for Testing and Materials, Special Technical Publication 528, 1973.

As a further note, it is important that the contractor use similar sampling procedures or sampling gear throughout the baseline monitoring program. Changes in sampling techniques or designs during the monitoring program may cause difficulty in later data interpretation and impact evaluation. If changes must be made, DOE should be consulted for approval prior to implementation.

As described for terrestrial biota in Sect. 2.2.1, it is desirable to store specimens of aquatic biota for possible future reference (a collection of voucher and baseline chemical body burden specimens). This collection may be used to verify species identification and to provide additional information in the event of unforeseen baseline chemical monitoring needs. For instance, this collection will allow background levels of toxic substances to be determined in retrospect if controversy or question arises during construction or operational phase monitoring. Collection and preservation of all specimens should follow accepted procedures, should include all dominant species obtained in normal field collections, and should follow the general preservation format as given in Sect. 2.2.1.2.2.

REFERENCES FOR SECTION 2.2.2

1. H. J. Oosting, *The Study of Plant Communities*, W. H. Freeman and Company, San Francisco, Calif., 1956.
2. R. W. Pennak, *Fresh-Water Invertebrates of the United States*, Ronald Press, New York, 1953.
3. O. Ward and O. Whipple, *Fresh-Water Biology*, W. T. Edmonson et al., 2d ed., John Wiley & Sons, New York, 1959.
4. R. L. Usinger et al., *Aquatic Insects of California*, University of California Press, Berkeley, 1956.
5. W. E. Ricker, *Methods for Assessment of Fish Production in Fresh Waters*, IBP Handbook No. 3, Blackwell Scientific Publications, Oxford, 1971.
6. K. S. Ketchen, "Stratified Subsampling for Determining Age Distributions," *Trans. Am. Fish. Soc.* 79, 205-12 (1950).
7. H. B. N. Hynes, *The Ecology of Running Waters*, University of Toronto Press, Canada, 1970.
8. R. G. Wetzel, "Primary Production," pp. 230-47 in *Studies in Ecology*, vol. 2. *River Ecology*, B. A. Whitton, ed., University of California Press, Berkeley, 1975.
9. C. E. Warren, *Biology and Water Pollution Control*, W. B. Saunders Company, Philadelphia, Pa., 1971.

2.3. Socioeconomic Variables

2.3.1 INTRODUCTION

2.3.1.1 Purpose and Scope

This section describes the socioeconomic baseline data needed for the evaluation of impacts of coal conversion plants. The socioeconomic impacts of coal conversion plants, whether pilot, demonstration, or commercial size plants, are similar to those of other industrial or energy facilities of comparable size having similar capital, labor, and material requirements. Accordingly, the baseline data needed for coal conversion plants are much the same as for other types of energy facilities (e.g., nuclear and coal-fired generating plants).

There are a number of general handbooks that describe the process of evaluating socioeconomic impacts of energy facilities. Some of the more useful ones are listed at the end of this section.¹⁻³ This section draws heavily on material from these handbooks, but it is necessarily shorter and focuses on baseline description instead of discussing the whole process of impact assessment. It would be worthwhile, therefore, for the analyst to read the general handbooks for background information.

The reader should also realize that these general handbooks do not cover the whole field of social impact assessment. Many qualitative changes in areas such as attitudes, social interaction patterns, life styles, or general quality of life may result from energy developments. However, such topics are not considered in this section. A narrow conception of social and economic impacts is used here. Attention is focused at the local level and on local changes in employment, population, economic structure, and service capacities. Regional impacts and the cumulative effects of multiple developments or growth in support industries are not discussed. These topics should be considered and addressed if they are important in specific cases. There is rather extensive literature on social impact assessment, and some basic references are given at the end of this section.⁴⁻⁶

2.3.1.2 Detail Required

The size of a coal conversion plant and its capital, labor, and material requirements are key determinants of its socioeconomic impacts. If a plant is very small—as some pilot plants are (e.g., a work force of fewer than 50)—socioeconomic impacts will be minimal. For larger plants the community setting will determine the magnitude of impacts. A community infrastructure provides the range of private and public needs of the local population. Examples include health services (hospitals, doctors, clinics, etc.), education (schools, teachers, administrators, school buses, etc.), and welfare (police and fire protection, employment, wage income, recreation, and transportation facilities). Beneficial impacts from a coal conversion plant occur if one or more of these needs are expanded or improved as a result of the plant; negative impacts may be defined as perceived or real deteriorations in the level or quality of the infrastructure services. If a plant is located near a large metropolitan

area, then even a fairly large work force (i.e., several hundred persons) probably can commute to the plant without producing significant effects. In a sparsely settled area, however, the relocation of a large work force may lead to major impacts.

Generally, infrastructure constraints will be encountered as a result of a new coal conversion plant when the

1. original population base is small
2. population growth rate is large
3. local unemployment rate is low
4. excess carrying capacity of the local infrastructure is low
5. scale of the coal conversion plant is large.

A first step in using this section is to make a judgment about the probable magnitude of the impacts of a particular plant. If it seems that the plant will have little impact, it is not necessary to describe community characteristics, such as housing market or political structure, in much detail. If, for example, a small pilot plant is to be built near Chicago, obviously it is not necessary to describe the housing market of Chicago. The statement that enough housing is available for workers would be sufficient. In areas where there is insufficient housing, a more detailed description would be needed to predict the amount of new housing required.

2.3.1.3 Impact Forecasting and Organization of This Section

A major purpose of baseline description is to provide the information needed for forecasting impacts. The utility of the baseline data can best be understood if its role in forecasting impacts is clear. Impacts are generated by an interaction of facility characteristics and community characteristics. A simple model of the interaction between facility and community characteristics is given in Fig. 2.3.1. This section is organized in the same way as the model in Fig. 2.3.1. First, baseline data needed on facility characteristics and then that needed on community characteristics are discussed. In a final section, forecasting techniques for one type of impact are presented. The forecasting techniques discussed are those that allow prediction of how much and what type of employment will be generated by the plant, how many people will move into the community because of plant construction and operation, and where these people will live. These employment and population changes should be forecast in the preconstruction stage because they are a major cause of most other socioeconomic impacts.

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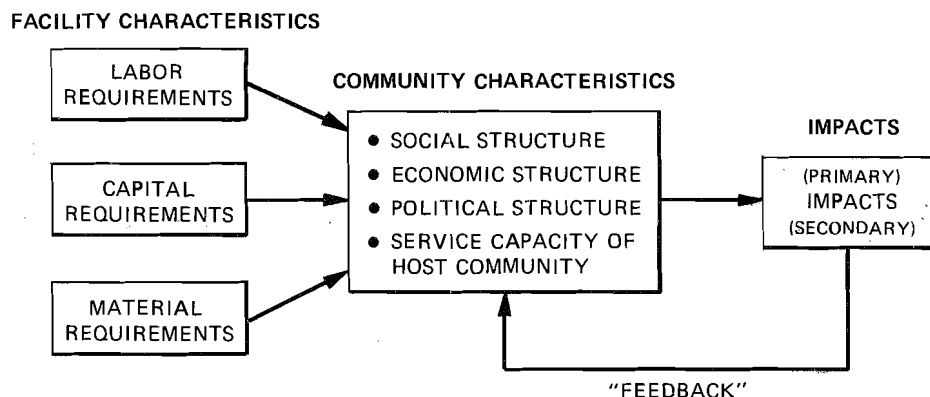


Fig. 2.3.1. Generation of socioeconomic impacts by interaction of coal conversion facility characteristics and community characteristics.

Note that most socioeconomic impacts must be predicted on the basis of professional judgment, using data that are typically incomplete and inconclusive. There are no precise formulas that can be used. Therefore, the degree of confidence in the predictions should be indicated. For impacts that can be predicted in quantitative terms, such as number of relocating workers or amount of sales tax, it is best to report a range instead of a single value. For impacts that are treated quantitatively, the degree of confidence held should be described as precisely as possible.

One of the first judgments that must be made is that of how to define impact areas. The area within 50 miles of the plant is often considered the impact area in nuclear-plant environmental impact statements. The 50-mile rule-of-thumb is useful because it represents an average acceptable commuting distance to work. In some areas, longer commuting distances might be usual. The condition of roads, amount of traffic congestion, and density of settlement within 50 miles of a plant site will influence commuting patterns. If it seems likely that workers will settle in areas more than 50 miles from the plant, the boundaries of the area analyzed should be expanded to reflect this expectation. Jurisdictional boundaries of counties, school districts, or other governmental districts should be used to define the impact areas for specific kinds of services, tax increases, or planning needs.

REFERENCES FOR SECTION 2.3.1

1. R. W. Holloron, *Suggestions for Preparation of Socio-Economic Impact Descriptions of Thermal Power Plants in the State of Washington*, M.A. thesis, University of Washington, 1975.
2. Centaur Management Consultants, Inc., *Managing the Social and Economic Impacts of Energy Developments*, prepared for Office of Planning and Analysis, Energy Research and Development Administration, July 1976.
3. U.S. Department of Housing and Urban Development, Office of Community Planning and Development, *Rapid Growth from Energy Products. Ideas for State and Local Action*, HUD-CPD-140, April 1976.
4. Kurt Finsterbusch and C. P. Wolf, eds., *Methodology of Social Impact Assessment*, Dowden, Hutchinson and Ross, Inc., Stroudsburg, Pa., 1977.
5. John S. Gilmore and Mary K. Duff, *Boom Town Growth Management: A Case Study of Rock Springs—Green River Wyoming*, Westview Press, Boulder, Colo., 1975.
6. C. P. Wolf, ed., *Social Impact Assessment*, Environmental Design Research Association, Inc., Milwaukee, Wis., 1974.

2.3.2 FACILITY CHARACTERISTICS

2.3.2.1 Site Location and Land Requirements

A map showing the geographical location of the proposed facility and the land area it will occupy should be provided by the contractor. Previous and projected alternative uses of the land area occupied by the facility should be discussed.

2.3.2.2 Labor Requirements

Information on the number of workers required for plant construction and operation should be provided by the contractor. The work force needed should be classified by skill or craft category. Information on craft categories is needed for better estimates of the proportion of the plant labor force that will be supplied by the local labor pool. Hiring practices vary among unions and will influence the number of local workers hired for different trades.

Data on the number and type of workers required should be presented by quarters of a year so that seasonal variation and the rates of increase and decline in the plant work force can be estimated. Scheduling of the construction and operation phases is important because it influences the timing and duration of demand for goods and services. A marked postconstruction decline in population and in demand for local services is expected for many types of facilities. If a "bust" period will follow the "boom" period, this should be anticipated in planning decisions. Coal conversion plants are expected to have operational work forces more similar in size to construction work forces than is typical for other types of energy facilities. Because the postconstruction declines in population will be smaller for coal conversion plants, it will probably be desirable to develop more permanent housing and public and private services for construction workers and to rely less on temporary facilities. Information on the timing of the construction and operation phases and on the associated labor force changes should be provided to aid in determining the appropriate ratio of temporary to permanent facilities.

2.3.2.3 Capital Value of Facility Over Time

A potentially important impact of facility siting is the alteration of a community's tax base by the substantial capital investment required for plant construction and operation. For example, the capital requirement for a commercial-scale, high-Btu gasification facility is expected to approximate \$1 billion. Depending on the tax status assigned to such a facility, the property taxes directly generated could be substantial (generally on the order of 1% to 2% of investment).

These taxes are not constant over the life of the project because the total investment may be spread out over time and the value of the facility increases with the cumulative investment. As a result, the increase in the tax base of the local community directly attributable to the conversion facility tends to be relatively small during the construction period and relatively large during the operating phase of the project. This time distribution of property tax receipts is in opposite phase to most of the other impacts generated by the facility. Consequently, local governments may be forced to borrow funds during the early years of the project and retire the debt during the later years to maintain a given level of services throughout the period. For this reason, estimates of tax-base effects over time not only serve to describe impacts for impact statement purposes but also provide the local community with valuable information concerning reasonable borrowing capacities which can be used in making capital budgeting decisions.

Therefore, an estimate of the capital value of the proposed facility over time should be obtained by the contractor and reported with the other variables monitored during the preconstruction baseline monitoring effort. This information may then later be combined with data on community tax-structure characteristics (discussed below) to generate estimates of the direct tax-base impact of the conversion facility.

2.3.2.4 Material and Service Requirements Over Time

The siting of any major production facility generates increased demands for materials and services to build and operate the facility. The nature of the inputs required will likely differ considerably between the construction and operation phases of the project. Generally, the construction phase will not be of sufficient duration to support the rise of local input supply industries. Therefore, if local firms do not already exist to supply construction materials and services (which is likely to be the case in the basically rural areas being considered for coal conversion facilities), these inputs will be imported. If, however, local firms capable of meeting the increased demands do exist, then it may be expected that the goods will be purchased from them; and the local economy will experience an immediate stimulus from construction of the facility.

Facility operation may also be expected to generate increased demands for certain inputs. This increase in demand may be of sufficient duration to warrant the rise of new local industries. If the volume required is also of sufficient size to support efficient production of these intermediate products, the local economy may experience an expansion of its industrial base as a result of the facility siting. Since the specific mix and quantity of inputs demanded will vary substantially according to the type and size of facility being considered, it is necessary for the contractor to have information regarding the major material and service inputs required by the facility over the life of the project. In addition to the labor requirements discussed above, these major inputs include such items as land, coal, water, and electricity requirements; transportation facilities for both inputs and outputs (coal, high-Btu gas, etc.); and other auxiliary products needed for plant operation. Combined with data on the existing community industrial structure, such information may be used to develop forecasts of facility impacts on the local economy.

2.3.3 COMMUNITY CHARACTERISTICS

Given the increase in demand for public and private goods and services, the severity of the impacts generated depends crucially on the capability of the local community to adjust to the increase. This capability, in turn, depends on the existing capacities of local supply sources. For convenience, these sources may be divided into four major categories:

1. Population and labor supply structure
2. Private industrial supply structure
3. Political and taxing system structure
4. Basic community infrastructure

A description of these community characteristics, together with the facility characteristics outlined above, provide the baseline information needed for impact assessment. Next, these community characteristics are described in greater detail, and some available data sources are indicated.

2.3.3.1 Population Structure

The size and distribution of the population within 50 miles of the plant are important determinants of impacts for three reasons. First, they are associated with the proportion of the plant's labor force that can be supplied locally. Second, they are associated with the general availability of the goods and services that people brought in by the plant will need. Third, knowledge of population size and distribution enables prediction of the rate of population growth that will occur during plant construction and operation.

Characteristics of the population such as age, sex, race, occupation, unemployment rate, and income distribution can be used to forecast local labor supplies. Furthermore, if the local population has characteristics varying greatly from those of the relocating workers, impacts on social systems will be larger and the potential for social conflict higher.

A map showing the location of the towns and cities within 50 miles of the plant and a table giving the population of each should be provided. The total population for each county within 50 miles should also be given. This information is available from U.S. Census Bureau publications. Breakdowns by age, sex, race, occupation, unemployment, and income are also provided by the Census Bureau. In the description of population characteristics, particular attention should be paid to the proportion of people on low or fixed incomes. Therefore, the proportion over 65 years old and the proportion with incomes under poverty level should be reported. These groups are most likely to be adversely affected by the increases in prices and rents that may accompany plant construction and operation.

2.3.3.2 Industrial Structure

The existing structure of the local economy will largely determine the fraction of facility input requirements that will be purchased locally. This fraction is, in turn, used in estimating the various multipliers (unemployment, income, etc.) needed for the prediction of secondary impacts (Sect. 2.3.4). Consequently, it is important to describe the economic structure of the local community in as much detail as possible to provide adequate information for impact assessment.

At a minimum, this description will incorporate information available in the most recent version of the Bureau of the Census publication, *County and City Data Book*. From this information, employment in the county or counties involved can be separated into major sectors—manufacturing; wholesale and

retail trade; business, repair, and personal services; educational services; construction; and government. In addition, the bureau's *County Business Patterns* provides mid-March estimates of county employment and payroll by major industrial sector.

Such data is sufficient for rough estimates but should be supplemented with more recent information when possible. This supplementary information may come from a variety of sources: local officials, state planning agencies, and, for particularly large projects, the local firms in the area may be independently surveyed. Again, the point must be emphasized that the degree of effort called for depends on the expected severity of the impacts.

2.3.3.3 Political Structure

Governmental officials of local towns, cities, and counties and the officials of special districts, such as school districts or fire protection jurisdictions, will be responsible for managing the growth associated with plant development. A description of the organization and jurisdictional boundaries of each local government or special district should be provided. Regional planning districts or programs should also be identified. Local officials and city or regional planners should be able to provide information on the jurisdictions and planning mechanisms for each service area supplied by the public sector.

Also, the tax structure of the local community should be described. Tax sources and rates will influence the public revenues generated by the facility, thereby affecting the funding of the public services required. In many areas, the property tax is the primary source of public revenues; but, in other localities, income and sales taxes are important sources of funds. Consequently, the baseline monitoring effort should incorporate data for tax rates from all three sources. Generally, these data will be used to forecast direct facility impacts, but in a few cases involving particularly large projects, indirect and induced tax effects may be projected. The basic source of these data is local governmental officials.

2.3.3.4 Infrastructure

One purpose of the baseline description is to provide information on the present (before the plant) availability of goods or services. For each area discussed below, it is also important to describe what excess capacities, if any, now exist and what resources are available for expanding service capacities.

2.3.3.4.1 Housing

Changes in the structure and composition of the housing market are often the first impacts of an energy facility on a community. Many construction workers who travel from job to job own mobile homes or rent them in the area. Mobile homes are frequently the only housing option when there is a large and rapid influx of people. Local ordinances controlling the location of mobile homes and the development of mobile-home parks should be described if the existing local housing market cannot absorb the expected population increase. Some of the elements of mobile-home ordinances that should be described include (1) restrictions on single-lot development, (2) zoning affecting the location of mobile-home parks, (3) maximum density allowed in mobile-home parks, and (4) requirements for open space, paving, laundry, and recreational facilities.

A baseline description of the existing housing market should contain the following information.

1. Number and type (owner-occupied vs rental) of units
2. Number and type of vacancies

3. Average annual number of housing starts in the area in recent years
4. Approximate price range of the units

A major data source for this information is the U.S. Census of Housing. If the census is outdated, housing information may be obtained from local realtors, multiple-listing services, saving and loan associations, building inspectors, housing codes, or local surveys often collected by university or research groups.

2.3.3.4.2 *Health Care*

Adequate health care in rural communities is often problematic, even without an increase in population. The influx of a large labor force may exacerbate existing inadequacies to the point that acceptable standards of health protection and care cannot be met. The health-care system, like other community services that may be affected by sudden, large population increases, must first be described in terms of the present range of services and the effectiveness of the delivery system for the existing population. Such a description gives the analyst a baseline from which to project the likely range and magnitude of impacts on the health-care system. A description of a community's health-care system should provide information on the following types of indicators: the number and location of physicians and physician extenders; the number and location of area hospitals, their capacities and occupancy rates; etc. Local and regional health planning offices are likely sources of health planning data or of a complete regional health profile. The American Medical Association's annual publication, *Distribution of Physicians, Hospitals and Hospital Beds in the United States*, also contains this kind of information.

2.3.3.4.3 *Transportation*

A coal conversion plant will place demands on the existing transportation system and may require modification or extension of the system. These demands will come from (1) workers commuting to the facility, (2) routine delivery of fuel to the facility and of conversion output from the facility, (3) special trips such as equipment and materials deliveries and waste removal, and (4) transportation demands resulting from general community growth. Transportation systems that may be impacted by facility development include roads and highways, electrical transmission systems, railroads, pipelines, and barge waterways. Information provided by the contractor on facility input requirements (Sect. 2.3.2.4) reveals the incremental demands that will be placed on these systems. To assess the likely impacts of these increased demands, however, adequate information on the capacities of the existing facilities to adjust must be available.

Data on current systems are usually available from local and state agencies. Data needed for roads and highways include the type of road, its current traffic volume and potential capacity, points of congestion, speed limits, and descriptions of any unusual features which may cause problems when facility demands are considered (e.g., railroad crossings, coal trucks passing through residential neighborhoods, etc.). If railroads will be used to transport coal during operation, the railroad system should be described, devoting special attention to (1) any changes in or additions to existing tracks, (2) any new tracks or facilities needed, and (3) potential traffic conflicts where road-railroad crossings exist. If barges will be used, the barge facilities needed and current barge traffic should be described. The distance to and capacity of existing pipelines and electric transmission systems should be described.

2.3.3.4.4 Education

A baseline description of the local school system(s) should include the following information: annual student enrollment by grade level, teaching staff employed and available for employment, annual educational expenditures per student, transportation services, and physical facilities available.

Data sources for the above information include local school officials and state boards of education and/or state superintendents of public instruction. School data are usually collected for state offices of public instruction by school districts and local or county boards of education. If state offices have the necessary data, it will be simpler and less time consuming to obtain data on all the potentially affected school systems from them.

2.3.3.4.5 Police and Fire Protection

An adequate baseline description of police and fire protection systems in the local community should provide information on staffing, equipment, and present (before the conversion facility) demands. For police protection, such information should include a description of the existing law-enforcement agencies (sheriff, police, state troopers, etc.) and manpower, the number of squad cars and other equipment (unmarked cars, communications, etc.), and the annual number and type of calls and response time. For fire protection, such information should include a description of the size and location of fire stations and manpower, the type and quality of fire-fighting equipment, and the annual number of fire calls and response time.

Representatives of police and fire departments will likely be helpful in providing such descriptive data and in assessing the probable impacts on their departments if provided with the contractor's best estimate of the incoming population by residential location. Other sources that may provide useful information are the National Board of Fire Underwriters (list of standards for fire protection service), the Insurance Services Organization (ratings for communities based on local levels of fire protection), and the Federal Bureau of Investigation (*Uniform Crime Reports*).

2.3.3.4.6 Recreation

A baseline description of recreational facilities should include a description of the current range of recreational opportunities available. The range of facilities may include outdoor open space such as parks, playgrounds, and natural areas; indoor commercial facilities such as bowling alleys, movies, and restaurants; and public facilities such as libraries, museum meeting rooms, and swimming pools.

The adequacy of the available facilities in terms of congestion, waiting times, and cost should be evaluated. Possibilities for expanding recreational facilities, both public and private, should be discussed. Local or regional officials who administer public recreational areas or programs are sources of information. Private owners of recreational facilities may also be able to provide information on possibilities for expansion.

2.3.3.4.7 Historic, Archaeological, and Cultural Sites

A number of federal laws and federal and state agencies are concerned with preserving historic and cultural resources. Some of these laws and agencies are described below. In the preconstruction phase, any historic, archaeological, or cultural resources that could be affected by plant construction or operation should be identified. Some of the agencies described below can provide help in

identifying such resources. Local historic or archaeological societies as well as university experts might also be consulted. Because of legal requirements, it is especially important to identify any resources included in, or eligible for inclusion in, the National Register of Historic Places.

The National Register of Historic Places is maintained by the Department of the Interior, and this office is responsible for determining the eligibility of any recommended district, site, building, structure, or object. Some of the legislation and agencies relevant to historic, archaeological, and cultural sites are given below.

1. *National Historic Preservation Act of 1966 (NHPA)*—declares a national policy of historic and cultural preservation. By the NHPA definition, historic and cultural resources include districts, site buildings, structures, or objects possessing historical, archaeological, architectural, or cultural significance. Although the act requires federal agencies to evaluate the impact of their actions on historic and cultural resources, Sect. 106 limits the resources that must be considered to those properties listed in the National Register of Historic Places.

2. *Advisory Council on Historic Preservation (ACHP)*—an independent agency of the executive branch of the federal government which was established by the NHPA to ensure compliance with Sect. 106 of that act and to advise the president and Congress on matters involving historic preservation.

3. *Executive Order 11593 (May 13, 1971)*—directs federal agencies to determine, in consultation with the ACHP, if any properties they own or control are eligible for inclusion in the National Register of Historic Places before they take actions that may adversely affect these properties.

4. *Title 36, Part 800, Code of Federal Regulations (36 CFR 800)*—details ACHP procedures for compliance with the NHPA and Executive Order 11593. Unlike many regulations, 36 CFR 800 is not binding under the laws that established the ACHP. Therefore, compliance with these procedures is optional.

5. *State Historic Preservation Officer*—the official, appointed by the governor of each state, responsible for the administration of the State Historic Preservation Program, which includes sites identified in the National Register of Historic Places.

6. *Reservoir Salvage Act of 1960 as amended by the Historical and Archaeological Preservation Act (HAPA) of 1974 (also known as the Moss-Bennett Act)*—the initial act required the survey and recovery of historic and archaeological data that would be destroyed by the construction of a dam and the associated impoundment. As amended, the act applies to all activities assisted or licensed by federal agencies and provides that the licensing agency may request that the Department of the Interior conduct a survey to recover significant historic or archaeological material that might be lost as a result of the licensed action.

7. *Interagency Archaeological Services Division, Office of Archaeology and Historic Preservation, National Park Service, Department of the Interior*—if data recovery or preservation is appropriate under the provisions of HAPA, the appropriate field office of this agency should be notified. This agency also is a particularly useful source of information on methods for identifying historic and cultural resources near the proposed plant site.

These brief summaries do not, of course, fully define the legal requirements and agency responsibilities in the area of historic and cultural resources preservation. Therefore, the contractor, being aware of the complexity of the issue, should consult with state and federal officials and agencies, such as the state historic preservation officer and the Office of Archaeology and Historic Preservation, to obtain further information.

2.3.3.4.8 Land-Use Management Alternatives

Land uses and land-use management alternatives for the site and surrounding environs should be detailed and synthesized for a general land-use profile. Characterization of land uses (both present and potential) for the site and surrounding areas should be based on factors such as:

1. geographic setting
2. topography
3. geology
4. soils
5. groundwater
6. cover characteristics
7. aquatic ecology
8. terrestrial ecology
9. unique natural features (including visual quality)
10. water quality and availability
11. cultural features (such as historical and demographic perspectives, development history, and accessibility)

This characterization will aid the evaluation of alternative sites in the environmental impact statement. Since the site may be in a developed urban region, alternative land uses may focus on potential for other industrial uses. Existing land-use plans, policies, and controls (such as zoning) will provide guidance to judgments in the characterization of potential uses and management alternatives.

The different levels of responsibility and functions of governmental and private agencies require correlation with their roles in land management.^{1,2} A matrix format should prove useful for this purpose.

2.3.3.4.9 Solid-Waste Disposal

Changes in the amount and type of solid waste produced may result from plant construction and operation and from the associated demographic and economic changes. Existing disposal areas may become overloaded, necessitating new landfill areas. Collection services may also need to be revised and expanded.

The contractor should estimate the amount of solid waste that the plant will put into the local community's system. A description of the existing storage, collection, transportation, processing, and disposal systems should be provided. Local officials responsible for the solid-waste disposal system should be contacted to obtain this information. The capacity of existing systems and their expandability should also be described.

2.3.3.4.10 Water Supply and Wastewater Treatment

A baseline description of the existing water supply and wastewater treatment facilities should incorporate information on three basic aspects. First, the existing supply (quantity), condition (quality), and competing uses of local water should be described. Quantitative descriptions should include the sources (rainfall, groundwater, or surface water) and variation in supply from these sources. Qualitative descriptions should include any local or state water quality standards that apply to local waters and whether any waters have been designated as "water quality limited." Competing-use descriptions should include information on the amount of water currently used for agriculture, industry, and public water supply.

Second, the present capacities of wastewater treatment facilities should be described. This description should include collection as well as treatment facilities. Information on the adequacy of existing systems, their excess capacity, and the ease of expansion should be provided.

Third, some indication of the legal aspects of water management should be given. This should include a description of the framework for water allocation: riparian rights, allocation laws, interstate pacts for water transfer, existing water resources agencies, etc.

Data for these descriptions generally must come from local agencies and officials. General references include (1) G. M. Fair, J. C. Geyer, and D. A. Okum, *Water and Wastewater Engineering, vol. 1, Water Supply and Wastewater Removal*, John Wiley and Sons, New York, 1966; (2) Metcalf and Eddy, Inc., *Wastewater Engineering: Collection, Treatment and Disposal*, McGraw-Hill, New York, 1972; and (3) J. W. Clark, W. Vessman, Jr., and J. M. Hammer, *Water Supply and Pollution Control*, 2nd ed., International Textbook Co., New York, 1971.

REFERENCES FOR SECTION 2.3.3

1. Research Applied to National Needs (RANN) Program, National Science Foundation and Harvard Graduate School of Design, *The Interaction Between Urbanization and Land: Quality and Quantity in Environmental Planning and Design* (progress reports for years one, two, and three), Landscape Architecture Research Office, Cambridge, Mass., October 1974.

2. Maine Department of Environmental Protection and Edward C. Jordan Co., Inc., *Guidelines for Lake Watershed Management Planning*, Division of Water Quality Evaluation and Planning, April 1976.

2.3.4 FORECASTING EMPLOYMENT AND POPULATION CHANGES

Estimates of population increases due to plant construction and operation consist of three parts: (1) estimates of plant employees who will move into the area, (2) estimates of the number and size of families that will accompany relocating workers, and (3) estimates of the number of secondary workers^a and their families who will move into the area. Techniques for making each of these three estimates are discussed below.

2.3.4.1 Estimates of Nonlocal Plant Employees

Estimation of the number of plant employees who will move into the area requires a comparison of the number and type of workers needed with the local availability of such workers. The number of relocating workers is, of course, the difference between the total number of workers the plant requires and the number of local workers who will fill the available jobs. Data on the number and type of workers were requested in the section on facility characteristics (Sect. 2.3.2.2): These data describe the plant's demand for labor. The supply of local workers will be influenced by factors such as the density of settlement within commuting distance of the site, unemployment rates among local construction workers, hiring practices used (e.g., union vs nonunion; local, regional, or nationwide recruiting) for specific job categories, and the competitiveness of plant wages with local wages. Local union officials and local employers who hire people with the same skills as those required by the plant may be helpful in determining how much of the plant work force will be locally supplied. Records from unemployment offices can also supply information on the availability of local labor having the required skills.

Estimates of the ratio of local to nonlocal plant employees can also be based on the experience of similar projects in similar areas. Mountain West Research, Inc., obtained information on the local and nonlocal composition of construction labor forces for fourteen energy projects in western states.^{1,2} For these fourteen projects, the percentage of local labor was reported to vary from 3.2% to 78.6% and to average 40%.³ The problem of estimating the local and nonlocal composition of a plant work force is discussed in some detail in the company's report.⁴ A regression model is presented which uses community size, number of employees on the project, distance from a community to the project, population of other communities in a commuting region, and total employment on other projects in the region to predict the number of local workers. This regression model may not be generalizable beyond the sample it was based on, and it is not a structural model of labor supply and demand for a local area. Nevertheless, the report takes a more systematic approach to estimating the local to nonlocal ratio of plant employment than do most discussions of the problem.

Some limitations of the regression model are pointed out:

It is essential to avoid creating the impression that the local/non-local composition of the work force can be predicted in a mechanical way. All that can appropriately be claimed is that more is now known about the way in which project size, community size, and distance between project and community will interact to determine the supply of local workers than was the case before this study. . . . It is equally true, however, that mechanical application of the results in the absence of careful analysis of the specifics of a particular situation can lead to judgments inferior to those which could have been obtained by careful field research of specifics alone.

Thus, if a model is used to forecast the local and nonlocal composition of the work force, it must be supplemented by information about the local community.

^aSecondary workers are workers such as sales clerks or teachers who will supply services to plant employees and their families.

2.3.4.2 Estimates of Number and Size of Families

Estimation of the number and size of families that will accompany relocating workers can rely on previous experience at energy facilities and on information about the specific location of the plant. Mountain West Research, Inc., reported that the proportion of construction workers who brought their families with them ranged from 46% to 77%, averaging 63%, and that the average family size was 3.78.⁵ A recent Department of Housing and Urban Development (HUD) publication on growth management for energy projects reported that 50% to 75% of construction workers brought their families with them and that average family size ranged from 3.5 to 3.9.⁶ Factors that influence the proportion of relocating workers who will bring their families with them include (1) the expected duration of employment, (2) the availability of housing and other services, and (3) the distance of the site from their permanent homes (i.e., can they commute for weekends). The family sizes reported for construction workers are slightly larger than the national average. Construction workers also tend to be younger than the general population and to have, as a result, more preschool- and school-age children.⁷

The ages and family sizes of operations employees tend to be more similar to national averages than do those of construction workers. Operations employees nearly always bring their families with them since they expect long-term employment at the plant. Attempts should be made to estimate the proportion of relocating workers who are single, married and have children, and married with no children, as these proportions will influence demands for housing, schools, and other services. Breakdowns by age, especially by children's ages, would also be very useful for planning. *The Construction Worker Profile* contains some information on these topics.^{1,2}

2.3.4.3 Estimates of Secondary Employment and Population Effects

The employment and population impacts of a coal conversion facility on a given area are not limited to the direct effects of plant employment, but also include the indirect effects from increased demand for the inputs used by the facility (Sect. 2.3.2.4) and the induced effects from increased overall demand in the community created by the increase in community income. Therefore, to avoid a downward bias in the assessment of total community impacts, an estimate of these secondary effects is required.

There is a rather extensive body of literature relating to methodologies for the estimation of these effects. Two of the most useful references are by Tiebout⁸ and Stenehjem.⁹ Generally, two basic approaches are discussed: input-output analysis and economic base analysis. Both may be used to derive estimates of employment multipliers which are applied to direct facility employment figures to predict the total (direct, indirect, and induced) community employment generated by a given facility. The input-output approach requires construction of a matrix of coefficients (referred to as "technical coefficients") that simulate the quantity of inputs required by each industry in the community from all other industries to produce one unit of output. From this may be derived a matrix of "direct and indirect coefficients," which illustrates the mechanisms through which an increase in the final demand for a given product generates increased production in all other industries in the community. Given this matrix, the employment impacts generated by a given facility can be analyzed. There are, however, substantial drawbacks (both practical and methodological) to the use of input-output analysis for impact assessment.¹⁰ In most cases, the costs involved are prohibitive because of the extensive data requirements for construction of the various matrices involved. For this reason, it is recommended that the use of this type of analysis be

confined to cases where some recent study has produced an input-output model of the local economy. Otherwise, secondary impacts should be predicted with the use of economic base multipliers.

These multipliers may be derived with a relatively small expenditure of time and effort and, if carefully constructed, will result in an estimate of total facility impacts which is essentially equivalent to that obtained with input-output analysis. Their derivation involves an identification of the key economic activities of the community. This is accomplished by dividing the local economy into two broad categories: (1) base activities—those that supply goods and services to markets in which the level of demand is determined by forces that lie outside the community and (2) nonbase activities—those that supply goods and services to markets in which the level of demand is determined by forces that lie within the community. It is then assumed that the former category (in which coal conversion facilities would be classified) represents the prime determinant of the overall economic growth of the region. The latter category of activities is assumed to be dependent on the former, and their ratio (in terms of employment) is assumed to remain stable over the long run. Calculation of the nonbase to base ratio, then, provides a multiplier (equal to one plus this ratio) that, applied to the figures for direct facility employment, generates an estimate of the total employment impact of the given facility on the local economy.

Since the ratio of nonbase to base employment can vary substantially across industries, some disaggregation within these two broad categories is advisable when deriving multiplier estimates.¹¹ Such disaggregation may be carried out by industry groupings (i.e., manufacturing may be broken down into various levels of the standard industrial classification system) or by economic sector (i.e., the export sector may be broken down into government and private categories). By so doing, indirect linkages may be delineated and a more accurate estimate of the employment multiplier obtained. The extent of disaggregation should depend on the particulars of the community under consideration and, of course, the budget available for the study.

Several indirect approaches exist for allocating industries (or portions of industries) to the various sectors (base, nonbase, and any subsectors that are defined). These include (1) the assumption approach, (2) location quotients, and (3) the minimum-requirements technique.¹² In addition, at least two direct approaches are available: (1) measurement of commodity and money flows from various data sources and (2) surveys of local firms and consumers.¹³ As with most research methodologies, the quality of the information obtained increases with the cost of obtaining it. The indirect methods are generally subject to greater error but are considerably less expensive. In most cases, budgetary constraints will dictate the use of one of these methods.

Regardless of the particular method chosen, the estimation of employment multipliers requires a considerable degree of judgment. The nonbasic to basic employment ratio is affected by a number of factors, including the size of the community, its proximity to larger metropolitan areas, the length of the construction phase, and the income of the workers. The county may not be a functional economic unit. Consequently, the local economy may be closely linked to a larger economic region surrounding the site. Base and nonbase components are easily underestimated or overestimated, and the multiplier response to a plant may vary with the degree of economic linkage between the site community and the larger economic area.

If secondary data sources are used, the results may be sensitive to the source selected. For example, the employment data reported by the Census Bureau is by place of residence, whereas data reported by the Census of Manufacturers is by place of work. For rural counties or communities within commuting distance of large metropolitan centers, the Census Bureau's population data may result in erroneous

estimates of the basic-nonbasic ratio. In addition, multiplier employment impacts will be overestimated if there is excess capacity in the nonbasic sector.

Separate employment multipliers should be estimated for the construction and operation phases of the project. For example, a recent HUD publication reports that between 0.3 and 0.9 secondary employees are typically required for each direct employee during the construction phase of a project; but, because operations work is more permanent, about 1.1 to 2.3 secondary workers can be expected for each direct employee during the operation phase.¹⁴

Given an estimate of the employment multipliers (construction and operation) for the local community, the total employment effects of the facility over time are forecast from project employment figures (Sect. 2.3.2.2). These estimates are then combined with the results of the demographic analysis to project the total population inflow expected to result from facility construction and operation. Figure 2.3.2 summarizes the basic steps involved in arriving at this forecast for the construction period. The same steps would be used in forecasting population increases during the operation phase of the project, but the employment figures and the ratio of support workers would differ.

In presenting estimates of total increased population due to plant development, the assumptions about local to nonlocal employment ratios, family migration and family size, and secondary employment multipliers should be explicit. The results of this forecast of population increases provide a basis for the prediction of socioeconomic impacts since most of these impacts depend on the flow of new residents into an area.

For use in assessment, this forecasted population inflow must be allocated to the various communities of the local area. Techniques to carry out this allocation are the subject of the following section.

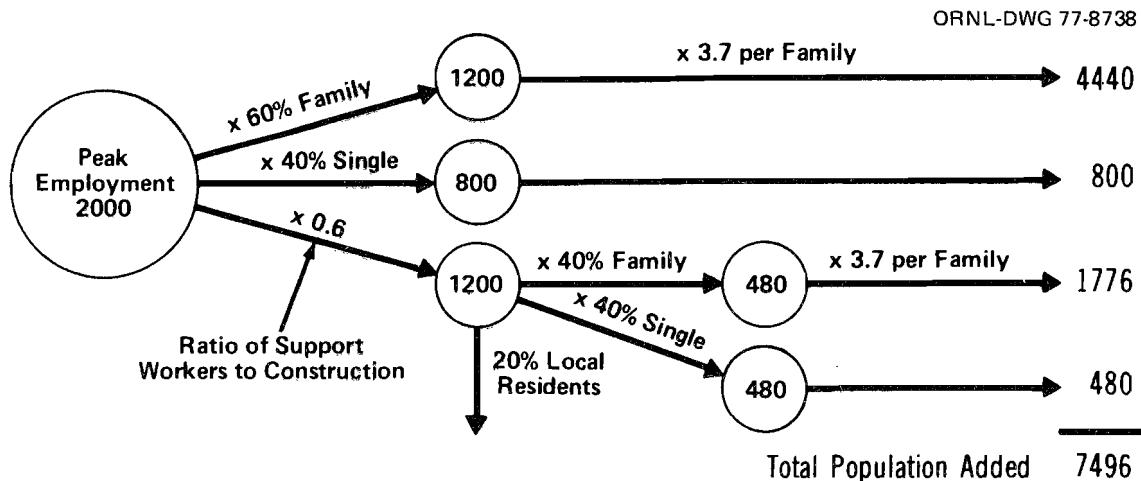


Fig. 2.3.2. Employment and population added by construction of 2250-MW coal-fired electric generating plant. From U.S. Department of Housing and Urban Development, Office of Community Planning and Development, *Rapid Growth from Energy Projects. Ideas for State and Local Action*, HUD-CPD-140, April 1976, p. 5.

2.3.4.4 Location of Incoming Population

Impacts on housing, public and private services, transportation systems, and tax bases will be influenced by where relocating workers and their families choose to reside during the construction

and operation phases. Location decisions will be affected by the availability of housing and services in local towns and cities, by the commuting routes and distances from these local communities to the plant site, and by the housing and commuting preferences of relocating workers.

One type of model that can be used to estimate spatial allocation of new workers is the gravity model. Gravity models for allocating population are based on an analogy to the functional dependence of the attractive force of gravity on mass and distance, assuming that the attractiveness of a town or city to migrants depends on the community's size and its distance from the work site. Community size is assumed to be an indicator of the availability of housing and other goods and services. Gravity models usually require the assumption that all relocating workers have similar preferences in making location decisions: They generally do not require the recognition of individual differences or the assignment of individuals to residences "by simulating the varying factors involved in their decision processes."¹⁵ Even though other types of allocation models do recognize individual differences, information on worker characteristics is not available in the preconstruction phase, so gravity models are recommended for estimating spatial distributions of new population.¹⁶

The simplest form of a gravity model assigns the relocating workers to local communities as a function of only two variables: population size and distance from the plant. Table 2.3.1 illustrates the use of this model. The derived proportions (equation) are then applied to the number of workers estimated to move into the area to give the number expected to settle in each community. Based on the calculations in Table 2.3.1, if 100 workers were expected to move into the area, 35 would live in community 1, 10 in community 2, etc.

The simple gravity model gives rough estimates of the proportion of workers who will relocate in each community. These estimates should be reviewed by people familiar with the area—local planners, public officials, prominent businessmen. If any community has particularly desirable or undesirable features, such as new housing, shopping or recreation centers, overcrowded schools, or inadequate sewerage or water systems, the knowledge of these features should be used to revise the model's rough estimates. Final estimates of the number of people who will settle in each community are crucial to the accurate forecasting of impacts in almost all socioeconomic areas. Therefore, the contractor should make a strong effort to incorporate the best judgments of knowledgeable local people into these estimates.

Table 2.3.1. Illustration of a simple gravity model calculation

Community	Population, P_n	Distance from plant, D_n (miles)	P_n / D_n	Derived proportion, $P_n / \sum_n (P_n / D_n)$ (%)
1	6251	24	260.46	35
2	1529	21	72.81	10
3	1005	16.5	60.91	8
4	8928	26	343.38	47
			$\sum_n (P_n / D_n)$ 737.56	

REFERENCES FOR SECTION 2.3.4

1. Mountain West Research, Inc., *The Construction Worker Profile*, summary report, prepared for the Old West Regional Commission, Denver, Colo., December 1975.

2. Mountain West Research, Inc., *The Construction Worker Profile*, final report, prepared for the Old West Regional Commission, Denver, Colo., December 1975.
3. Ref. 1, p. 2.
4. Ref. 2, chap. V.
5. Ref. 1, p. 6.
6. U.S. Department of Housing and Urban Development, Office of Community Planning and Development, *Rapid Growth from Energy Products. Ideas for State and Local Action*, HUD-CPD-140, April 1976, p. 5.
7. Ref. 2, p. 33.
8. C. M. Tiebout, *The Community Economic Base Study*, Supplementary Paper No. 16, Committee for Economic Development, December 1962.
9. E. J. Stenehjem, *Forecasting the Local Economic Impacts of Energy Resource Development: A Methodological Approach*, Argonne National Laboratory, Regional Studies Program, December 1975.
10. Ref. 9, pp. 17, 39-42.
11. Ref. 8, pp. 28-43.
12. Ref. 8, pp. 46-50.
13. Ref. 8, pp. 50-55.
14. U.S. Department of Housing and Urban Development, Office of Community Planning and Development, *Rapid Growth from Energy Products. Ideas for State and Local Action*, HUD-CPD-140, April 1976.
15. E. J. Stenehjem and James E. Metzger, *A Framework for Projecting Employment and Population Changes Accompanying Energy Development*, prepared for Planning, Analysis and Evaluation, Energy Research and Development Administration, 1976, p. 22.
16. Ref. 15, p. 27.

2.3.5 SUMMARY

In the discussion of forecasting employment and population changes, a series of steps was recommended. Figure 2.3.3 illustrates the sequence of steps and the techniques for moving from step to step.

Once estimates of the number of people who will move into each community are obtained by the steps shown in Fig. 2.3.3, forecasting of impacts on areas such as housing, schools, and health care is quite straightforward. Present capacities are compared with future needs on a per capita basis. To the extent that the needs of the projected population cannot be met by existing capacities, consideration of means of expansion will be needed. Planning and financing expansions of community infrastructure involve complex issues which have not been discussed, but gathering the baseline information described in this section is a first step toward effective management of the socioeconomic impacts of a coal conversion plant.

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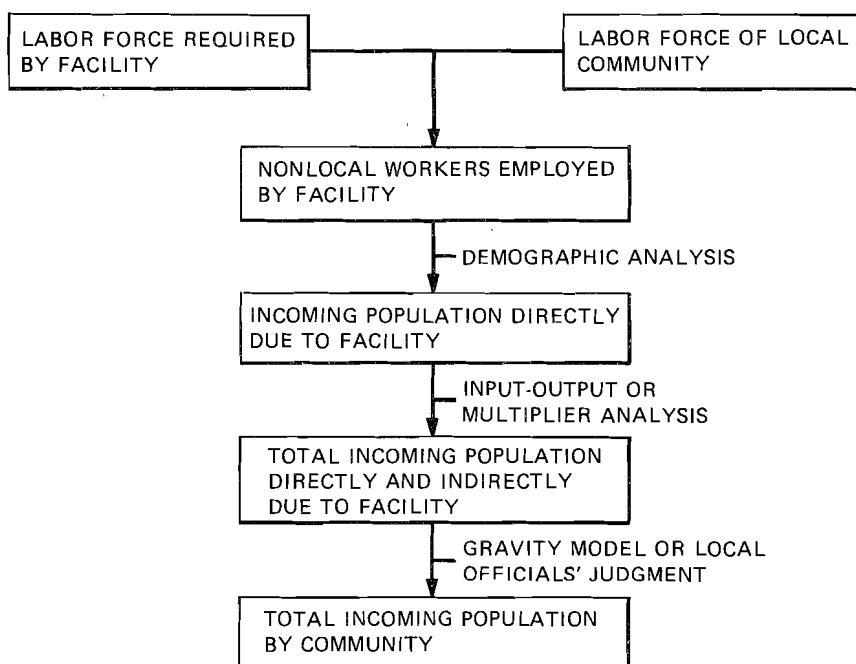


Fig. 2.3.3. Steps in forecasting community employment and population changes induced by a coal conversion facility.

2.4 Data Management

2.4.1 PURPOSE AND SCOPE

The environmental monitoring programs discussed in the preceding sections will generate a large volume of valuable (and expensive) information on the local environment and the physicochemical composition of plant effluents. In this section a generalized protocol for documentation and submission of monitoring data to DOE is discussed.

As part of the monitoring program the contractor will be submitting reports regularly. These reports usually will contain data in summary form (e.g., monthly means). Although this serves a useful purpose, it is equally important that the raw data be maintained in some accessible form. This can be achieved by developing a data base of monitoring data from all the coal conversion plant sites. Some of the major items that can be accomplished by maintaining a centralized data base are:

1. Synthesis of intrasite and intersite monitoring data
2. Synthesis of monitoring data and data from other sources
3. Automated generation of reports
4. Development of site-specific impact models
5. Development of regional models or process-oriented models based on monitoring data from several locations
6. Rapid search for available information
7. Rapid transfer of data among investigators
8. Quality control of monitoring data
9. Easy updating of data base as more information becomes available
10. Availability of monitoring data from pilot and demonstration plants to the ecologist designing a monitoring program for a commercial site
11. Use of data base as a *management tool*. The monitoring program can be reviewed and updated regularly with minimum effort since the information will be available in an organized, integrated format. For instance, if management wishes to determine if a particular aspect of the program has been analyzed satisfactorily, the data base can be queried for information on that aspect of the program—for example, fish population—and a printout of the current status of the program obtained.

It is beyond the scope of this handbook to recommend specific data-management computer software. There are several systems available and the choice will depend on the particular installation. *However, the contractor should meet certain basic requirements in submitting monitoring data if the data are to be used for the development of a data base.* In the remainder of this section, these requirements will be discussed in detail.

Some Definitions

Data item. The smallest unit of definable data; also known as unit of information, element, elementary item.¹

Record. A collection of data items. Usually a record will contain several data items along with some descriptor variables.

Set (data set). A collection of records for a specific study, for example, aquatic biology or water quality.

Data base. A collection of sets. Palmer¹ requires that a data base be:

1. An organized, integrated collection of data
2. A natural representation of the data, with few imposed restrictions or modifications to suit the computer
3. Capable of use by all relevant applications without duplication of data

Types of Data

The data base should consist of two types of data:

Type I—numeric data

Type II—textual data that describe the numeric data

Both types are important to a complete description of the data records.

The textual records describe the following in detail:

1. *Why* the numeric data were collected (for example: “phytoplankton was monitored to detect the effect of discharge water on ...”)
2. *Who* collected it
3. *How* it was collected (sampling design, sampling techniques, etc.)
4. *What* the numeric data consist of (a description of the data records, codes for stations, codes for parameters, etc.)
5. *Where* the numeric data reside (a magnetic tape serial number, name of the data set resident on a direct-access device on a computer, etc.)
6. Other pertinent information (such as references to other related data sets)

The textual records are usually called “abstracts.” The abstract is an essential half of the data base. It allows the analyst (biologist) to determine the available information very rapidly. With this knowledge, the analyst can decide what numeric data to obtain.

The numeric data are the other half of the data base. Each numeric record must be self-contained to the extent that it must have the following pieces of information.

1. Where the data were collected (station number, depth, etc.)
2. When the data were collected (month, day, year, and time of sampling, etc.)
3. Identification of the parameters (codes for parameters such as phytoplankton, water temperature, etc.)
4. Values of each parameter, that is, the observed value of each parameter

Numeric and textual information go hand in hand. The form in which the information is stored on a computer and is accessed will depend on the particular system used. However, the contractor must submit the two types of data in some standardized form. It would be ideal to have all

monitoring data submitted to DOE in a fixed format, but past experience has shown that this is not a practical goal. Hence, each contractor must decide on his own format for submission and maintain that format throughout the monitoring period.

In Sect. 2.4.2, a format for reporting textual information is discussed; Sect. 2.4.3 discusses a generalized format for reporting numeric data.

2.4.2 TEXTUAL DATA BASE

Figure 2.4.1 shows a form for reporting descriptive information. This form is based on those developed for the International Biome Program² and the National Inventory of Biological Monitoring Programs.³ The form has five major sections:

- A. General Information
- B. Monitoring Program Description
- C. Sampling Program
- D. Data Description
- E. Data Management

In the following paragraphs the various segments of this form are presented. The number in front corresponds to the number in Fig. 2.4.1.

1. <ABSTRACT IDENTIFICATION NUMBER> A nine-character identifier. This is used as the key for cross-referencing the abstract and the numeric data (Sect. 2.4.3). The first three characters are identifiers unique to the contractor.

8. <PRINCIPAL INVESTIGATOR> The person to be contacted for further information. This usually will refer to the person in charge of conducting the monitoring program.

14. <TITLE> Descriptive title for the data set subject matter.

15. <ABSTRACT> Description of the data set in condensed form.

17. <LIFE-FORM ASPECT> Biological or nonbiological aspect of the data set.

18. <ENVIRONMENTAL ASPECT> Portion(s) of the environment represented by the data set.

19. <ECOLOGICAL ASPECT> Ecological or abiotic process(es) represented by the monitoring data.

20. <KEYWORDS> Informative words which best describe the scientific content of the data as selected from a thesaurus.⁴ Use as many key words as necessary.

21. <TAXA> List of Latin binomial names of organisms included in the data set.

22. <PRIMARY PARAMETERS ESTIMATED> Describe briefly the parameters to be estimated—diversity index, production rate, etc.—from the actual environmental measurements covered in paragraph 32.

23. <HYPOTHESIS> Describe in detail all the hypotheses to be tested using the monitoring data, that is, the purpose of the monitoring. Relate this to any federal or state laws pertaining to hypothesis.

24. <RELATIONSHIP TO OTHER STUDIES> Other measured parameters that might be relevant to the parameters discussed here.

30. <LATITUDE> Latitude of plant site in degrees and minutes, prefixed by N or S for Northern or Southern Hemisphere (e.g., N4515 = 45°15' in Northern Hemisphere).

31. <LONGITUDE> Longitude of data collection in degrees and minutes prefixed by E or W (e.g., W08550 = 85°50', west longitude).

32. <PARAMETERS MEASURED> A list of parameters to be measured in tabular form.

Parameter—For example, dissolved oxygen, phytoplankton, etc.

Code—Any codes assigned to these parameters. Each parameter must have a unique code for a given site. Once assigned, the code must be maintained throughout the study. A useful reference is the Environmental Protection Agency STORET system coding scheme.

Units—Metric units are recommended.

Error bounds—Essential for proper interpretation of data.

MONITORING PROGRAM ABSTRACT

A. GENERAL INFORMATION

[illegible]

B. MONITORING PROGRAM DESCRIPTION

16. <LEVEL OF STUDY> (circle one or more)

A – organism	D – ecosystem
B – population	E – region
C – community	F – other (specify) _____

17. <LIFE-FORM ASPECT> (circle one or more)

A – abiotic	D – protista
B – animals	E – other (specify) _____
C – plants	

18. <ENVIRONMENTAL ASPECT> (circle one or more)

A – aquatic	D – meteorology
B – hydrology	E – terrestrial
C – land-water interaction	F – other (specify) _____

Fig. 2.4.1. Monitoring program abstract form.

19. <ECOLOGICAL ASPECT> (circle one or more)

A – first order consumer

E – decomposition

A – first-order consumer

B – second order consumer

F – primary production

B – second-order consumer

C – third order consumer

G – secondary production

C – third-order consumer

D – mineral cycling

H – other (specify) _____

20. <KEYWORDS>

21. <TAXA>

22. <PRIMARY PARAMETERS ESTIMATED>

23. <HYPOTHESIS>

24. <RELATIONSHIP TO OTHER STUDIES>

C. SAMPLING PROGRAM

25. <REGION>

26. <STATE>

27. <COUNTY(IES)>

28. <RIVER/STREAM>

29. <LAKE/RESERVOIR>

30. <LATITUDE>

31. <LONGITUDE>

32. <PARAMETERS MEASURED>

No.	Name	Code	Units	Error bounds

Fig. 2.4.1 (continued)

[illegible][illegible][illegible]

Fig. 2.4.1 (continued)

36. <ANALYTICAL METHODS> (with error bounds)

37. <CROSS-REFERENCES>

38. <BIBLIOGRAPHY>

39. <COMMENTS>

40. <DISSEMINATION> (circle one)

A — unlimited distribution

C — limited to government contract use

B — limited distribution

D — available via publication only

Fig. 2.4.1 (continued)

D. DATA DESCRIPTION

41. <DATA DESCRIPTION>

42. <MISSING VALUE>

43. <RECORD LAYOUT>

Column No.	Format description	Units of measure	Mnemonic	Description of fields and codes

E. DATA MANAGER USE ONLY

44. <DATE RECEIVED>

45. <TAPE NUMBER>

46. <FILE NAME>

47. <FILE DESCRIPTION>

Fig. 2.4.1 (continued)

33. <SAMPLING STATIONS> A brief description of the sampling stations.

Code—A short code for identifying station. This must be a unique code and must not be assigned to any other location within a site.

Depth—If applicable (metric units preferred).

Latitude—Use the same convention as in paragraph 30 of Fig. 2.4.1.

Longitude—Use the same convention as in paragraph 31 of Fig. 2.4.1.

River-mile—If applicable.

Sampling frequency—Monthly, weekly, etc.

Data-date—Period covered by the sampling program (e.g., 1/1/75 to 1/1/77).

Remarks—A brief description of the station (e.g., trawl station, offshore station).

34. <SAMPLING DESIGN> A detailed description of the experimental design. Include details on any statistical techniques used. Explain how this relates to section on <HYPOTHESIS>.

35. <FIELD METHOD> Discuss briefly the methods used in the field. Include estimates of error bounds for all parameters listed in paragraph 32.

36. <ANALYTICAL METHODS> Discuss briefly the analytical methods used in the laboratory. Include estimates of error bounds for each parameter.

37. <CROSS-REFERENCES> Include references to other data sets submitted as part of the monitoring program.

38. <BIBLIOGRAPHY> Include all references to published reports that discuss the data set (e.g., semiannual reports, environmental impact statements, etc.).

39. <COMMENTS> Any pertinent additional comments.

41. <DATA DESCRIPTION> A brief description of the data set.

42. <MISSING VALUES> A special code for missing values. (See Sect. 2.4.3 for more detail.)

43. <RECORD LAYOUT> If the data are submitted in machine-readable form (e.g., punched cards, magnetic tapes), use this section to describe the format of these records. If the data are submitted on data sheets (i.e., tables), use this section to describe the table.

2.4.3 NUMERIC DATA

Figure 2.4.2 is a generalized format for reporting numeric data. The various elements of this format are discussed below. The number in front corresponds to the number in Fig. 2.4.2.

Paragraphs 1 through 3 form the header information, that information which is common to several records; paragraphs 4 through 7 are the data items that form a record.

1. <HEADER IDENTIFICATION NO.> Generally a given location will be sampled several times during the period of interest. Hence, there can be a single header for several records. This number is a key to relate the header information to the actual data record.

2. <ABSTRACT IDENTIFICATION NO.> Since several abstracts and data sets will be submitted at the same time, this number is the key for relating the abstract to the numeric data. This might not be needed if the data are submitted in sets in which a set comprises both an abstract and the numeric data. This number, if used, must be the same as that of paragraph 1 of Fig. 2.4.1.

3. <STATION CODE> This code should be the same as defined in paragraph 32 of Fig. 2.4.1. It is emphasized again that this must be a unique code.

4. <HEADER IDENTIFICATION NO.> This number is the same as that of paragraph 1. This number is useful if several data records refer to the same header information.

5.j. <STATION DESCRIPTOR_j> This is an additional station descriptor which might be needed. For example, at station S, samples might be taken at depths of 0.5, 1.0, and 5.0 m: Depth would be the descriptor. Another example might be results from a transect. Then the first descriptor is the location on the transect (e.g., 5 m from start) and the second might be depth (e.g., 0.5 m). Use as many descriptors as needed. Some of the descriptors could be used as secondary-level codes for the stations.

6.a. <START-DATE> This is the date of sampling. Use only one representation: month/day/year (e.g., 1/1/76) or Julian date [e.g., 76001 (Jan. 1, 1976)].

6.b. <START-TIME> This is the time the experiment was started. Use 24-hr clock (e.g., 1330 is 1:30 PM).

Paragraphs 6.a and 6.b will be the start times for certain types of experiments (such as trawl samples). For instantaneous sampling, this is the date and time of sampling.

6.c. <END-DATE> Date on which the sampling ended (e.g., if the gill nets are set on January 1 and removed on January 2, END-DATE is 1/2/76).

6.d. <END-TIME> Time at which the sampling ended. Use 24-hr clock as in 6.b. Note that 6.c and 6.d are required only for certain types of experiments.

7.k. <PARAMETER_k CODE> This code should agree with the codes specified in paragraph 36 of Fig. 2.4.1. Considerable attention must be paid to this coding. The most important point is that unique codes must be assigned to each parameter. For most biological organisms a hierarchical coding scheme is recommended.

The parameter code might not be needed if the data are always submitted in a fixed format. For example, if a record always contains information in the following form—(1) station code, (2) depth, (3) date, (4) time, (5) water temperature, (6) dissolved oxygen, (7) turbidity—it is sufficient to record the order of the parameters in paragraph 43 of Fig. 2.4.1.

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<HEADER INFORMATION>

1. <HEADER IDENTIFICATION NO.>
2. <ABSTRACT IDENTIFICATION NO.>
3. <STATION CODE>

Items 4 through 7 should be reported in tabular form.

<DATA RECORD>

4. <HEADER IDENTIFICATION NO.> (see 1)
- 5.1. <STATION DESCRIPTOR _ 1>
2. <STATION DESCRIPTOR _ 2>
- .
- .
- .
- j. <STATION DESCRIPTOR _ j>
- i. <STATION DESCRIPTOR _ i>
- 6.a. <START-DATE>
- b. <START-TIME>
- c. <END-DATE> } if required
- d. <END-TIME> }
- 7.1. <PARAMETER _ 1 CODE>
2. <PARAMETER _ 1 VALUE>
3. <PARAMETER _ 2 CODE>
4. <PARAMETER _ 2 VALUE>
- .
- .
- .
- k. <PARAMETER _ k CODE>
- k+1. <PARAMETER _ k VALUE>

Fig. 2.4.2. General layout for numeric data.

7.(k+1). <PARAMETER_k VALUE> This is the observed value of the parameter coded in 7.i. In recording observed values, it is helpful to follow a standard convention. One such convention is shown below:

Value	Coded value
0.1	1(-1)
-0.1	-1(-1)
1.0	1(+0)
-1.0	-1(+0)
-20.512	-20512(-3)
0.1375	1375(-4)
-0.1375	-1375(-4)

Missing Values

If an observation is missing and has to be recorded (see paragraph 42 in Fig. 2.4.1), do not use 0.0 or a blank to represent this. Use a very large negative number [e.g., -99999(+0)] as the designated code for a missing value.

Trace Values

A measured element often is present only in traces (e.g., magnesium), and it is common practice to report these as <0.001 ppm. To represent this value using the method discussed above and at the same time to indicate that it is present only in trace amounts, use -1(-3). Since in most cases the lower limit is zero (absence), a negative value will indicate that the parameter is present in trace. The data-base system can be programmed easily to handle such situations.

2.4.4 SUMMARY AND CONCLUSIONS

In the preceding sections some of the basic features of an efficient documentation of monitoring data were discussed. Maintaining an elaborate data documentation and reporting scheme is essential to the development of an environmental monitoring data base (EMDB). The formats presented in Figs. 2.4.1 and 2.4.2 are reasonably flexible and can be adapted to meet the needs of the contractor.

A useful protocol for reporting monitoring data could be as follows.

1. The regulatory agency and the contractor should decide:
 - (a) the frequency of data submission (e.g., monthly, semiannually, etc.)
 - (b) the format to be used for the submission of the numeric and textual data
2. The contractor should submit both numeric and textual data for every aspect of the program. For example, there could be separate reports for
 - (a) water quality data
 - (b) benthic organisms
 - (c) fish

Each submission should be complete in the sense that both textual and numeric data must have all the information pertaining to that study even though similar information might have been submitted during the preceding period. The contractor should be held responsible for the accuracy of these reports.

REFERENCES FOR SECTION 2.4

1. I. Palmer, *Data Base Systems: A Practical Reference*, Q.E.D. Information Sciences Inc., Wellesley, Mass., 1975.
2. R. H. Strand, R. J. Olson, and D. G. Taylor, *NUTIS: Numerical and Textual Information System, Version 1.1. A Directory and Input Manual*, EDFB/IBP-75/7, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1975.
3. H. T. Kemp, *National Inventory of Biological Monitoring Programs: A Summary of Current or Recently Completed Projects*, ORNL/TM-5792, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1977.
4. J. K. Huffstetler and L. W. Rickert, *Environmental/Biomedical Terminology Index*, ORNL/EIS-98, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1976.

3. Construction Monitoring

3.1 Physical-Chemical Environment

3.1.1 DESCRIPTION OF CONSTRUCTION ACTIVITIES AND ASSOCIATED EFFLUENTS

Project stages during construction are preconstruction, site work, permanent facilities construction, and project closeout. Preconstruction includes site selection, monitoring, and implementation of temporary control measures. Site work includes site clearing, erection of temporary facilities, earth-moving work, drainage, and landscaping. Permanent facilities construction includes major facility buildings, roads and railroad spur lines, parking lots, and fences. Project closeout includes removal of temporary buildings and final landscaping. Consideration of offsite facilities should be included. Examples may include water intake and discharge structures, utility corridors and rights-of-way, and solid waste disposal sites.

The quantities of pollutants originating during construction stages are variable and generally unquantified. The main pollutants and their environmental impacts have been identified and are listed in Table 3.1.1.

Air emissions, aquatic discharges, and solid wastes associated with construction activities are identified in Table 3.1.2, along with their sources and methods for controlling their impact.

Noise, aesthetic, social, and economic impacts will also be associated with the construction stages. Noise originates from materials processing, worker transportation, blasting, pile driving, earth moving, riveting, and the use of loudspeaker public address systems. Aesthetic impacts result from the presence of large pieces of machinery and temporary structures, change in land character, creation of large areas of exposed soil, dirt, and materials piles, and increased vehicular traffic. Social and economic impacts are produced by the influx of construction workers and their families.

Table 3.1.1. Potential environmental impacts resulting from construction practices

Construction phase	Construction practice	Primary pollutants	Potential environmental impacts and extent
Preconstruction	Site inventory		Short-term and nominal
	Vehicular traffic	Dust, noise, sediment	Dust, sediment, and tree injury
	Test pits		Tree root injury, sediment
	Environmental monitoring	Visual	Negligible if properly done
	Temporary controls		Short-term and nominal
	Stormwater		Vegetation, water quality
	Erosion and sediment	Sediment spoil, nutrients, solid waste	Vegetation, water quality
Site work	Vegetative	Fertilizers in excess	
	Dust		Negligible if properly done
	Clearing and demolition		Short-term
	Clearing		Decrease in the area of protective tree, shrub, and ground covers, stripping of topsoil; increased soil erosion, sedimentation, and storm-water runoff; increased stream water temperatures; modification of stream banks and channels, water quality
		Dust, sediment, noise, solid wastes, wood wastes	Increased dust, noise, solid wastes
	Demolition		Long-term
	Temporary facilities		Increased surface areas impervious to water infiltration, increased water runoff
	Shops and storage sheds	Gases, odors, fumes, particulates, dust, deicing chemicals, noise, petroleum products, wastewater, solid wastes, aerosols, pesticides	Increased surface areas impervious to water infiltration, increased water runoff, generation of dust on unpaved areas
	Access roads and parking lots		
	Utility trenches and backfills		Increased visual impacts, soil erosion, and sedimentation for short periods
	Sanitary facilities		Increased visual impacts, solid wastes
	Fences		Barriers to animal migration
	Laydown areas		Visual impacts, increased runoff
	Concrete batch plant	Sediment, dust	Increased visual impacts, disposal of wastewater, increased dust and noise
	Temporary and permanent pest control (termites, weeds, insects)	Pesticides	Nondegradable or slowly degradable pesticides are accumulated by plants and animals, then passed up the food chain to man Degradable pesticides having short biological half-lives are preferred for use
	Earthwork	Dust, noise, sediment, debris, wood wastes, solid wastes, pesticides, particulates, bituminous products, soil conditioner chemicals	Long-term
	Excavation		Stripping, soil stockpiling, and site grading; increased erosion, sedimentation, and runoff, soil compaction; increase in soil levels of potentially hazardous materials; side effects on living plants and animals, and the incorporation of decomposition products into food chains, water quality
	Grading		
	Trenching		
	Soil treatment		
	Site drainage		Long term
	Foundation drainage		Decrease in the volume of underground water for short and long time periods, increased stream flow volumes and velocities downstream damage water quality
	Dewatering	Sediment	
	Well points		
	Stream channel relocation		
	Landscaping		
	Temporary seeding	Nutrients, pesticides	Decreased soil erosion and overland flow of storm-water, stabilization of exposed cut and fill slopes, increased water infiltration and underground storage of water, minimize visual impacts
	Permanent seeding and sodding		

Table 3.1.1 (continued)

Construction phase	Construction practice	Primary pollutants	Potential environmental impacts and extent
Permanent facilities	Transportation and heavy traffic areas	Sediment, dust, noise, particulates, petroleum products	Long-term
	Parking lots		Storm-water runoff
	Switchyard		Visual impacts, sediment, runoff
	Railroad spur line		Storm-water runoff
	Buildings	Solid wastes	Long-term
	Warehouses		Impervious surfaces, storm-water runoff, solid wastes, spillages
	Sanitary waste treatment		Odors, discharges, bacteria, viruses
	Cooling towers		Visual impacts
	Related facilities	Waste discharges ¹	Long-term
	Cooling water intake and discharge		Shoreline changes, bottom topography changes, fish migration, benthic fauna changes
	Water supply and treatment		Water quality
	Storm-water drainage		Sediment, water quality
	Wastewater treatment	Sediment, trace elements, noise, caustic chemical wastes, sediment spoil, flocculants, particulates, fumes, solid wastes	Sediment, water quality, trace elements
	Dams and impoundments		Dredging, shoreline erosion
	Breakwaters, jetties, etc.		Circulation patterns in the waterway
	Fuel handling equipment		Spillages, fire, and visual impacts
	Oil storage tanks, controls, and piping	Sediments, wood wastes	Visual impacts
	Conveying systems (cranes, hoists, chutes)		Visual impacts
	Waste handling equipment (incinerators, wood chippers, trash compactors)		Noise and visual impacts
	Security fencing		Long-term
Project closeout	Access road	Noise, dust, solid wastes	Increased runoff
	Fencing		Barriers to animal movements
	Removal of temporary offices and shops	Sediment, dust	Short-term
	Demolition		Noise, solid waste, dust
	Relocation	Nutrients, petroleum products	Storm-water runoff, traffic blockages, soil compaction
	Site restoration		Short-term
	Finish grading	Nutrient runoff, water quality	Sediment, dust, soil compaction
	Topsoiling		Erosion, sediment
	Fertilizing	Vegetation	Nutrient runoff, water quality
	Sediment controls		Vegetation
	Preliminary startup	Short-term	Short-term
	Cleaning		Water quality, oils, phosphate and other nutrients
	Flushing		

Source: D. R. MacFarlane et al., modified from *Power Facility Siting in the State of Illinois: Part II—Environmental Impacts of Large Energy Conversion Facilities*, Illinois Institute for Environmental Quality, IIEQ Doc. No. 75-03, Chicago, 1975.

Table 3.1.2. Primary effluents during construction

	Source	Control
Aquatic impacts		
Increased runoff	Vegetation removal Land erosion	Keep ground disturbance to a minimum
Increased siltation, turbidity, and nutrient concentrations	Runoff and erosion	Limit slope steepness Terrace Design to direct and dissipate runoff Provide siltation basin Provide vegetation buffer strips along waterways Save topsoil Provide proper seeding and mulching Provide proper surfacing
Depression of water table Groundwater intrusion and groundwater contamination	Dewatering	Monitor and where adverse impacts develop import water or deepen the well
Sanitary waste	Sanitary waste Chemical toilets	Treat with portable facilities or dispose at local sanitary waste treatment plants Satisfy federal, state, and local regulations and permit procedures
Dewatering	Aggregate washing Concrete lift operations Washing concrete trucks and batch plants	Collect in sedimentation basin and treat prior to discharge
Chemicals	Pesticides Soil conditioners Deicing chemicals	Use only when necessary Use biodegradable pesticides
Air emissions		
Dust, dirt, particle matter	Excavation, movement of vehicles, wind, erosion, concrete plant, crushing operations, material storage piles	Sprinkle or use chemical treatments Provide early and temporary seeding Use good construction practices including air filters, water sprinkling, and covering storage piles
Pesticides	Applied at the site	Use only as needed Use biodegradable pesticides
Vehicular emissions	Construction equipment Supply deliveries Worker transportation	Follow federal and state regulations
Emissions from burning	Burning of cleared trees and brush, garbage, and other solid wastes where permitted	Burn only when atmospheric conditions are favorable Comply with federal, state, and local regulations
Solid wastes		
Sediment	Runoff, erosion	
Wood wastes	Clearing and demolition work	Landfill or burn
Other solid wastes	Clearing Earthwork Permanent facilities construction	Landfill

Table 3.1.2 (continued)

	Source	Control
	Miscellaneous	
Noise	Vehicular traffic	Restrict activities
	Clearing and demolition	to daylight hours
	Construction of temporary facilities	Use small charges which are regulated for noise reduction while blasting
	Permanent facility construction	Provide noise control devices or mufflers where appropriate
	Removal of temporary facilities	

3.1.2 CHEMICAL AND INSTRUMENTAL METHODS FOR CONSTRUCTION EFFLUENTS

3.1.2.1 Purpose and Scope

During the construction period of a coal conversion facility, organic compounds, trace elements, airborne pollutants, particulates, and other pollutants should be monitored. Methods for monitoring these pollutants have been described fully in Sect. 2.1.4.3. In addition, several additional pollutants will be introduced as a result of building activities. Among these are oil and grease from construction machinery, nitrate and phosphate from topsoil leachates, and suspended sediments. Nitrates and phosphates promote the formation of explosive growths of algae. When the algae are decomposed by bacteria, oxygen is consumed and often this results in extensive fish kills. Nitrates are also responsible for methemoglobinemia in very young infants.

Useful information on sampling philosophy is given by Wilson.¹

3.1.2.2 Suspended Solids and Airborne Particulates

Suspended matter in water or air will be one of the major pollutants during the construction period of a coal conversion facility. Sampling methods for airborne particulates are described fully in Sects. 2.1.3.3.6 and 2.1.4.3.4. Methods² for the analysis of aqueous sediment samples are described in Sect. 2.1.2.4.5.

Two methods³ are normally used for the determination of suspended solids in water. The Gooch crucible method involves the filtration by suction of a known volume of the shaken sample through a specially prepared asbestos mat in a Gooch crucible, which is then dried at 100° to 105°C. The preparation of a series of such crucibles for routine work is rather laborious, and filtration is sometimes very slow, particularly with polluted samples containing much colloidal matter and greasy suspended matter.

In the alternative method, a known volume of the shaken sample (usually 50 to 200 ml) is centrifuged under standardized conditions using special conical-end centrifuge tubes. After pouring off the separated liquid, the suspended matter at the bottom of the tubes is washed with distilled water, recentrifuged, the separated water again removed, and the suspended matter is transferred to a weighed platinum or other suitable basin by means of a jet of water from a wash bottle and dried at 100° to 105°C. Generally, this method is much quicker than the Gooch crucible method, especially when large numbers of samples are being examined. However, it gives slightly lower results since it does not include any colloidal matter, which tends to be retained by the Gooch mat. Another advantage of the centrifuge method lies in the ease with which a determination of volatile solids can be subsequently carried out by ignition of the platinum basin containing the suspended solids. During this ignition, valuable information about the nature of the suspended solids can be obtained by noting any blackening, darkening or color changes, any odors produced, evolution of fumes, appearance of sparks, flame, etc. The mineral residue remaining after ignition should be subjected to a qualitative analysis for the more common cations and anions, especially calcium, magnesium, iron, chromium, copper, zinc, lead, sulfate, chloride, and phosphate.

The filtrate from the Gooch crucible, or the separated liquid in the centrifuge, can be used for a determination of dissolved solids or soluble solids by evaporating a known volume to dryness. Any colloidal matter present will also be included in this determination.

Total solids can be determined by evaporating a known volume of the well-shaken sample to dryness on the water bath and drying at 100° to 105°C.

A current trend is to replace the Gooch crucible technique with membrane filters. Riley⁴ has listed criteria that a suitable filter should satisfy and concludes that plastic membrane filters (0.45- μ m pore size) are most suitable.

3.1.2.3 Other Pollutants

3.1.2.3.1 Oil and Grease

The EPA describes three methods⁵ for the determination of oil and grease. The Soxhlet extraction method includes the measurement of Freon-extractable matter from surface and saline waters and industrial and domestic wastes. It is applicable to the determination of relatively nonvolatile hydrocarbons, vegetable oils, animal fats, waxes, soaps, greases, and related matter. The method is not applicable to measurement of light hydrocarbons that volatilize at temperatures below 70°C. Petroleum fuels from gasoline through No. 2 fuel oil are completely or substantially lost in the solvent removal operation. The method covers the range from 5 to 1000 mg/liter of extractable material. The sample is acidified to a low pH (<2) to remove the oils and grease from solution. After they are isolated by filtration, they are extracted with Freon using the Soxhlet extraction method. The solvent is evaporated from the extract and the residue weighed. When 1-liter portions of the sewage were dosed with 14.0 mg of a mixture of No. 2 fuel oil and Wesson oil, the recovery was 88% with a standard deviation of 1.1 mg.

In a second method, a separatory funnel is used for extraction; otherwise, it is very similar to the Soxhlet extraction method. Some crude oils and heavy fuel oils contain a significant percentage of residue-type materials that are not soluble in Freon. Accordingly, recoveries of these materials will be low. This method covers the range from 5 to 1000 mg/liter of extractable material. When 1-liter portions of the sewage were dosed with 14.0 mg of a mixture of No. 2 fuel oil and Wesson oil, the recovery was 93% with a standard deviation of 0.9 mg.

A third method includes the measurement of Freon-extractable matter from surface and saline waters and industrial and domestic wastes. It is applicable to the determination of hydrocarbons, vegetable oils, animal fats, waxes, soaps, greases, and related matter. The method is applicable to measurement of most light petroleum fuels, although loss of about half of any gasoline present during the extraction manipulations can be expected. The method covers the range from 0.2 to 1000 mg/liter of extractable material. The sample is acidified to a low pH (<2) and extracted with Freon. The oil and grease are determined by comparison of the infrared absorbance of the sample extract with standards. When 1-liter portions of sewage were dosed with 14.0 mg of a mixture of No. 2 fuel oil and Wesson oil, the recovery was 99% with a standard deviation of 1.4 mg.

3.1.2.3.2 Nitrate

Two methods⁵ are currently used by the EPA for the determination of nitrate. In the brucine spectrophotometric method the applicable range of concentration is 0.1 to 2 mg NO₃-N/liter. This method is based on the reaction of the nitrate ion with brucine sulfate in a 13 N H₂SO₄ solution at a temperature of 100°C. The color of the resulting complex is measured at 410 nm. Temperature control of the color reaction is extremely critical. Interferences are dissolved organic matter, strong oxidizing or reducing agents, and manganese(IV). A disadvantage of the method is the necessity for absolute control of temperature during the critical color development period. In a study of the precision and accuracy of the method, 27 analysts in 15 laboratories analyzed natural water samples containing exact increments of inorganic nitrate (Table 3.1.3).

Table 3.1.3. Precision and accuracy of EPA method for nitrate

Increment as nitrogen, nitrate (mg N/liter)	Precision as standard deviation (mg N/liter)	Accuracy as	
		Bias (%)	Bias (mg N/liter)
0.16	0.092	-6.79	-0.01
0.19	0.083	+8.30	+0.02
1.08	0.245	+4.12	+0.04
1.24	0.214	+2.82	+0.04

The second method (cadmium reduction method) pertains to the determination of nitrite singly, or nitrite and nitrate combined in drinking, surface, and saline waters and domestic and industrial wastes. The applicable range of this method is 0.01 to 1.0 mg/liter nitrate-nitrite nitrogen. The range may be extended by sample dilution. A filtered sample is passed through a column containing granulated copper-cadmium to reduce nitrate to nitrite. The nitrite (that originally present plus reduced nitrate) is determined by diazotizing with sulfanilamide and coupling with *N*-(1-naphthyl)-ethylenediamine dihydrochloride to form a highly colored azo dye which is measured spectrophotometrically. Separate, rather than combined, nitrate-nitrite values are readily obtained by carrying out the procedure first with, and then without, the initial copper-cadmium reduction step. Suspended matter interferes in the reduction column by restricting sample flow. Since nitrate-nitrogen is found in a soluble state, the sample may be prefiltered through a glass fiber filter or a 0.45- μ membrane filter. Highly turbid samples may be pretreated with zinc sulfate before filtration to remove the bulk of particulate matter present in the sample. Low results might be obtained for samples that contain high concentrations of iron, copper, or other metals. EDTA is added to the samples to eliminate this interference. Samples that contain large concentrations of oil and grease will coat the cadmium. This interference is eliminated by pre-extracting the sample with an organic solvent. This procedure determines both nitrate and nitrite. If only nitrate is desired, a separate determination must be made for nitrite and subsequent corrections made. The nitrite may be determined by a procedure that omits the reduction step.

In a single laboratory using sewage samples at concentrations of 0.04, 0.24, 0.55, and 1.04 mg $\text{NO}_3 + \text{NO}_2\text{-N}$ /liter, the standard deviations were ± 0.005 , ± 0.004 , ± 0.005 , and ± 0.01 respectively. In a single laboratory using sewage samples at concentrations of 0.24, 0.55, and 1.05 mg $\text{NO}_3 + \text{NO}_2\text{-N}$ /liter, the recoveries were 100%, 102%, and 100% respectively.

An automated version of the above method is described in ref. 5.

3.1.2.3.3 Phosphate

Two methods⁵ for the determination of specified forms of phosphorus in industrial wastes and waters are recommended by the EPA. The methods are based on reactions that are specific for the orthophosphate ion. Thus, depending on the prescribed pretreatment of the sample, the various forms of phosphorus given in Fig. 3.1.1 may be determined. Full details are reported for measurements of the various forms of phosphate. The methods are usable in the 0.01- to 0.5-mg P/liter range.

The methods involve the reaction of ammonium molybdate and antimony potassium tartrate in an acid medium with dilute solutions of phosphorus to form an antimony-phospho-molybdate

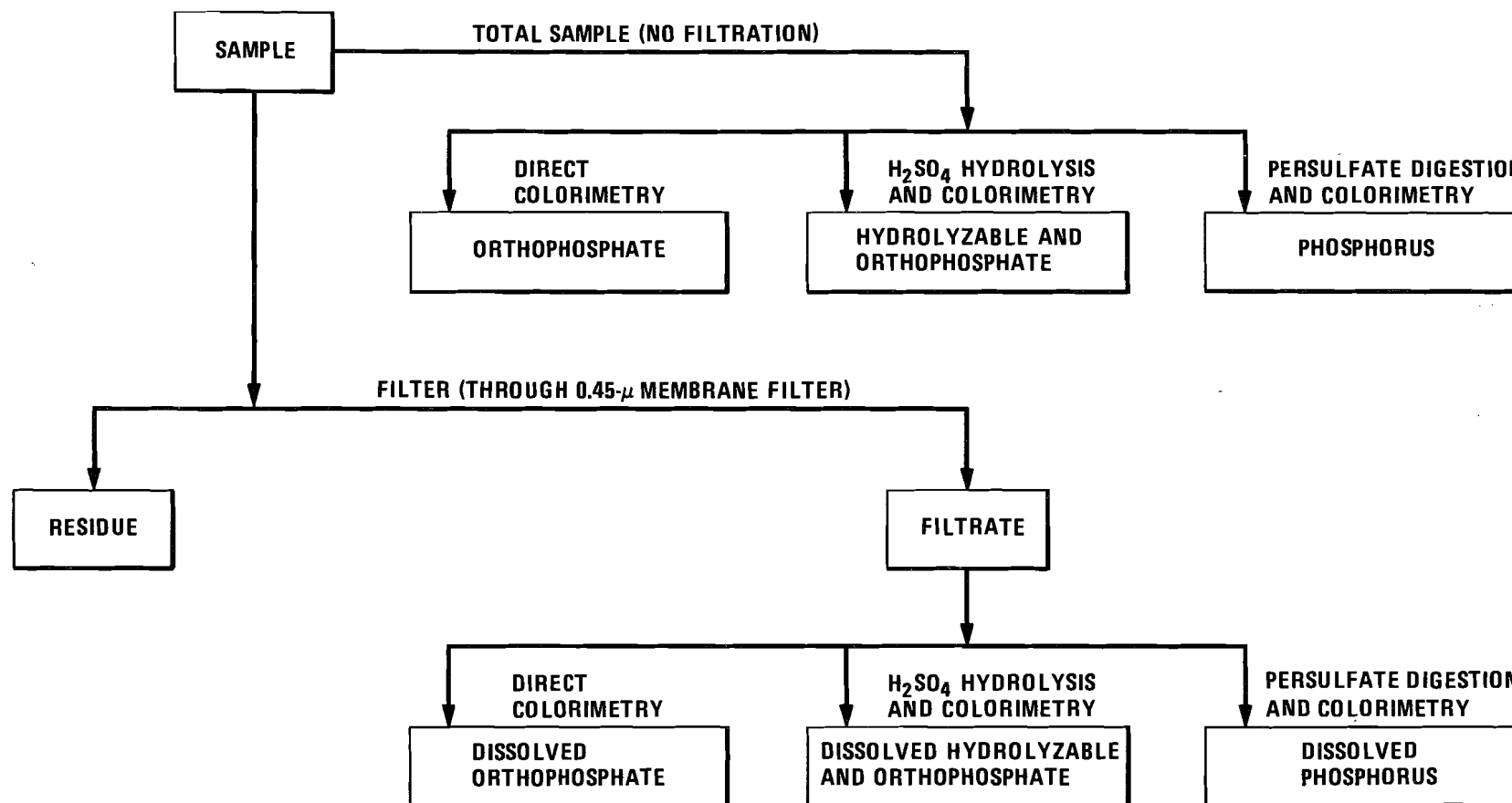


Fig. 3.1.1. Analytical scheme for differentiation of phosphorus forms. Source: U.S. Environmental Protection Agency, *Methods for Chemical Analysis of Water and Wastes*, 1974, p. 250.

complex. This complex is reduced to an intensely blue colored complex by ascorbic acid. The color is proportional to the phosphorous concentration. Only orthophosphate forms a blue color in this test. Polyphosphates (and some organic phosphorus compounds) may be converted to the orthophosphate form by sulfuric acid hydrolysis. Organic phosphorus compounds may be converted to the orthophosphate form by persulfate digestion.⁶ Interferences are arsenate, mercuric chloride, and high concentrations of iron. Twenty-six analysts in 16 laboratories analyzed natural water samples (Table 3.1.4).

Table 3.1.4. Precision and accuracy of EPA method for phosphate

Increment as orthophosphate (mg P/liter)	Precision as standard deviation (mg P/liter)	Accuracy as	
		Bias (%)	Bias (mg P/liter)
0.029	0.010	-4.95	-0.001
0.038	0.008	-6.00	-0.002
0.335	0.018	-2.75	-0.009
0.383	0.023	-1.76	-0.007

The second method⁵ describes the use of a Technicon Autoanalyzer for an automated version of the colorimetric ascorbic acid reduction method. The method is usable in the 0.001- to 1.0-mg P/liter range. Approximately 20 to 30 samples per hour can be analyzed. In a single laboratory using surface water samples at concentrations of 0.04, 0.19, 0.35, and 0.84 mg P/liter, standard deviations were 0.005, 0.000, 0.003, and 0.000 respectively. In a single laboratory using surface water samples at concentrations of 0.07 and 0.76 mg P/liter, recoveries were 99% and 100% respectively.

REFERENCES FOR SECTION 3.1.2

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4. J. P. Riley, *Chemical Oceanography*, vol. 2, Academic Press, New York, 1965, pp. 299-301.
5. U.S. Environmental Protection Agency, *Methods for Chemical Analysis of Water and Wastes*, 1974.
6. M. Gales, Jr., E. Julian, and R. Kroner, "Method for Quantitative Determination of Total Phosphorus in Water," *J. Am. Water Works Assoc.* **58**(10), 1363 (1966).

3.1.3 MONITORING FOR PHYSICAL IMPACTS ON THE TERRESTRIAL ENVIRONMENT

Monitoring of soils during the construction phase excludes two areas: those that will be designated for permanent features and those set aside for construction activities. Monitoring data acquired during the baseline program may be used for comparison to detect impacts not visible to the eye. Monitoring techniques should be identical in both programs to permit valid data comparisons. Unmonitored areas such as those for structures, storage facilities, access roads, parking lots, and landscaping are clearly identified on architects' and engineers' blueprints. Their locations should be sketched on the low-altitude aerial photographs obtained during preconstruction monitoring. It is also customary for construction engineers to have a large-scale preconstruction topographical map prepared for design purposes. A topographical map overlay of the installations to be built will also clearly define the buffer zone surrounding the facility, which is an important area for soils monitoring.

Areas set aside for construction stockpiles, parking lots, and spoil piles adjacent to excavations will be landscaped toward the end of the construction phase. As such, these areas also will not require monitoring.

Environmental monitoring of soils in the buffer zone that surrounds the facility is recommended due to the impact of events that could occur during construction. Among these events are unauthorized stockpiles and spoil piles, vehicular traffic, and inadvertent spills of construction materials beyond areas where landscaping is planned. Depending on the severity of such impacts, the buffer zone may require restoration. Landscaping is, itself, a form of restoration. Visual inspection of the buffer zone can be used to appraise the impact on soils. Vehicular traffic, stockpiles, and spoil piles will destroy vegetation and compact the soil, making revegetation difficult.

Low-altitude aerial photographs are used to document the presence or absence of moderate- to large-scale and severe terrestrial impacts on the buffer zone. These photographs should be taken during and near the end of construction. It is desirable to have photographs taken in late fall or early winter (pre-snow pack) when foliage does not obstruct the ground.

Small-scale impacts, as well as verification of impacts seen from aerial photographs, require a ground-level, onsite inspection. If any chemical spills are discovered, spot soil samples, salinity, and pH tests should be taken as described in Sect. 2.1.1.2.

3.1.4 MONITORING FOR PHYSICAL IMPACTS ON THE AQUATIC ENVIRONMENT

3.1.4.1 Hydrologic Monitoring of Surface Water

3.1.4.1.1 Impact of Construction on Surface Water

Construction activities in many cases may have a significant impact on the hydrologic environment. For a demonstration-size coal conversion plant, however, the hydrologic impacts on surface waters are not expected to be significant if good construction practices are implemented. Site-specific impacts are possible, however, and the probability of an unforeseen impact should not be ignored. Hence, a brief review of the possible impacts is included with a presentation of likely indicators that can be used to recognize unforeseen impacts. It is assumed that the major impacts of construction will have been recognized during the preparation of an environmental impact statement (EIS) and that appropriate mitigating measures and additions to the monitoring program will have been made.

Construction impacts are examined with respect to flow, temperature, sedimentation, and erosion. Changes in infiltration and evapotranspiration are not discussed due to the small impacts on the watershed characteristics that are likely to occur from changes in these parameters during construction.

Impacts on surface waters during construction can be temporary or permanent. In addition to onsite activities, impacts can result from construction activities associated with the intake and discharge structures. Usual activities at these sites include cofferdam construction and associated dewatering, spoil disposal, and bank modifications. Table 3.1.5 is a list of usual onsite construction activities and their effect on surface-water flow. Despite the best construction practices, sedimentation is certain to be caused by construction activities. To monitor the impact of sedimentation and its related effects, representative flow data are required. For any activity that will alter the nature of flow patterns or the quantity of stream flow, additional monitoring should be considered. Where stage and discharge data are routinely monitored in the baseline program, dye studies may be appropriate. For study areas that only monitor stream stage, additional effort should be directed towards measuring the discharge. Consideration should be given to measuring the rate of change of stage and changes in bottom topography, channel width, and sediment load. The needs of

Table 3.1.5. Impacts to surface water flow characteristics
resulting from construction activities

Construction activity	Impact	Effect on flow rate
Site clearing	Permanent	Increase
Laydown areas	Temporary	Increase
Concrete batch plant	Temporary	Decrease
Drinking water consumption	Permanent	Decrease
Sanitary wastewater usage	Permanent	Increase
Earth-moving	Temporary	Increase
Dust control	Temporary	Decrease
Site drainage	Permanent	Increase
Stream channel relocation	Permanent	Both are possible
Transportation areas (railroad, parking lot)	Permanent	Increase
Removal of temporary facilities and landscaping	Temporary	Increase

other facets of the monitoring program (water quality, groundwater, aquatic ecology) must be considered before finalizing the construction-phase monitoring plan. Cautionary indicators of significant changes on the flow characteristics of surface waters are outlined later in this section. No attempt has been made to quantify these possible changes since site-specific parameters are needed to characterize them.

Temperature characteristics of surface waters may be inadvertently elevated by construction activities. Land clearing and bank modifications near surface water will increase the local temperature of the water. Depending on the currents, this effect may adversely impact surface waters. Such local changes can have serious adverse effects on critical aquatic habitats. Becalmed waters created by temporary structures, such as cofferdams, may experience great increases in temperature. This effect could be permanent if the intake structure causes a similar situation when the cofferdam is removed. If these or similar changes occur, additional monitoring is necessary. A fixed thermograph with digital readout could be added to monitor any buildup of excess temperatures. Cautionary indicators of the presence of changes in temperature characteristics are outlined later in this section.

Erosion and sedimentation characteristics of construction areas are certain to be affected. Activities that alter existing sedimentation patterns include every aspect of construction. Activities that contribute to increased erosion and sedimentation are presented in Table 3.1.6, including an indication of the construction phase that incorporates the activities. Examples of impact and means for mitigating the effect of sedimentation are included in ref. 1. Close coordination of sediment monitoring with the needs of the water quality and aquatic ecology programs is essential during construction. In planning monitoring for erosion and sedimentation, serious consideration should be given to increasing the frequency of monitoring to provide a basis for a complete analysis. Storm events should be monitored several times a day for most cases. As mentioned in Sect. 2.1.2.3, detailed

Table 3.1.6. Construction activities that produce erosion and sedimentation

Construction phase	Construction activity
Site preparation	Clearing Access roads Parking lots Laydown areas Concrete batch plant
Earthwork	Excavation Grading Dredging Trenching Spoil pile removal
Site drainage	Foundation drainage Dewatering Stream channel relocation
Permanent facilities	Stormwater drainage Stream bank Landscaping Security fence installation
Site restoration	Site landscaping Sediment control removal and restoration

sediment measurements require an accurate determination of the stream flow and temperature. Since sediment data is likely to change during construction, special care in data collecting and the establishment of a statistically valid number of sediment samples are necessary. It should be emphasized that changes in erosion and sedimentation are the most likely source of adverse impact from construction activity. The effect of construction activity on sedimentation characteristics does not necessarily end with the completion of construction. Until it can be firmly established that construction-related impacts have ceased, the additions made to the baseline monitoring program at the onset of construction should be continued, although the frequency of sampling can be gradually reduced.

3.1.4.1.2 Monitoring Program

The environmental monitoring program for the construction phase of a demonstration-size coal conversion plant should continue all the hydrologic monitoring activities initiated during the preconstruction phase. It will be necessary to continue the baseline monitoring to evaluate construction and operational activities. In addition to the continuation of the baseline monitoring program, additional monitoring may be required based on the conclusions of the EIS. These additions will reflect site-specific problems that should be addressed during the construction-phase monitoring. With the continuation of the baseline monitoring program and the appropriate additions suggested by the EIS, a data record of at least two years will be available for examining the impact of operational activities on the hydrologic environment.

Although the EIS will address the probable impacts of construction activities, it is possible to overlook a significant impact to the hydrologic environment. To detect such an error, cautionary indicators of changes in the hydrologic environment are useful. Monitoring personnel should be relied on to observe such indicators as they might occur during construction of a coal conversion plant. Indicators for each aspect of the surface water hydrology are included.

Changes in flow characteristics of surface water are best indicated by changes in the behavior of the water's free surface. Differences in the complexion of the free surface should be noted by monitoring personnel. Reductions in current are indicated by a deadwater region with a smooth, glassy surface during windless conditions. A second indicator of current reduction is the collection of floating debris. Areas that begin to collect debris during construction are cause for attention. Deadwater regions are usually areas of sediment deposition and if these regions were scoured previous to construction, mitigating measures or increased monitoring may be necessary. Construction activities may also increase surface water currents. Again, such changes are visible on the free surface. Indicators are increased surface waves, vortices, eddies, upwellings, or foam production. The presence of these cautionary indicators can be used to suggest further monitoring or investigation of environmental impacts to the surface water hydrology.

Surface water areas most likely to experience changes in temperature characteristics are those which have become still and are poorly flushed; the regions of water most likely to experience such changes are those near the construction site of intake structures. A likely indicator is dead fish. The presence of dead fish does not necessarily mean that temperatures have increased; however, their presence should be sufficient to raise the issue of excess temperature buildup and to warrant further investigation. Odor and taste changes in the water may also indicate temperature changes.

Cautionary indicators for marked changes in erosion characteristics are most clearly evident by changes in the land surface. The presence of well-developed gullies and hills along the shoreline or downslope from sediment control facilities is a cause for attention. The consequence of excessive

erosion is an increase in sedimentation. Sediment impacts are of two forms: impacts due to changes in sediment deposition and impacts due to increased sediment load. The former change is best indicated by changes in flow characteristics, whereas the latter can be seen as changes in some of the water quality parameters. The best water quality indicators of sedimentation effects are turbidity, color, and total suspended solids. Turbidity and color often can be detected visually and validated by analysis of water samples.

Evidence of any of these indicators does not necessarily mean that further monitoring or mitigating measures are required. The indicators are mentioned with the intention of alerting monitoring personnel to possible environmental impacts on surface water hydrology that may have been overlooked in the EIS. Responsibility must be placed on the monitoring personnel to observe and report such indications so as to facilitate an effective monitoring program of construction activity impacts.

Throughout the construction monitoring period, the collected data should be analyzed and compared with the baseline information and the EIS predictions. Such comparisons can be used to effect a cost-effective and complete program. Complete data records that can be used to provide an extension of the baseline program and a basis for operational monitoring should remain the objective of the monitoring program throughout construction-phase monitoring.

3.1.4.2 Hydrogeologic Monitoring

Monitoring of groundwater during the construction phase of a demonstration-size coal conversion plant must provide data on the impacts of construction and must continue the baseline monitoring program. Determination of the impacts of construction may require or suggest modifications to the hydrogeologic and groundwater quality monitoring programs. A continuation of the baseline monitoring program, however, is essential to the best characterization of the groundwater regime, which will be used for comparison during the operational phase.

Recommendations for the design of the construction-phase monitoring program will be made in the EIS. Unforeseen impacts on the groundwater regime may require further modification. With the continuation of the baseline monitoring program and the appropriate modifications for construction monitoring, at least two years of data will be available for the determination of the impact of plant operation on the groundwater regime.

Construction-related impacts on the groundwater regime are site-specific and will depend on the amount of land disruption, dewatering, and consumptive groundwater use during construction. Since the impacts will be site-specific, the utility of the monitoring results will depend on the ability of monitoring personnel to anticipate impacts. The construction monitoring program as discussed here assumes that groundwater availability will not be a significant problem during the construction phase.

Plant construction may include extensive blasting, excavation, deforestation, and landscaping. In addition to land disturbances, the geohydrology of the site may require dewatering during construction. All these construction activities could impact the hydrogeology by altering groundwater flow patterns, establishing new connections between aquifers, altering aquifer characteristics, changing groundwater levels, and changing soil characteristics. Most of these impacts will require several years before equilibrium is reestablished. Since these impacts could extend well into the operational phase, they should not be considered as merely temporary changes to the environment, but as events that could change the definition of the local groundwater regime.

Any additions to the groundwater monitoring program during construction should be focused on determining changes in the groundwater regime caused by construction activity. Since the

possible changes in the groundwater regime will vary widely from site to site, the most useful approach is to itemize additions to the program that should be considered. Table 3.1.7 lists construction activities, their possible impacts, and the additions to the monitoring program that should be considered. It must be emphasized that this is only a partial list. For program completeness, a review of all available information, the EIS, and all monitoring data is essential. Data that are difficult to explain, that describe sensitive geologic formations, or that reveal anomalies may suggest the use of surface geophysics to provide further information to either clarify such questions or suggest further modifications to the monitoring program. The application of surface geophysics to groundwater studies is discussed in ref. 2. Prior to the final design of the construction-phase hydrogeologic monitoring program, the needs of the surface water quality, surface water hydrology, aquatic ecology, terrestrial ecology, and plant process monitoring programs should be considered.

Table 3.1.7. Potential construction impacts and suggested monitoring additions

Construction activity	Potential impacts	Suggested monitoring additions
Temporary facilities (buildings, laydown areas, sanitary facilities)	Groundwater contamination	Increased frequencies, additional wells, expanded water quality parameters
	Changes in perme- ability infiltra- tion	Increased monitoring for soil characteristics
Excavation, earthwork, blasting	Altered ground- water levels	Expand piezometric field
	Changes in recharge infiltration	Monitor soil character- istics quarterly, expand piezometric field, additional water quality monitoring
	Altered subsurface geology	Borehole geophysics study near blasting site
	Altered ground- water movement	Borehole geophysics, step- drawdown test, expand piezometric field
Dewatering, consumptive use of water, stream relocation	Reduced water avail- ability	Expand piezometric field and frequency of monitoring
		Monitor groundwater dewater- ing, pumping, withdrawal, and consumptive use
Permanent facility construction	Changes in soil characteristics	Monitor soil characteristics quarterly
	Chemical waste, solid waste contamination of groundwater	Expand water quality parameters, frequencies and locations
Landscaping	Nutrient waste contamination	Expand parameters in groundwater quality monitoring
	Changes in soil characteristics	Monitor soil characteristics quarterly

Variations in groundwater quality should not be significant if sound construction practices are followed. Some potentially harmful pollutants, however, are derived from pesticides, solid wastes, construction chemicals, wastewater, garbage, cement, lime, sanitary wastes, and fertilizers. Effective erosion and sediment control coupled with effective storm-water management should mitigate the impact of these pollutants. To verify the effectiveness of control methods, additional parameters, altered frequencies, and additional monitoring locations may be necessary. A discussion of appropriate methods for controlling construction hazards to groundwater quality is contained in ref. 1.

The list of parameters monitored during construction should be expanded to include those pollutants used that may present a threat to groundwater quality. Table 3.1.8 lists parameters additional to those of the baseline monitoring program that should be considered for inclusion during construction. This list should necessarily include all the parameters monitored during the preconstruction phase, as well as those additions deemed necessary and those recommended in the EIS.

**Table 3.1.8. Additional
parameters to be
considered for inclusion in
construction-phase monitoring**

Rodenticides	Nitrite-Nitrite
Herbicides	Nitrate-Nitrite
Pesticides	Silica
Insecticides	Fecal streptococcus

The frequency of monitoring should be unaffected by the start of construction unless site-specific impacts can be foreseen. At least one data set that includes the construction program additions should be collected prior to construction. Increases in the frequency of monitoring should be considered for any anomalous data collected during the construction phase. The detection of anomalies in the data requires that data analysis be completed quickly after sample collection. Careful comparison with the existing data is the best technique for detecting unforeseen impacts and initiating appropriate mitigating measures.

Additional monitoring wells should be considered if extensive excavation occurs during construction. If changes in groundwater movement are detected, new wells must be drilled to establish up- and down-gradient groundwater quality at all potential pollution sites. Also, additional locations to detect any groundwater quality impacts down-gradient of the wells drilled for the baseline program may be necessary. Additional monitoring locations should also be considered down-gradient from sediment ponds and stormwater collection basins if chemicals, herbicides, or other toxics are used during construction. Any additional wells should be drilled, cored, logged, and finished in the same manner as the wells drilled for the baseline program.

3.1.4.3 Surface Water Quality Monitoring

3.1.4.3.1 Introduction

Monitoring of surface water quality during the construction phase of a coal conversion demonstration plant should serve a dual purpose: (1) to detect impacts of construction activities on

surface water quality and (2) to continually develop the characterization of site water quality in an effort to more completely describe the baseline conditions for future comparison with water quality resulting from plant operation. The surface water quality monitoring effort during the construction period should, therefore, be a continuation of the baseline (preconstruction) program with modification based both on the results of the preconstruction effort and anticipated construction-related impacts.

Table 3.1.9 summarizes potential water-quality-related impacts on aquatic systems due to general construction activities for a demonstration coal conversion plant. The majority of potentially adverse effects are associated with land clearing, which can cause erosion and siltation of site aquatic systems. This general class of impacts is addressed in Sect. 3.1.4.1. Additional potential impacts are associated with excavation; trenching; operation of heavy equipment; use and discharge of water, including sewage treatment facilities for the construction work force; landscaping; and discharge of oil and construction chemicals.

Prior to the design of the surface water quality construction monitoring program, an EIS will have been prepared by the Department of Energy. The EIS will evaluate the results of the baseline (preconstruction) monitoring effort and, based on current process design information, make recommendations on needed construction monitoring on a site-specific basis. In the discussion that

Table 3.1.9. Summary of potential construction impacts on the aquatic environment

Perturbation	Physical and chemical impacts	Biological and ecological impacts
Land clearing and vegetation removal	More rapid runoff	Washout of benthic organisms
	Higher peak flows in streams	
	Scouring and channel erosion	
	Reduced filtration of precipitation, producing higher concentrations of air pollutants and lower pH of runoff	Toxic effects of rainwater contaminants
	Increased runoff	
	Decreased infiltration to groundwater	
	Lower base flow, producing reduced dilution capacity, higher temperatures, and lower dissolved oxygen	Sublethal or lethal effects on aquatic biota; shifts in community structure
	Erosion	
	Siltation and sediment deposition downstream, causing O ₂ depletion	Smothering of fish eggs and benthic organisms, covering of macrophyte beds, habitat destruction
	Turbidity and reduced light penetration	Reduced primary productivity
Excavation and trenching	Nutrient mobilization	Stimulation of plant growth
	Groundwater disruption	Impacts vary with type of disturbance
Heavy equipment operation	Discharge of oil and grease	Toxicity and aesthetic effects
	Erosion impacts (see above)	
Water usage and discharge	Discharge of alkaline limewater from concrete batch plant	Population changes or death of organisms
	Discharge of sanitary wastes	Nutrient enrichment
Landscaping	Release of nutrients, herbicides, pesticides	Enrichment of streams; eutrophication of lakes; toxicity effects

follows, we assume, at this time, that the surface water quality monitoring program will be similar in scope to the baseline program described in Sect. 2.1.2.4. The types of modifications deemed possible by the analysis of baseline program results will be briefly addressed.

3.1.4.3.2 *Parameter Selection*

To maintain continuity with the baseline monitoring program, the parameters listed in Table 2.1.6 should be included in the construction monitoring program. However, it may be possible to delete some inorganic elements (Table 2.1.4) or organic compounds (Table 2.1.5) for consideration during construction if levels determined from at least two baseline sampling times indicate ambient levels are below levels that warrant concern and that there is no reason to anticipate construction-related discharge of these elements. The recommended diurnal measurement of dissolved oxygen, pH, and total dissolved solids (Table 2.1.6 and Sect. 2.1.2.4) may be reduced or deleted based on results of the baseline program. Section 3.1.4.1.2 addresses these parameters also.

Total suspended solids introduced to surface waters by construction activities should receive special consideration (Sect. 3.1.4.1). Water quality criteria established by the National Academy of Sciences states:

Aquatic communities should be protected if the following maximum concentrations of suspended solids exist:

high level of protection	25 mg/l
moderate protection	80 mg/l
low level of protection	400 mg/l
very low level of protection	>400 mg/l

The potential discharge of oil and grease from construction activities necessitates the inclusion of these parameters in the construction program. If sanitary wastes will be discharged during construction, the routine bacteriological parameters will be a necessary inclusion in the construction monitoring effort, along with biochemical oxygen demand and dissolved oxygen. Any potential toxicants used for land clearing and landscaping during construction should be added to the baseline monitoring parameters.

In the final analysis, the construction monitoring effort is intimately tied to the baseline program with modification of parameters monitored emanating from experience, DOE review, and the site-specific assessment in the EIS.

3.1.4.3.3 *Sampling Frequency*

To maintain continuity with the baseline monitoring program, the sampling frequency recommended in Table 2.1.6 as adapted in the baseline program should be followed during the construction period. However, an evaluation based on the sampling conducted prior to construction activities should be made to determine if observed parameter variation suggests that frequencies can be reduced. Potential impacts on aquatic systems due to construction activities (Table 3.1.9) may be directly related to rainfall frequency and intensity on disturbed construction sites. It is possible that such impacts may be missed by a periodic sampling program. Therefore, it is imperative that, in addition to periodic monitoring, construction personnel make visual observations during or shortly after rainstorms with respect to sediment, oil, and grease additions to surface water bodies. By comparing conditions at an upstream or control station with conditions at affected stations, an observer often can determine

visually if there are serious problems with erosion, sediments, oil, and grease coming from the construction site. Spot-check observations of this type should be made for the first rainstorm after each significant new construction activity has begun (e.g., land clearing, groundbreaking, excavation, etc.). Any particularly severe rainstorms (especially summer thundershowers) should also be visually monitored. (Water samples should be collected occasionally to check the reliability of visual observations.) Using spot-check monitoring (in addition to routine monitoring), measures can be taken rapidly to keep construction impacts to minimal levels. In addition to spot-check observations, biological and ecological observations can reveal impacts (Sect. 3.2.2.3), but, with these, feedback to improve control measures is slower.

The contractor's environmental report should contain a discussion of measures that will be taken to control construction-related perturbations to surface water bodies. The EIS prepared by DOE will incorporate these control measures into the recommended final design of construction-phase water quality monitoring.

We emphasize that the construction-phase surface water quality monitoring effort is intended to provide additional baseline water quality information for measuring the impacts of operation in addition to detecting construction-related impacts.

3.1.4.3.4 Sampling Stations

Monitoring should continue at the sampling stations established in the baseline monitoring effort unless these sites have proven unsatisfactory or are eliminated by changes in the construction plans. It is extremely disadvantageous to change the position of a sampling station since this involves losing knowledge of the baseline conditions for that station. However, if the sampling stations were poorly located during the baseline period, changes may be necessary, and such changes should be made as early as possible.

If the coal conversion plant is located near a stream or river, the major concern is whether impacts can be detected by comparing the upstream (control) station with various downstream stations. If construction activities vary from those anticipated and cause disruptions at the control station, establishment of a new control station may be necessary.

In addition to monitoring the established sampling stations, observations at areas closer to the construction site may be useful. The areas of spillage or discharge, holding ponds created for erosion control, drainage ditches, and other affected areas should be evaluated for possible inclusion in the construction-phase surface water quality monitoring program.

REFERENCES FOR SECTION 3.1.4

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2. A. A. R. Zohdy, G. P. Eaton, and D. R. Mabey, "Application of Surface Geophysics to Ground-Water Investigations," *Techniques of Water-Resources Investigations of the United States Geological Survey*, 1974, Book 2, Chap. D1.

3.1.5 ATMOSPHERIC MONITORING

During the construction period of a coal conversion facility some airborne emissions will occur, although most will be of a temporary nature. The atmospheric monitoring program during this stage of the project should essentially be the same as the monitoring program established during the preconstruction stage. This provides a means of detecting construction impacts and provides a stronger data base for measuring the impacts of operation. As a result of excavation and vehicular movement, particles of dirt and crushed rock powder may become airborne, depending on moisture and wind conditions. Other sources may be concrete plants or material storage pits. Generally, such particulates will be large ($>5 \mu$) and will tend to settle out by gravity within short distances. Some control of dust is possible by sprinkling roads, seeding bare areas as soon as possible, and covering storage pits.

Burning of cleared trees and brush and other solid wastes will produce some airborne particulates and gases. Some airborne organic material may result from pesticide applications in the construction area.

In addition to stirring up dust, moving vehicles will produce exhausts containing various gases. Methods for monitoring all these airborne emissions have been described fully in Sect. 2.1.3.3.



3.2 Biota

3.2.1 TERRESTRIAL ECOLOGY

3.2.1.1 Purpose and Scope

Monitoring of terrestrial ecology during the construction period will elucidate the effects of construction activities and extend the period of baseline monitoring for the determination of operational-phase effects. Additional guidance for the design of the construction-phase monitoring program will be provided by the environmental impact statement (EIS) for the proposed facility. The EIS will indicate likely significant effects of the construction program based on analysis of the results of the baseline monitoring program and the construction plan. These site-specific considerations will help determine the exact nature of the monitoring program within the guidelines provided by this handbook.

A further result of the construction-phase monitoring will be a preliminary determination of the sensitivity of the local biota to disturbance. This determination will indicate the adequacy of proposed mitigation measures and will suggest the necessity of further mitigation measures.

3.2.1.2 Monitoring Program

The construction-phase monitoring program should be based on the analytical monitoring program (Sect. 2.2.1.3) of the preconstruction period. Continuity of plot locations, periods of sampling, and methods of sampling are necessary to analyze project effects on the basis of the data collected. However, analysis of the results of baseline monitoring may indicate that the intensity of sampling is not appropriate. Changes in sampling intensity should be made only on the basis of careful analysis of the magnitude of natural variance, sample variance, and the desired sensitivity of the monitoring program.

Biological parameters are subject to several sources of natural variance which make it necessary to continue the baseline monitoring program during construction even when no specific effects of construction activities are anticipated. These include climatic variance, population fluctuations (e.g., defoliating insect and microtine rodent cycles), and the various aspects of community succession (e.g., changes in species composition and accumulation of biomass and mineral nutrients). The magnitude of these sources of variance can only be estimated by analysis of time series extending over a period of years.

3.2.1.2.1 Changes in Community Composition

The program of monitoring local populations of threatened and endangered species should be continued. Not only should population size estimates be made but also changes in behavior should

be observed where appropriate. The noise and increased human presence associated with construction could result in disturbance of normal behavior which may affect population viability. Therefore, observations should be made of flight and other startle responses, abandonment of formerly used areas, and changes in reproductive behavior. Behavioral changes may also be monitored for other species of concern identified in the EIS.

3.2.1.2.2 Measures of Stress

The monitoring of plant stress by remote sensing, lichen examination, and leaf condition analysis should continue. The remote sensing program can detect the area of vegetation lost due to construction activities and erosion as well as changes in the photosynthetic status of vegetation that has not been directly disturbed. Remote sensing can also supplement simple ground observation in determining the success of revegetation programs.

3.2.1.2.3 Measures of Ecosystem Function

Both primary production rates and decomposition rates should be measured during this period in order to allow estimation of variance and correlation of primary production with the measures of plant stress. Collection and analysis of litter bags emplaced during the preconstruction period should continue.

3.2.1.2.4 Sampling for Chemical Analysis

Sampling for chemical analysis would normally need to be continued only if baseline concentrations of an effluent are known to be changing. Usually, emissions of atmospheric contaminants are not significant during the construction period and, therefore, their concentrations in the biota need not be monitored. If the EIS indicates that dust production will be a significant problem, particulate deposition on leaves can be determined by washing. If an existing source of gaseous effluents (e.g., a power plant) is contaminating the project area, samples should be taken for chemical analysis in order to monitor the rate of toxicant accumulation in biotic materials from these sources.

3.2.2 AQUATIC ECOLOGY

3.2.2.1 Purpose and Scope

Construction impact monitoring of the aquatic receiving system is necessary to determine the magnitude and spatial extent of temporary biotic impacts resulting from construction activities. Long-term impacts of the aquatic receiving system will be considered during the analytical baseline operational-phase monitoring programs when aggregate responses from plant construction (physical changes) and operation (plant-related effluents) can be evaluated in a cost-effective manner. It may not be possible in all cases to separate potential temporary and long-term impacts. If the distinction is unclear, potential impacts should be considered during construction-phase monitoring.

Significant temporary construction impacts to be considered will usually be addressed in the EIS for the proposed facility. The EIS, derived from the baseline characterizations of the receiving system and from site-specific considerations, should state the ecologically important functional components of the receiving system and the biotic impacts expected to occur. The construction impact monitoring program should, therefore, (1) verify the magnitude and spatial extent of predicted temporary construction impacts, (2) monitor particularly sensitive and important habitats that will suffer significant temporary construction impacts, and (3) monitor those particularly sensitive organisms or biotic communities that are functionally, economically, or recreationally important, or which are endangered or protected. Monitoring may also be necessary for those impacts whose reversibility or importance is uncertain or unknown, especially those impacts involving functionally important biotic components identified in the EIS and commercially or recreationally valuable species.

An important function of the construction impact monitoring program is to determine that acceptable impact limits as given in construction permits, statutory regulations, or DOE guidelines are not exceeded. Mitigating procedures should also be tested for sufficiency in the construction-phase monitoring program.

As in the baseline monitoring program, site-specific considerations will determine the exact construction impact monitoring program. The following section of the handbook will, therefore, only deal with general topics which can be discussed without site-specific considerations.

3.2.2.2 Continuity with Baseline Monitoring Program

Continuity of construction impact monitoring with the overall baseline monitoring program must be stressed. Consideration of functionally important habitats and the spatial and temporal species use of these habitats, in a food-web context, should be continuous with the baseline monitoring program. This should allow potential construction impacts to be placed into an ecological perspective as a guide to development of the monitoring program.

Areas which have baseline data available and which will receive construction-related impacts should be emphasized. For instance, the spatial extent or travel of turbidity plumes or shoreline habitat disturbances in relation to particularly important habitats such as spawning areas, nursery grounds, areas of high concentrations of aquatic organisms, or migration routes should be emphasized. The appropriate control areas should also be sampled to allow before-after or control-experimental comparisons to be made. The number and location of important disturbed habitats are site-specific.

Sampling frequency and intensity should follow the general guidelines given in Sect. 2.2.2 unless modifications are necessary according to the temporal aspects of construction activities. For

instance, monitoring should be concentrated during the height of the seasonal construction activity. Another consideration is the potential construction impacts on seasonal events such as spawning or migration. These coincidences should be emphasized under site-specific considerations, to allow maximum cost-effective sensitivity in construction impact assessment. Sampling intensity should reflect the basic goals of the construction monitoring program as determined in the EIS. Both quantitative and descriptive data should be obtained with sufficient precision to allow construction impacts to be distinguished from natural changes. It is important that the contractor use sampling techniques similar to those applied during the baseline study to avoid problems of data interpretation.

3.2.2.3 Construction Impact Monitoring Program

Sampling station placement should be integrated with water quality measurements (Sect. 3.1.4.3) and should follow the general recommendations given in Sect. 2.2.2.3.1 ("Sampling Station Placement").

3.2.2.3.1 *Alteration of Habitat*

Some construction activities by necessity will alter aquatic habitats near the site environs. Based on the EIS prediction of where and to what extent such impacts will occur, the construction impact monitoring program should investigate the changes caused by construction activities in functionally important habitats. Habitat considerations should be emphasized in the construction monitoring program due to the sudden and many times drastic habitat changes that may result from construction activities. Operational-phase impacts will usually involve less extreme habitat modification.

Habitat alteration usually occurs from movement of disturbed sediment, physical removal or disturbance of the bottom substrate, removal or alteration of stream side vegetation, or from dewatering or water consumption activities. All such construction activities (Sect. 3.1.4), as analyzed in the EIS for their potential significant impacts, should be included in the construction impact monitoring effort.

Spatial considerations of habitat modification should be based on construction effluent or sediment transport predictions and verified by field data collection (see Sect. 3.1.4). Any disagreement between predicted and measured spatial limits of habitat modification from construction activities should be reflected in the location and number of sampling stations or areas used to assess impacts.

Alteration of habitat is a somewhat artificial separation from biotic impacts themselves. For instance, macrophyte beds constitute important habitat for many aquatic organisms and they may also be an important biotic component of the receiving system. However, the distinction will be maintained on a working basis and will include such events as siltation, scouring, increased turbidity, habitat removal by dredging, and temporary bridge or stream ford construction. This information is contained in Sect. 3.1.4 of this handbook and will be discussed in the site-specific EIS.

Generally, habitat destruction or modification should be evaluated for its loss of breeding potential, nursery function, use as a migration route or wintering area, or use as a concentrating and preferred growth area for aquatic communities. Consideration should be given to the availability of similar habitat nearby in undisturbed areas which can carry over the disrupted ecological function until recovery occurs (e.g., spawning or nursery habitat). Mitigation procedures may be necessary if recovery is slow or reversibility is not apparent.

3.2.2.3.2 Biotic Effects of Construction Effluents

Since the construction period and potential construction impacts for coal conversion plants may be substantial (a minimum of two to three years), biotic effects of construction effluents or activities should be considered. Important target organisms or biotic communities that will suffer impact should be monitored. These may be appraised according to the effluent or disturbance to be generated, the receiving system biota and their functional importance as determined in the EIS, and the known impacts on particular organisms or biotic communities from specific impact source terms from construction activities (Sect. 3.1.4).

Runoff from construction sites

From characterization of surface-water or groundwater effluent from drainage ditches or other water discharge areas including dredging releases (Sect. 3.1.4), involving petroleum products, pesticides, fertilizers, heavy metals, etc., the contractor should establish a monitoring program for aquatic biota designed to measure the impacts on suspected target organisms or biotic communities. For instance, discharge of silt will affect sessile or resident species inhabiting the disturbed area. Smothering or interference with gill or respiratory function in both invertebrates and vertebrates is a potential impact on biota. Reduction of light penetration and siltation of macrophyte or periphyton communities may cause drastic decline in these communities and the organisms dependent on them.

Although the biotic effects of various construction-related effluents can be numerous, the entire spectrum of baseline monitoring components as given in Sect. 2.2.2 of this handbook need not be considered in the construction impact monitoring program. Rather, the contractor should use the analysis presented in the EIS and guidance from DOE to decide which biotic constituents should be monitored. If little environmental impact information exists on particular effluents or if the reversibility of the impact is in question, the biotic complement as given in Sect. 2.2.2.3.2 of this handbook should be monitored. Appropriate spatial constraints determined by effluent transport considerations should be applied to delimit the sampling area.

Construction sewage wastes

Sewage wastes from the construction force discharged into the receiving system should be assessed for their environmental impact. Their possible impact on algal and macrophyte production and growth, dissolved oxygen, and chemical and physical quality of the receiving waters should be determined to assess the nature of the biotic response to these releases (Sect. 3.1.4). Target organisms or target communities should be emphasized, under guidance from the EIS. Spatial considerations should include the dilution of the wastes to background or ambient conditions in the receiving system.

Bioaccumulation of toxic substances

Toxic substances which will be released into the aquatic receiving system by normal construction activities or by accidental spills and which present potential bioaccumulation problems should be considered in the construction monitoring program (Sect. 3.1.4).

For those recreationally or commercially valuable species which are consumed by man and which inhabit or travel through effluent dispersion areas, tissue quality analysis for toxic substances should be performed at least once a year. Only the edible or commercially valuable portion of the

organism need be monitored. Sampling intensity and frequency should reflect the expected magnitude of the release or spill, the toxicity and bioaccumulation hazard of the substance, and the appropriate seasonal period(s) of resource consumption by man.

Generally, the need for tissue quality analysis may be restricted to only a few hazardous chemicals used during preparation of the site environs or construction of the facility. It is not anticipated that tissue quality monitoring will be necessary at all coal conversion construction sites. DOE will determine the applicability of this portion of the construction-phase monitoring effort to site-specific construction activities or occurrences.

3.3 Socioeconomic Variables

3.3.1 INTRODUCTION

As was pointed out in the preconstruction section (Sect. 2.3), the social and economic impacts of a coal conversion plant are generated by an interaction of facility characteristics and community characteristics. Descriptions of plant capital, material, and labor requirements and of selected community characteristics were asked for in the preconstruction monitoring section. These descriptions were to be used to predict employment and population effects of the plant. Given these predictions, a straightforward analysis of the likely impacts can be carried out by comparing incremental demands with existing capacities of important goods and services. Then, in the construction phase of the project, a major purpose of the monitoring effort is to determine the accuracy of these basic predictions and to identify any unforeseen impacts that may require additional mitigative measures.

Often, the major adverse social and economic impacts resulting from the siting of a given facility in a given area are concentrated in the construction phase of the project. Beneficial impacts (e.g., improved services that may result from increased tax revenues) are generally slower to be realized, however, and are spread out over a longer period of time. This asymmetry between the temporal distributions of the costs and benefits accruing to the local community arises for two basic reasons. First, the construction period is usually of relatively short duration. Second, the labor force required for the construction phase of the project is typically quite large relative to that required for the operational phase (although the ratio of annual construction period employment to annual operation period employment is lower for coal conversion plants than for nuclear facilities). As a result, local supply sources that provide important goods and services (e.g., housing, education, health care, etc.) do not have sufficient incentives to expand capacities to meet the increased demands placed on them. The capital investment required to increase production to meet these demands cannot be amortized within the brief construction period, and the anticipated postconstruction slump in demand makes longer-term amortization impractical. Consequently, situations of excess demand develop during this period and are allowed to persist. The result is increasing prices and shortages of many goods and services. Therefore, the monitoring of social and economic impacts during the construction phase of the project is particularly important.

In carrying out this monitoring effort, one should distinguish between projected impacts that are directly or indirectly attributable to facility construction activities and more general forecasts of community conditions. That is, when a total employment impact of x jobs is predicted for a given area, this does not mean that the area's employment is necessarily expected to expand by x . Other exogenous events may occur that will either increase or decrease total employment in the area at the same time that the facility-related employment impact is generated. Consequently, a simple

measurement of community employment before and during construction provides an inadequate test of impact forecasts. Instead, an effort should be made to identify the source of observed employment changes and compare projections only with those that can be traced to the construction of the facility. A similar distinction should be made in all other areas in which impacts are forecast (population changes, housing, education, etc.). Given the current state of the art and limited budgets for construction period monitoring, this effort is necessarily imprecise and must incorporate a great deal of judgment on the part of the contractor. It is a necessary step, however, if impact projection capabilities are to be improved and if unpredicted adverse impacts are to be mitigated.

The principal types of information needed for construction-phase monitoring are (1) descriptions of the employment, population, and land-use changes actually resulting from the construction of the plant, (2) descriptions of wages, taxes, and local purchases generated by construction, and (3) descriptions of the impacts of these population, employment, and fiscal changes on community infrastructure such as housing, schools, and transportation. The detailed information needed on each of these topics and the methods for obtaining the information are discussed in the following sections.

3.3.2 POPULATION AND EMPLOYMENT CHANGES

In the preconstruction phase, estimates of the number of employees required by the plant and of the proportion that would be supplied locally were made. In the construction phase, the accuracy of these estimates should be checked. The contractor should supply a listing of the number and type (by craft) of workers employed. The local-nonlocal mix of the plant work force should be determined by asking employees to fill out a short questionnaire similar to the one shown in Fig. 3.3.1. Information from the questionnaire on marital status, family size, ages of children, and employment of spouses will provide data on population increases due directly to plant employment, on changes in the school age population, and on numbers of secondary jobs filled by employee family members. The questions listed in Fig. 3.3.1 are selected from those asked in *The Construction Worker Profile* project survey¹ and in *A Monitoring Study of the Community Impacts of the Susquehanna Steam Electric Station*.² The same type of information was obtained in Tennessee Valley Authority surveys of construction workers at four nuclear plant construction sites (Brown's Ferry, Cumberland, Sequoyah, and Watts Bar).³

1. What is your present occupation (job title)? _____
2. What is your address (street and town)? _____
3. About how far is this from the construction site? _____
4. What type of home are you living in now (circle one)? apartment,
single-family home, mobile home, motel or rooming house, other _____
5. a. Are you living in the same town you lived
in before you started working on your present job? yes no
b. If no, where did you live previously (town and state)? _____
6. Are you married, single, widowed, divorced? (circle one)
7. a. If married, is your spouse living with you at your local address? yes no
b. Is your wife/husband employed locally? yes no
c. Was she/he employed locally before construction of this project started? yes no
8. How many children under 18 live with you at your local address? _____
9. What are the ages of these children? _____

Fig. 3.3.1. Questionnaire for plant employees.

The basic information from a questionnaire of this type can be used to describe a number of variables that determine impacts of the construction phase, including the local-nonlocal composition of the work force; the size of the area from which the work force is drawn; the size of the population increases resulting directly from plant employment; the distribution of the new population in terms of the distances workers live from the plant, the numbers of school age children in various school districts, and the numbers of people added to the areas under various political jurisdictions; the family size of workers; and the housing choices of workers. Knowledge about these variables will make it easier to evaluate construction impacts on housing, schools, health care, recreation, etc.

REFERENCES FOR SECTION 3.3.2

1. Mountain West Research, Inc., *The Construction Worker Profile*, final report, prepared for the Old West Regional Commission, Denver, Colo., December 1975.
2. Pennsylvania Power and Light Company, *A Monitoring Study of Community Impacts for the Susquehanna Steam Electric Station*, Allentown, Pa., June 1976.
3. Ronald M. Traub, *An Investigation on the Socio-Economic Impact of Nuclear Power Plants on Small Communities*, Ohio Power Siting Commission, 1975.

3.3.3 ECONOMIC IMPACTS

In addition to the employment effects discussed above, the construction project will exert other influences on the local economy which should be monitored. As with monitoring the impact on population and employment, tremendous difficulties arise in attempting to identify and measure the secondary (indirect and induced) impacts. If one observes an increase in nonplant employment or in area sales, for example, it is extremely difficult to determine if facility construction activity is the primary cause or if some other exogenous influences are at work. As a result, monitoring efforts should focus on verification of the direct effects that have been forecast, and secondary impacts should be included only when blatant errors in predicted outcomes are observed. If such errors are observed, an attempt should be made to determine the cause of the discrepancy between the predicted and the observed outcomes (either an error in the process by which the prediction was obtained or an exogenous influence that could not have been anticipated at the time the forecast was made). Again, this requires a considerable degree of judgment on the part of the contractor.

Construction-phase monitoring of direct economic impacts should focus on three basic areas. First, the direct effect on local incomes can be determined from the total wages paid by the project during the construction period (applying the proportion of local to nonlocal workers obtained from the worker survey described above). Secondary income effects cannot be observed directly, but some inferences can be made from reasonable assumptions about the marginal propensity to consume locally.¹ Second, major material purchases should be determined and separated into those made locally and those made outside the region. These direct purchases provide information on the extent of economic stimulus provided by the construction project. Again, however, secondary effects are not observable. Third, the taxes paid by the facility (or payments in lieu of taxes) to both state and local governments should be determined. These payments may be used to mitigate adverse impacts that are generated in the region.

Information pertaining to all three of these areas should be available from the contractor during the construction phase of the project. By examination of these data, the direct economic impact forecasts can be verified. Significant discrepancies that might arise between observed and predicted outcomes should be investigated in order to determine the source of the error, and any additional mitigation procedures that are called for should be initiated.

REFERENCE FOR SECTION 3.3.3

1. C. M. Tiebout, *The Community Economic Base Study*, Supplementary Paper No. 16, Committee for Economic Development, December 1962.

3.3.4 INFRASTRUCTURE IMPACTS

The construction-phase monitoring effort should also focus on verifying predictions made for each area of the local infrastructure. Here, the primary purpose is to identify those areas in which significant stress is exerted so that corrective actions may be taken early.

3.3.4.1 Housing

Increases in population during the construction phase can be expected to have impacts on the housing market. When there is a large and rapid influx of new population, demand for housing generally exceeds the available supply. As a result rents and prices rise, and mobile homes are often the only housing option. The proportion of construction workers who live in mobile homes can be determined from responses to the questionnaire given to workers (Sect. 3.3.2). A high proportion of mobile home dwellers is sometimes an indication that other types of housing are not available. Comparisons of the number of new families that moved in (again, based on questionnaire responses) to the number of housing units estimated to be available before construction began will also indicate the degree of excess demand for housing. If information on housing turnover and vacancy rates is available from local planning authorities, this can also be used to evaluate the state of the housing market. Realtors are another source of information on the housing market, particularly on prices and rents and numbers of units listed. Information on housing starts, development plans, and changes in assessed valuation also will be useful for evaluating the response of the housing market to increased demands. Records of building permits, bank loans and mortgages granted, and property tax assessments could provide data relevant to these topics.

3.3.4.2 Health Care

Large, sudden population increases may overload the health care system. Changes in hospital occupancy rates, in case loads handled by physicians and by other health care personnel, and in the number of emergency room visits are indicators of increased demand for health care. Hospital administrators, physicians, and emergency room admittance records are sources of such information. The contractor also should have records of emergency cases resulting from accidents on the job, which is a direct health care demand generated by the plant.

3.3.4.3 Transportation

Several studies of major construction projects have shown the willingness of a construction labor force to commute over fairly long distances for a period of several years. If good highway links to a large metropolitan area are available, up to 90% of the labor force will commute from within a 1- to 2-hr driving time radius.¹ Although the construction phase may last for a number of years, each craft usually will be involved only a part of the time. Because of the temporary nature of the employment, construction workers usually prefer to commute if it is possible.

A high proportion of commuting workers will minimize impacts in most areas (e.g., housing, health care, schools, recreation, etc.), but the impacts on transportation systems will be increased. Commuting workers, local citizens, and law enforcement officers should be able to provide information on the location of major traffic congestive areas. Traffic counts can provide data on congestion and on peak traffic periods. Increased accident rates are another indicator of traffic impacts. A number of contractors have instituted bus service, carpooling systems, and staggered work shifts as remedies for severe traffic problems. This type of mitigating action should be considered if traffic problems are severe.

3.3.4.4 Education

The educational system of the region should be closely monitored during the construction phase of the project. The rapid inflow of a large construction labor force with their families could place severe demands on the existing school facilities. Whereas the short length of the construction period might forbid construction of permanent expanded facilities, excessive overcrowding might be avoided by employing some temporary structures. The construction-phase monitoring effort should identify such conditions and, thereby, signal the need for these facilities.

To carry out this monitoring effort, the contractor should obtain data on the following items: total school enrollments, enrollments separated by grade level, total classrooms available, classrooms separated by primary-secondary classification, total teaching staff, and teaching staff by grade level. Generally, this information is available from local school officials for each school district in the region.

3.3.4.5 Police and Fire Protection

Construction-phase monitoring of the police and fire protection systems of the region can be carried out by periodic surveys of local law enforcement and fire protection officials. Two basic types of information should be sought. First, staffing levels and equipment should be determined in order to assess the capacity response that has occurred (by comparison with information obtained during baseline monitoring). Second, the adequacy of the performance of these systems during the construction phase should be assessed (by examination of average response times, crime rates, etc.). Again, the purpose is both to verify impact forecasts and to identify necessary mitigative actions.

3.3.4.6 Recreation

Some effort should be made during the construction-phase monitoring effort to identify any significant overcrowding of existing recreational facilities. This can be accomplished by contacting local recreation department officials and by assessing existing conditions at area parks, playgrounds, and natural areas. Also, some information may be obtained from private owners of recreational facilities.

3.3.4.7 Historic and Archaeological Sites

Historic and archaeological sites should have been identified and plans made for their protection, or for recovery of materials, in the preconstruction stage. As a result, the construction monitoring effort should focus on ensuring the implementation of such plans. Monitoring of sites for indirect impacts (e.g., visual impacts, noise) also should be done during construction, and mitigating action should be taken, if needed.

3.3.4.8 Solid Waste Disposal

Construction-phase monitoring should describe any expansions in the existing solid waste disposal system and identify any overloading of the collection system, landfill areas, etc. Local officials responsible for the system should be contacted to obtain this information. Compliance with state and federal standards also should be evaluated.

3.3.4.9 Water Supply and Wastewater Treatment

Three basic aspects of the water supply and wastewater treatment facilities should be described during the construction-phase monitoring effort. First, the water supply (quantity) available during this period should be determined and competing uses described. Second, any capacity adjustments that occur in the wastewater treatment facilities should be described. Third, any shortages that might arise should be identified for mitigative action. Local agencies and officials should be contacted for this information.

REFERENCE FOR SECTION 3.3.4

1. Mountain West Research, Inc., *The Construction Worker Profile*, final report, prepared for the Old West Regional Commission, Denver, Colo., December 1975.

4. Operational Monitoring

Introduction

The operational phase of the environmental monitoring program is the largest of the three principal monitoring phases. The subject is divided into two distinct but complementary parts—monitoring the process [4a (prepared by the Radian Corp.)] and monitoring the environment (4b). Part 4a traces substances from their origin in the process to the point of introduction into the environment. Part 4b traces the pathway of these substances to detect their impacts on the physical, chemical, and biotic environments.

The Department of Energy (DOE) should be consulted regarding the scheduling of startup operations; DOE will also determine the level of monitoring desired during startup.



4a. Environmental Process Monitoring

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The demonstration phase of coal conversion technology development offers the first real opportunity for determining environmental acceptability and for developing sound information on which to base reasonable, economically achievable standards. As a result, environmental testing to characterize the process is a major objective of coal conversion demonstration. This section of the handbook describes an approach to development of an environmental process monitoring program for a coal conversion demonstration facility sufficient to demonstrate performance of control equipment and to characterize emissions.

Environmental process monitoring may accomplish all or part of the following objectives:

1. define plant effluents
2. verify process compliance with environmental regulations
3. verify control technology performance
4. characterize the process or a segment of the process

Development of an environmental process monitoring program requires:

1. identification of monitoring objectives and scope
2. performance of process analysis
3. review and selection of sampling procedure
4. review and selection of analytical procedure
5. definition of characterization test plan

The important considerations and factors involved in each of these steps are discussed in the following subsections.

A more extensive discussion of environmental process monitoring program development can be found in *Environmental Characterization Plan Development for a Coal Conversion Demonstration Facility*, Department of Energy Contract EX-76-C-01-2314, Radian Corporation, Austin, Texas, December 1977 (available through National Technical Information Service, Springfield, Va.).

4a.1 Purpose and Scope

The first step in an environmental process monitoring program is to determine the specific purpose and to make a preliminary estimate of the scope of the required program. The specific objectives of the environmental testing are selected from the possible goals toward which a process monitoring program might be directed. A clear understanding of objectives is important at this early stage since different objectives require different monitoring programs.



4a.1.1 OBJECTIVES

There are four basic objectives of environmental process monitoring:

1. to identify and quantify pollutants in gaseous, liquid, and solid waste effluent^a streams from the coal conversion plant
2. to verify that the plant is in compliance with environmental control regulations
3. to determine the pollutant removal performance of environmental control systems used in the plant
4. to characterize selected internal process streams that affect the plant effluent streams

A specific environmental process monitoring effort may be intended to accomplish all or part of these basic objectives. The specific objective and timing of each monitoring effort are generally designated by the DOE project officer in conjunction with the program manager for the principal contractor. Decisions will be based on the environmental requirements of the demonstration project and the operating schedule of the demonstration plant.

Once the specific objectives are defined, the monitoring effort may be considered in terms of three types of plant tests which are associated with the different environmental goals of (1) effluent characterization, (2) environmental control characterization, and (3) process unit characterization.

Effluent characterization entails the measurement of pollutants in plant effluent streams. Although in concept this is the least complex type of characterization, the work involved can be extensive, depending on the number of effluent streams, the number of pollutants considered, and the number of plant operating conditions tested. If the work is performed to ensure compliance with environmental regulations, this type of characterization can become very complex. In such a case, all potential sources of a pollutant must be characterized.

In environmental control characterization, the operating performance of one or more pollutant control systems is investigated. The test involves sampling both the input and effluent streams for selected environmental control equipment. At least one pollutant—often several—will be analyzed. The scope depends on the same factors influencing effluent characterization.

Process unit characterizations pertain to stream analysis at least one step earlier in the process than the environmental control systems. The output stream of the process units normally will be the environmental control input stream. The performance of an environmental control depends on the physical and chemical characteristics of the input streams. Process measurements define the effect of process parameters on the performance of control modules. This adds another layer of analysis to environmental control characterization and its scope depends on the same factors. Taken to an extreme, process characterization could involve starting with the effluent streams and environmental control systems and working back through the entire plant.

^aThe term "effluent" without other modification is used to designate any process stream exiting the plant. Emission refers specifically to gaseous exhaust streams.

4a.1.2 SCOPE

An estimation of scope indicates the total data collection effort—sampling analysis and data evaluation—required to achieve the environmental objectives. Scope is primarily determined by four factors:

1. objectives of the process monitoring program
2. number and types of process streams to be sampled
3. number and types of analytical parameters^a to be tested
4. number of plant operating conditions to be tested

Table 4a.1.1 indicates the effect of each factor on the scope of the test plan.

If the objectives of the characterization have been established, only the last three items must be determined to estimate the scope of the process monitoring effort. These items are closely associated with the specific process, and a process review (Sect. 4a.3) is required to fully define the streams, analytical parameters, and test conditions of interest. Only a preliminary estimate of test plan scope can be made at an early planning stage; however, a preliminary estimate is useful and should be undertaken to indicate whether testing goals are realistic in terms of budget and resources available.

Table 4a.1.1. Factors determining the number of monitoring analyses

General objectives of plant stream monitoring
Effluent stream monitoring and characterization
Verification of process compliance with environmental regulations
Control module monitoring and characterization
Selective process module monitoring and characterization
Plant streams to be monitored
Effluent streams
Effluent streams or effluent sources of a particular species
Inlet and outlet streams of environmental control systems
Inlet and outlet streams of selected process units
Analytical parameters to be measured
Plant-discharge regulations and guidelines
Ambient-environment regulations and guidelines
Other standards or considerations
Sets of plant conditions for analysis
Steady-state conditions
Normal operating variations
Cyclic operation
Startup
Shutdown
Emergency upsets

^aAnalytical parameters are defined as variables that characterize some physical property or specify the identity and/or quantity of some physical or chemical species.

4a.1.2.1 Stream Selection Criteria

The total number of streams designated for sampling is a major indication of the level of effort required in the program. Process streams to be tested are initially specified when the monitoring purpose is defined. For example, (1) effluent characterization or compliance testing primarily involves sampling effluent streams; (2) control system characterization involves sampling environmental control input and effluent streams; and (3) selective process characterization involves sampling of internal process streams and control system input and effluent streams.

Therefore, the monitoring objective determines the process streams of interest and is the primary factor in identifying the types of streams to sample. The actual streams are identified in the process analysis (Sect. 4a.3). Other important criteria for considering streams to sample or which might qualify the sampling of additional streams include (1) pollutants present, (2) material balance considerations, (3) presence of contaminants that might adversely affect environmental control performance—for example, known catalyst poisons, and (4) degree of specificity of the stream to the particular demonstration process.

The concept of process specificity can be a useful criterion in defining the sampling and analytical procedures. A stream may be specific to a particular coal conversion process (e.g., the spent acceptor purge stream from the Conoco CO₂ Acceptor process), in which case special techniques may be required. On the other hand, if a stream is common to other unrelated processes (e.g., fuel combustion off-gases), the composition may already have been defined and accepted test methods probably exist.

4a.1.2.2 Analytical Parameter Selection Criteria

Analytical parameters are selected based on regulatory considerations or on factors such as material balance requirements, health and safety factors, or other process-related concerns.

Two general types of regulations determine the pollutants to be analyzed: pollutant discharge limitations and ambient pollutant standards. Such regulations exist at the federal, state, and/or local levels and will not necessarily be identical. Consequently, regulations applicable to the specific location of a demonstration plant should be reviewed when selecting analytical parameters. Key federal environmental laws and regulations affecting stationary sources are shown in Table 4a.1.2.

Federal ambient air quality standards and atmospheric discharge standards are primarily intended for controlling the criteria pollutants: sulfur dioxide, particulate matter, nitrogen oxides, carbon monoxide, hydrocarbons, and photochemical oxidants.^b Consequently, these pollutants should definitely be sampled as part of the environmental process monitoring program. The necessity of addressing these criteria pollutants should also be considered in the selection of analytical parameters. Any analytical parameter that might contribute to these categories or any precursor to the criteria pollutants should also be included in the monitoring program. Federal guidelines for pollutants in effluent liquid streams also should be consulted. Even though specific federal standards applicable to first-of-a-kind demonstration plants will not exist, it is important to include high-priority pollutants in the test program. The results will serve as the basis for future standards. Also, state or local regulatory agencies may apply general standards which require that certain pollutants be monitored.

^bPhotochemical oxidants are not direct emissions from sources but form in the atmosphere via a complex mechanism involving hydrocarbons, nitrogen oxides, and sunlight. Hence, they should not be considered as analytical parameters.

Table 4a.1.2. Key environmental laws and regulations affecting stationary sources

Air	
Laws	Clean Air Act Energy Supply and Environmental Coordination Act of 1974 Energy Policy and Conservation Act of 1975
Regulations	40 CFR 50 – National Primary and Secondary Ambient Air Quality Standards 40 CFR 60 – Standards of Performance for New Stationary Sources 40 CFR 61 – National Emission Standards for Hazardous Air Pollutants
Water	
Laws	Federal Water Pollution Control Act Rivers and Harbors Act of 1899 Safe Drinking Water Act Wild and Scenic Rivers Act Marine Protection, Research, and Sanctuaries Act of 1972
Regulations	40 CFR 128 – Pretreatment Standards 40 CFR 129 – Toxic Pollutant Effluent Standards 40 CFR 401 – General Provisions for Effluent Guidelines and Standards 40 CFR 402–699 – Effluent Guidelines and Standards for Industry Categories 40-CFR 141 – National Interim Primary Drinking Water Regulations
Other areas	
Laws	Noise Control Act of 1972 Archaeological and Historic Preservation Act of 1974 Coastal Zone Management Act of 1972 Endangered Species Act of 1973 Fish and Wildlife Coordination Act National Environmental Policy Act Resource Conservation and Recovery Act of 1974 (Solid Waste Disposal Act) Toxic Substances Control Act

Construction of some demonstration plants may be allowed on the basis of a variance—legally granted delay—from a provision of a federal, state, or local regulation. Examples of potentially applicable regulations include:

1. the federal “offset” policy for construction of pollutant sources in air-pollutant “nonattainment” areas
2. the federal regulations for prevention of significant deterioration in “attainment” areas (regions where the air is cleaner than the standards require)
3. federal, state, or local ambient air quality or water standards
4. state or local emission or effluent standards

Obtaining a variance from any of these regulations frequently requires monitoring a particular pollutant, sometimes on a continuous basis. In these instances, the subject pollutant automatically becomes part of the selected analytical parameters.

As indicators of regulatory trends and potential future regulations, federal—and possibly state or local—guideline documents should be studied. The establishment of baseline effluent levels for guideline pollutants would be highly useful if the guideline later becomes a regulation for commercial plants.

Whereas regulatory issues certainly take precedence in the selection of analytical parameters, several other criteria are also important. These include (1) the need to close material balances for chemical species selected by use of other criteria (e.g., regulatory considerations), (2) the need to analyze for materials that have adverse effects on environmental controls, (3) the usefulness of some analytical parameters as sensitive indicators of control or process performance, and (4) any chemical species that DOE has interest in documenting as a part of the environmental aspect of its demonstration program. In some cases, health or safety requirements may dictate the monitoring of some chemical species: for example, the use of carbon monoxide as a leak indicator in coal gasification processes. An “indicator” species can be used to indicate the presence of another species which is more difficult to measure.

4a.1.2.3 Sets of Plant Conditions To Be Characterized

It is unlikely that a demonstration plant would be characterized at only one set of operating conditions. Most process monitoring programs will involve testing at several sets of operating conditions. Different operating conditions which might be designated for environmental testing are various production rates, upset conditions such as startup and shutdown, different feedstocks, different reactor conditions, different modes of operation such as equipment bypassed, and combinations of these parameters. When monitoring at several sets of operating conditions (test levels) is required, it is essential to plan the work to provide data needed for evaluation, with a minimum of manpower and a minimum interference with plant operations.

In selecting conditions for testing, the initial factors that should be considered are:

1. The operating condition represents a mode of operation that the plant will be in a significant amount of time and therefore could be used to characterize the process (design conditions or projected normal operating conditions).
2. The operating condition represents a condition of environmental interest (maximum plant throughput, different feedstock, equipment bypassed).
3. The operating condition exists for a short time period but environmental effects are either difficult to estimate or they are unknown (upset conditions, startup, shutdown).
4. The operating condition is bracketed by other proposed test conditions and therefore could possibly be eliminated.

These criteria may be used to develop a preliminary list of operating conditions for environmental process monitoring.

The operating conditions for monitoring may then be finalized by review in the context of the following factors:

1. the total number of samples and analyses required per test level (including replicates)
2. the sensitivity of the analytical parameters to plant operating conditions
3. the difficulty of varying the operating conditions

The maximum number of samples and analyses per test level is determined by the selection process described previously. (Sample replication is a data quality control requirement discussed in Sect.

4a.2.5.) The last two factors listed above normally will have been assessed during the pilot-plant and bench-scale development of the process. If an analytical parameter of interest has proved in other tasks to be insensitive to plant operating conditions, the different test levels for this parameter possibly may be omitted.

Difficulties in changing the operating conditions can result from two factors: (1) The plant might have inherently limited flexibility; (2) the operating schedule may be inflexible. The former problem should be addressed during the analysis of the process to identify which plant conditions can be tested. The latter problem is a matter of plant priorities and should be considered in development of a test schedule for the process monitoring program.



4a.2 Test Plan Development

A test plan is a set of procedures which will accomplish the objectives of the environmental process monitoring effort. After defining the objective and scope of the plan, the following information should be available:

1. an identification of the objectives of the monitoring effort—for example, characterization of effluents, verification of process environmental control performance, or process characterization
2. a preliminary determination of process segments to be monitored
3. a preliminary determination of streams and analytical parameters of interest
4. a preliminary determination of the operating conditions of interest

This information is the starting point. To complete the development of a test plan, the information from the remaining steps (process analysis, sample methods, and analytical methods) is required. A process analysis is required to determine the best way to break down the process for testing and to establish process data pertinent to the test plan effort. A review of available sampling and analytical procedures must also be conducted to select the sampling methods and analytical techniques to be used.

In summary, the steps involved in finalizing a monitoring test plan are:

1. Finalize the identification of process streams to be sampled and their important analytical parameters.
2. Define a process stream-analytical parameter matrix.
3. Define the process operating parameters that should be monitored prior to^a and during execution of the test plan.
4. Define the sets of operating conditions (test levels) for which characterizations will be made.
5. Develop a matrix of streams and parameters (analytical and operating) for each set of operating conditions.
6. Identify the stream and analytical parameter combinations for which data from other sources (plant records and operating personnel) will be adequate.
7. Select sampling and analytical techniques for measuring the parameters remaining after the previous step.
8. Determine sampling frequency and timing based on sampling method and data evaluation requirements.

^aKey process operating parameters should be monitored before test plan execution to establish a baseline for determining steady-state test conditions and to ensure that no previous process upset will influence test results.

9. Develop a quality control program for the plan.
10. Prepare a test schedule based on the plant operating schedule and the manpower and equipment requirements of sampling and analysis.
11. Make provision for revisions to the plan based on interim results.

These points are discussed in the following sections.

4a.2.1 STREAM AND ANALYTICAL PARAMETER SELECTION

The following describes the selection of streams and analytical parameters for each monitoring objective. Tables 4a.2.1 through 4a.2.5 contain lists of species of probable interest, including gaseous, liquid, and solid components. These tables describe toxic, organic, and carcinogenic substances, as well as species on the EPA effluent guidelines list.

4a.2.1.1 Emission/Effluent Characterization

Every effluent stream (gas, liquid, or solid) from the plant should be reviewed to determine if it contains potential pollutants. The process analysis will be based on process development results and detailed engineering plans, so this review will serve as a sound guide for test plan development. Where there is doubt concerning a pollutant's presence, the stream should be analyzed.

Table 4a.2.1. Typical tabulation of physical and chemical parameters^a
for effluent and process streams

Title _____ or _____	Operation (gas purification) _____ Type (feed, product, by-product, effluent) _____ Physical state (gas, liquid slurry, solid) _____	Code No. (from/to) _____
Composition/flow related to (code or title of streams) _____		
Basis	Units	Design Normal High Other
Flow ^a	lb/hr	
Temperature	°F	
Pressure	psig	
Physical data ^a		
Density	lb/gal	
Particulates	gr/scf	
Ash	wt %	
Moisture	wt %	
Size distribution		
Heating value		
Caking index		
Etc.		
Chemical composition ^a		
H ₂ O	vol %	
H ₂	vol %	
N ₂ + argon	vol %	
O ₂	vol %	
CO	vol %	
CO ₂	vol %	
CH ₄	vol %	
COS	ppm	
H ₂ S	ppm	
NO _x	ppm	
SO _x	ppm	
Etc.	ppm	

^a Actual parameters and units of measurement should be selected to best describe the stream.

Table 4a.2.2. Analytical parameters for liquid and slurry samples

Physical characteristics	Species			
	Inorganic		Organic	
pH ^a	Dissolved oxygen ^a		Biological oxygen demand ^a	
Solids content (TDS and TSS) ^a	Ammonia		Chemical oxygen demand ^a	
Water hardness ^a	Chloride		Oil and grease ^a	
Specific electrical conductance ^a	Fluoride		Phenol	
Acidity ^a	Sulfate		Total organic carbon	
Alkalinity ^a	Sulfite		Speciation	
Turbidity ^a	Sulfide		Polynuclear aromatics	
Temperature	Nitrate		Heterocyclics	
	Nitrite		Halogenated organics	
	Phosphate		Aromatics	
	Cyanide		Other hydrocarbons	
	Carbonate			
	Iodide			
	Orthophosphate			
	Total phosphate			
	Major elements			
	S	Mg		
	Al	P		
	Ca	K		
	Fe	Si		
	Na	Ti		
	Trace elements			
	Sb	Cr	Hg	V
	As	Cu	Mo	Zn
	Be	F	Ni	
	B	Pb	Se	
	Cl	Li	Tl	
	Cd	Mn	U	

^aWater-quality parameters.

4a.2.1.2 Environmental Control Characterization

The input and effluent streams of each pollution control device will be sampled to fulfill this objective. In addition, pollutant-containing effluent streams that are not controlled should be indicated in the test plan. Uncontrolled effluents can result because (1) there are not available controls for the pollutant in the prevailing stream conditions, (2) the stream is of negligible size or is expected to contribute negligible amounts of harmful materials, and (3) control costs are unreasonable. In any of these cases, future developments might make the effluent stream subject to control, and the information gained will serve as a sound basis for defining any control needs. Also, it may be useful to document the fact that a stream contains a negligible amount of a pollutant species, or that specific pollutants of interest are not present in a stream.

4a.2.1.3 Process Characterization

Process characterization necessitates a more in-depth process evaluation than do the preceding types. Two considerations are important:

1. Do some process segments significantly affect environmental control performance or uncontrolled effluent streams?

Table 4a.2.3. Parameters of probable interest

Solids	Liquids	Gases
Morphology	Physical factors	Particulate loadings ^a
Leachability study ^b	pH	Major components
Ultimate analysis	Temperature	CO, CO ₂ , N ₂ , H ₂ , O ₂
Proximate analysis	Specific conductance	Acid gases
Elemental analysis	Residue	HCN
Al, Ca, Fe, Mg, K,	Dissolved	H ₂ S
Si, Na, P, Ti, Sb,	Suspended	COS
As, Be, B, Cd, Cu,	Total	CS ₂
Cl, Cr, F, Pb, Li,	Hardness, acidity	SO ₂
Hg, Mn, Mo, Ni, Se,	Chemical oxygen demand	NH ₃
Ag, Tl, Sn, U, V,	Anions	NO _x
Zn	Cl ⁻ , F ⁻ , SO ₄ ²⁻ ,	Metal carbonyls
Organic species ^c	SO ₃ ²⁻ , S ²⁻ , NO ₃ ⁻ ,	Fe(CO) ₅
	PO ₄ ³⁻ , CN ⁻	Ni(CO) ₄
	NH ₃	Elemental analysis
	Biochemical oxygen demand,	Al, Ca, Fe, Mg,
	total organic carbon	K, Si, Na, Pb,
	Oil and grease	Ti, Sb, As, Be,
	Phenols	B, Cd, Cu, Cl,
	Elemental analysis	Cr, F, Pb, Li,
	Al, Ca, Fe, Mg, K, Si,	Hg, Mn, Mo, Ni,
	Na, P, Ti, Sb, As, Be,	Se, Ag, Tl, Sn,
	B, Cd, Cu, Cr, Pb, Li,	U, V, Zn
	Hg, Mn, Mo, Ni, Se, Hg,	Hydrocarbons
	Tl, Sn, U, V, Zn	Total methane, nonmethane
	Organic species ^c	Organic species ^c

^aSame parameters as solids.^bLeachability study includes the same parameters as liquids.^cOrganic species of environmental concern are presented in Tables 4b.2.4 and 4b.2.5.

2. Is it possible to adjust process operating conditions to reduce pollutant effluents?

If the answer to either of these questions is "yes," the input and output streams of internal segments of the process should be sampled and analyzed for the analytical parameters of interest.

4a.2.1.4 Stream-Analytical Parameter Matrix

A matrix is a convenient means of displaying the set of sampled streams and analytical parameters. The columns represent the streams and the rows represent analytical parameters. (See Table 4a.2.6 for an example of a stream-analytical parameter matrix.) Such a matrix clearly indicates the analytical parameters to be measured in each sampled stream. Where more than one set of plant operating conditions is to be tested, there can be—and frequently are—more than one matrix.

Table 4a.2.4. Some environmentally hazardous organic species

Compound	Hazard	Compound	Hazard
Polycyclic aromatics		Benzophenanthrenes	
Naphthalenes		Benzo[<i>c</i>]phenanthrene	Carcinogen
Naphthalene	Suspected carcinogen	2-Methylbenzo[<i>c</i>]phenanthrene	Suspected carcinogen
1-Methyl naphthalene	Toxic	Benzofluoranthenes	
Acenaphthenes		Benzo[<i>j</i>]fluoranthene	Carcinogen
Acenaphthene	Suspected carcinogen	Benzo[<i>b</i>]fluoranthene	Carcinogen
Anthracenes		Benzo[<i>k</i>]fluoranthene	Suspected carcinogen
Anthracene	Suspected carcinogen	Benzopyrenes	
9-Methylanthracene	Suspected carcinogen	Benzo[<i>a</i>]pyrene	Carcinogen
Phenanthrenes		Benzo[<i>e</i>]pyrene	Carcinogen
Phenanthrene	Toxic	3-Methylbenzo[<i>a</i>]pyrene	Suspected carcinogen
Pyrenes		Perylenes	
Pyrene	Carcinogen	Perylene	Suspected carcinogen
Fluoranthenes		Dibenzanthracenes	
3-Methylfluoranthene	Suspected carcinogen	Dibenz[<i>a,h</i>]anthracene	Carcinogen
Fluoranthene	Toxic	Dibenz[<i>a,c</i>]anthracene	Suspected carcinogen
Indenopyrenes		Dibenz[<i>a,j</i>]anthracene	Suspected carcinogen
Indeno[1,2,3- <i>cd</i>]pyrene	Suspected carcinogen	Dibensopyrenes	
Cholanthrenes		Dibenzo[<i>a,i</i>]pyrene	Carcinogen
Cholanthrene	Suspected carcinogen	Dibenzo[<i>a,d</i>]pyrene	Suspected carcinogen
3-Methylcholanthrene	Suspected carcinogen	Dibenzo[<i>a,e</i>]pyrene	Suspected carcinogen
Chrysenes		5-Methyldibenzo[<i>a,i</i>]pyrene	Suspected carcinogen
Chrysene	Carcinogen	Benzoperlylenes	
5,6-Dimethylchrysene	Suspected carcinogen	Benzo[<i>ghi</i>]perylene	Carcinogen
5-Methylchrysene	Carcinogen	Dibenzopentaphenes	
Benzanthracenes		Dibenzo[<i>h,rsi</i>]pentaphene	Suspected carcinogen
Benz[<i>a</i>]anthracene	Carcinogen	Dibenzoperlylenes	
6,8-Dimethylbenz[<i>a</i>]anthracene	Suspected carcinogen	Peropyrene	Suspected carcinogen
7,12-Dimethylbenz[<i>a</i>]anthracene	Suspected carcinogen	Nitrogen heterocyclics	
8,12-Dimethylbenz[<i>a</i>]anthracene	Suspected carcinogen	Pyrroles	
1-Methylbenz[<i>a</i>]anthracene	Suspected carcinogen	Pyrrole	Toxic
2-Methylbenz[<i>a</i>]anthracene	Suspected carcinogen	Morpholines	
		Morpholine	Irritant
		<i>N</i> -Ethylmorpholine	Irritant
		Bismorpholinomethane	Carcinogen

Pyridines	
Pyridine	Irritant
<i>α</i> -Picoline	Irritant
3,4-Dihydroxypyridine	Carcinogen
Indoles	
Indole	Suspected carcinogen
Carbazoles	
Carbazole	Toxic
Benzocarbazoles	
Benz[<i>a</i>]carbazole	Suspected carcinogen
Dibenzocarbazoles	
7 <i>H</i> -Dibenzo[<i>c,g</i>]carbazole	Carcinogen
7 <i>H</i> -Dibenzo[<i>a,i</i>]carbazole	Suspected carcinogen
7 <i>H</i> -Dibenzo[<i>a,g</i>]carbazole	Suspected carcinogen
Quinolines	
Quinoline	Toxic
Isoquinoline	Toxic
Benzacridines	
Benz[<i>c</i>]acridine	Suspected carcinogen
7,9-Dimethylbenz[<i>c</i>]acridine	Suspected carcinogen
7-Methylbenz[<i>c</i>]acridine	Carcinogen
Dibenzacridines	
Dibenz[<i>a,j</i>]acridine	Carcinogen
Phenazines	
Phenazines	Suspected carcinogen
Nonheterocyclic nitrogen compounds	
Nitriles	
Acetonitrile	Toxic
Acrylonitrile	Toxic

Aliphatic amines	
Piperidine	Toxic
Methylamine	Irritant
Ethylamine	Irritant
<i>n</i> -Propylamine	Irritant
<i>n</i> -Butylamine	Irritant
Triethylamine	Irritant
Ethylenediamine	Irritant
Cyclohexylamine	Irritant
Dicyclohexylamine	Irritant
Dimethylamine	Mutagenic
Allylamine	Irritant
Anides	
Acrylamide	Toxic
Acetamide	Carcinogen
<i>N,N</i> -Diethylacetamide	Suspected carcinogen
Acetylaminofluoranthene	Suspected carcinogen
Thioacetamide	Mutagenic
Acetanilide	Mutagenic
Aromatic amines	
<i>o</i> -Toluidine	Suspected carcinogen
<i>m</i> -Toluidine	Suspected carcinogen
<i>β</i> -Naphthylamine	Carcinogen
Diphenylamine	Suspected carcinogen
Benzidine	Suspected carcinogen
4-Amino-biphenyl	Suspected carcinogen
Aniline	Toxic
4,4-Methylenedianiline	Suspected carcinogen
Aminoazobenzene	Suspected carcinogen
Benzylamine	Irritant
<i>p</i> -Phenylenediamine	Irritant
Imines	
Ethylenimine	Toxic
Hydroxylamines	
<i>N</i> -Hydroxyaniline	Mutagenic
<i>N</i> -2-Naphthylhydroxylamine	Suspected carcinogen
Hydroxylamine	Mutagenic

Table 4a.2.4 (continued)

Compound	Hazard	Compound	Hazard
Hydrazines		Sulfides	
Hydrazine	Suspected carcinogen	Carbon disulfide	Toxic
1,3-Diethylhydrazine	Suspected carcinogen	Thiophenes	
Methylhydrazine	Suspected carcinogen	Thiophene	Toxic
Hydroazobenzene	Suspected carcinogen		
Semicarbazides		Benzene derivatives	
Semicarbazide	Carcinogen	Polyaryls	
Azo compounds		Biphenyl	Toxic
Azobenzene	Suspected carcinogen	Double-bond conjugated benzenes	
Azoethene	Suspected carcinogen	Styrene	Toxic
Thioureas		Alkylbenzenes ^a	
Thiourea	Suspected carcinogen	Benzene	Suspected carcinogen
Mercaptans, aliphatic		Phenols	
Methylmercaptan	Disagreeable odor	Phenol	Suspected carcinogen
Ethylmercaptan	Disagreeable odor	<i>o</i> -Chlorophenol	Suspected carcinogen
Isopropylmercaptan	Disagreeable odor	2,4-Xylenol	Suspected carcinogen
<i>a</i> -Propylmercaptan	Disagreeable odor	2,5-Xylenol	Suspected carcinogen
2-Pentylmercaptan	Disagreeable odor	2,6-Xylenol	Suspected carcinogen
Isoamylmercaptan	Disagreeable odor	3,4-Xylenol	Suspected carcinogen
<i>n</i> -Amylmercaptan	Disagreeable odor	3,5-Xylenol	Suspected carcinogen
<i>n</i> -Hexylmercaptan	Disagreeable odor	<i>o</i> -Cresol	Toxic
β -Mercaptoethanol	Mutagenic	<i>m</i> -Cresol	Toxic
Mercaptans, aromatic		<i>p</i> -Cresol	Toxic
Thiophenol	Disagreeable odor	1-Naphthol	Toxic
Benzylmercaptan	Disagreeable odor	2-Naphthol	Toxic
<i>p</i> -Thiocresol	Disagreeable odor	Pyrogallol	Irritant
Thionaphthol	Disagreeable odor	Hydroquinone	Irritant
Sulfonic acids		Carboxylic acids	
Benzenesulfonic acid	Irritant	Aliphatic acids	
Methanesulfonic acid	Irritant	Formic acid	Caustic
Sulfuric acid esters		Acetic acid	Caustic
Dimethylsulfate	Suspected carcinogen	Propionic acid	Disagreeable odor
<i>n</i> -Propylmethanesulfonate	Mutagenic	Butyric acid	Disagreeable odor
Sulfoxides		Valeric acid	Disagreeable odor
Dimethylsulfoxide (DMSO)	Suspected carcinogen	Caproic acid	Disagreeable odor

^aOther major alkylbenzenes present as major constituents of their class are also significant.

Table 4a.2.5. Organic species from EPA effluent guidelines

1,3-Dichlorobenzene	Pyrene	Carbon tetrachloride
1,4-Dichlorobenzene	Benzidine	Bromodichloromethane
Hexachloroethane	Butyl benzyl phthalate	bis(Chloromethyl)ether
1,2-Dichlorobenzene	Chrysene/Benzo[<i>a</i>]anthracene	1,2-Dichloropropane
bis(2-Chloroisopropyl)ether	bis(2-Ethylhexyl)phthalate	<i>trans</i> -1,3-Dichloropropene
Hexachlorobutadiene	Benzo[<i>b</i>]fluoranthene/	Trichloroethylene
1,2,4-Trichlorobenzene	Benzo[<i>k</i>]fluoranthene	Dibromochloromethane
Naphthalene	Benzo[<i>a</i>]pyrene	1,1,2-Trichloroethane
Nitrobenzene	Indeno[1,2,3- <i>cd</i>]pyrene	<i>cis</i> -1,3-Dichloropropene
bis(2-Chloroethyl)ether	Dibenzo[<i>a,h</i>]pyrene	Benzene
bis(2-Chloroethoxy)methane	Benzo[<i>g,h,i</i>]perylene	2-Chloroethyl vinyl ether
Hexachlorocyclopentadiene	<i>N</i> -nitrosodimethylamine	2-Bromo-1-chloropropane (IS)
2-Chloronaphthalene	<i>N</i> -nitrosodi- <i>n</i> -propylamine	Bromoform
Acenaphthylene	Endrin aldehyde	1,1,2,2-Tetrachloroethane
Acenaphthene	Endosulfan sulfate	1,4-Dichlorobutane (IS)
Isophorone	3,3'-Dichlorobenzidine	1,1,2,2-Tetrachloroethene
Fluorene	2,3,7,8-TCDD	Toluene
2,6-Dinitrotoluene	Chloromethane	Chlorobenzene
2,4-Dinitrotoluene	Dichlorodifluoromethane	Ethylbenzene
4-Chlorophenyl phenyl ether	Bromomethane	Phenol
Diphenylhydrazine	Vinyl chloride	2-Chlorophenol
Dimethyl phthalate	Chloroethane	2,4-Dimethylphenol
<i>N</i> -nitrosodiphenylamine	Methylene chloride	2-Nitrophenol
Hexachlorobenzene	Trichlorofluoromethane	2,4-Dichlorophenol
4-Bromophenyl phenyl ether	1,1-Dichloroethylene	<i>p</i> -Chloro- <i>m</i> -cresol
Diethylphthalate	Bromochloromethane (IS)	2,4,6-Trichlorophenol
Phenanthrene/Anthracene	1,1-Dichloroethane	2,4-Dinitrophenol
<i>d</i> ₁₀ -Anthracene	<i>trans</i> -1,2-Dichloroethylene	4-Nitrophenol
Di- <i>n</i> -butylphthalate	Chloroform	4,6-Dinitro- <i>o</i> -cresol
Fluoranthene	1,2-Dichloroethane	Pentachlorophenol
	1,1,1-Trichloroethane	<i>d</i> ₁₀ -Anthracene (IS)

Table 4a.2.6. Sampling points and analytical parameters for CO₂ Acceptor pilot plant solid streams

Stream	Analytical parameters																Percentage ash	Proximate analysis	Leachate	Trace organics
	H ₂ O	C	H	O	N	S	Al	Ca	Fe	Mg	P	K	Si	Na	Ti	Trace elements ^a				
Lignite grinding and drying vent fines	X	X	X	X	X	X											X	X		
Lignite screening fines	X	X	X	X	X	X											X	X		
Sized and dried lignite	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Purged acceptor	X					X	X	X	X	X	X	X	X	X	X	X	X		X	
Makeup acceptor	X					X	X	X	X	X	X	X	X	X	X	X	X			
Makeup char	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
Gasifier external cyclone ash and char	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Regenerator first cyclone ash	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	
Regenerator second cyclone ash	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	
Solids from product-gas quench water blowdown		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
Solids from quenched product-gas filter	X					X	X	X	X	X	X	X	X	X	X	X	X			
Solids from regenerator quench water blowdown						X	X	X	X	X	X	X	X	X	X	X	X			
Solids from laboratory-scale chance reaction						X													X	

^aSb, As, Be, B, Cl, Cd, Cr, Cu, F, Pb, Li, Mn, Hg, Mo, Ni, Se, Ti, U, V, and Zn.



4a.2.2 OPERATING PARAMETERS

A major purpose of the process analysis (Sect. 4a.3) is to identify process variables that have significant effects on stream analytical parameters. Process variables that are frequently important include feedstock composition, production rate, environmental control operating parameters, and other basic operating parameters (temperatures, flow rates, pressures).

Once the principal determinants (independent variables) of stream analytical parameters (dependent variables) have been established, the sets of operating conditions to be characterized can be selected. In many cases, there will be no need for a complete plant characterization at every set of test operating conditions, because only a few analytical parameters would be significantly affected by the changed conditions. A different stream-parameter matrix can be prepared for each case, but it will always be a subset of the full characterization matrix.

Many operational, and some analytical, parameters will be routinely monitored and logged by the plant operators for process control purposes. If the process analysis indicates that both the quality and quantity of the collected data are suitable for characterization purposes, there is no need to duplicate the effort.



4a.2.3 SELECTION OF SAMPLING AND ANALYTICAL TECHNIQUES

Selection of sampling and analytical techniques, in conjunction with a review of the piping and control system for the process analysis, should establish the approximate sampling location for each sampled stream,^a handling and preservation techniques for each sample, operation data collection requirements, and quality control procedures (Sect. 4a.2.5).

Some important considerations in finalizing the specification of sampling and analytical methods include:

1. possible last-minute process equipment modifications
2. steps for ensuring needed cooperation among plant operator, sampler, sample handler, and analyst in a field test situation
3. revisions to approved regulatory agency test methods or agency approval of more convenient test methods
4. health and safety consequences of the proposed port locations and sampling methods (e.g., toxic or explosive gases, high internal pressures and/or temperatures, elevated or exposed positions)

^aPrior to firm designation of sample port locations, a site visit should be made to ensure that any deviations from the construction plans can be noted.

4a.2.4 SAMPLING FREQUENCY AND TIMING

Sampling frequency and timing involve decisions concerning how often and when to sample respectively. Sampling frequency constraints include the sampling technique itself, plant operational variations, quality control requirements, and data evaluation needs. The timing is somewhat process-dependent, but, to the extent possible, it is left to the discretion of the test plan developer.

4a.2.4.1 Frequency

Sampling frequency may be limited by either the method or the process. Some methods require several hours for collection of a suitable sample; shorter sampling times (higher frequencies) reduce the accuracy. Other methods use very short collection times, and compositing techniques must be used to obtain valid sampling averages.

For continuous modules, the sampling time should be sufficiently long to average out normal process variations. Cyclic modules can be approached in either of two ways:

1. If the steps in the cycle are relatively long and well defined, individual samples can be taken for each step, if such data are useful.
2. Sample collection can proceed over one or more cycles, as required.

In some cyclic modules, there will be no input or output flows except at the beginning or end of the cycle. Sample collection will take place only under flow conditions for most such modules.

The requirements for quality control should also be reviewed and incorporated into the sampling frequency determination. Sampling method limitations or plant operating constraints may require adjustment of desired schedules but deviations should be made with care and only when essential.

4a.2.4.2 Timing

The general timing for samples is established largely by the plant operating schedule. The following factors are important in final timing of the sample collection:

1. For any sampling, the plant should be given sufficient time to stabilize at the prescribed conditions. (For baseline testing, test conditions should correspond to the "normal" conditions defined in Sect. 4a.3.)
2. In steady-state testing, the residence time considerations of Sect. 4a.3 should be noted in setting sampling times for control technologies and/or process unit inputs and outputs.
3. Data concerning abnormal conditions—startup, shutdown, or upset conditions—are very important and, for complete characterization, impose urgent demands. (Extra equipment might be maintained for immediate use.)

4a.2.5 QUALITY CONTROL

A quality control program is intended to prevent the propagation of determinative errors (bias) through the sampling-analysis-evaluation chains of the test program.

To provide assurance that the collected data will be both accurate and precise, the quality control program should include the following elements:

1. calibration of sampling and analytical equipment to establish accuracy
2. replication at the sampling and analytical stages to establish the limits on precision
3. use of alternative (replicate) sampling and analysis methods and correlation analysis of the results to confirm accuracy, as judged necessary by a sampling statistician to ensure sampling accuracy
4. establishment of a chain of responsibility for data generation: from sample collection to sample recovery to sample analysis to evaluation of results. (This is best done by means of a strict record-keeping system, which includes a master log for tracking sample.)

Useful discussions of quality control procedures and documentation are available in refs. 1 through 3.

Several aspects of a demonstration project have a direct bearing on data quality and should be specifically called out in the environmental test plan.

4a.2.5.1 Facilities and Equipment

The test plan should include an inventory of all equipment, work space, and materials available for the monitoring process. There should be periodic checks of the laboratories, sampling platforms, and data logging and processing areas to ensure that they are in good operating condition.

4a.2.5.2 Training Program

Before starting field work, personnel should be thoroughly indoctrinated in the sampling and analysis program, with emphasis placed on the quality control aspects. All workers should be aware of the need for instrument calibration, duplicate samples, and other elements of quality control.

4a.2.5.3 Document Control

Provision must be made for maintaining complete security of sample log books, sampling and analytical data recording forms, and operating procedure documents so that data will not be lost or mishandled. Duplicate record keeping is recommended. In addition, procedures for making and distributing revisions to documents affecting the quality control program should be detailed.

4a.2.5.4 Quality Control Charts

For day-to-day maintenance of quality control standards, it is essential that routine tracking procedures be established. Quality control charts should be kept for duplicate analyses, calibration constants, "spiked" sampling results (percentage recovery), isokinetic sampling rates, and other factors that have a direct bearing on quality control. Normally 3σ control limits are used, with 2σ being used as a warning limit. (σ is the standard deviation of two or more duplicate sample results.)

4a.2.5.5 Operational Quality Control and Information Feedback

Observers should routinely check the conformance of test-team members to standard procedures for sampling, calibration, analysis, and data handling. Any deviations should be corrected immediately and an assessment of the effect of the deviation on results should be made. If necessary, tests should be repeated to ensure data validity.

4a.2.5.6 Material Inventory and Procurement

Routine inventories of all reagents and supplies needed for quality control maintenance should be made. Purchasing guidelines should be documented so that no delays in delivery will affect data quality.

4a.2.5.7 Reliability and Maintenance

All equipment which is part of a measurement system should be serviced in accordance with the manufacturer's or developer's recommendations. The reliability of the equipment should be routinely checked to ensure that maintenance procedures are adequate, and revisions should be made as needed to maintain data quality. Maintenance and reliability data should be recorded in log books.

4a.2.5.8 Data Validation

Criteria for data validation should be stated in the test plan and revised as needed to maintain quality control. Ideally, data validation consists of two components:

1. A routine set of checks of measurement accuracy at various points in the sampling-analysis-data processing sequence.
2. Random audits of quality control performance by nontest-team members. The quality control audit will check test-team adherence to standard procedures (a system review) and make independent quantitative checks as needed.

4a.2.5.9 Equipment Calibration

No quality control program can succeed unless all equipment is routinely calibrated by appropriate standards. In addition, recovery tests for "spiked" samples should be a regular part of laboratory procedures, to avoid chemical interferences (matrix effects). A quality control chart should be retained for recording recovery results.

4a.2.5.10 Correlation Tests

Where judged necessary by a sampling statistician, alternative sampling and analysis methods should be used to provide added assurance of data accuracy. Statistical correlation analysis can be used to ensure that the two methods are producing identical results, within experimental error.

REFERENCES FOR SECTION 4a.2.5

1. James Buchanan, *Guidelines for Demonstration Project Quality Assurance Programs*, EPA 600/2-76-081, Research Triangle Institute, Research Triangle Park, N.C., March 1976.
2. James Buchanan, *Development and Trial Field Application of a Quality Assurance Program for Demonstration Projects*, EPA 600/2-76-083, Research Triangle Institute, Research Triangle Park, N.C., March 1976.
3. National Institute for Occupational Safety and Health, Public Health Service, *The Industrial Environment—Its Evaluation and Control*, U.S. Government Printing Office, Washington, D.C., 1973.

4a.2.6 TEST SCHEDULE

A sampling schedule is necessary to ensure that all needed samples will be collected during an available time period without using excessive manpower. For test work conducted under normal conditions, there are few expected time constraints. However, special tests under unusual process conditions are usually conducted around the plant operating schedule.

The test schedule should be based on (1) the expected plant operating schedule, (2) preparation (setup) time requirements for sampling and any required onsite sample recovery and analysis, and (3) personnel and equipment availability. The expected plant operating schedule must be established and continually updated through close liaison with plant personnel. Laboratory facilities and sampling shelters should be available well in advance of test work initiation. A final survey of all sampling locations should be made before arrival of the test team so that any problems can be corrected.

4a.2.7 TEST PLAN REVISIONS

Revisions in test plan content or scheduling can result from (1) changes to the plant operating schedule as a result of equipment failures or changing objectives, (2) identification of problems in sampling and analytical methods, (3) feedback of data from the quality control and data evaluation programs which indicate a problem with quality control in the sample-analysis-evaluation chain, and (4) revisions of program scope arising from preliminary monitoring results.

4a.3 Process Analysis

The purpose of performing a process analysis is to determine how the specific coal conversion plant may be tested to achieve the objectives of the environmental process monitoring program and to establish process information necessary to the development of the test plan and the subsequent data evaluation effort. The process analysis considers the objectives of the monitoring effort and examines the process to establish (1) process streams to be sampled; (2) flow rate, operating conditions, and estimated composition of these streams; (3) analytical parameters of interest; (4) plant operating conditions to be tested; and (5) process information that is available and process data that must be gathered during environmental testing.

A suggested method for conducting the process analysis consists of the following analytical procedure:

1. identification of process operations
2. identification of process modules^a and preparation of analytical block flow diagrams
3. compilation and analysis of process and effluent data for the process module
4. performance of an onsite survey to relate process data and monitoring plan objectives to equipment in the field
5. input process analysis to monitoring plan development

^aA module is defined as a process subsection with a single, well-defined, and intended function. In most cases, the module performs a unit operation, but closely related unit operations can be combined in a single module. A control module is a process subsection which has as its primary function the removal of a pollutant from a process effluent stream.

4a.3.1 IDENTIFICATION OF PROCESS OPERATIONS

The first step in the process analysis is to identify the basic process operations. Any coal conversion plant, no matter how complex, can be represented by the operations listed below and shown schematically in Fig. 4a.3.1.

Process operations

- Coal pretreatment
- Coal conversion
- Product purification and upgrading
- Auxiliary process(es)

Effluent control operations

- Air pollution control
- Water pollution control
- Solid waste management

The coal pretreatment operation receives the raw coal and prepares it for feeding to the conversion operation. The coal conversion operation then transforms the coal via physical or chemical reactions (using steam, air, oxygen, hydrogen, or solvents) to low-, medium-, or high-Btu gas, liquid products, or synthesis gas. If multiple products are produced, the basic product split may

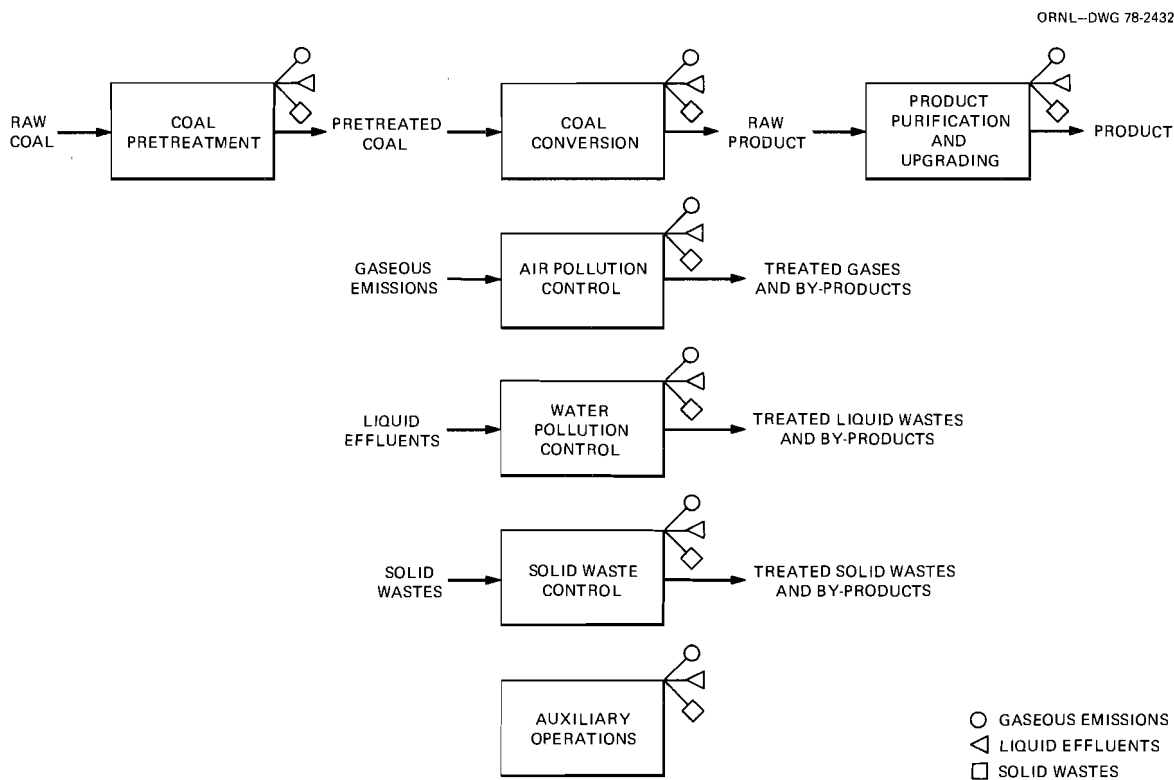


Fig. 4a.3.1. Major process and effluent control operations in a typical coal conversion plant.

also be accomplished as part of this step. In the purification and upgrading operation, heat is recovered, the product is cooled, undesirable constituents such as particulates, acid gases, and sulfur compounds are removed, and, if desired, further processed to a more beneficial finished product. Examples of auxiliary processes are power generation, hydrogen and oxygen generation, and makeup water treatment. Flags atop the blocks in Fig. 4a.3.1 indicate the types of effluents (gaseous, liquid, or solid waste) generated within each operation during normal conditions. In most plants, there will be all three types of effluents from each of the basic operations.

These various waste streams are normally directed to one of the three appropriate pollution control operations for further treatment. The air pollution control operation reduces the pollutants in the waste gas streams to levels acceptable for venting to the atmosphere and may recover them as by-products (e.g., sulfur, ammonia). Dissolved and suspended organic and inorganic species are removed, or recovered as by-products, from the liquid effluents in the water pollution control operation so that they may be recycled or sent to evaporation ponds. The solid waste control operation treats and disposes of the solids generated in the process and other control operations.

If the objective of the environmental testing is to make an effluent characterization or to verify control performance, the process analysis can be concentrated on the effluent control operation and on uncontrolled effluent streams. If the purpose is to provide more detailed process characterization, all of the basic operations must be analyzed.

4a.3.2 IDENTIFICATION OF PROCESS MODULES

Each of the general operations normally consists of several processing steps. These processing steps are typically well-defined segments of an operation with specific input and output streams. In this part of the analysis, the processing steps involved with each operation should be identified and defined. Once defined, these processing steps will serve as the process modules and the building blocks of this analysis and, ultimately, of the monitoring plan.

The specific modules defined may vary according to where the interface between modules is designated. A module may consist of one piece of equipment (a distillation column) or many pieces of equipment (as an acid gas removal process). In the latter case, the module would consist of an absorber, a stripper, and the attendant pumps, exchanger, and process tankage. What is most important about the module is that it be a segment of the operation which can be well defined and which does not require any awkward division of process equipment.

The specific modules used with a particular conversion process may differ depending on the specified end products and the nature of the coal feedstock. Accurate flow sheets provide the basic information for identifying the modules for a specific process. Usually, the major streams—feed, product, and waste—for each defined module may also be obtained from process flow sheets.

Possible modules for each of the coal conversion and pollution control operations and their associated effluents are as follows.

4a.3.2.1 Coal Pretreatment

The coal pretreatment operation contains one or more of the following processing steps (process modules):

1. coal drying
2. partial oxidation
3. crushing and sizing
4. pulverization
5. briquetting
6. handling and transporting
7. storage

Gaseous emissions are generated in all the pretreatment modules either as coal dust resulting from mechanical agitation and wind action, as volatile matter, or as combustion products from thermal and oxidation processes. Liquid effluents containing a wide range of organic and inorganic components may result from water sprays used to control dust emissions or from runoff from storage piles. The crushing, sizing, and pulverizing steps usually discharge rock or other mineral matter and undersized coal particles.

4a.3.2.2 Coal Conversion

Although the coal conversion operation characterizes the entire process, it is often the simplest operation to diagram.

The modules within the conversion operation do not normally contain a major emission source. The gaseous emissions from the gasification module include volatile coal components or combustion products and entrained solids. The solids are coal and ash dust from the coal feeding and ash removal systems or the gasifier startup vent. Liquid effluents include ash quenching and/or sluicing system wastes and blowdown from steam generation. Solid wastes include ash, unreacted coal, char, coal feed additives, and sediment from the ash quench water.

4a.3.2.3 Product Purification and Upgrading

Modules associated with the product purification and upgrading operation will vary widely depending on the specific conversion process used and the product desired. For a coal gasification facility, the gas purification operation would consist of the following modules:

1. particulate removal
2. heat recovery
3. gas quenching
4. acid gas removal and/or
5. oil and tar removal
6. shift reaction
7. methanation

The types and arrangement of these modules depend on the nature of the raw gas, the coal feedstock, the gasifier design, and the end use of the product—for example, combustion, chemical synthesis, etc. If high-Btu gas were the designated product, a shift reaction module and a methanation process module would also be a part of this operation.

Gaseous emissions of hydrocarbons, nitrogen compounds, and sulfur compounds are generated in the acid gas removal systems. Examples of typical gas components include HCN, NH₃, H₂S, COS, and mercaptans. Liquid effluents laden with tar, oil, particulates, and spent solvents may be produced by the particulate removal modules if wet scrubbing is used. The gas quenching and acid gas removal steps can also produce liquid effluents. Solid and ash entrained in the raw product gas are discharged dry from cyclones or electrostatic precipitators. Solid wastes can also be emitted as a slurry in quench liquor or acid gas removal process solvent.

4a.3.2.4 Auxiliary Processes

This category is intended for any process that cannot be readily associated with the processing sequence that converts coal to product. These processes include power generation, water treatment, air compression, fuel gas generators, and oxygen and hydrogen generation processes.

Gaseous emissions from these modules might include combustion products, hydrocarbon vapors, sulfur and nitrogen oxides, and particulates. Liquid effluents may include oils, spent chemicals, solvents, and suspended solids. Solid wastes generated in power plants and by feedwater treatment would consist of coal ash and fines, sludge, and miscellaneous mineral wastes.

4a.3.2.5 Air Pollution Control

The modules required in the air pollution control operation depend on the composition of the gaseous effluents generated in the other operations. Typically, one or more of the following modules will be used:

1. particulate control
2. sulfur control and recovery
3. nitrogen oxides control
4. hydrocarbon control

These control modules, in turn, release all three types of effluents, the liquid and solid streams frequently requiring further treatment. The gaseous streams may be released to the atmosphere or

processed in another air pollution control module. Liquid effluents may contain spent sorbents, scrubbing liquors, or sour condensate. Solid wastes include coal fines, ash, sulfur, spent sorbents, and catalysts.

4a.3.2.6 Water Pollution Control

The configuration of modules in the water pollution control operation may vary considerably depending on the conversion process used, the size of the plant, and the geographical location. Modules usually included are the following:

1. oil and water separation
2. suspended solids removal
3. dissolved organic species removal
4. dissolved inorganic salts and volatile contaminants removal
5. forced-circulation evaporation and/or
6. evaporation ponds

Where zero discharge is achieved, the wastewater is treated to a level such that it can either be reused or is ultimately discharged to an evaporation pond. Water pollution control processes that discharge contaminated gaseous streams containing organic vapors, NH_3 , H_2S , COS , etc., include acid gas stripping, forced circulation and evaporation, and activated carbon absorption. Most of the aqueous streams also require further treatment. Many of the nonaqueous liquids such as tar, oil, and phenols are recovered as by-products before reuse or disposal. Solid wastes are discharged from the suspended solids removal units as well as the bio-oxidation, ion-exchange, and carbon absorption systems.

4a.3.2.7 Solid Waste Control

The solid waste control operation may contain any or all of the following modules to treat the solid effluents generated by the plant:

1. sludge reduction
2. chemical fixation
3. landfill
4. land farm

Gaseous emission of volatile organics, combustion products, particulates, and liquid wastes from the sludge reduction module require further treatment before venting. Solid wastes in landfills may be a source of water pollution from the leaching of toxic compounds unless the proper precautions are taken. Those solid wastes that cannot be recycled or sold as by-product include "fixed" solids from chemical fixation and ash from sludge reduction. They are usually disposed of in a landfill. (Other sections of the handbook discuss aspects of landfill monitoring such as groundwater quality.)

After the process modules have been identified, analytical block diagrams defining process streams entering and leaving each of the modules should be established. These diagrams serve as the basis for analyzing each module individually, for deciding which process streams are of interest, and for developing the process module information.

Figure 4a.3.2 is a typical analytical block diagram for a coal gasification process module. Similar diagrams should be developed for the actual modules identified in a given facility. The variations in process systems, however, may necessitate additions, deletions, or modifications of the stream associated with each module.

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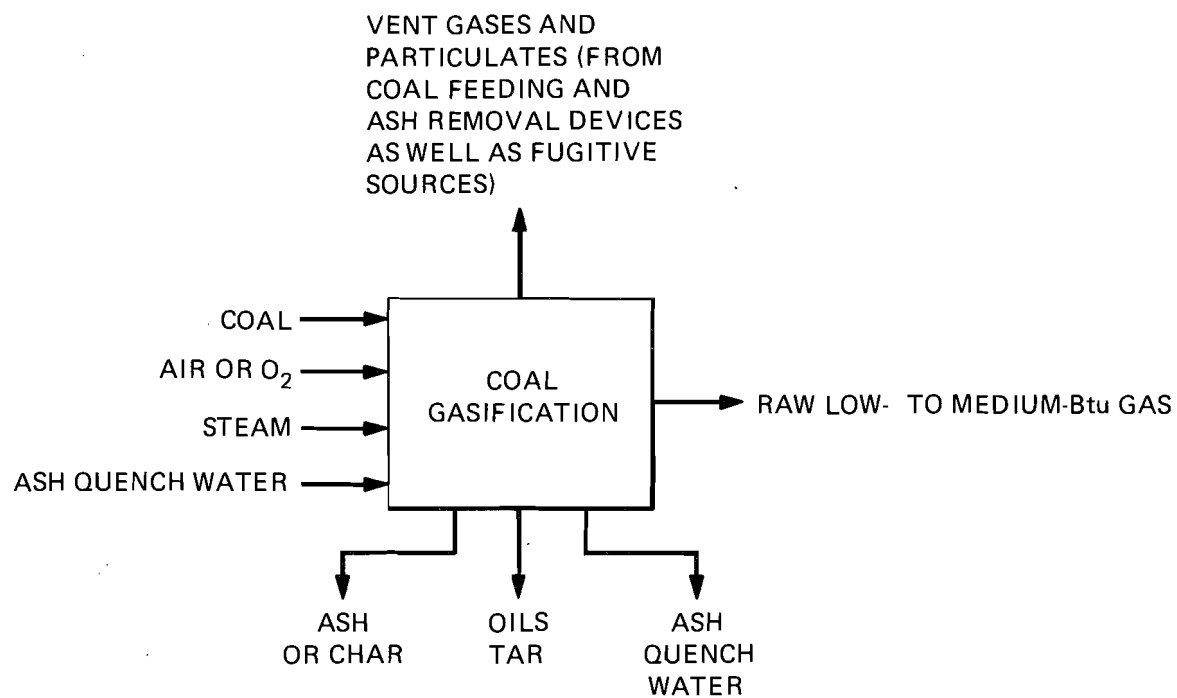


Fig. 4a.3.2. Analytical block diagram for a typical module in the gasification operation.

4a.3.3 COMPILATION, ANALYSIS, AND DEVELOPMENT OF PROCESS MODULE DATA

After the process modules are identified and the analytical block diagrams are developed, the next step is to determine or provide an estimate of all process module data pertinent to the monitoring effort. There is no specific recommended format for compiling the information, but it should be adapted to the operations or modules at the particular plant site and should be organized for easy retrieval. A typical tabulation might appear as in Table 4a.2.1.

Although the process data compilation is started during the analysis, this data-gathering effort should continue throughout the environmental process monitoring program and should be updated as new information becomes available. It is on these data that decisions are based to determine which streams to sample next, which test methods to use, which sampling and analytical procedures to follow, and any changes to be made in scope or test plan—for example, elimination of streams or parameters.

For each module stream the following information should be established and recorded:

1. stream type (e.g., feed, product, by-product, effluent)
2. physical characteristics (e.g., gas, liquid, solid, mixed phases)
3. basic composition (e.g., product gas, ash, flue gas, vent gas, and particulates)
4. detailed chemical and physical analyses

The following data also should be included since they will be useful in selecting sampling points and methods:

1. operating conditions (flow rates, temperature, and pressure)
2. typical range of operating conditions
3. physical location of sample points and alternate points and flow meters

Information that cannot be easily presented on the block diagrams, figures, or tables should be included in written format (e.g., process descriptions, operating instructions, special studies, etc.) so that all pertinent data will be available to those responsible for preparing and conducting the test program.

Two other process-related aspects that should be determined for each module are residence times and normal operating conditions for the module. Residence time information affects how long and how often a stream is sampled; a definition of operating conditions determines appropriate sampling times. Flow rates and estimated volumes of major equipment items and piping are used to calculate residence times.

Normal operating conditions are those at which the process operates for the greatest percentage of the time. In the best situation these might be the design operating conditions; however, if the process has encountered some problems, "normal" might be considerably different from design.

Steps that should be followed to determine what conditions constitute normal operations are:

1. Review process design bases and design operating conditions to establish how the process was intended to operate. Are there any fundamental differences in design bases or operating modes in which the plant will operate a significant amount of time? Are two substantially different feed coals to be routinely used? Will major pieces of equipment be routinely bypassed?
2. Review process controls to determine the control parameters and control set points by which the plant obtains design or other designated operating conditions and how these control variables are monitored. This step should involve review of process piping and instrumentation diagrams.

3. If the plant is operational, review process records and discuss operation history with plant personnel to determine how successfully the process obtains and maintains design or other designated operating conditions. What degree of variations around control set points historically has proved to be acceptable in plant operation? Have any process modifications occurred?

4a.3.4 ONSITE SURVEY

An important element of the process analysis is an onsite survey by those responsible for the monitoring plan in conjunction with the plant operating supervisor(s). Specifically, the purpose of the survey is to relate the objectives of the monitoring plan and the process module information to the actual equipment in the field. An onsite survey provides the planners with a better working understanding of the individual processes and facilities to be tested.

During the onsite survey, particular attention should be given to the following:

1. location and physical layout of the process(es) of interest
2. types of vessels and equipment within each module
3. types and location of piping
4. location and origin of input streams
5. location and destination of product, by-product effluent streams, and emissions
6. types and location of process instrumentation
7. availability of plant data (what data pertinent to the monitoring plan is normally measured, what process data may have to be gathered in conjunction with the environmental testing effort)

4a.3.5 INPUT TO CHARACTERIZATION TEST PLAN DEVELOPMENT

The final step of the process analysis is to provide input to the development of the test plan. As discussed in Sect. 4a.1.2, as the process analysis progresses, the scope of the environmental testing effort can be more completely defined. Aspects of the test plan for which the process analysis should provide direction are discussed in Sect. 4a.2. After streams for sampling have been designated and sampling methods selected, information from process piping and instrumentation diagrams should be used to help identify appropriate primary sample points and alternate sample points for the test plan.

Information from the process analysis effort should provide continuous input to the test plan development as any changes in effort occur and as new information becomes available.

4a.4 Sampling Procedures

The careful selection and execution of sampling procedures is a critical step in producing reliable monitoring data and is therefore an important part of environmental process monitoring plan development. Samples must accurately represent the composition of the stream and must be compatible with the analytical techniques applied. Factors that must be considered to maintain sample integrity and provide a representative sample include:

1. spatial and temporal variations in stream composition
2. changes in sample composition following removal from the stream
3. limitations of the analytical techniques to fulfill the test plan's requirements for accuracy

Sampling procedures may be grouped into two basic categories—manual methods and continuous sampling. The following discussion of sampling equipment design and sampling procedures stresses the intermittent manual methods. The other major category, that of continuous automated instruments, is treated briefly in supplemental sections. The manual methods are generally more flexible and more easily executed, but are more labor intensive. Manual methods are often used as precursors to installation of continuous techniques, or as calibration or replication procedures for continuous sampling. Continuous automated techniques are more complicated and more capital intensive. Therefore, continuous techniques are usually preferred for long-term applications.

4a.4.1 GASEOUS STREAMS

The selection, design, and execution of procedures for the monitoring and characterization of gas streams require knowledge of the following:

1. stream physical conditions (temperature, pressure, particulate and condensable content, etc.)
2. major chemical components of the stream
3. reactivity of stream components relating to both sample stability and safety considerations
4. physical arrangement of the piping or ducting containing the stream

This information is available from the process analysis and from knowledge of process chemistry. Physical and/or chemical stabilization methods should be specified at this point.

The major emphasis in this discussion is on manual methods of gas monitoring, since the decision to use continuous monitoring is often based on the results of these methods. Execution of either approach requires (1) a carefully selected sampling point and (2) access to the stream for withdrawal of a portion of the gas (some continuous techniques avoid the withdrawal of gas from the stream by in situ analysis) with immediate or delayed analysis.

4a.4.1.1 Sampling Point Selection

The process streams designated for sampling and the areas in which these streams are accessible are the first considerations in sampling point selection. These considerations define the potential sampling points of interest. These sampling points must then be assessed in terms of their location and the flow characteristics of the gas stream.

The flow characteristics of the gas stream are a basic consideration that affect the ease with which a sample representative of the total stream can be collected. Method 1, promulgated by the EPA, presents criteria for selecting a gas stream sampling point. This approach is based on selecting a location having minimum turbulence (important for particulate sampling) and traversing a cross section of the stream to provide a statistically valid sample. The number and location of the traverse points depends on the distance to the nearest disturbance and the specific configuration of the pipe or duct. These variables for stacks and ducts are shown in Fig. 4a.4.1.

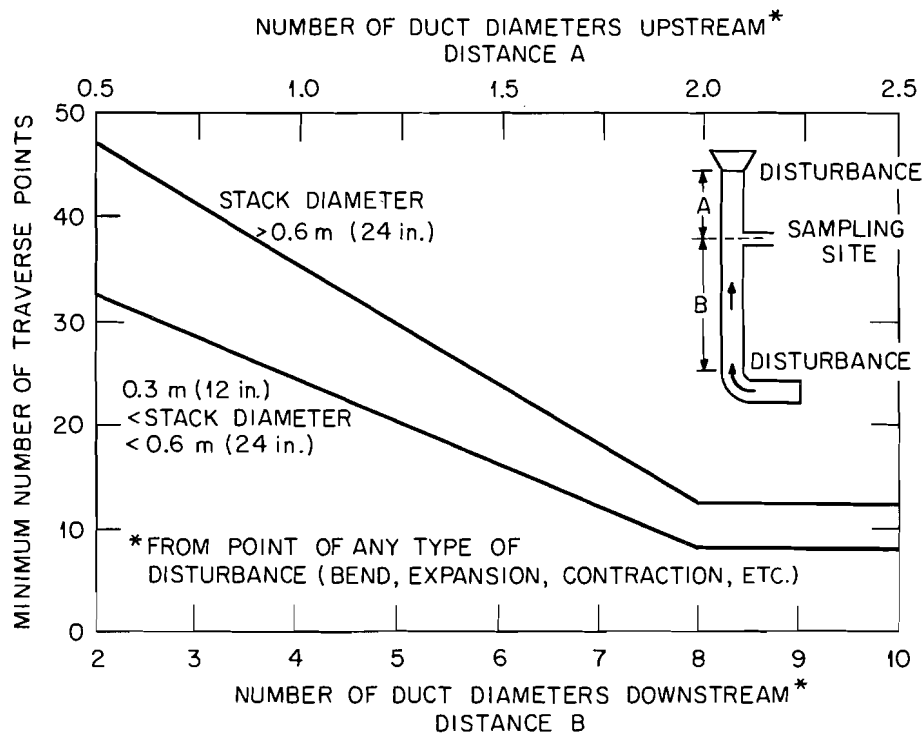
Small pipes and ducts present a special problem in the selection of a sampling point. The traverse approach of method 1 requires that the sampling port (or ports) be constructed at a right angle to the direction of flow. This allows traversing the stream's cross-sectional area. For small pipes, the sampling port itself may be a source of turbulence. As a general rule, if the cross-sectional area of the required sample port is greater than one-fifth of the cross-sectional area of the pipe to be sampled, the port should not be constructed at the proposed sampling point. The recommended alternative is to find a section of pipe having a minimum length of ten pipe diameters and terminating downstream in an elbow. The sampling port should be constructed in the elbow so that a probe can be inserted into the center of the stream at a distance of two pipe diameters upstream of the elbow. The probe's cross section should be less than one-fifth of the pipe cross-sectional area to avoid significant turbulence created by the probe.

4a.4.1.2 Sampling Train

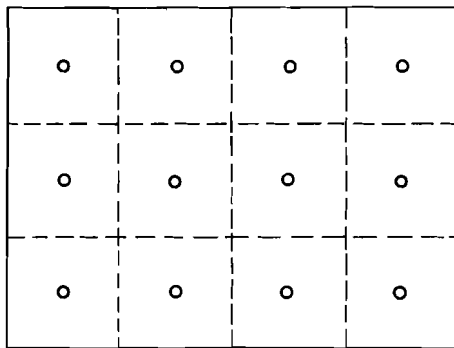
The sampling train, or system of collection devices, performs several functions, each of which must be considered during design:

1. transports a portion of the gas stream, unaltered physically or chemically, to the collection (and conditioning) sections

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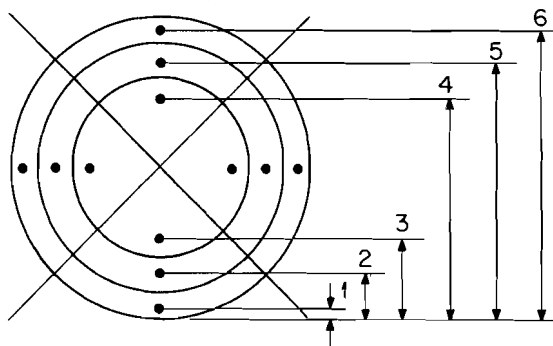


MINIMUM NUMBER OF TRAVERSE POINTS



(a)

TRAVERSE POINT	DISTANCE (% of diameter)
1	4.4
2	14.7
3	20.5
4	70.5
5	85.3
6	66.6



(b)

Fig. 4a.4.1. Number and location of traverse points by EPA method 1. (a) Example showing rectangular stack cross section divided into twelve equal areas, with traverse points at centroid of each area. (b) Example showing circular stack cross section divided into twelve equal areas, with traverse points at centroid of each area.

2. provides a controlled interface between the gas stream and the plant work environment
3. conditions the sampled gas as required for the collection sections
4. collects the components of interest
5. measures the volume of gas sampled
6. measures stream conditions (temperature, pressure, flow rate)

The sampling train designed to fulfill these functions consists of four sequential sample-processing units: (1) probe assembly, (2) particulate collection unit, (3) vapor collection unit, and (4) metering unit. Through various combinations of its individual components, this general-purpose sampling train is used to monitor a wide range of analytical parameters. Sampling involves removing the gas sample from the stream over a specified period of time under isokinetic conditions. The train concept presented here is based on EPA's method 5 for monitoring particulates.¹ The method 5 system is shown schematically in Fig. 4a.4.2.

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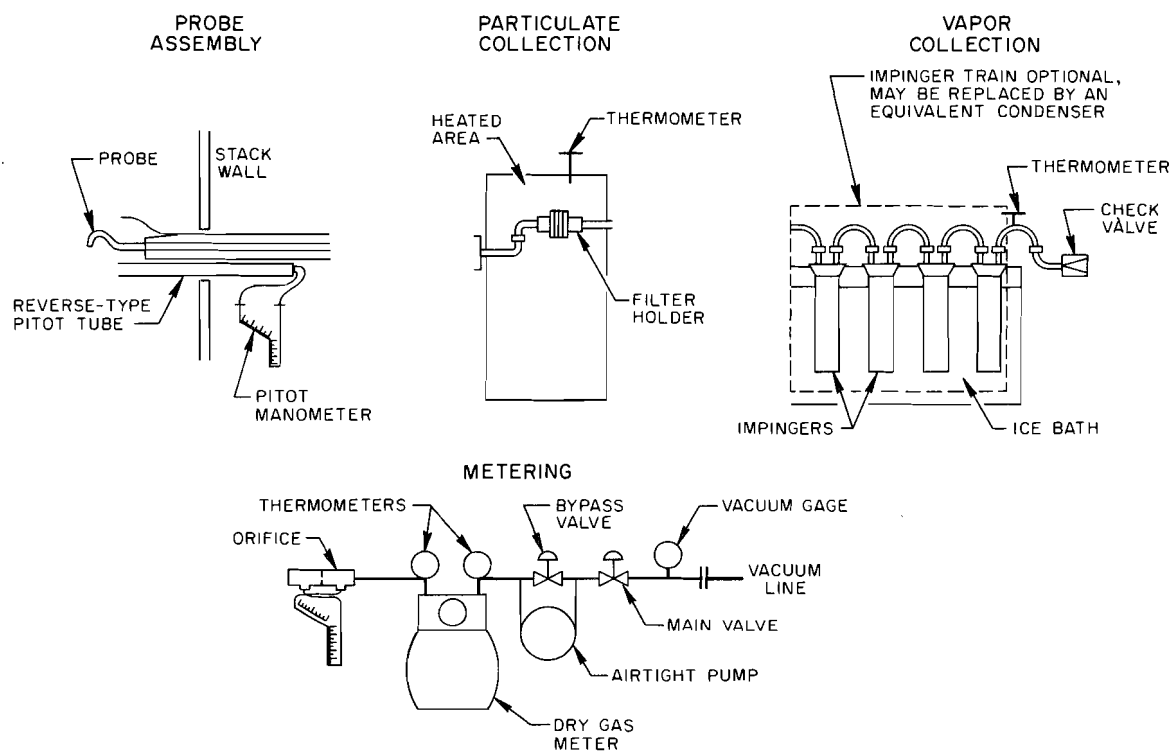


Fig. 4a.4.2. EPA method 5 sampling train.

4a.4.1.3 Grab Sampling

For gaseous sampling, the use of rigid or nonrigid containers for the collection of spot samples of process or emission gas is termed grab sampling. There are two major sources of error which restrict the use of this technique: (1) adsorption on (or reduction by) the container walls and (2) the reaction of gas components with each other.

These effects can be minimized through the use of inert materials such as glass or Teflon in container construction and in the preconditioning of the container prior to sampling. Analysis of

grab samples should be conducted as soon after collection as possible, and sample stability as a function of time should be determined. The most difficult source of error to avoid is the loss of components by sorption in condensate (usually water vapor) produced during cooling of the sample. Maintaining the container at a temperature high enough to prevent condensation is not usually practical, and reheating rarely is effective. Removal of moisture by sorption on silica gel or some other desiccant may be a solution if the component of interest is not lost on the desiccant.

As this discussion indicates, severe problems may arise with the reliability of grab sampling techniques and they can only be used with confidence for nonreactive fixed gases or following extensive verification.

4a.4.1.4 Continuous Monitoring

The results of an extensive sampling and analytical program may call for the continuous monitoring of some species in a gas stream. The basis for deciding which stream and analytical parameter to monitor must be a part of the overall test plan. The decision could be based on many factors, including (1) grab sampling is inappropriate, (2) compliance with governmental regulations, (3) reduction of undesirable chemical effects (including toxicity), (4) process control, and (5) research and development investigation.

Due to the repetitious and long-term nature of continuous monitoring, automated or instrumented systems are inherently more suitable than the manual techniques previously described. Physical conditions—including temperature, pressure, flow rate, and density—are conveniently monitored using commercially available instrumentation, such as normally is installed for process control. Although not directly a part of the test plan, such instruments supply process information related to the testing.

REFERENCE FOR SECTION 4a.4.1

1. U.S. Environmental Protection Agency, "Determination of Particulate Emissions from Stationary Sources, 40 CFR 60, App. A, Reference Method 5," *Fed. Regist.* **41**(111), 23076083 (1976).

4a.4.2 LIQUID STREAMS

Liquid or slurry streams are numerous in a coal conversion plant, and the variety of materials composing them can be great. Fortunately, the methods for sampling them are relatively simple.

Multiphase liquid sampling poses special problems, as indicated by the following four general sample types:

1. two liquid phases
2. high suspended solids content
3. pressurized liquid with dissolved gases
4. high-temperature streams subject to phase change on sampling (condensable vapor, liquid that vaporizes with pressure reduction, and molten solid)

For a two-phase liquid, separation and separate analysis of two immiscible phases is usually the simplest method. The relative amounts of each phase are then used to calculate total material flows.

With a slurry, or liquid-solid stream, the major problem is stream homogeneity. Unlike gas streams, which mix fairly easily, liquid streams tend to stratify because of their differing viscosities and densities. Extreme care must be taken to ensure representative samples. This is discussed further in Sect. 4a.4.2.1.

For pressurized single or multiphase liquid streams that contain dissolved gases, it must be resolved whether or not the escaping gas needs analysis. Two sampling techniques may be used. In one method, the sample is taken at atmospheric pressure and the dissolved gases are allowed to escape; only the liquid portion of the sample is then analyzed. In the other, the sample is caught under process pressure in a suitable sampling bomb. Later the pressure is reduced, and the gases emitted are analyzed separately.

High-temperature streams may require the application of cooling methods to reduce the sample temperature to a level that is both below its boiling point and compatible with the sampling techniques used. Molten solid streams must be sampled by methods and equipment that allow for the fact that the sample will solidify on cooling.

References 1 through 7 give liquid sampling methods.

4a.4.2.1 Sampling Point Selection

The preferred sampling points for liquid streams are existing valves, either in-line or on a side stream. These valves provide a ready source from the stream and should be used when compatible with the objectives of the test program. Another point of easy access is at outflow orifices where the liquid streams flow into ponds, tanks, or other open surfaces. Open or noncontained streams may be sampled at any point compatible with accuracy requirements.

The major restriction in selecting sampling points is stream homogeneity. To ensure a well-mixed sample, sampling should be done just downstream from points of turbulence, such as elbows or pump-discharge lines. It may be necessary to have sampling valves installed at points where none exist.

Sampling method, sample size, collection frequency, and preservation method must be selected based on the goals of the test program.

In selecting sampling methods for liquids, the analytical techniques planned also must be considered. Analytical parameters for liquid slurry streams consist of four types: (1) physical characteristics, (2) inorganic species, (3) organic species, and (4) water quality parameters.

Table 4a.2.2 lists typical analytical parameters for each of the first three categories. Overlap with water quality parameters is also indicated in this table. Generally, sample size will be determined by the number of analyses to be made and the specific requirements of each technique.

Samples may be taken at regular intervals over the duration of the test and then either analyzed individually or combined to give an averaged sample. If possible, the test duration should be long enough to cover normal process variations. For some cyclic processes, it may be best to sample at each step of the operation. In cases where sample requirements are less stringent, a single sample may suffice.

4a.4.2.2 Continuous Sampling

Continuous sampling from a liquid stream will be much more representative than will grab sampling. With a continuous sample, the sample may be withdrawn periodically at a uniform rate. This can be done in increments with a smaller time interval between each unit volume fraction of the sample, thus providing a representative sample. The continuous sampling of a slurry in the most representative manner requires isokinetic sampling with the velocity of the stream equaling the velocity at which the sample enters the sample probe. This avoids deviations from actual stream composition by the exclusion of suspended solids.

During continuous sampling, it is also possible to remove solids, if desired, by filtering or centrifuging and to add the required preservatives as the sample is collected.

REFERENCES FOR SECTION 4a.4.2

1. American Society of Testing and Materials, "Water; Atmospheric Analysis," part 23, 1973 *Annual Book of ASTM Standards*.
2. American Society of Testing and Materials, *Standard Recommended Practice for Sampling Industrial Chemicals*, 1973.
3. U.S. Environmental Protection Agency, *Handbook for Monitoring Industrial Wastewater*, 1973.
4. U.S. Environmental Protection Agency, *IERL-RTP Procedures Manual, Level 1: Environmental Assessment*, 1976.
5. U.S. Environmental Protection Agency, *Tentative Procedures for Sampling and Analysis of Coal Gasification Processes*, 1975.
6. Radian Corporation, *Assessment, Selection, and Development of Procedures for Determining the Environmental Acceptability of Synthetic Fuel Plants Based on Coal*, rev., Austin, Tex., May 1977.
7. Radian Corporation, *Characterization of the Effluents from the CO₂ Acceptor Process*, Austin, Tex., 1976.

4a.4.3 SOLID STREAMS

Solids commonly found in coal conversion plants are fuels, process additives, by-products, and waste products. They can range in size from fine powder to lumps, and they can vary in consistency from dry solids to thick, nonflowing pastes. To accommodate all possible situations, a variety of sampling techniques is required. However, the analyses desired and analytical methods used must be considered for defining.

The types of analyses performed on solid samples are highly dependent on the material sampled. For solids, the nature of the analytical method rarely affects the sampling methods used or the handling and preservation methods.

Sampling methods for solids use two general techniques: grab sampling and grab-and-composite sampling. Grab sampling is used if low precision is required; grab-and-composite sampling is the more precise technique. In this technique, grab samples are collected periodically over the duration of the test, then composited to form a single sample. In most cases, the difference between the two is only a matter of degree; the sample collecting methods are identical. References 1 through 3 give specific methods: ref. 1 is ASTM method D 2083-72 for sample handling and D 2234-74 for gross sample collection; ref. 2 is ASTM method E 300-73 for sample handling and collection; and ref. 3 concerns general considerations for the collection of samples to measure trace components. Reference 4 concerns general considerations for sample collection, handling, and analysis. Although most of these methods are for coal, they are readily adaptable to other solid streams.

Solid samples are usually obtained from either of two general types of sources: unit aggregations (storage piles) or process conveyers. Samples from process conveyers represent solid materials being used continually during defined periods and under defined operating conditions. These streams, therefore, are the important ones for material balances and control-module response tests.

4a.4.3.1 Sampling Methods for Storage Facilities and Transport Containers

Solids found in coal conversion plants are usually stored in piles or in enclosed bins of relatively large circumference and depth. The selection of sampling techniques for these materials will depend on the test requirements, the sample pile form, and its accessibility. Samples of solids normally are obtained by using a shovel or scoop, a pipe borer, or an auger.

Use of a shovel or scoop is the simplest solids' sampling technique; however, it may well be inadequate. Unless there is reason to believe that the pile is homogeneous, a highly nonrepresentative sample may result. Somewhat more representative samples of materials stored in piles, silos, or bins can be obtained by using boring techniques. These techniques involve inserting a pipe into the pile from top to bottom; the sample in the pipe represents a vertical composite of the pile. This technique cannot be used, however, with wet, coarse-grained, or lump materials. Small borers can be used in sampling solids in sacks if the borers will reach the bottom of the container. The auger sampler is particularly suitable for materials that are packed too tightly for pipe or thief techniques (e.g., wet, coarse-grained, or lump materials). When the auger is withdrawn, the sample is packed in the helical grooves. If necessary to prevent sample spilling, it can be enclosed in a casing.

4a.4.3.2 Sampling Methods for Process Conveyers

The sampling of process conveyers is the preferred method for obtaining representative solid materials, because there is less segregation according to particle size, and the material obtained is

often a true sample of solids actually being used in the process. For process monitoring, it may be important to know the exact nature of the solids being used at the time of testing. Generally, the best samples from conveyers are obtained at a terminus where the exiting solid material falls vertically from the conveyer. An inert container having sharp parallel sides is passed laterally through the falling stream at a uniform rate, thus collecting a representative sample. This container should not be allowed to overflow.

The method for collection depends on which type of conveyer is used: belt, ladder-tray, screw, or duct.

Samples may be taken from belt conveyers while they are moving but preferably while they are stopped. In both cases, a shovel is used to remove a full cross-section cut (having parallel sides). The cut should be at least three times as wide as the largest piece of solid material encountered.

Ladder-tray conveyers are sampled by periodically removing a sample from one of the trays by use of a shovel or scoop.

Screw conveyers, which usually transport sludge-type materials, are enclosed systems. These must be sampled at the inlet or exit of the system by passing a sampling container laterally through the stream.

Duct conveyers are either gravity-feed systems or employ chain-drive scrapers. These conveyers can be either open top or completely enclosed. Open ducts are sampled from above, whereas closed ducts must be sampled at the exit point.

Reduction is required to make the sample manageable for analysis. The quantity of material collected in solid-stream sampling is usually much larger than that needed for analysis. Therefore, the samples must be reduced in size without affecting the distributions of components and particle sizes. Two methods generally are accepted for accomplishing this: (1) coning and quartering and (2) riffing.

In coning and quartering, the sample is shaped into a conical pile which is then sharply divided into quarters. Two opposite portions are combined and the composite is then further reduced by again coning and quartering. This is repeated until a sample of the desired size is obtained.

The riffing technique is a mechanical way of systematically subdividing the sample. When the sample is poured evenly over the top of the riffler, it is divided into two equal fractions. Further sample size reduction is accomplished by recycling one of the fractions.

It is frequently necessary to reduce the sample's particle size before sample reduction can begin. Above a certain particle size, coning and quartering a sample into smaller quantities is not a valid technique. Particle size reduction is also necessary for most riffers.

Continuous samplers for solid streams are commercially available. In most cases, they are an automated version of the falling-stream sampler, followed by an automated sample-reduction system such as a riffler (or a whistle pipe), with the excess sample returned to the solid stream.

REFERENCES FOR SECTION 4a.4.3

1. American Society for Testing and Materials, "Gaseous Fuels; Coal and Coke; Atmospheric Analysis," part 26, *1974 Annual Book of ASTM Standards*, Philadelphia, Pa.
2. American Society for Testing and Materials, "Standard Recommended Practice for Sampling Industrial Chemicals," E300-73, in *1973 Annual Book of ASTM Standards*, Philadelphia, Pa., p. 601.
3. W. E. Harris and Byron Kratochvii, "Sampling Variance in Analysis for Trace Components in Solids. Preparation of Reference Samples," *Anal. Chem.* **46**(2), 313 (1974).
4. Radian Corporation, *Environmental Characterization Plan Development for a Coal Conversion Facility*, Austin, Tex., December 1977.

4a.4.4 SAMPLE HANDLING AND PRESERVATION

After samples have been obtained from various streams in the process, they are prepared for analysis and/or storage. The bulk samples from each sampling point usually are taken to some central location equipped to perform the preservation and treatment procedures, probably a stationary or mobile laboratory facility. The handling and preservation requirements for the analytical parameters of interest in each stream should be integrated into a total sampling-preservation-analytical scheme for greatest efficiency. Figures 4a.4.3 through 4a.4.5 provide examples of integrated sample preservation for gaseous, liquid, and solid samples respectively.

The requirements of such a scheme will determine the number of individual aliquots into which the bulk sample is divided. For many of the analytical parameters of interest, preservation will allow the sample to be transported to offsite facilities for analysis. Others will require immediate onsite analysis due to instability.

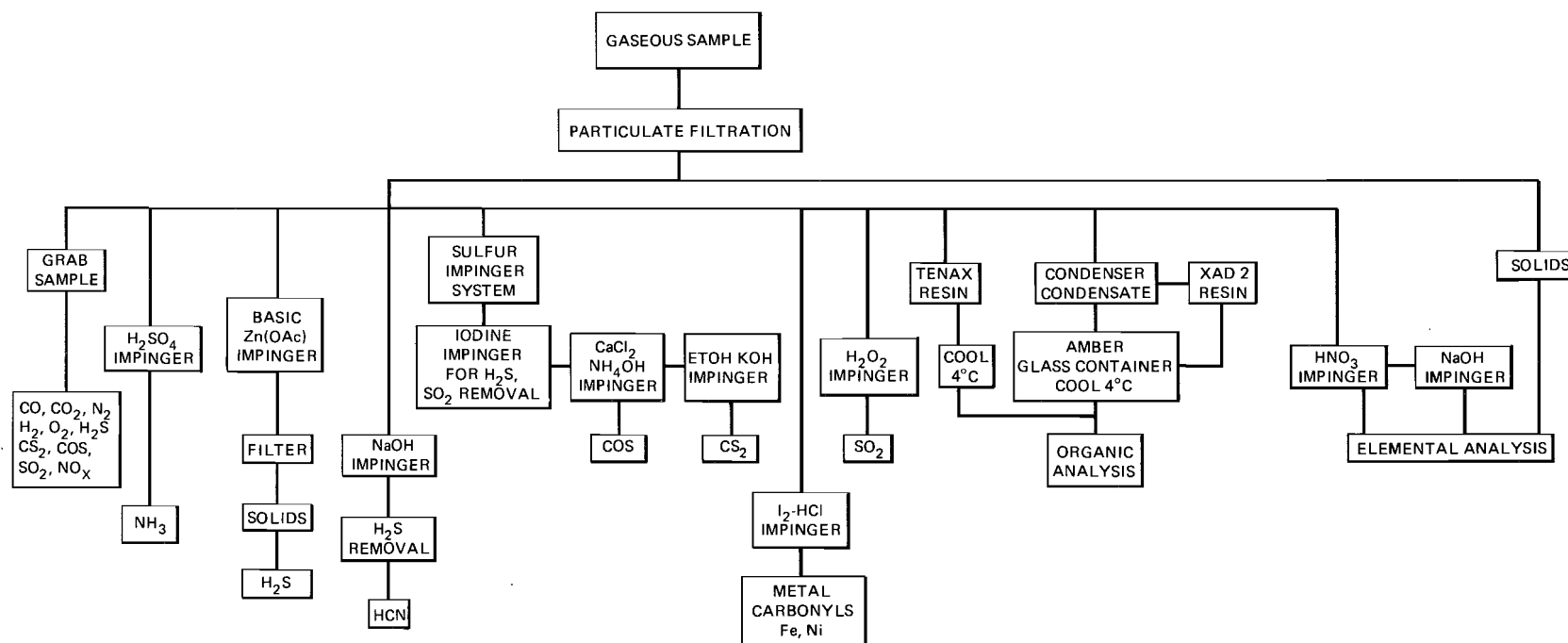


Fig. 4a.4.3. Preservation of gaseous samples. The final box denotes the substance to be measured.

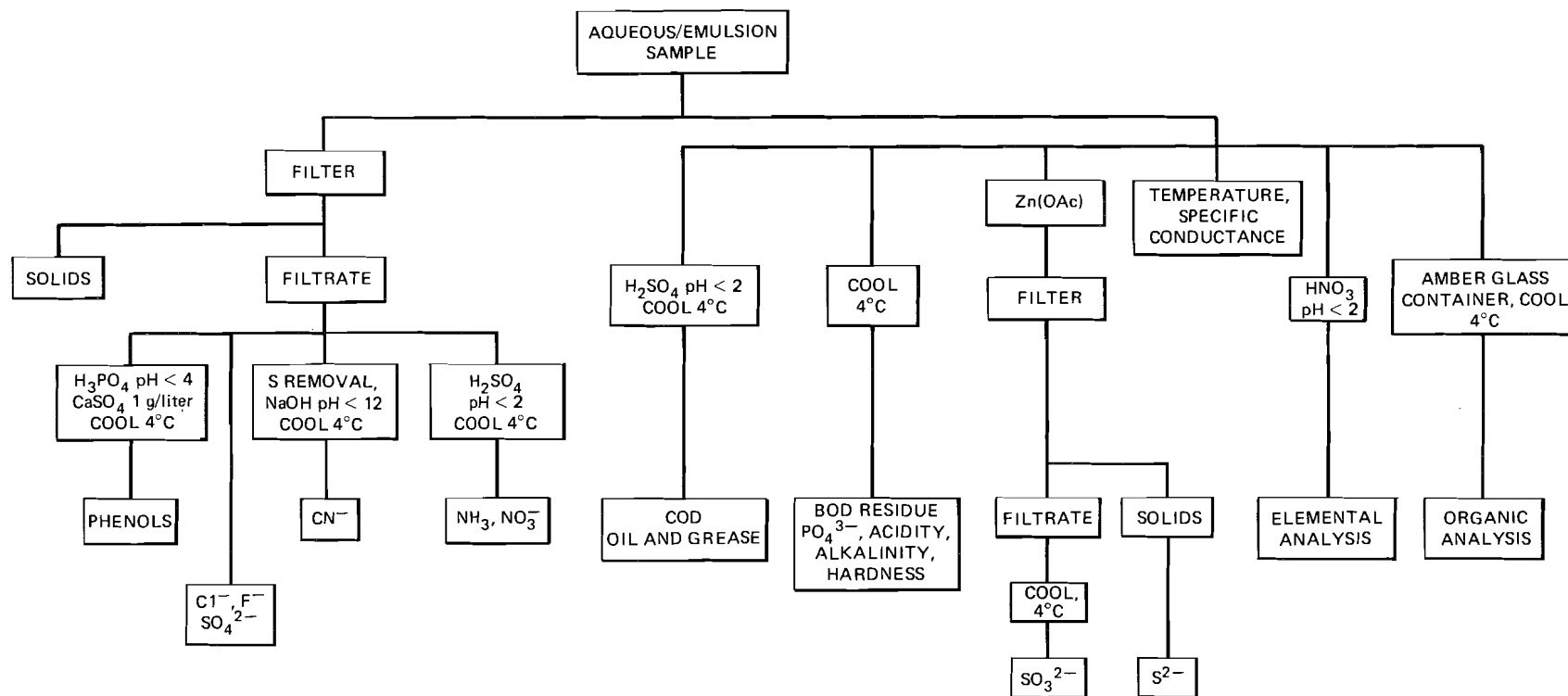


Fig. 4a.4.4. Preservation of liquid samples. In case of high solids' loadings (>0.5%), they may need to be removed onsite and retained for separate elemental organic analysis. The final box denotes the substance to be measured.

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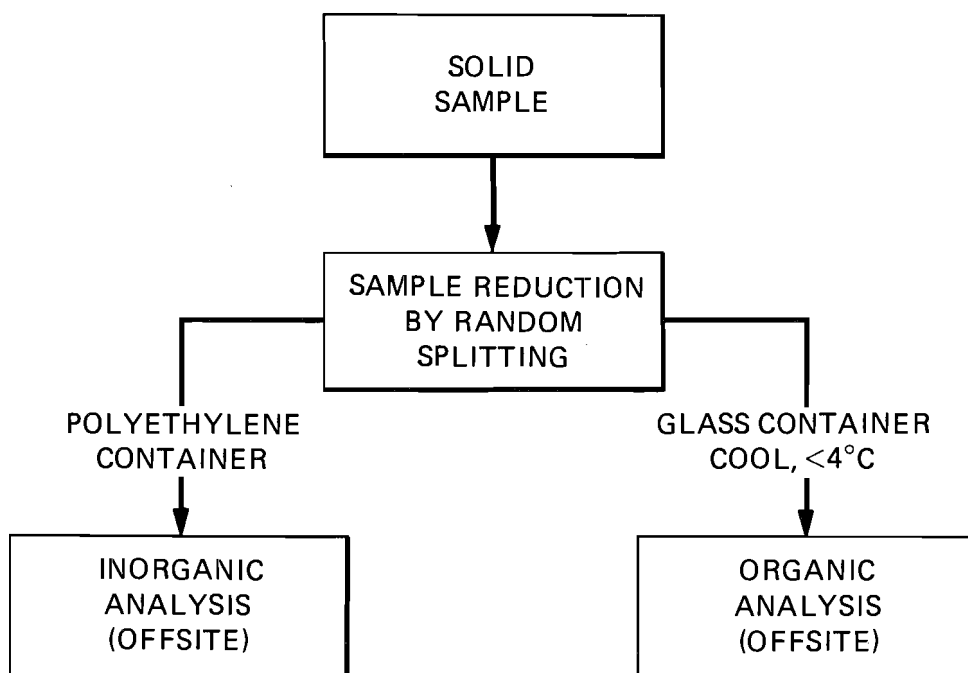


Fig. 4a.4.5. Preservation of solid samples.

4a.5 Analytical Methods

The purpose of an analytical method is to provide qualitative and/or quantitative data for the analytical parameters identified in the test plan. Following identification of the streams and analytical parameters in the process analysis step, the analytical techniques for each must be selected in conjunction with the sampling procedures. Factors affecting this selection include:

1. compatibility with sampling procedure
2. expected concentration level and required detection limits
3. presence of interfering species
4. accuracy and precision requirements
5. requirements of the established quality control program
6. time, equipment, and cost limitations

Selection and validation of methods should be the province of the analyst involved with the program. A number of alternate methodologies may be applied, depending on available facilities and personnel.

Analytical procedures should be considered in terms of the inorganic and organic analyses required in the environmental process monitoring effort. Table 4a.2.3 contains a list of species of species of probable interest in each of the three stream types. Table 4a.2.4 lists some organic species of environmental concern due to their toxic and carcinogenic natures and probable association with coal conversion processes. Table 4a.2.5 contains most of the organic species presently on the EPA effluent guidelines list.

4a.5.1 INORGANIC ANALYSIS

Inorganic species of interest in the characterization of coal conversion processes include elements, cations, and anions in liquid samples and gaseous components as given in Table 4a.2.3. Inorganic analysis generally consists of two steps: sample preparation and determination (identification and quantification).

4a.5.1.1 Preparation for Analysis

Many of the sample types, after preservation and treatment, are ready for analysis. Others, particularly solids, require preliminary treatment and preparation prior to analysis. This may include dissolution, mixing, drying, sizing, extractions, and phase separation or other procedures designed to convert the sample to a form compatible with the analysis procedure and to ensure that an aliquot representative of the total sample is analyzed.

4a.5.1.2 Identification and Quantification

Once the samples are in a form compatible with the analytical technique, the species of interest is identified and/or quantified. The extent of this determination can range from the identification of classes or groups of species to the accurate quantification of specific components.

The techniques available for inorganic identification and quantification may be considered as survey methods (semiquantitative analysis of a large number of species at low cost) and quantitative methods.

4a.5.1.2.1 Survey Methods

1. Spark source mass spectrometry
2. X-ray fluorescence

4a.5.1.2.2 Quantitative Methods

1. Neutron activation analysis
2. Atomic absorption spectrometry
3. Specific-ion electrodes
4. Ion chromatography
5. Colorimetry
6. Fluorescence
7. Titrimetry
8. Gravimetry

Gas chromatography, although applicable to inorganic analysis, is generally more useful in organic analysis.

General sources for inorganic analysis include those given in refs. 1 through 6.

REFERENCES FOR SECTION 4a.5.1

1. American Public Health Association, American Water Works Association, and Water Pollution Control Federation, *Standard Methods for the Examination of Water and Wastewater*, 14th ed., Washington, D.C., 1976.

2. American Society for Testing and Materials, "Water," part 23, *1977 Annual Book of ASTM Standards*, Philadelphia, Pa.
3. U.S. Environmental Protection Agency, *Methods for Chemical Analysis of Water and Wastes*, EPA 625-/6-74-003, 1974.
4. Radian Corporation, *Assessment, Selection, and Development of Procedures for Determining the Environmental Acceptability of Synthetic Fuel Plants Based on Coal*, rev., Austin, Tex., May 1977.
5. Maurice Pinta, *Detection and Determination of Trace Elements. Absorption Spectrophotometry, Emission Spectroscopy, and Polarography*, Miriam Bivas, trans., Ann Arbor, Mich., 1972.
6. Walter E. Ruch, *Quantitative Analysis of Gaseous Pollutants*, Interscience, Ann Arbor, Mich., 1970.

4a.5.2 ORGANIC ANALYSIS

By comparison of the species listed in Tables 4a.2.3 and 4a.2.4 with those in Table 4a.2.5, the relative complexity of the field of organic analysis as compared with inorganic analysis should be readily apparent.

4a.5.2.1 Separation

Samples from coal conversion processes that contain highly complex mixtures of organic species will require at least some degree of simplification by fractionation prior to identification and/or quantification. The examination of these fractions can then range in depth from the identification of functional groups, which will indicate the presence or absence of classes of species, to the quantification of individual species.

The separation step performs three primary functions:

1. removal of the species of interest from the sample matrix (solid, liquid, or sorbent)
2. concentration of these species in a solvent suitable for introduction into the remainder of the analytical scheme
3. simplification of the sample by fractionation into groups containing fewer individual species

Separation techniques applicable to samples from coal conversion processes include (1) extractions from solid and liquid samples, (2) liquid-liquid partitioning, (3) distillation, (4) inert gas stripping, (5) ion exchange, (6) gel permeation, and (7) column chromatography.

4a.5.2.2 Identification Techniques

Identification techniques used in organic analysis are as follows:

1. high-performance liquid chromatography
2. thin-layer or paper chromatography
3. functional group analysis
4. high-resolution mass spectrometry
5. low-resolution mass spectrometry
6. nuclear-magnetic resonance spectrometry
7. infrared spectrometry

Some of these techniques can provide semiquantitative data without extensive calibration or development; however, the accuracy and precision expected of quantitative techniques are impossible or extremely difficult to attain.

4a.5.2.3 Quantification Techniques

Three analytical techniques are primarily used for quantitative analysis of organics: (1) gas chromatography (GC), (2) gas chromatography-mass spectrometry (GC-MS), and (3) colorimetry. Gas chromatography is the most widely used technique available today for both identification and quantification of organic compounds. Gas chromatography-mass spectrometry is considered as a separate technique attesting to the unique power of this combination. Colorimetric techniques were widely used in the past but due to their limitations are currently secondary to GC and GC-MS.

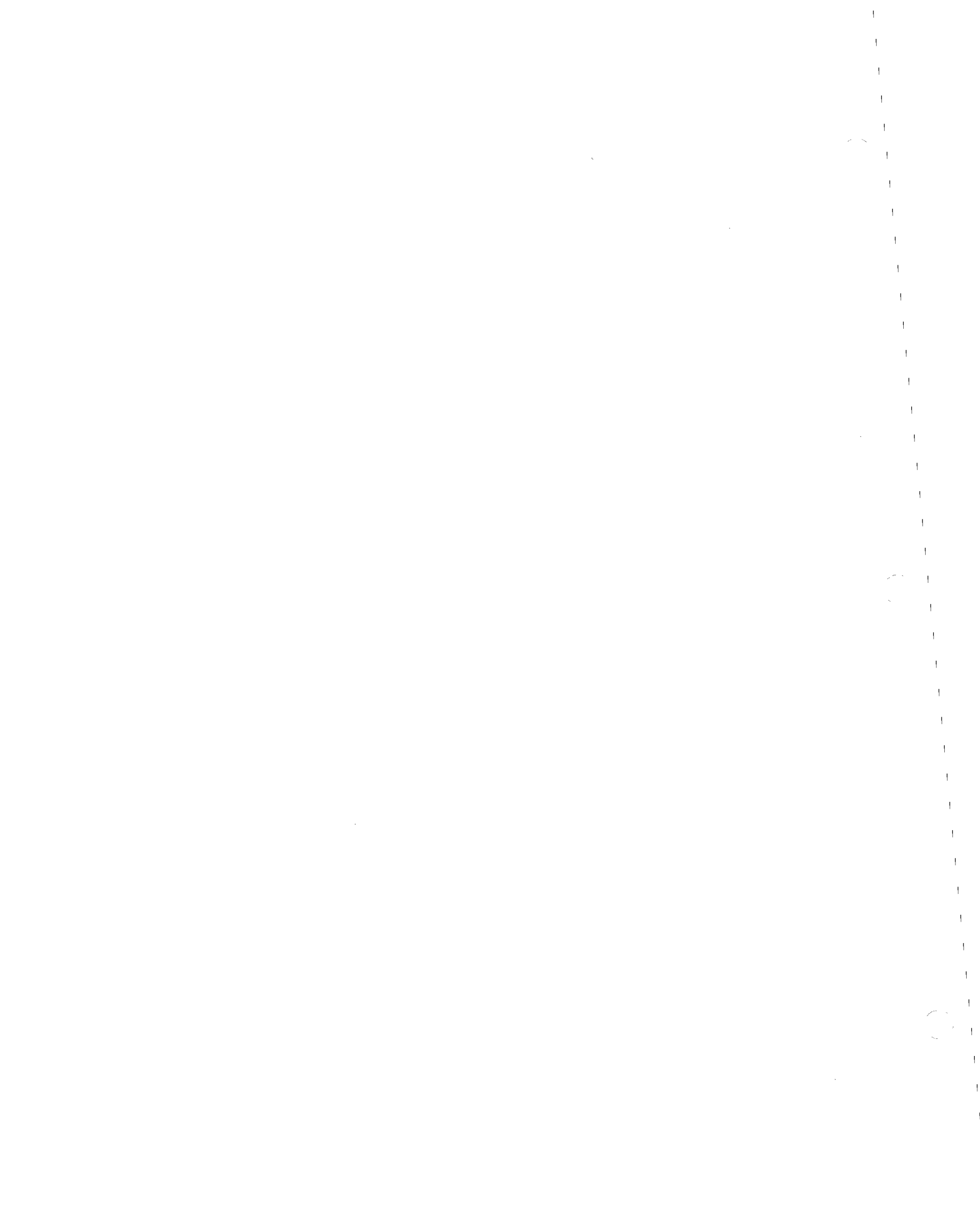
General sources that could prove useful in the analysis of organic compounds are given in refs. 1 through 5.

REFERENCES FOR SECTION 4a.5.2

1. U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, *Sampling and Analysis Procedures for Screening of Industrial Effluents for Priority Pollutants*, rev., Cincinnati, Ohio, April 1977.
2. Lawrence H. Keith, ed., *Identification and Analysis of Organic Pollutants in Water*, Ann Arbor Science Publishers, Ann Arbor, Mich., 1976.
3. William McFadden, *Techniques of Combined Gas Chromatography/Mass Spectrometry*, Wiley, New York, 1973.
4. Radian Corporation, *Assessment, Selection, and Development of Procedures for Determining the Environmental Acceptability of Synthetic Fuel Plants Based on Coal*, rev., Austin, Tex., May 1977.
5. Ronald G. Webb et al., *Current Practice in GC-MS Analysis of Organics in Water*, EPA-R2-73-277, 16020 GHP, EPA, Southeast Environmental Research Laboratory, Athens, Ga., 1973.

4a.6 Example Process Monitoring Program

An example of how the methodology described in Sects. 4a.1 through 4a.5 may be applied to a specific case is presented in this section. The CO₂ Acceptor process, being piloted by Conoco Coal Development Company in Rapid City, South Dakota, is used to illustrate components of a typical test plan as applied to a specific process and site.



4a.6.1 ENVIRONMENTAL PROCESS MONITORING SCOPE

The test plan for the CO₂ Acceptor pilot plant presented in the following sections has been designed to address the following objectives:

1. characterization of effluent streams from the pilot plant
2. generation of a data base from which the emissions and control technology for a full-scale plant can be projected
3. generation of elemental material balances to provide support for the validity of the data produced
4. characterization of sulfur species at the reactor outlets

The first objective is addressed by characterizing the solid, liquid, and gaseous discharges from the pilot plant. This includes monitoring of the liquid effluents for general water quality parameters, leaching characteristics of the solids to identify potential environmental problems from landfill disposal, and criteria stationary-source air pollutant species in the vents to the atmosphere. (See Tables 4a.2.6, 4a.6.1, and 4a.6.2.)

To address the second objective, the configurations of the pilot plant and a conceptual full-scale plant are compared; streams are identified in the pilot plant which are equivalent to (1) effluent streams from the conceptual full-scale plant and (2) input streams to control technology in the full-scale plant.

The third objective is addressed by defining three material-balance loops in the pilot-plant process: (1) regenerator flue-gas quench system, (2) gasifier product-gas quench system, and (3) regenerator-gasifier (see Fig. 4a.6.1). The inlet and outlet streams around each of these loops will be monitored with respect to major and trace elements to generate material balances around each of these process segments.

The fourth objective requires the development of sampling and analytical procedures to characterize the distribution of sulfur among several possible species—including H₂S, COS, CS₂, SO_x, and elemental sulfur—in the overhead gases as they exit the gasifier and regenerator. Special sampling procedures are required due to the extreme temperatures and high pressure of the process streams and the highly reactive nature of the possible species.

Table 4a.6.1. Sampling points and analytical parameters for CO₂ Acceptor pilot plant gaseous streams

Stream	Analytical parameters																								Trace elements ^a	
	NH ₃	CO ₂	CO	N ₂	O ₂	H ₂	HCN	H ₂ S	SO _x	NO _x	CS ₂	COS	H ₂ O	Particulates	Total hydrocarbons	S	Al	Ca	Fe	Mg	P	K	Si	Na		Ti
Coal grinding and drying vent		X	X	X	X	X			X	X			X	X	X											
Coal preheater vent downstream of venturi		X	X	X	X	X			X	X			X	X	X		X									
Coal preheater vent upstream of venturi		X	X	X	X	X			X	X			X		X		X									
Regenerator flue gas vent header									X	X				X	X											
Regenerator flue gas downstream of cyclones	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Regenerator overhead								X	X		X	X														
Quenched regenerator flue gas		X	X	X	X	X							X	X			X	X	X	X	X	X	X	X	X	X
Gases dissolved in regenerator quench water																	X									
Gasifier overhead								X	X		X	X														
Product gas downstream of external cyclone	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Quenched product gas	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Product gas dissolved in quench water	X	X	X	X	X	X	X	X	X		X	X			X		X									
Recycle flue gas																	X									
Recycle product gas																	X									
Gases stripped from gasifier quench water	X	X						X																		
Gases from laboratory chance reaction								X		X	X															
Coal transfer cyclone exit		X	X	X	X	X			X	X			X	X	X											

^aSb, As, Be, B, Cl, Cd, Cr, Cu, F, Pb, Li, Mn, Hg, Mo, Ni, Se, Tl, U, V, and Zn.

Table 4a.6.2. Sampling points and analytical parameters for CO₂ Acceptor pilot plant liquid streams

Analytical parameter	Stream							
	Regenerator quench water inlet	Regenerator quench water blowdown	Gasifier quench water inlet	Gasifier quench water blowdown	Preheater venturi		SO ₂ scrubber blowdown	Raw water
					Inlet	Outlet		
Solids				X	X	X		
pH				X				
Hardness				X				
TOC/COD ^a				X				
NH ₃				X	X	X		
Phenol				X				
Cl ⁻				X				
F ⁻				X				
SO ₄ ²⁻				X			X	
SO ₃ ²⁻				X			X	
S ²⁻				X				
NO ₃ ⁻				X				
PO ₄ ³⁻				X				
CN ⁻				X				
S	X	X	X	X				X
Al	X	X	X	X				X
Ca	X	X	X	X				X
Fe	X	X	X	X				X
Mg	X	X	X	X				X
P	X	X	X	X				X
K	X	X	X	X				X
Si	X	X	X	X				X
Na	X	X	X	X				X
Ti	X	X	X	X				X
Trace elements ^b	X	X	X	X				X
Trace organics				X				

^aTotal organic carbon/chemical oxygen demand.^bSb, As, Be, B, Cl, Cd, Cr, Cu, F, Pb, Li, Mn, Hg, Mo, Ni, Se, Tl, U, V, and Zn.

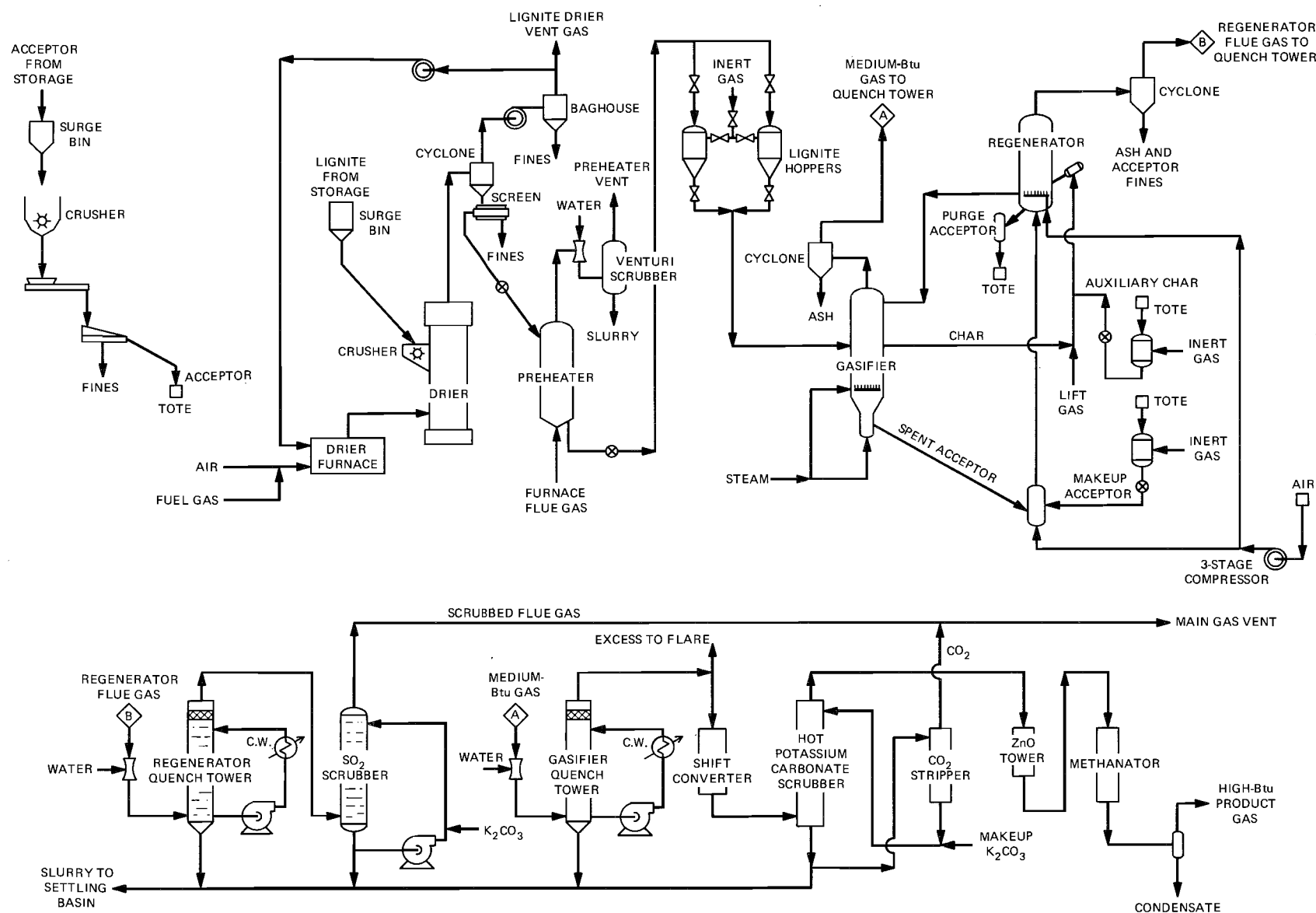


Fig. 4a.6.1. CO₂ Acceptor pilot-plant process flow diagram.

4a.6.2 PROCESS DESCRIPTION AND ANALYSIS

To develop a comprehensive pilot-plant sampling plan that characterizes the waste streams from a full-scale CO₂ Acceptor coal gasification plant, a comparison of the pilot process flow scheme and the full-scale process flow scheme is required. From this comparison a selection can be made of pilot-plant streams that will be similar to those of the full-scale plant. The monitoring data from these pilot-plant streams can be scaled to characterize the waste streams from a commercial plant.

4a.6.2.1 Pilot Plant Process Description

The CO₂ Acceptor pilot plant processes lignite or subbituminous coals in a fluidized-bed system in the presence of a regenerable CO₂ absorbent. The product is a medium-Btu gas which can be upgraded to high-Btu gas by methanation. Figure 4a.6.1 is a simplified process flow diagram of the CO₂ Acceptor pilot plant.

4a.6.2.1.1 Coal and Acceptor Pretreatment

Coal is sized so that it may be conveyed, fluidized, and reacted. In the pilot unit, coal is partially dried during the grinding process and subsequently heated to 260°C with hot flue gases from the combustion of natural gas. The gases from the preheater are scrubbed with recycled pond water before being vented to the atmosphere. The hot, dry, sized coal is then pressurized in a lock hopper with recycled product gas and transferred to the gasifier by a rotary feeder.

The "acceptor" [dolomite (CaCO₃, MgCO₃) or limestone (CaCO₃)] is ground, sized, and fed to the solids' recirculation loop between the gasifier and the acceptor regenerator. Undersized acceptor fines are disposed of as a dry solid.

In the pilot plant, "auxiliary char" is ground, preheated, and fed to the regenerator to be burned as a supplementary fuel.

4a.6.2.1.2 Gasification-Regeneration

In the fluidized gasifier, preheated coal is gasified at 815°C and 150 psig by steam and hot "calcined acceptor" (CaO) from the regenerator to produce a mixture of H₂, CO, CO₂, and CH₄. The hot acceptor provides heat for the gasification in two ways: (1) from the sensible heat of the mass (1010° to 788°C) and (2) from the exothermal heat of reaction in absorbing CO₂ to form CaCO₃ (76,200 Btu/mole). The crude product gas exits overhead to the gas purification operation.

The carbonated acceptor is removed from the bottom of the gasifier, combined with makeup dolomite, and conveyed by air to the regenerator. Char, primarily made up of unreacted coal, is removed from the gasifier fluidized bed, combined with auxiliary char from storage, and conveyed by recycle flue gas to the regenerator to serve as fuel.

In the regenerator, the carbonated acceptor is recalcined to oxide using the heat of char combusted with air to supply the necessary endothermic heat of reaction. Calcined acceptor is returned continuously to the top of the gasifier at 1010°C. The regenerator flue gas exits through a cleanup system before being vented to the atmosphere. A continuous purge of acceptor is withdrawn from the regenerator to waste storage bins prior to ultimate disposal offsite.

4a.6.2.1.3 Gas Purification

The gasifier product gas consists primarily of H₂, CO, CO₂, CH₄, 1-2% N₂, suspended ash and char particulates, and low concentrations of NH₃, H₂S, HCN, naphthalene, and other hydrocarbons.

The bulk of the particulates are removed in a cyclone. A water quench tower removes heat, NH_3 , some of the H_2S , and the remaining particulates. A portion of the gas is reheated and recycled to the gasifier, but the major portion passes through a shift converter to increase the H_2/CO ratio by means of the reaction, $\text{CO} + \text{H}_2\text{O} = \text{H}_2 + \text{CO}_2$. The gas is then scrubbed with hot K_2CO_3 to absorb CO_2 and H_2S . Residual H_2S is then removed in a zinc oxide tower. The clean medium-Btu product gas (about 350 Btu/scf) is upgraded to a high-Btu gas (820 Btu/scf) by passing it over a methanation catalyst at about 327°C where H_2 and CO react to form CH_4 and H_2O .

4a.6.2.1.4 Auxiliary Processes

The major auxiliary processes associated with the pilot plant are the cooling tower system and the water treatment facilities.

4a.6.2.1.5 Air Pollution Control

The major gaseous stream to be treated prior to release to the atmosphere is the flue gas from the regenerator. Two cyclones in series remove the bulk of ash and acceptor particulates. The flue gas then passes through a water quench tower for additional particulate removal and cooling. The quenched flue gas passes through an SO_2 absorber using a K_2CO_3 solution and is either recycled to the regenerator or vented to the atmosphere. Quench tower blowdown is routed to the waste pond.

In the pilot plant, all product gas from the methanation unit is discharged to the plant flare.

4a.6.2.1.6 Water Pollution Control

Cooling tower, boiler blowdown, and process drains also flow to the waste pump and to the settling basin. Several slurry streams are also collected and processed through the settling basin: (1) coal and acceptor storage and preparation areas, (2) gasifier and regenerator cyclones and quench towers, and (3) SO_2 scrubber. Water from the settling basin is recovered for recycling or discharged to the city sewer. The settling basin solids are periodically dredged and sent to the landfill.

4a.6.2.1.7 Solid Waste Pollution Control

The rejected fines from the acceptor grinding process are transported directly by truck to the landfill. Other solid wastes can be discharged directly to the landfill also, but, for convenience, they are generally slurried with water and processed through the settling basin as described above.

4a.6.2.2 Comparison of Pilot-Plant and Full-Scale-Plant Process Flow Schemes

A similar review of conceptual plans for a full-scale CO_2 Acceptor plant would now have to be performed to identify differences between pilot-plant and full-scale-plant process flow schemes. Conceptual plans for a full-scale CO_2 Acceptor plant flow scheme differ from the pilot-plant flow scheme in the following areas:

1. The coal drying area uses flue gases from coal-fired furnaces and the regenerator instead of natural-gas-fired furnace flue gases.
2. Off-gases from the coal preheater are used for drying in the coal drier instead of being water-scrubbed and vented.
3. Heat and power are recovered from the regenerator flue gas instead of being quenched by direct contact with water.

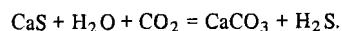
4. Flue gases off the coal drying and grinding area are scrubbed with limestone slurry to remove SO₂ before being vented to the atmosphere.
5. A water recycle system and evaporation pond are used to achieve zero wastewater discharge.
6. A number of additional auxiliary process units are used.

A comparison of the waste streams from the pilot plant and the full-scale plant is made in Table 4a.6.3. The differences in waste streams are due to the different process schemes used in the plants. The major objective of the test plan is to selectively analyze the pilot-plant waste streams and process streams that will yield data on the waste streams of the full-scale plant.

Table 4a.6.3. Comparison of CO₂ Acceptor pilot-plant and full-scale-plant waste streams

Pilot plant	Full-scale plant
Fugitive dust from lignite and dolomite storage and receiving areas	Fugitive dust from lignite and dolomite storage and receiving areas
Fugitive dust from dolomite grinding mill	Fugitive dust from dolomite grinding mill
Lignite drying and grinding mill vent gas	Lignite drying and grinding mill vent gas to SO ₂ scrubber
Lignite preheater scrubber vent gas	Lignite preheater vent gas to furnace
Regenerator flue gas vent	Regenerator flue gas to lignite drying
Flare	Flare
No sulfur plant	Sulfur-plant tail gas
No ammonia recovery	Fugitive emissions from NH ₃ purification and storage
Drains from receiving and storage areas	Drains from receiving and storage areas
Process drains (waste sump)	Process drains
Cooling tower blowdown (waste sump)	Cooling tower blowdown
Gasifier quench tower blowdown	Gasifier quench tower blowdown to sour water stripper
SO ₂ scrubber blowdown	Acid gas scrubber blowdown
Flare condensate	Flare condensate
Regenerator quench tower blowdown	Dry methods of power and heat recovery
Lignite grinding fines slurry	Lignite grinding fines to lignite furnaces
Lignite preheater fines slurry	Preheater off-gas and dust to lignite furnace
No sulfur plant	Sulfur plant tail gas scrubbing blowdown
Boiler blowdown (waste sump)	Boiler feedwater system blowdown
No limestone scrubber	Limestone scrubber blowdown
Regenerator cyclone ash	Chance reaction slurry ^a
Dolomite fines	Dolomite fines (used to make limestone slurry)
Purged acceptor	Chance reaction slurry ^a
Gasifier cyclone ash and char	Gasifier cyclone ash and char to regenerator
Flue gases from natural-gas-fired boilers and furnaces	Ashes and flue gases from lignite-fired furnaces and boiler (furnace flue gases are scrubbed with limestone slurry)
Solids from waste pond	Solids from evaporation pond

^aPurged acceptor and regenerator cyclone ash should contain a large amount of calcium sulfide (CaS). In a full-scale plant, this will be slurried with water and subjected to a CO₂ gas stream to produce CaCO₃ and H₂S via the chance reaction:



The H₂S will be routed to sulfur recovery, whereas the CaCO₃ may be returned to the process or sent to the landfill.



4a.6.3 TEST PLAN

In the following subsections, a test plan is developed to achieve the environmental process monitoring objectives as described in Sect. 4a.6.1. This involves selection of streams and parameters for analysis, selection of sampling and analytical techniques for the parameter in each stream, and designation of a sampling schedule.

4a.6.3.1 Selection of Streams and Parameters for Analysis

The pilot plant streams to be sampled and the parameters to be analyzed in each stream must be developed in relation to the overall objectives of the sampling effort and the projected design of a full-scale gasification facility. To meet the general objectives of the CO₂ Acceptor sampling and analysis program, four specific goals have been defined as the basis for construction of the comprehensive sampling plan:

1. characterization of the effluent streams from the pilot plant
2. characterization of process streams that are projected inputs to effluent control systems or recycle gas streams in a full-scale plant
3. generation of material balances around selected portions of the pilot plant to support the data produced in the other segments of the project and to determine the fate of the various elemental species in the system
4. characterization of the distribution of sulfur among the possible molecular species in the regenerator and gasifier overhead gases

A tabular summary of the streams to be sampled to meet these project objectives is presented in Table 4a.6.4.

4a.6.3.1.1 Pilot-Plant Effluents

In this section, a discussion of the pilot-plant effluent streams and parameters selected for sampling is presented.

Atmospheric emissions

The purpose of this objective of the sampling effort is to determine the concentration levels of chemical species that are currently under emission regulation. To accomplish this, the pilot-plant vents should be sampled and analyzed for (1) oxides of sulfur, (2) oxides of nitrogen, (3) particulates, and (4) total hydrocarbons.

Selection of pilot-plant emission sources for sampling was limited to those vents where effluents would contain observable levels of most of the above four pollutants. Of five existing atmospheric emissions, the first three were selected for sampling: (1) coal grinding and drying vent, (2) coal preheater venturi vent, (3) regenerator flue gas vent header, (4) fugitive dust from storage areas, and (5) fugitive dust from limestone grinding. Fugitive emissions from the storage and limestone grinding areas will not be monitored due to the difficulty in obtaining representative samples and the fact that only particulate emissions are involved.

The coal grinding and drying vent and the coal preheater venturi vent gases are expected to contain all the species of interest. Each of the processes vented involves heating of the coal, which is expected to evolve hydrocarbon, sulfur, and nitrogen species; hot-gas flow and solids movement will generate particulate matter which can escape through the vents.

Table 4a.6.4. Pilot-plant process streams to be sampled to achieve project goals

Stream	Pilot-plant effluent studies	Stream characterization for scale-up	Material balance	Sulfur species
Lignite grinding and drying vent	X	X		
Preheater vent after venturi	X			
Preheater vent before venturi		X		
Vent header	X			
Gasifier quench water		X		
Regenerator flue gas downstream of cyclones		X	X	
Lignite preheater fines		X		
Lignite grinding fines		X		
Purged acceptor		X	X	
Gasifier cyclone ash		X	X	
Settling pond solids				
GQW solids		X	X	
Limestone fines		X		
Regenerator ash		X	X	
Product gas after external cyclone		X	X	
Product gas after quench		X	X	
Regenerator flue gas after quench			X	
Water into regenerator quench			X	
Water out of regenerator quench			X	
Dissolved flue gases in quench water			X	
Water into gasifier quench			X	
Water out of gasifier quench	X		X	
Dissolved gases in GQW		X	X	
Recycle flue gas			X	
Recycle product gas			X	
Makeup char			X	
Dry lignite			X	
Sized acceptor			X	
Regenerator flue gas at reactor nozzle				X
Product gas at reactor nozzle				X

The regenerator flue gas vent header effluent is a mixture of gases from several sources within the process. The two major sources are the flue gas stream after SO₂ scrubbing and the hot K₂CO₃ stripper off-gas. Hydrocarbons are not expected to be a major component in this vent gas.

Effluent water quality characterization

Monitoring the water effluent from the CO₂ Acceptor pilot plant requires a three-step approach:

1. generation of substantiated water quality data for a wide range of species in all effluent water streams
2. identification of those parameters in each stream whose levels are high enough to pose potential water quality problems at the full-scale facility
3. continued monitoring of these selected parameters

The pilot-plant wastewater streams will be analyzed for 23 parameters:

Dissolved solids	Chloride
Suspended solids	Fluoride
Total solids	Sulfite
Volatile dissolved solids	Sulfate
Volatile suspended solids	Sulfide
Total volatile solids	Nitrate
pH	Phosphate
Hardness	Cyanide
Specific conductance	Thiocyanate
Chemical oxygen demand	Ammonia
Total organic carbon	Phenol
Carbonate alkalinity	

Elemental analyses will also be performed on the pilot-plant wastewater streams. (Table 4a.6.2 lists the specific elements tested.)

A comparison of water quality parameters for the process streams of the CO₂ Acceptor with similar process streams from other gasification facilities would be in order. However, extensive comparable data are not available. Other alternatives are comparison of the process streams with (1) drinking water quality regulations; (2) recommendations for agricultural industry (for irrigation, livestock consumption), aquatic life, and wildlife; and (3) surface waters that have been used for industrial water supplies. These comparisons will indicate any potential water quality problems.

4a.6.3.1.2 Process Streams Related to Scale-Up Effluent Projections

A second objective is to characterize various process streams to provide data to scale effluents and control technology to a full-scale gasification facility. In designing such a plant, planners have a need for stream composition data to assess process control equipment, process stream contaminant removal, process effluent control methods, and other design variables.

A description of the pilot-plant process streams that will be sampled to meet this objective of the characterization effort follows.

Coal grinding and drying vent gas

In a full-scale process, this stream will be sent to an SO₂ scrubbing unit and then vented to the atmosphere. Information is needed on the gas composition and particulate loading to aid in scrubber design and to determine if additional treatment of this material will be necessary before venting to the atmosphere. The present vent stack will be sampled at a point of representative flow before the gas reaches the exit port, and the following species will be quantified:

CO ₂	H ₂ O
CO	SO _x
N ₂	NO _x
O ₂	Particulates
H ₂	Total hydrocarbons

Coal grinding fines

These solids arise from the Sweco screening of ground coal and are currently disposed of; however, in a scaled-up process, they will be used to fire a coal furnace. Samples of this stream will be taken from tote bins before dumping and analyzed for the following:

Proximate analysis	N
H ₂ O	O
C	S
H	

Preheater vent gas

In the pilot plant, this stream is passed through a venturi scrubber before being vented to the atmosphere; however, in a large-scale process, this gas will be combusted in a furnace without prior scrubbing. Consequently, this stream will be sampled in the vent line before it reaches the venturi scrubber. To characterize this vent gas as a furnace fuel and to make emission predictions, the following parameters will be examined:

CO ₂	SO _x
CO	NO _x
N ₂	Total sulfur
O ₂	Total hydrocarbons
H ₂	

Coal preheater fines

These fines are currently sluiced to the waste pond from the venturi scrubber and vented to the atmosphere through the venturi vent, but, in future plants, they will be used as a furnace fuel. Since these solids are merely coal dust, no analytical data will be collected for this stream; however, the particulate mass flow measured in the venturi vent and the solids collected will be measured and combined to give a total particulate flow rate.

Product gas downstream of external cyclone

Analytical data from this stream will provide the basis for design of the product-gas quench system projected in a full-scale gasification facility. Sampling of the high-temperature (~232°C) and high-pressure (~150 psig) gas below the cyclone was selected because the stream at this point would be most representative of the gas emanating from a full-scale gasifier unit, which is also projected to have an external cyclone, prior to entering any other process units. Comprehensive stream monitoring will consist of analyzing for the following species:

NH ₃	H ₂ O	CS ₂
CO ₂	HCN	Particulate loading
CO	H ₂ S	Trace elements ^a
N ₂	SO _x	Total hydrocarbons
O ₂	NO _x	Total sulfur
H ₂	COS	

^aTrace elements are defined in this document as Sb, As, Be, B, Cl, Cd, Cr, Cu, F, Pb, Li, Mn, Hg, Mo, Ni, Se, Tl, U, V, and Zn.

Gasifier external cyclone ash and char

In the pilot plant, this material is disposed of as solid waste in the settling pond. In a production facility, this solid effluent from the gasifier will be fed to the regenerator as fuel. Characterization of these solids by monitoring the following parameters will supply data as to the nature of one of the inputs to the regenerator:

Proximate analysis	S	K
H ₂ O	Al	Si
C	Ca	Na
H	Fe	Ti
N	Mg	Trace elements
O	P	

Product gas downstream of quench tower

Complete monitoring of the product gas at this point is critical to the design of a full-scale plant. From the quench tower the gas will be further processed to remove unwanted compounds (e.g., NH₃, H₂S, CO₂) before being recycled or methanated. The necessity and design of such equipment will be based on the nature of the gas stream to be processed as defined by the following parameters:

NH ₃	H ₂ O	COS
CO ₂	H ₂ S	Particulates
CO	HCN	Trace elements
N ₂	SO _x	Total hydrocarbons
O ₂	NO _x	Total sulfur
H ₂	CS ₂	

Gasifier quench water blowdown

Currently this effluent is depressurized from ~150 psig and sent to the waste pond without treatment. However, in a full-scale gasifier system, the product quench water blowdown will be sent first to a sour water stripper. Characterization of the present effluent is needed to provide data for the design of the stripper. The sample will be caught before depressurization so that dissolved gases can be quantified and analyzed, because the depressurization off-gases will possibly constitute another process stream in the scale-up design. Laboratory-scale stripping experiments are planned for this sample, as well as these chemical analyses:

Solids	Sulfate	Fe
pH	Sulfite	Mg
Hardness	Sulfide	P
Total organic carbon	Nitrate	K
Chemical oxygen demand	Phosphate	Si
NH ₃	Cyanide	Na
Phenol	S	Ti
Chloride	Al	Trace elements
Fluoride	Ca	Trace organics

Gases dissolved in gasifier quench tower blowdown

These gases will present a potential disposal problem when the blowdown water is depressurized from its ~150-psig process pressure. Analysis of the off-gases resulting from pressure letdown will provide guidance for handling this stream. Monitoring of these gases will consist of analyzing for the following species:

NH ₃	HCN
CO ₂	H ₂ S
CO	SO _x
N ₂	CS ₂
O ₂	COS
H ₂	Total hydrocarbons

Solids from gasifier quench tower blowdown

In the pilot plant, this stream is allowed to settle in the waste pond and is then disposed of as solid waste. In a commercial facility, similar treatment is expected; therefore, these solids will be treated as potential landfill materials. Leaching studies will be done, in addition to these analyses:

Percentage ash	Mg
C	Fe
H	P
O	K
N	Si
S	Na
Al	Ti
Ca	Trace elements

Purged acceptor

This material is also a solid effluent in the current pilot plant and the projected full-scale plant. Leaching studies and the following chemical analyses will be performed:

Percentage ash	Fe
H ₂ O	Mg
C	P
H	K
O	Si
N	Na
S	Ti
Al	Trace elements
Ca	

Regenerator flue gas downstream of cyclones

Currently, this stream is sent to a quench tower and hot K₂CO₃ absorber. However, in a full-scale unit, the hot flue gas emerging from the cyclones will not be quenched, but will be fed to a CO boiler and heat and power recovery equipment, followed by further processing for use as a recycle process gas. A complete analysis of this stream is important to the design of the heat

recovery equipment and for the selection of additional process uses. Samples of this gas stream will be taken under high-temperature ($\sim 413^{\circ}\text{C}$) and high-pressure (~ 150 psig) conditions and analyzed for the following:

NH_3	SO_x
CO_2	NO_x
CO	CS_2
N_2	COS
O_2	Particulates
H_2	Trace elements
H_2O	Total hydrocarbons
HCN	Total sulfur
H_2S	

Ash from regenerator external cyclones

In the pilot plant, this effluent is disposed of in the settling pond as solid waste. In a full-scale plant, however, due to the effluent's high sulfur content (as CaS), it will be slurried to a chance reactor to remove sulfur before being sent to the landfill. The CaS ash is removed from the flue gas in two cyclones.

Due to the design of the regenerator, bed material is periodically entrained in the regenerator flue gas stream and collected in the first cyclone. This is not expected to occur in a full-scale plant, which will have different regenerator design parameters. A rough separation of the bed material will be accomplished by sieving the solids collected in the first cyclone at 100 mesh. The material below 100 mesh from the first cyclone and all the material from the second cyclone will be treated as separate samples in the analyses listed below:

Percentage ash	Fe
H_2O	Mg
C	P
H	K
O	Si
N	Na
S	Ti
Al	Trace elements
Ca	Carbonate

Additionally, the ash from both cyclones, with regenerator bed material removed by sieving, will be combined in proportion to their respective flow rates, and the resulting composite will be used in leaching studies and in laboratory experiments to test the effectiveness of the chance reaction.

4a.6.3.1.3 Material Balances

Material balances of elemental species in the CO_2 Acceptor will validate the data produced in the preceding sections and give insight into the distribution and destination of the species throughout the process. Since many materials in the pilot-plant process have long residence times within a given process unit, a material balance encompassing the entire process is not technically feasible. Instead, it has been decided to segment the process into a series of three well-defined

process module balance loops such that each can be addressed separately to simplify the tasks of sampling and analysis and greatly improve the reliability and accuracy of the data generated. To characterize the CO₂ Acceptor pilot plant, three balance sections have been selected for monitoring:

1. regenerator flue gas quench system
2. gasifier product gas quench system
3. gasifier-regenerator

Inflow and outflow streams for each balance loop have been identified and are shown in the analytical block diagrams in Fig. 4a.6.2.

Only elemental species will be considered for analyses during the material balance efforts. Since the distribution of sulfur species has received much attention in the CO₂ Acceptor process, total

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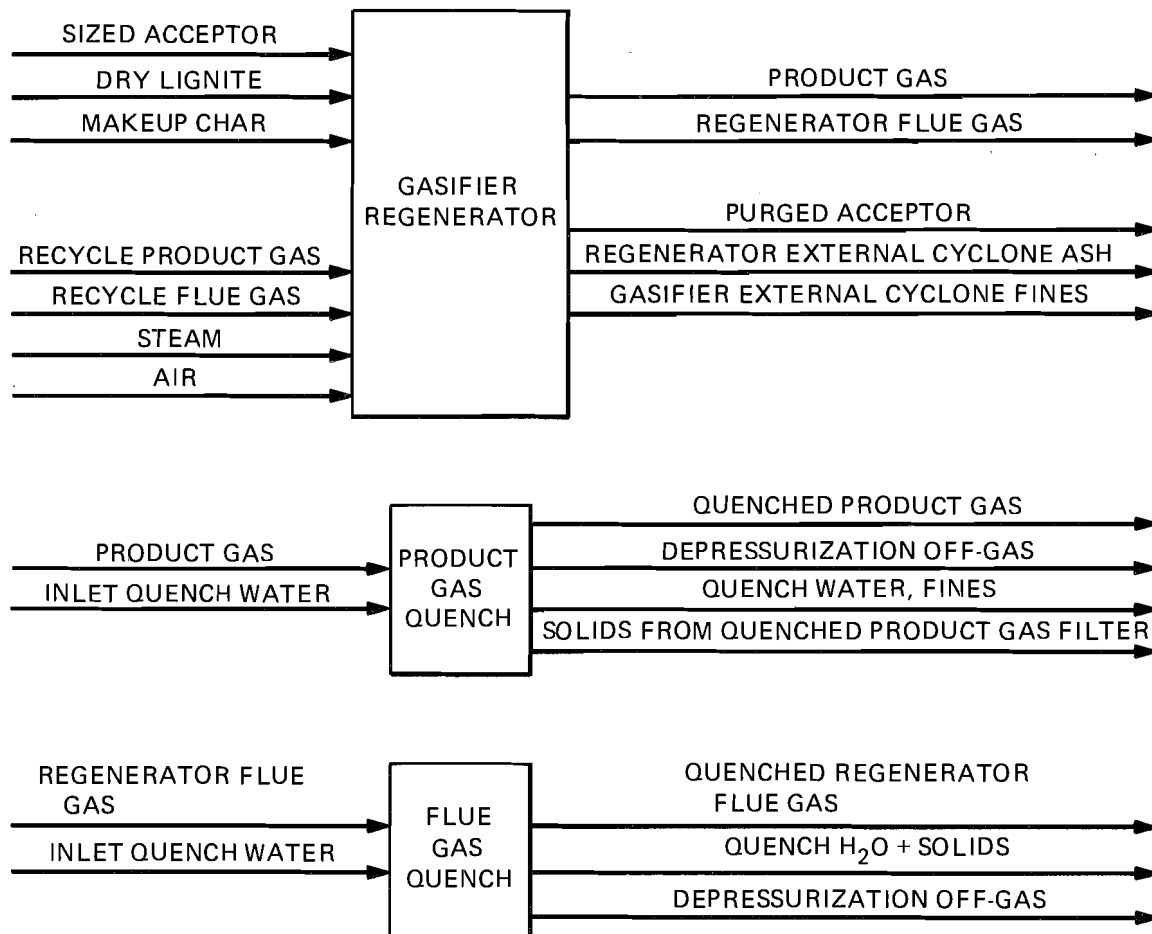


Fig. 4a.6.2. Plant analytical block diagram for material balances.

sulfur balances around each balance loop will receive high priority. In addition to sulfur, a variety of elements encompassing a range of volatiles will be examined. The elemental species that will be considered in the material balance work are:

S	Cr	P
Al	F	K
Sb	Fe	Se
As	Pb	Na
Be	Li	Ti
B	Mg	Tl
Cd	Hg	U
Ca	Mn	V
Cl	Mo	Zn
Cu	Ni	

4a.6.3.1.4 Sulfur Species

The fourth objective is to determine the distribution of sulfur species in the regenerator and gasifier overhead gases. The expected species are S_2 - $S_8(g)$, COS, CS_2 , H_2S , $CaSO_3(s)$, SO_2 , $CaSO_4(s)$, and $CaS(s)$. The problem is to quench the species from off-gas conditions (1010°C and 148 psig for the regenerator; 827°C and 150 psig for the gasifier) to conditions at which the material can be handled and analyzed without disturbing the sulfur distribution.

Currently, there is no way to absolutely determine sulfur distribution at off-gas conditions. This arises from (1) not knowing if the system is at thermodynamic equilibrium, and (2) the lack of instrumentation that can operate at stream temperatures. However, sulfur distribution can be determined if the rates of reaching equilibrium are sufficiently fast to allow equilibrium to exist in the gas stream and, concomitantly, so fast that it cannot be "frozen" at flue gas distribution. In this case, the distribution of sulfur species at process conditions would be estimated by extrapolating from the conditions existing in the sampling apparatus.

By quenching the gas stream at different inert gas dilutions and temperatures while observing the change in species distribution, an approximation can be made of the actual distribution in the stream. There are four possible results of such an experiment.

Case I

There is no change in distribution over the whole range of accessible quench rates. This will indicate either of two possibilities:

1. The equilibrium is established more rapidly than the reactions can be quenched, indicating that the gas stream is probably at thermodynamic equilibrium.
2. The slowest accessible quench rate is adequate to "freeze" the reaction at off-gas distribution, indicating that equilibrium is achieved very slowly and that thermodynamic equilibrium probably does not exist in the stream.

Case II

Distributional changes are seen only at the fastest quench rates. This would point to rapid attainment of equilibrium and the high probability of equilibrium in the off-gas. By extrapolation, it may be possible to estimate the stream distribution of sulfur species.

Case III

Distributional changes are observed only under the slowest quench rate conditions. This would indicate that the faster quench rates are actually freezing stack gas distribution and that achievement of equilibrium is relatively slow. The off-gas may or may not be at equilibrium, but the actual distribution is being observed at the faster quench rates.

Case IV

Changes in species distribution are observed over the entire range of observable quench rates. Such a result would indicate that the flue gas is at thermodynamic equilibrium, and, therefore, it should be possible to predict a quench rate to obtain stream condition distribution and/or extrapolate to that distribution.

Thus, a two-phase approach is required. The first phase, bomb sampling with dilution quenching, will attempt to answer the following questions:

1. Is the off-gas at thermodynamic equilibrium with regard to the distribution of sulfur species?
2. Can the distribution of sulfur species be "frozen" at stream concentration?
3. If the distribution of sulfur compounds cannot be frozen at stream conditions, can the concentration values at stream conditions be obtained by extrapolation?

The second phase, sampling of a continuous process gas flow with variation in retention time, will be directed toward determining the actual sulfur species distributions.

4a.6.3.1.5 Organic Characterizations

An analysis for organic species will be made on the following pilot-plant streams:

1. gasifier quench water
2. solids entrained in the gasifier quench water
3. regenerator cyclone ash
4. purged acceptor

Each sample will be extracted with selected solvents, including methanol, pentane, and diethyl ether. The organic extracts will be dried and concentrated with a Kederna-Danish concentrator. The organic concentrates will then be analyzed by GC-MS. Polar and nonpolar chromatographic columns will be used to analyze the selected samples.

Four additional areas will be under study from the viewpoint of organic characterization. The areas include:

1. monitoring of aqueous leachates
2. analysis of solids entrained in the gasifier quench water for minor polynuclear aromatic compounds

3. monitoring of vents and product gas streams if significant nonmethane hydrocarbons are found by flame ionization detector analysis for total hydrocarbons
4. additional preservation studies in the areas of liquid extraction and reverse osmosis

The proposed areas of study are important to fully characterize various waste and product streams.

4a.6.3.1.6 Summary

Each of the preceding sections has described the streams to be sampled and the analytical parameters for each stream in relation to the monitoring objectives. Several streams have been selected for sampling for more than one task, and duplicate analytical requirements are not uncommon. To clearly define all the streams that will be sampled and the analytical parameters for each stream, sampling and analytical requirements should be summarized in a stream-analytical parameter matrix. Stream-analytical parameters matrixes for the environmental process monitoring of the CO₂ Acceptor pilot plant are given in Tables 4a.2.6, 4a.6.1, and 4a.6.2.

4a.6.3.2 Sampling and Analytical Techniques

4a.6.3.2.1 Solids

Solid samples will be collected daily by obtaining splits of solid samples collected by plant personnel. After the initial drying and combining of fractions over the sampling period, the composite will be reduced in particle size by systematic crushing and mixing in a porcelain jar ball mill to allow passage through a No. 200 (75- μ m) sieve. The resulting fraction will be reduced in size by coning and quartering or riffing. The prepared solids will then be stored in a desiccator under vacuum prior to analysis. The analytical scheme for solid samples is presented in Fig. 4a.6.3.

4a.6.3.2.2 Liquids

Streams will be sampled at 2-hr intervals over a 10-hr period. Standard EPA preservation techniques for aqueous samples will be used on splits of the 2-hr samples. A composite for each day will be formed by combination of the individually treated samples to provide the required sample quantities. Figure 4a.6.4 gives the analytical scheme for aqueous samples.

Quench-water samples will be collected in Teflon-lined stainless steel containers. The sample will fill the container under pressure and the resulting sample will be returned to the laboratory. The amount of dissolved gases will be measured by volume displacement. An additional sample will be collected in which the dissolved gases will be sorbed in a microimpinger solution. Analyses of the sample and impinger solution will determine total ammonia and sulfide concentrations. The gasifier quench-water sample will be steam-stripped to determine the removable ammonia and sulfide in order to provide data for design of scale-up treatment facilities.

Samples of four treatment chemicals currently in use at the pilot plant will be scanned by ion chromatography to determine if the following species contribute significantly to process streams:

chloride	nitrate
fluoride	phosphate
sulfite	cyanide
sulfate	

The concentrations of ammonia and phenol in the process stream will also be examined.

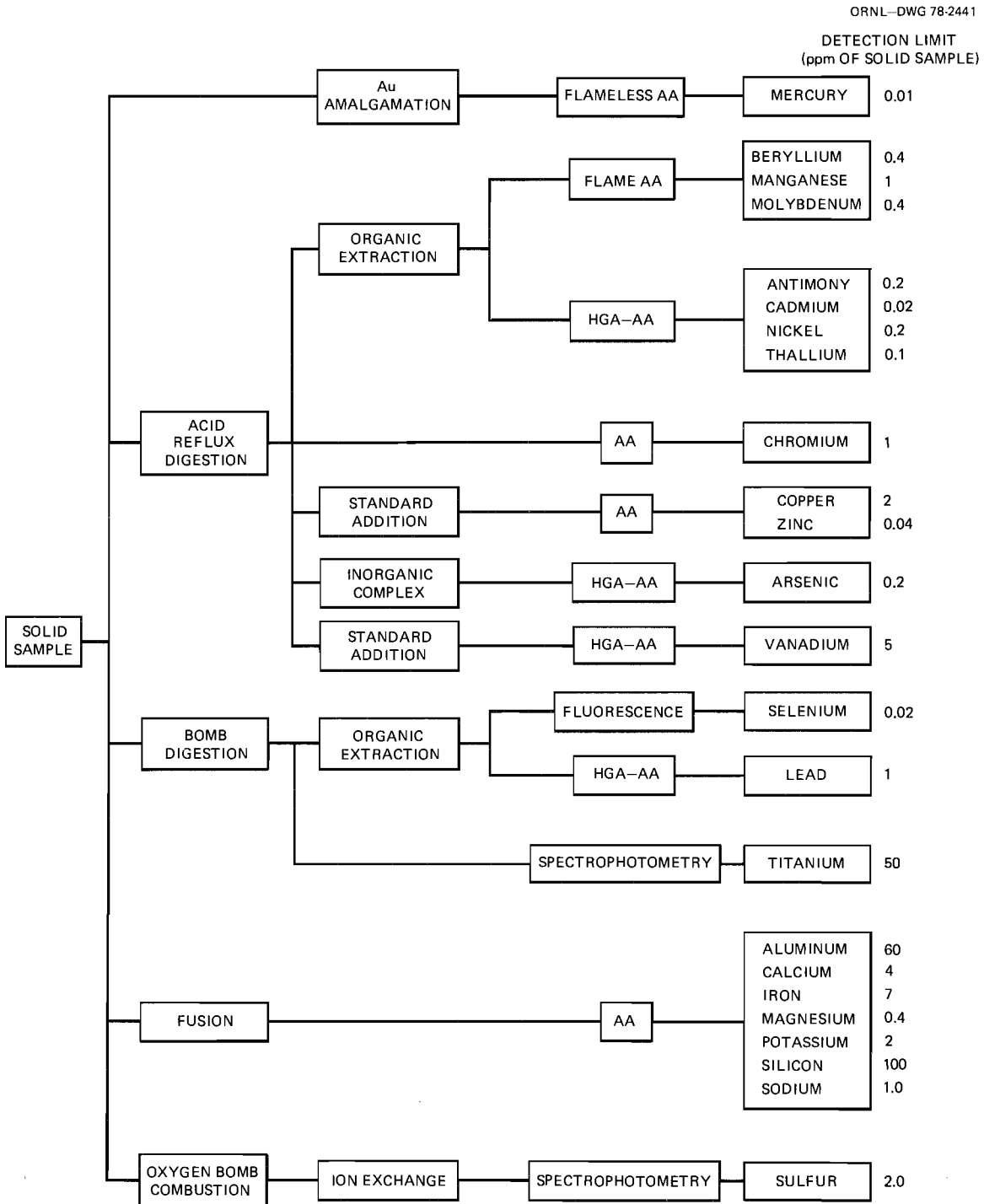


Fig. 4a.6.3. Analytical scheme with detection limits for solid samples.

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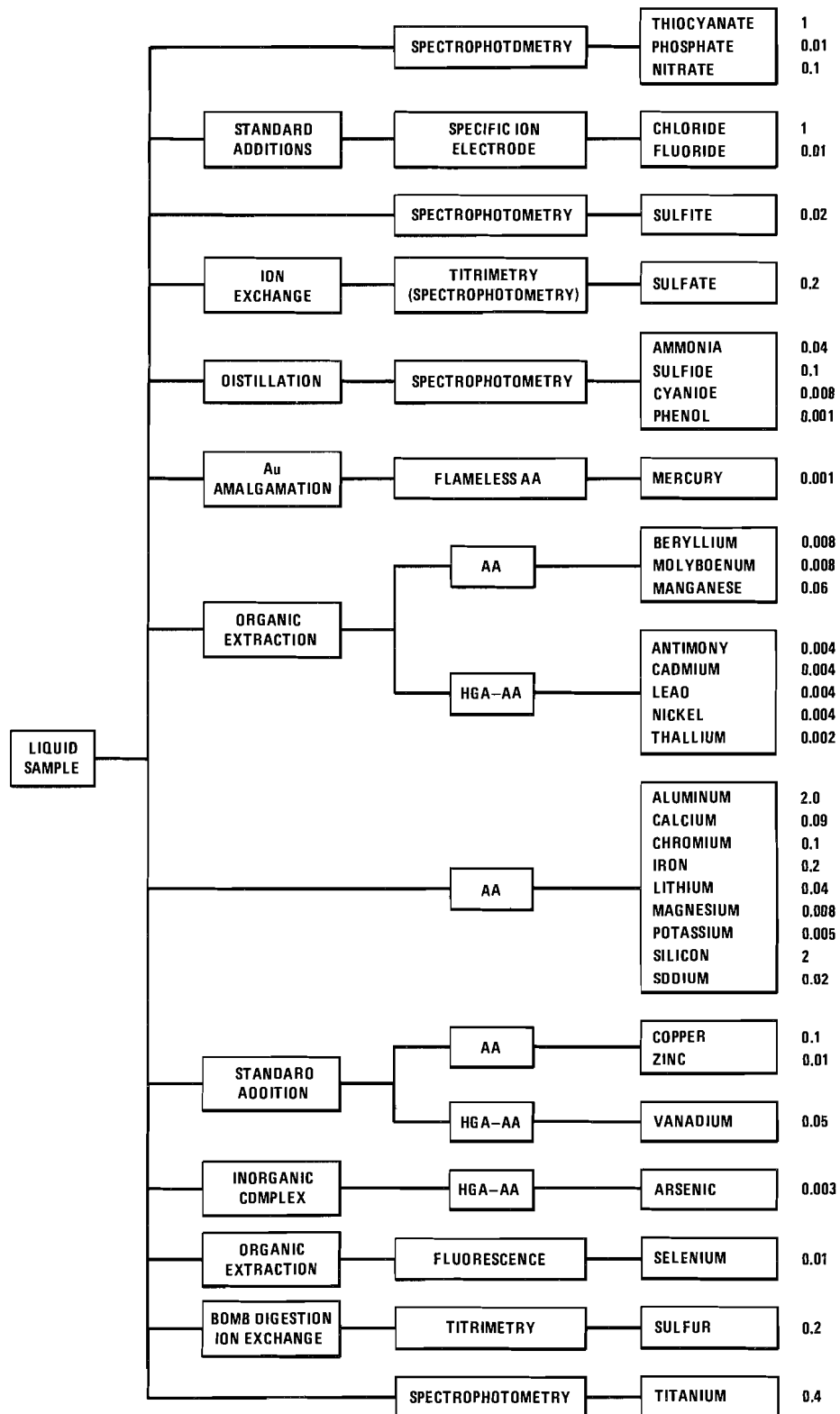
DETECTION LIMIT
(ppm OF SOLID SAMPLE)

Fig. 4a.6.4. Analytical scheme for aqueous samples.

4a.6.3.2.3 Vents

Standard stack sampling procedures will be used to determine particulates, SO₂, and NO concentrations in the three vents of interest: (1) main process vent, (2) preheater venturi vent, and (3) coal drying and grinding vent. Samples will also be taken to determine total hydrocarbons by gas chromatography.

Three samples will be taken at each vent to determine particulates and SO₂ by EPA methods 5 and 6 respectively. Three bomb samples will be taken at each vent for NO_x analysis by a technique equivalent to EPA method 7. One bag sample will be drawn at each vent for total hydrocarbon analysis.

4a.6.3.2.4 Process Gas Streams

The regenerator flue gas and gasifier product gas will each be sampled at three locations: (1) downstream of the quench towers, (2) between the cyclones and quench tower, and (3) at the reactor outlet nozzle. The gas streams exiting the quench towers will be sampled for determination of major and trace elements in both the particulate and vapor phase in the streams as part of the quench system material balances. Similarly, the flue gas and product gas between the cyclones and quench towers will also be monitored for major and trace elements as inlet streams to the quench systems and outlet streams from the gasifier-regenerator balance loop. In addition, both gas streams (between the cyclones and quench towers) and quenched product gas will be monitored for various major and minor molecular gas components. Sampling of gas streams for major and trace elements will require insertion of a sampling probe into the streams to allow isokinetic collection of particulates.

Due to the extreme temperatures and the sensitivity of the process operation to disturbances at the reactor outlets, monitoring at the reactor nozzles will be limited to determination of the distribution of sulfur among the various possible sulfur compounds.

4a.6.3.3 Test Plan Schedule

The collection of samples described in the previous sections will be conducted as five separate efforts:

1. criteria pollutants on atmospheric vents
2. regenerator flue-gas quench system material balance
3. product-gas quench system material balance
4. gasifier-regenerator material balance
5. sulfur species

Effluent water quality monitoring will be conducted concurrently with each effort.

Table 4a.6.5 shows a CO₂ Acceptor pilot-plant program supplied by Conoco. The following test schedule may be developed around the scheduled pilot-plant program.

Criteria Pollutants on Vents—Run 42

Environmental testing during run 42 is projected to include the following activities:

1. monitoring of particulates, SO_x, NO_x, and total hydrocarbon emissions from the main process vent, preheater venturi vent, and coal drying and grinding vent

Table 4a.6.5. Projected programs for CO₂
Acceptor pilot plant

	Objective
Run 40A	Demonstrate steady-state operation of pilot plant using Texas lignite
Shutdown	Plant inspection and repair
Run 40B	Same as run 40A
Shutdown	Install refractory lift line
Run 41	Demonstrate operability of new lift line
Shutdown	Plant inspection and reduction of regenerator inside diameter to 24 in.
Run 42	Operate regenerator without recycle gas (Velva lignite)
Shutdown	Plant inspection
Run 43	Operate regenerator at neutral or oxidizing conditions and at various fluidizing rates (6–8 ft/sec) (Velva lignite)
Shutdown	Plant inspection
Run 44	Regenerator operation – air injection into regenerator disengaging space (Velva lignite or subbituminous)
Shutdown	Plant inspection
Run 45	Demonstrate plant operability using Glenharold lignite (typical mine-blended material)
Shutdown	Plant inspection
Run 46	Operate plant on synthetic acceptor (Velva lignite)
Shutdown	Plant inspection
Run 47	Study effect of acceptor makeup rate on activity (decrease rate to 300 lb/hr) (Velva lignite)
Shutdown	Plant inspection
Run 48	Same as run 47 (900 lb/hr makeup)
Shutdown	Plant inspection
Run 49	Study gasification kinetics for lignite (add air to gasifier) (Velva lignite)
Shutdown	Plant inspection
Run 50	Study gasification kinetics of subbituminous coal (add air to gasifier) (Wyodak subbituminous)
Shutdown	Plant inspection
Run 51	Operate pilot plant at 15-atm system pressure. Study effects of gasifier steam partial pressure and regenerator O ₂ partial pressure (Wyodak subbituminous)
Shutdown	Plant inspection
Run 52	Operate plant at 10-atm gasifier pressure (demonstrate use of 100% steam to fluidize recarbonated acceptor when Glenharold lignite is used as feedstock)
Shutdown	Plant inspection
	Additional plant operation (one month) to account for time slippage during runs
Mothballing	

2. dilution quench bomb sampling and analysis for sulfur species from the regenerator and gasifier overhead gas streams
3. solids collection for leaching and chance reaction experiments
4. effluent water quality monitoring

Although run 42 is projected to have Velva lignite as feedstock, the efforts planned, particularly the vent sampling, are not feedstock-sensitive. A summary of the samples and analyses projected for run 42 is presented in Table 4a.6.6.

Table 4a.6.6. Run 42 – projected sampling and analysis

Stream	Parameters
Main process, preheater venturi, and coal drying and grinding vents	Particulates, SO _x , NO _x , total hydrocarbons
Preheater venturi inlet gas	SO _x , NO _x , total hydrocarbons
Preheater venturi inlet and outlet water	Sulfur, total dissolved solids, total suspended solids
Regenerator and gasifier overhead gas	Bomb sampling for sulfur species
Preheater venturi inlet and outlet water; regenerator and gasifier quench water	Water quality parameters
Coal	Percentage ash, sulfur

Regenerator Flue-Gas Quench System Material Balance—Run 44

The main effort in sampling during run 44 with Wyodak subbituminous as a possible feedstock is projected to be the monitoring of the four streams constituting a material balance loop around the regenerator quench system:

1. regenerator flue gas between the cyclones and quench tower
2. regenerator flue gas downstream of the quench tower
3. regenerator quench inlet water
4. regenerator quench outlet water

This effort will be the first to include sampling of high-pressure gas streams. In addition to the monitoring of the regenerator flue gas prior to the quench for the major trace elements included for material balances, the gas at this location will be fully analyzed for the following:

NH ₃	H ₂ S
CO ₂	SO _x
CO	NO _x
N ₂	CS ₂
O ₂	COS
H ₂	Particulates
Moisture	Total hydrocarbons
HCN	

A summary of the streams projected to be sampled and the analyses to be performed during run 44 is presented in Table 4a.6.7. In addition, effluent water quality monitoring will be performed.

Table 4a.6.7. Run 44 – projected sampling and analysis

Analytical parameter	Stream				
	Regenerator flue gas upstream of quench	Regenerator flue gas downstream of quench	Inlet regenerator quench water	Outlet regenerator quench water	Preheated coal
NH ₃	X				
CO ₂	X	X			
CO	X	X			
N ₂	X	X			
O ₂	X	X			
H ₂	X	X			
H ₂ O	X	X			X
HCN	X				
H ₂ S	X				
SO _x	X				
NO _x	X				
CS ₂	X				
COS	X				
Particulates	X	X			
Major elements ^a	X	X	X	X	X
Trace elements ^b	X	X	X	X	X
Total hydrocarbons	X				
Dissolved gases				X	
Percentage ash					X
Sulfur					X
Proximate					X
Ultimate					X

^aAl, Ca, Fe, Mg, P, K, Si, and Na.^bSb, As, Be, B, Cl, Cd, Cr, Cu, F, Pb, Li, Mn, Hg, Mo, Ni, Se, Tl, Ti, U, V, and Zn.*Product-Gas Quench System Material Balance—Run 45*

Run 45 is projected to be the run during which sampling for material balances around the product-gas quench system will be performed. The main effort during this run will be to determine the major and trace elements in the five streams around the product-gas quench system:

1. product gas between external cyclones and quench
2. product gas downstream of quench
3. inlet product-gas quench water
4. outlet product-gas quench water
5. solids from quenched product-gas filter

In addition, the product gas before and after the quench system will be fully analyzed for:

NH ₃	H ₂ S
CO ₂	SO _x
CO	NO _x
N ₂	CS ₂
O ₂	COS
H ₂	Particulates
Moisture	Total hydrocarbons
HCN	

During this sampling effort, the monitoring and characterization of sulfur species in the regenerator overhead gas and the gasifier overhead gas, using a continuous flow sampling system and an "on-line" gas chromatograph, will be initiated. Table 4a.6.8 provides a summary of the streams projected to be sampled and analyses to be performed during run 45. In addition, effluent water quality monitoring will be carried out.

Table 4a.6.8. Run 45 – projected sampling and analysis

Analytical parameter	Stream							
	Product gas upstream of quench	Product gas downstream of quench	Product-gas quench water		Quench product-gas filter solids	Gasifier overhead	Regenerator overhead	Preheated coal
			Inlet	Outlet				
NH ₃	X							
CO ₂	X	X						
CO	X	X						
N ₂	X	X						
O ₂	X	X						
H ₂	X	X						
H ₂ O	X	X						X
HCN	X	X						
H ₂ S	X	X				X	X	
SO _x	X	X				X	X	
NO _x	X	X						
CS ₂	X	X				X	X	
COS	X	X				X	X	
Particulates	X	X						
Major elements ^a	X	X	X	X	X			X
Trace elements ^b	X	X	X	X	X			X
Total hydrocarbons	X	X						
Dissolved gases				X				
Percentage ash								X
Sulfur	X	X	X	X	X	X	X	X
Proximate								X
Ultimate								X

^a Al, Ca, Fe, Mg, P, K, Si, and Na.

^b Sb, As, Be, B, Cl, Cd, Cr, Cu, F, Pb, Li, Mn, Hg, Mo, Ni, Se, Tl, Ti, U, V, and Zn.

Gasifier-Regenerator Material Balance—Run 50

Run 50 is projected to be the run during which the material balances around the gasifier-regenerator system are generated for the major and trace elements. The main effort during this run will be the collection of samples from the ten streams contributing to the balance calculations:

1. sized acceptor
2. preheated coal
3. makeup char
4. recycle product gas
5. recycle flue gas
6. product gas prior to quench
7. regenerator flue gas prior to quench

8. purged acceptor
9. regenerator cyclone ash
10. gasifier external cyclone char

In addition to the elemental determinations, the regenerator flue gas and product gas prior to the quench systems will be fully analyzed for:

NH ₃	HCN
CO ₂	H ₂ S
CO	SO _x
N ₂	NO _x
O ₂	CS ₂
H ₂	Particulates
Moisture	Total hydrocarbons

Monitoring of sulfur species in the regenerator and gasifier overhead gases will be continued. Table 4a.6.9 provides a summary of the samples to be collected and analyses to be performed during run 50. Water quality monitoring will be performed on the gasifier quench water.

Additional Sampling Efforts

Run 51 would provide an excellent opportunity to characterize the sulfur species distribution in the regenerator and gasifier overheads at a significantly different operating pressure (~15 atm). A continuous-flow sampling system with "on-line" gas chromatograph could be used in this effort. Water quality data on the gasifier quench water should also be collected during run 51.

Run 52 with Glenharold lignite would provide a backup opportunity for material balance work in the event that plant operation or sampling problems cancel any of the previously scheduled efforts.

Leaching and chance reaction experiments are being performed on solids collected during run 42 and would, therefore, require no additional sampling effort.

Table 4a.6.9. Run 50 – projected sampling and analysis

Analytical parameter	Stream											
	Product gas upstream of quench	Regenerator flue gas upstream of quench	Sized acceptor	Preheated coal	Makeup char	Recycle product gas	Recycle flue gas	Purged acceptor	Regenerator cyclone ash	Gasifier external cyclone char	Gasifier overhead	Regenerator overhead
NH ₃	X	X										
CO ₂	X	X										
CO	X	X										
N ₂	X	X										
O ₂	X	X										
H ₂	X	X										
H ₂ O	X	X	X	X	X			X	X	X		
HCN	X	X										
H ₂ S	X	X									X	X
SO _x	X	X									X	X
NO _x	X	X										
CS ₂	X	X									X	X
COS	X	X									X	X
Particulates	X	X										
Major elements ^a	X	X	X	X	X			X	X	X		
Trace elements ^b	X	X	X	X	X			X	X	X		
Total hydrocarbons	X	X										
Percentage ash			X	X	X			X	X	X		
Sulfur	X	X	X	X	X	X	X	X	X	X	X	X
Proximate				X	X					X		
Ultimate				X	X				X	X		

^aAl, Ca, Fe, Mg, P, K, Si, and Na.^bSb, As, Be, B, Cl, Cd, Cr, Cu, F, Pb, Li, Mn, Hg, Mo, Ni, Se, Tl, Ti, U, V, and Zn.

4b. Environmental Monitoring

4b.1 Purpose and Scope

Monitoring in the environment during the operational phase of the demonstration program is needed to assess the degree and significance of environmental impacts from a developing technology under actual operating conditions. Ideally, environmental problems of energy technology development should be assessed or predicted before they occur. In actuality, some environmental impacts may escape prediction, whereas others may be less significant than anticipated.

The operational monitoring program should, therefore, be designed to detect environmental impacts early in their development to allow application of the least expensive adjustments to process designs, operating procedures, pollution control measures, effluent disposal techniques, etc., which may be necessary to protect environmental quality. If effective, the operational monitoring program at the demonstration plant stage should serve to avoid expensive, inefficient retrofitting at the commercial plant stage. It should also minimize or avoid hastily conceived and expensive special studies if an environmental problem becomes recognized late in the commercial-scale development.

The operational monitoring program will primarily address site-specific environmental impacts predicted in the Environmental Impact Statement (EIS) for a particular plant. The operational monitoring program should provide the information necessary to verify, evaluate, and refine predictions of environmental impacts. It should address methods to mitigate adverse impacts at commercial-scale development. To accomplish these goals, the operational monitoring program must (1) rely on an adequate baseline characterization of the receiving system, (2) be guided by the impact evaluation synthesized in the EIS using site-specific considerations, and (3) integrate ongoing research and development work on the environmental interactions of new process effluents.

Operational-phase monitoring will initially entail a continuation of the baseline program and appropriate aspects of construction monitoring as modified by the EIS synthesis, by DOE review, and by new information from research and development efforts. Continuity with the baseline program is important because it allows direct comparisons of before-after data at control and impacted sampling areas.

Because of present uncertainties in coal conversion plant design, effluent characterization, and effluent disposal, and because of present research on environmental monitoring strategies, most of the discussion in this section of the handbook will be generic. Furthermore, site and process specificity will determine most of the operational monitoring program and only its general form can be presented here.

Potential entrainment and impingement impacts will be evaluated in the EIS on the basis of the location and design characteristics of intake structures, the seasonal flow data for the surface water under use, the nature of the aquatic system biota, its persistence near the intake structures, the percentage of the total flow that will be drawn into the coal conversion plant, and other site-specific considerations. In many cases, the percentage of flow used will be insignificant compared with the total flow of the receiving system, and monitoring may only consist of a periodic check.

4b.2 Physical-Chemical Environment

4b.2.1 DESCRIPTION OF COAL CONVERSION PLANT OPERATION AND ASSOCIATED EFFLUENTS

Knowledge of coal-conversion-related materials is the key to evaluating possible environmental impacts. Unfortunately, not only are few definitive data available on which to base analytical programs, but indications are that, when available, analyses may involve a virtual galaxy of chemical species, physical states, and matrices (Table 4b.2.1). Thus, because the coal-derived substances of interest are process-stream-related, it is felt that it would be most helpful to examine them in the context of the unit operations or streams in which they are generated.

4b.2.1.1 Purpose and Scope

The purpose of this section is to identify and quantify those effluents that are potential environmental and health hazards. This objective will be accomplished by examining the various conversion plant process units and the effluents associated with each of these (Sect. 4b.2.1.2). The discussion will center on high-Btu gas coal conversion plants having the processes and discharges unique to liquefaction processes delineated in Sect. 4b.2.1.2.8. The known background levels of anticipated chemicals in each of the environmental media—air, water, soil—and in biota are discussed in Sect. 2.1.4.2. Analytical techniques, centered around EPA standard methods whenever possible, reporting that agency's desired limits of detection, precision, accuracy, and elimination of interferences, are described in Sects. 2.1.4.3 and 4b.2.2.2.

4b.2.1.2 Identification of Process Effluents

Point sources for discharge from high-Btu coal conversion plants are (1) coal storage, (2) coal preparation, (3) coal gasification, (4) acid gas cleanup, (5) wastewater treatment, and (6) utility production. Except for the gasification step, these sources are common to most conversion process schemes; thus the content and treatment of effluent streams from these sources may be expected to be similar from process to process. This is true, not only for the various SNG plant designs, but also for fuel gas and liquefaction plant designs. Fuel gas plants may be expected to resemble high-Btu gasification plants with the exception of catalytic methanation, which is not necessary. The unique aspects of liquefaction processes are discussed in Sect. 4b.2.1.2.8.

Table 4b.2.2 summarizes the unit operations, their streams, and some anticipated effluents. It is clear that analyses will involve solids, liquids, gases, and mixtures of these, as well as organic and inorganic substances. The subsections below, as well as Sect. 4a.3.2, describe the process functions and anticipated effluents of each unit operation. These are only predictions based on a relatively

Table 4b.2.1. Some gasification product and by-product species of interest

Component	Class	Item or property of interest
Gases	Inorganic	H ₂ , CO, O ₂ , N ₂ , Ar, NH ₃ , H ₂ O
	Acid gases	H ₂ S, CO ₂ , SO _x , NO _x , HF, HCl, HCN
	Organic	CH ₄ , C ₂ H ₆ , C ₂ H ₄ , C ₃ H ₈ , C ₃ H ₆ , C ₄ H ₁₀ , C ₄ H ₈
	Sulfurous	COS, CS ₂ , CH ₃ SH, C ₂ H ₅ SH
Organic liquids and solids	Hydrocarbons	C ₅ -C ₁₂ hydrocarbons, benzene, toluene, xylene, indenes, naphthalenes
	Polynuclear aromatic compounds	Pyrenes, fluoranthenes, phenanthrenes, fluorenes, acenaphthenes, benzopyrenes, chrysenes, coronene
	Nitrogen compounds	Pyridine, picolines, lutidines, quinoline, iso-quinoline, quinaldine, indole, carbazole, acridine
	Phenols	Phenol, cresols, xylenols, naphthols
	Sulfur compounds	Mercaptans (thioalcohols), thiophenol, thiocresol, benzothiophene
Trace elements	Nonvolatile	Ba, Be, Ca, Cr, Cu, Mn, Mo, Ni, Sr, V, Zn
	Volatile	As, B, Cd, F, Hg, Pb, Sb, Se, Sn
Coal, ash, and particulate	Ultimate	C, H, N, S, Cl, O
	Proximate	Moisture, heat content, ash, volatiles, fixed carbon
	Sulfur forms	Total, pyritic, sulfate, sulfide
	Ash (particulate)	SiO ₂ , Al ₂ O ₃ , Fe ₂ O ₃ , TiO ₂ , P ₂ O ₅ , CuO, CaO, MgO, Na ₂ O, K ₂ O, F, SO ₄ ²⁻ , trace elements
Water	Dissolved gases	See items listed above
	Organics	
	Trace elements	
	Ions	S ²⁻ , SO ₄ ²⁻ , NO ₃ ⁻ , F ⁻ , Cl ⁻ , Br ⁻ , CN ⁻ , PO ₄ ³⁻ , CO ₃ ²⁻ , HCO ₃ ⁻ , SCN ⁻ , H ⁺
	Gross characteristics	BOD, COD, TOC, suspended solids, oil and grease, specific conductance

Source: J. A. Dorsey, "Sampling Strategies," in *Sampling Strategy and Characterization of Potential Emissions from Synfuel Production, Symposium Proceedings, Austin, Tex., June 8-10, 1976*, ERDA CONF-760602, 1976, p. 50.

small data base from pilot plants and conceptual designs. These effluent predictions should be continually upgraded as the data base expands and as the actual design for the plant at hand is developed.

4b.2.1.2.1 Coal Storage

Coal storage is necessary and desirable for both production and use. However, there are possible undesirable results of coal storage: oxidation and spontaneous combustion, rain drainage and runoff, windblown dust, changes in coal properties, degradation of coal due to handling, and the added cost of handling and storage facilities (see Sect. 4a.3.2.1). Most coal conversion plant designs allow for an approximate 30-day stored supply. For designs using low-ranking lignites (CO₂ Acceptor), the amount of stored coal will be much larger than for plants using higher-ranking bituminous feeds. Typical sizes of storage piles found in the literature for 250 × 10⁶ scfd (7.1 × 10⁶ m³/day at STP) SNG plants are 15 acres (6 ha) at 25 ft (7.6 m) high;¹ 4 piles, each about 200 ft (60 m) wide, 20 ft (6 m) high, and 1000 ft (300 m) long;² and 6 storage areas, each area being 1750 ft (533 m) long, 124 ft (37.8 m) wide, and 25 ft (7.6 m) high.³

An immediate problem is that of airborne dust due to wind. Because coal storage piles are extensive, a loss of only a fraction of a percent could be excessive in terms of environmental insult

Table 4b.2.2. Summary of effluents and wastes

Unit	Operation	Effluents	Comments
Coal storage	Coal usually is stored outdoors for about 30 days use. For a 250×10^6 scfd (7.1×10^6 m ³ /day at STP) synthetic natural gas (SNG) plant, 15 acres (6 ha) piled 25 ft high (7.6 m) are required	Effluents consist of wind-blown particulates, rain-water leachate and runoff containing suspended solids, inorganic compounds, trace elements, and considerable acidity (pH $\approx$ 2.9)	Coal storage piles can ignite, evolving smoke, fumes, and volatile compounds
Coal preparation	Coal will be broken, washed, dried, and ground to the fineness needed for gasification	Primary size reduction will release about 20% of the run-of-mine coal as rock, debris, gangue, and some coal. Washing will produce solid wastes—12 to 25 lb/100 lb (12 to 25 kg/100 kg) clean coal; drying will release fine coal particulates and gaseous effluents; grinding will produce fine coal dust	Particulate control to achieve related new source standards [0.1 lb/ 10^6 Btu (43 μ g/J) input] may require high collection efficiencies; flue gas desulfurization will be required to achieve 1.2 lb/ 10^6 Btu (516 μ g SO ₂ /J) input and NO _x will be controlled to achieve 0.7 lb/ 10^6 Btu (300 μ g NO ₂ /J) input
Coal gasification	Coal is heated in the presence of steam and air or oxygen to drive off volatile gases	Solid residuals [$\approx$ 1000 tons/day (900 metric tons) for 250×10^6 scfd (7.1×10^6 m ³ /day at STP) plant] will be produced (ash, slag, or char). If quenched, this will be in the form of a slurry. Slurry water will contain soluble inorganic compounds and suspended solids	Char will be transferred to the utility boiler for firing as fuel. Finely divided ash may be entrained in the gas stream. Slurry water may be recycled
Acid gas cleanup	The product gas stream is treated for removal of acid gases, primarily H ₂ S and CO ₂ , usually by absorption into a solvent or on a solid or by conversion into another compound	The ultimate product of acid gas removal is generally elemental sulfur [5 to 28 long tons/hr (5 to 28 metric tons/hr) for a 250×10^6 scfd plant (7.1×10^6 m ³ /day at STP)], although the form of the sulfur (liquid, solid, or finely divided particulate) depends on the removal process	Most acid gas processes bypass other sulfur gases such as COS, CS ₂ , and sulfur-containing organics such as CH ₃ SH and C ₂ H ₅ SH. Vented cleanup gas should be virtually pure CO ₂ with the equivalent of 250 ppm of SO ₂ in sulfur-containing gases
Wastewater treatment	Treatment may be designed for zero discharge and include biological oxidation, trace metal removal, and filtration or clarification	Primary effluent will be spent treatment sludges—the quantities and composition are largely unknown	Little water will be discharged. Most water will be recycled from one plant unit to another according to the capacity of the unit to tolerate contaminants. Water loss will be primarily by evaporation from cooling towers

Table 4b.2.2 (continued)

Unit	Operation	Effluents	Comments
Utility production	The power plant will generate process steam and electric power. Fuels ranging from cleaned coal or char to low-Btu gas will be used	Emissions will be similar to conventional power plants—SO ₂ , NO _x , and particulates. Controls will convert these to flue gas desulfurization sludges, collected fly ash, and bottom ash or slag	Emissions will be held to new source performance standards and will lead to a need for solid waste disposal
Cooling towers	Much of process cooling uses recirculated water. Chemicals are added to inhibit corrosion and biological fouling	Possible emissions in air and entrained droplets are zinc and chromium compounds, chlorine, sulfuric acid, phosphates, phenols, copper complexes, ammonia, carbon monoxide, cyanide, thiocyanates, and trace elements	Replacing evaporation in the tower and drift loss, makeup water comes from recycling treated aqueous process waste streams. Residual contaminants may remain in makeup water and be stripped out by the large volume of air passing through the tower

and loss of feedstock. Ways to control this loss, such as coating the surface of the pile with oil or asphalt or covering it with a plastic sheet, have been suggested.⁴

Rainwater penetration is an additional problem. It has been suggested that effluent limitation guidelines published by the EPA for the coal mining industry under The Refuse Act Permit Program will apply to conversion plant storage facilities.³ Because the volume of the storage pile will be large, the residence time of rainwater will be long, allowing acid-forming reactions, extraction of organics, sulfur, and soluble metals, and the carrying away of suspended matter (Table 4b.2.3).

A coal storage pile allows the possibility of fires and spontaneous combustion which would result in evolution of smoke, fumes, and volatiles. Although opinions vary as to the exact mechanism of oxidation, the process appears to take place in five general stages:⁵

1. The coal begins to oxidize slowly until a temperature of about 50°C is reached.
2. Oxidation occurs at an increasing rate (aided by higher temperatures) until the temperature of the coal is about 100° to 140°C.
3. At about 140°C, carbon dioxide and water vapor are given off.
4. Carbon dioxide liberation increases rapidly until a temperature of 232°C is reached, at which stage spontaneous combustion may take place.
5. At 350°C the coal ignites and vigorous combustion occurs. Generally, the critical temperature for bituminous coal in storage is about 50° to 65°C; from this temperature, heating will usually increase rapidly to ignition unless preventive steps are taken.

The tendency of a coal to heat spontaneously, which depends on its tendency to oxidize, closely correlates with rank. The lower the rank, the greater the tendency to oxidize. For example, lignite and subbituminous coals are difficult to store without occurrence of spontaneous combustion, whereas anthracite has never been known to ignite spontaneously.⁵ Other factors contributing to spontaneous combustion are (1) coal size, (2) method of stocking, (3) temperature at which it is piled, (4) external heat additions, (5) amount and size of pyrite present, (6) moisture content and

Table 4b.2.3. Characteristics of coal pile drainage

Constituents	Concentration (mg/liter)	
	Plant J	Plant L
Acidity (total), as CaCO ₃	1700	270
Calcium	240	350
Chemical oxygen demand	9	
Chloride	0	
(Conductance, μ mho/cm	2400	2100)
Dissolved solids (total)	3200	1500
Hardness, as CaCO ₃	600	980
Magnesium	1.2	0.023
(pH, unit	2.9	2.9)
Potassium		0.5
Silicon (dissolved)	91	
Sodium		4.1
Sulfate	2600	
Suspended solids (total)	550	810
(Turbidity, JTU	300)	
Aluminum	190	
Arsenic	0.01	0.009
Barium		0.1
Beryllium		<0.01
Cadmium	<0.001	0.006
Chromium	<0.005	<0.005
Copper	0.56	0.18
Iron	510	830
Lead	<0.01	0.023
Manganese	27	110
Mercury	<0.0002	0.027
Nickel	1.7	0.32
Selenium	0.03	0.003
Titanium	<1	
Zinc	3.7	1.0

Source: H. M. Braunstein, E. D. Copenhaver, and H. A. Pfuderer, eds., *Environmental, Health, and Control Aspects of Coal Conversion: An Information Overview*, vol. 1, ORNL/EIS-94, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1977, Table 1.1, p. 1-9. Information obtained from T. J. Chu, R. J. Ruane, and G. R. Steiner, "Characteristics of Wastewater Discharges from Coal-Fired Power Plants," in *31st Annual Purdue Industrial Waste Conference, May 4-6, 1976*, Purdue University, West Lafayette, Indiana, Table 14, p. 34.

ventilation conditions, (7) time in storage, and (8) presence of foreign materials. The variability of coals adds to the complexity of these factors and makes prediction of behavior of storage piles difficult.⁵

4b.2.1.2.2 Coal Preparation

Coal conversion plants will have facilities for coal preparation. In some cases coal may be broken and washed at the mine, but it is assumed that most plants will have complete coal preparation facilities.

The purposes of coal preparation—to remove impurities such as rock, gangue, tramp iron, pyritic sulfur, and moisture and to reduce the particle size of the coal to meet gasifier

requirements—are carried out by four primary operations: primary size reduction, washing, drying, and grinding. The major effluent in coal preparation is refuse from the primary size reduction and washing operations. However, the vent gas and particulates from the thermal driers can be equally important (see Sect. 4a.3.2.1).

Primary size reduction

Primary breakers receive the raw coal and initiate size reduction, whereas secondary and final crushers reduce the coal to gasifier size. During size reduction, a large quantity of rock, debris, gangue, and some coal is rejected, most of it at the primary breaker. This quantity, which can often be 20% of the run-of-mine (ROM) coal received at the preparation facility, represents a significant solid waste stream. Jahnig estimates that the Bi-Gas process will produce 4804 tons (4362 metric tons) of refuse daily for an ROM coal feed of 23,243 tons (21,086 metric tons) per day,⁶ whereas Grace and Diehl estimate 4567 tons (4143 metric tons) of refuse per day from the Bi-Gas preparation facility alone.⁷

Although airborne dust and coal fines will be generated by the size reduction operations, size reduction should not constitute a significant airborne emission source since the technology to control these emissions is well established. Recovered solids should follow the same solid waste disposal path as the rejected debris.

Washing

Coal is washed to remove refuse, usually by immersing crushed coal in a fluid having a density intermediate between that of the coal and the refuse. Since “pure” bituminous coal has a specific gravity of about 1.3, “rock,” about 2.0 to 2.7, and pyrite, about 4.8 to 5.0, the coal floats and the debris settles.⁸ The Interagency Task Force on Synthetic Fuels from Coal estimates the solid wastes from coal washing as 12 to 25 lb per 100 lb (12 to 25 kg per 100 kg) of clean coal.⁹ Ideally, the washing system should be designed for complete recycle of the wash water so that there is no water effluent from the operation. Water may be contaminated with solids or leachates from the coal. However, wash water probably will be sent to a settling pond for removal of fines before recycling. Thus, leaching or seepage through the bottom of the tailing pond will need to be controlled, possibly requiring a barrier of clay or plastic.

Drying

Industrial coal driers use convection to transfer heat, bringing hot gases and wet coal into intimate contact on a continuous gas-flow-coal-feed basis. Effluents from the drier depend on the firing fuel, the nature of the drying gases (e.g., flue gases from the utility boiler), and the efficiency of particle collectors. Source emission standards that may be applicable for 10^6 Btu (1 J) heat input are 0.1 lb (43 μg) of particulates, 1.2 lb (516 μg) of sulfur dioxide (SO_2), and 0.7 lb (300 μg) of nitrogen dioxide (NO_2). As an example of heat input, 150×10^6 Btu/hr (158 GJ/hr) is required to dry 515 tons (467 metric tons) of western Kentucky coal from 8.4% to 1.3% moisture. This gives an estimated uncontrolled emission rate for particulates, according to Table 4b.2.4, of 68 lb/ 10^6 Btu (29,000 $\mu\text{g}/\text{J}$) compared with the allowable 0.1 lb/ 10^6 Btu (43 $\mu\text{g}/\text{J}$) input standard and requires a collection efficiency of 99.85%.

Control of NO_2 in drier flue gases is usually effected by carefully regulating the combustion parameters. Low flame temperature and low excess air are the conventional means of limiting NO_2

Table 4b.2.4. Particulate emission factors for thermal coal driers^aEmission factor rating: B^b

Type of drier	Uncontrolled emissions ^c	
	lb/ton	kg/metric ton
Fluidized bed	20	10
Flash	16	8
Multilouvered	25	12.5

^aEmission factors expressed as units per unit weight of coal dried.^bA process ranked B should be considered above average, that is, based on a limited number of field measurements.^cTypical collection efficiencies are: cyclone collectors (product recovery), 70%; multiple cyclones (product recovery), 85%; water sprays following cyclones, 95%; and wet scrubber following cyclones, 99 to 99.9%.Source: U.S. Environmental Protection Agency, *Compilation of Air Pollution Emission Factors*, EPA-AP-42, 1972, p. 8-10.

production. If SO₂ emission cannot be maintained in compliance with federal regulations through fuel selection, flue gas desulfurization will be necessary.

Grinding

Grinding is the final stage in size reduction. Because the ground coal is often a very fine powder, the potential exists for it to become airborne. Additionally, because the dust is "pure" coal dust, it has a lower explosive limit (LEL) in air. Since ball-mills and other grinding devices generate heat while operating, the concentration of coal dust in the air becomes rather critical to explosion potential. Air aspirated into the ball-mill is treated with a cyclone and either a baghouse or electrostatic precipitator before discharge to the atmosphere. Particulate loading in the vent stream will be 0.1 lb particulate per ton of coal (50 g/metric ton) fed to the grinder.

4b.2.1.2.3 Coal Gasification

The principal waste leaving a gasifier unit is solid ash, char, or slag (Table 4b.2.5). Solid waste usually is slurried with water and the slurry is dewatered to some extent in a retention pond before disposal. The slurry water, which is contaminated with solids and leachates from the ash, should not be allowed to become a plant effluent. A partial list of major components in ash slurry water is given in Table 4b.2.6. Recycle to the quench tank should be possible, although treatment and reuse is also a possibility, as is solar evaporation.

The presence of trace elements in ash depends on their presence in coal. Trace elements are either removed from the coal through volatilization during gasification or they remain in the gasifier ash. Table 4b.2.7 lists estimated amounts of trace elements in ash from a 10,000 ton (9000 metric ton) per day gasifier and the amounts volatilized into the gas stream. For gasification processes producing primarily char, such as Synthane, this product will be transferred to the utility boiler so

Table 4b.2.5. Ash and char generation in gasifiers

	Bi-Gas		Synthane	CO ₂ Acceptor	Hygas
Char, tons per day (metric tons per day)	None		4350 (3950) (dry) to utility boiler	5960 (5410) to regenerator	1667 (1512) (dry) char quenched and disposed. A slurry (25% solids) will be formed
Gasifier ash, slag [tons per day (metric tons per day)]	820 (740) (dry) granular slag. After quenching, 820 (740) H ₂ O will be added to form a slurry		1050 (950) ash leaving utility boiler	2795 (2536) carbonated dry ash and 2795 (2536) H ₂ O from regenerator (wet ash disposal)	Ash disposed of in char system
Plant size, 10 ⁶ scfd (10 ⁶ m ³ /day at STP)	250 (7.1)		250 (7.1)	250 (7.1)	250 (7.1)
Coal feed rate to gasifier, tons per day (metric tons per day)	11,400 (10,340) (1.3% H ₂ O)		14,250 (12,930)	16,960 (15,390)	12,695 (11,516)
Coal type	W. Kentucky, No. 11 <i>Dried</i>		Pittsburgh seam	Lignite	Illinois No. 6
Percentage H ₂ O	8.4	1.3	2.5	0	0
Percentage ash	6.7	7.2	7.4	11.45	11.54
Percentage S	3.48	3.75	1.6	0.9	4.2

Source: H. M. Braunstein, ed., *Environmental and Health Aspects of Disposal of Solid Wastes from Coal Conversion: An Information Assessment*, vol. 1, draft report, Oak Ridge National Laboratory, Oak Ridge, Tenn., March 1977, Table 1.2, pp. 1-6 and 1-7.

that virtually all the ash will leave from the power plant; nonvolatile trace elements will be associated with the bottom ash, whereas volatilized trace elements will exit either with flue gases or be collected with fly ash as in a conventional power plant.

Ash disposal options include return to the coal mine, pond retention, use as landfill, or resale to industries. When burial, pond retention, or landfill is chosen, either the ash must be treated or the site must be constructed to minimize leachate contamination of groundwater systems in compliance with the Resource Conservation and Recovery Act of 1976. Ash leachates may constitute a significant source of trace metal environmental pollution.¹⁰

Ash from the CO₂ Acceptor regenerator can cause secondary pollution problems due to release of H₂S from the contained CaS. However, based on pilot-plant experience, reject acceptor, after sulfur removal, is low enough in sulfur, 0.084%, to preclude pollution problems upon disposal as landfill.¹¹

Table 4b.2.6. Example of water analysis from gasifier ash slurry tank^a

Component	Amount ($\mu\text{g/liter}$)
(pH	8.8)
CaO	101
MgO	161
Na	17.5
K	8.5
Zn	0.03
Fe	0.22
NH ₄	157
NO ₂	0.13
NO ₃	3.32
PO ₄ (total)	0.81
Cl	85
SO ₄	216
CN	0.52
H ₂ S	9
KMnO ₄ (consumed)	18
Chemical oxygen demand	16.0
SiO ₂	4612
Suspended solids	3918

^aKoppers-Totzek process plant, Kutahya, Turkey.

Source: H. M. Braunstein, E. D. Copenhaver, and H. A. Pfuderer, eds., *Environmental, Health, and Control Aspects of Coal Conversion: An Information Overview*, vol. I, ORNL/EIS-94, Oak Ridge National Laboratory, Oak Ridge, Tenn., August 1977, Table 4.37, p. 4-89. Information obtained from J. F. Farnsworth, D. M. Mitsak, and J. F. Kamody, "Clean Environment with Koppers-Totzek Process," pp. 115-30 in *Symposium Proceedings: Environmental Aspects of Fuel Conversion Technology*, St. Louis, Missouri, May 1974, EPA-650/2-74-118, U.S. EPA, 1974, Table 4, p. 126.

Hygas char that is quenched and slurried in water (25% solids) forms steam which may contain particulates and other contaminants. Consequently, the steam should be returned to the process or collected for treatment and disposal. However, a baghouse operated above the dew point of the gas may provide sufficient cleanup to allow the steam to be vented to the atmosphere. The amount of steam produced in a 250×10^6 scfd (7.1×10^6 m³/day at STP) plant should be about 50,000 lb/hr (22 metric tons/hr).

The nature of gasifier ash or char is important. If the original coal particles maintain their size during gasification, their density will decrease as the carbonaceous content falls to the indicated 10.3% carbon. The particles will not only be light, but friable as well, so that severe turbulence associated with char quenching and slurry depressuring may create very fine particles. Additionally, if the char particles break up, very fine dust may result, with complications in ash handling and disposal. Disposal of very fine particulates requires careful design of the landfill to prevent washout of the particulates into groundwater as suspended matter in flowthrough water.

Table 4b.2.7. Disposition of trace elements

Constituent	Mean concentration in coal (ppm)	Feed rate ^a		In exit gas		In gasifier ash	
		lb/day	kg/day	lb/day	kg/day	lb/day	kg/day
As	14	280	127	182	82	98	45
B	100	2,000	910	200	90	1,800	820
Be	1.6	32	15	6	3	26	12
Cd	2.5	50	23	31	14	19	9
Cr	14	280	130	Neg.		280	130
F	61	1,220	553	122	55	1,098	498
Hg	0.20	4	2	4	2	Neg.	
Mo	7.5	150	68	15	7	135	61
Ni	21	420	190	101	45	319	145
Pb	35	700	317	441	200	259	117
Sc	2.1	42	19	31	14	11	5
V	33	660	300	198	90	462	210
Zn	270	5,400	2,450	540	245	4,860	2,205
(Cl	0.14%)	28,000	12,700	<25,200	<11,430	2,800	1,270
(Ti	0.07%)	14,000	6,350	1,400	635	12,600	5,715
Sb	1.3	26	12	9	4	17	8
Co	9.6	192	87	Neg.		192	87

^aFeed rate based on 10,000 tons/day (9000 metric tons/day) of clean coal (after removal of rock, debris, and gangue).

Source: R. R. Ruch, H. J. Gluskoter, and N. F. Shimp, "Distribution of Trace Elements in Coal," in *Symposium Proceedings: Environmental Aspects of Fuel Conversion Technology*, St. Louis, Missouri, May 1974, EPA-650/2-74-118, October 1974, p. 52.

The major effluent from a Bi-Gas gasifier is the slag formed from ash in the coal. Essentially all of the ash in the feed is rejected here, after having fused in the lower zone of the gasifier which operates at 1600°C. For a 250×10^6 scfd (7.1×10^6 m³/day at STP) plant, production of dry sulfur-free slag is 820 tons (740 metric tons) per day, corresponding to about 90 acre-ft per year (11×10^4 m³/year); consequently, adequate provision for disposal is needed. The raw gas product leaving the gasifier contains a large amount of char which is blown out of the gasifier and recovered in cyclones for recycling to the lower zone of the gasifier. No other streams are normally released to the environment from the gasification section. (The reader is also referred to Sect. 4a.3.2.2.)

4b.2.1.2.4 Acid Gas Cleanup and Sulfur Recovery

In the treatment of acid gases and the subsequent recovery of sulfur, the primary point of atmospheric emission is the vent stack on the tail gas treatment unit for the sulfur recovery plant. The undesirable contaminants are sulfur compounds (H₂S, COS, CS₂, SO₂). Manufacturers of several systems are presently claiming that the effluent will be equivalent to less than 250 ppm SO₂. (Refer to Sect. 4a.3.2.3.)

The sulfurous compounds to be removed during acid gas treatment are generated during coal gasification. The primary sulfur compound is hydrogen sulfide (H₂S). However, when carbon monoxide (CO) is present in the process gas stream, carbonyl sulfide (COS) will be formed. If the H₂ and CO concentrations in the primary reaction stage are approximately equal, the thermodynamically expected COS concentration is about 3% of the H₂S concentration, and the carbon disulfide (CS₂) concentration will be even lower. Hydrogen sulfide is more readily removed from the process gas stream than is COS or CS₂. Therefore, the processing conditions that affect the manufacture of COS and CS₂ should be examined to determine the overall pollutant discharge of these important contaminants from the facility.¹²

Other forms of sulfur, such as organic sulfides, mercaptans, and thiophenes, are also produced in the primary reaction step during the devolatilization of coal but these heavier sulfur compounds should be collected with the tars and oils. Thus, H_2S , COS, and CS_2 are the primary sulfur types to be found in the process gas as it reaches the acid gas treatment section of the facility.

Removal of sulfur compounds, such as in a Claus plant, consists usually of ultimate conversion of these to elemental sulfur, which, if not sold, must be disposed of. As the fused solid, elemental sulfur is stable in the environment, but as finely divided particulate in air, it is susceptible to microbial oxidation to sulfate with considerable hydrogen ion production. Agricultural land has become seriously acidified by windblown sulfur dust, which has created barren acid soils that are subject to severe erosion and acid runoff.¹⁰

Sulfur removal units, themselves, must have tail gas treatment units to reduce sulfur emissions. Unrecovered sulfur in Claus plant tail gas includes primarily H_2S , elemental sulfur, SO_2 , and lesser amounts of other sulfur compounds. Additionally, most units using Claus technology are not capable of recovering sulfur from COS or CS_2 , leaving these gases to be vented to the environment. Tail gas cleanup processes often operate at temperatures below the melting point of elemental sulfur and produce a froth which, when filtered, results in a wet or dry filter cake of micron-size particles. Disposal of this particulate sulfur requires great care to ensure environmental safety.

4b.2.1.2.5 Wastewater Treatment

The wastewater treatment plant will be a major facility in a conversion plant. The design goal for water use in commercial-scale coal conversion plants will probably be zero discharge. The 1972 Water Pollution Control Act requires that this goal be attained by 1985. Thus, the philosophy in designing treating facilities for liquid wastes is to purify liquid streams only to the extent necessary for reuse in specific areas of the plant. Examples of contaminated water reuse are shown in Fig. 4b.2.1. Less than 5% of all water consumed in most commercial-plant designs leaves as an aqueous discharge and this water leaves in ash slurries, treatment sludges, and aqueous by-product ammonia. Demonstration-scale plants may or may not have a final liquid discharge. Location, flow rate, and composition must be known to design the water quality and aquatic ecology monitoring programs.

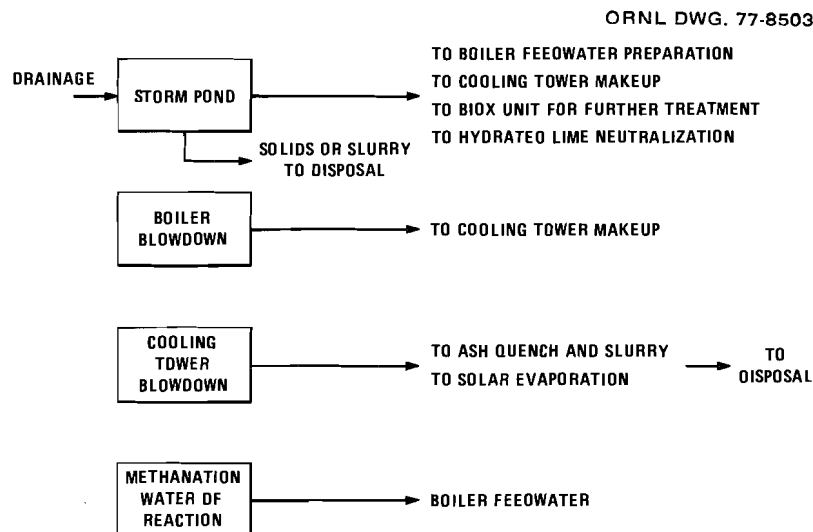


Fig. 4b.2.1. Disposition of liquid wastes.

Contaminated aqueous streams are generated in coal conversion processes because product or effluent gases are either water-washed to remove soluble contaminants or are quenched for temperature control. A third potential source of an aqueous stream is from simple condensation of excess steam which might have been used in a gasification process. Thus, the type and quantity of contaminants found in the wash water are functions of the chemical characteristics of the initial feedstock to the process, the type and severity of conditions in the primary gasification units, and the type of subsidiary treatment upstream of the water-wash, quench, or cooling-condensation steps¹² (see Sect. 4a.3.2.6).

The contaminants and their process origin in primary coal gasification streams are:¹²

1. *Fly ash.* Fly ash and/or coal dust enters the aqueous stream if a hot gas is quenched directly after gasification.

2. *Tars, oils, and BTX.* Many of the gasification processes produce tars, oils, and BTX (benzene, toluene, and xylene) in varying amounts. They might emulsify into the aqueous stream if the gasifier effluent is directly quenched.

3. *Sulfur compounds.* Most gas streams contain soluble sulfurous compounds such as H_2S and COS . Thus, a fraction of the sulfur in the gas will, when washed, dissolve into the wash water. The presence of ammonia in the gas enhances the sulfur solubility.

4. *Ammonia.* If the initial feedstock contains chemically combined nitrogen, as in the case of most coals, the nitrogen will partially hydrogenate to ammonia unless the primary reaction occurs at very high temperatures. Ammonia will be removed from the gas stream in a water wash.

5. *Hydrogen cyanide.* Ammonia reacts with carbon at high temperatures to form hydrogen cyanide according to the $H-C-N$ thermodynamic equilibrium. The hydrogen cyanide dissolves in the aqueous stream if the gasifier effluent is quenched directly. It may also catalytically hydrogenate to ammonia over a shift catalyst if condensation and wash occur later in the processing scheme.

6. *Thiocyanate.* Some process developers report nearly quantitative conversion of hydrogen cyanide with hydrogen sulfide to form thiocyanates. The thermodynamics do not favor this reaction in a reducing atmosphere, but the conversion is rapid when foul water is exposed to air.

7. *Phenols.* Aromatic-based feedstocks, such as coal, may produce small quantities of phenols, cresols, and xylenols during the primary treatment step (devolatilization) if the processing conditions are not severe. These hydroxylated compounds are water-soluble and will appear in the aqueous stream.

Cleanup of wastewater streams is a complex multistep process directed at removing contaminants group by group, each of which requires a different methodology. Fortunately, although complex, conversion wastewater can be treated by many of the same techniques used to treat industrial wastewater. For example, as secondary and tertiary treatment, a coal conversion wastewater processing scheme may include (1) physical ammonia removal, preferably through ion exchange, leaving a sufficient concentration of ammonia to serve the nutritional requirements for subsequent biological operation; (2) phenol removal via solvent extraction or biological oxidation in a biochemical reactor; (3) nitrification (if required) of the remaining ammonia to nitrate in a second biochemical reactor; (4) denitrification (if required) of the nitrate to nitrogen gas in the third and final reactor; (5) polycyclic compound removal by carbon adsorption; and (6) trace metal removal.¹³

Spent wastewater sludge, about which little is known but which may resemble that from municipal or industrial wastewater treatment, will require disposal as a solid waste. The most important constituents of this sludge are trace elements, which, when removed from the spent wastewater by the best known methods, may accumulate as indicated in Table 4b.2.8. Leaching of

Table 4b.2.8. Estimate of trace element effluents from wastewater treatment facility (WWT)

Constituent	Quantity entering WWT		Best removal efficiency (%)	Emission rate ^a in final liquid effluent		Rate of accumulation in WWT sludge	
	lb/day	kg/day		lb/day	kg/day	lb/day	kg/day
As	182	83	97.1	5	2	177	80
B	200	90	Unknown	Unknown		Unknown	
Be	6	3	99.5	Neg.		6	3
Cd	31	14	99.6	Neg.		31	14
Cr	Neg.		99.3	Neg.		Neg.	
F	122	55	Unknown	Unknown		Unknown	
Hg	4	2	98.3	Neg.		4	2
Mo	15	7	80	3	1	12	5
Ni	101	45	99.5	1	0.5	100	45
Pb	441	200	99.4	3	1	438	199
Se	31	14	95	2	1	29	13
V	198	89	97.8	4	2	194	87
Zn	540	245	94	32	15	508	230
Cl	25,200	11,430	Unknown	Unknown		Unknown	
Ti	1,400	635	98.5	21	10	1379	626
Sb	9	4	72	3	1	6	3
Co	Neg.		95	Neg.		Neg.	

^aBased on 10,000 tons/day (9000 metric tons/day) of clean coal feed having a trace element composition equal to the average of 101 U.S. coals and the use of removal processes demonstrating the highest removal efficiency for each element.

potentially hazardous trace elements into surface waters or groundwaters constitutes a serious environmental hazard.

4b.2.1.2.6 Utility Production

In all cases except the CO₂ Acceptor process, a large utility power plant will be used to generate process steam and electric power. Various utility processes use fuels ranging from clean coal (as fed to the gasifier) to low-Btu fuel gas. Emissions of SO_x, NO_x, and particulates will be quite varied but will be held below specified maximum values by legislation regarding performance standards for new stationary sources. Fly-ash particulates will contain certain of the trace metals found in the coal. Other trace elements will be vaporous at stack temperatures and will be emitted as flue gas. Sources of residuals may be slurried ash and spent limestone slurry from the flue gas desulfurization unit. These, too, will depend on the type of fuel fired and, if fired with coal, will resemble effluents and wastes characteristic of conventional coal-burning power plants. (Refer to Sects. 4a.3.2.4 and 4a.3.2.7.)

4b.2.1.2.7 Cooling Towers

Much of process cooling is done by first recirculating cooling water through heat exchange equipment and then wet-cooling towers for temperature reduction by direct heat exchange with ambient air. Because cooling tower makeup is a large sink for water, treated process wastewater may be a major source of recycled water. This water may have trace quantities of contaminants remaining after treatment, in addition to chemicals added to the tower as corrosion and biological growth inhibitors. As air contacts the water in the tower, stripping occurs, thus opening the possibility for a variety of contaminants to become air pollutants. Entrained droplets also carry out dissolved and suspended materials. However, modern cooling towers have extremely low drift,

which reduces this hazard. Even pure water vapor leaving the tower is often considered a serious nuisance problem due to fogging, icing, and meteorological influence. Because of the huge volume of air moving through the tower these aspects can take on environmental significance.

Possible contaminants in the gas stream and in entrained mist are (1) zinc and chromium compounds, (2) chlorine, (3) sulfuric acid, (4) phosphates, (5) phenols, (6) copper complexes, (7) ammonia, (8) carbon monoxide, (9) cyanide, (10) thiocyanates, and (11) trace elements.

4b.2.1.2.8 Liquefaction Processes

Liquefaction processes share many of the unit operations inherent in processing schemes directed at the production of high-Btu substitute natural gas (SNG) and medium-Btu fuel gas. In fact, gaseous products are usually produced in liquefaction processes. These three categories of coal conversion share the following operations for which the effluents are expected to be similar: coal preparation, coal storage, acid gas removal, sulfur recovery, tail gas cleanup, gasification, gas quenching, dust removal, shift conversion, oxygen production, steam and electricity production, flue gas desulfurization, cooling towers, product or by-product storage, and extensive wastewater treatment. Of these operations, the gasification step yields the widest number of variations: Whereas SNG and fuel gas processes strictly gasify coal, the liquefaction processes may gasify coal, an oil-slurried filter cake (containing ash and unreacted coal) from raw oil purification step, or vacuum bottoms from the distillation of raw product oil (a slurry of raw heavy oil fractions, unreacted coal, and ash). In some cases—the COED process, for example—coal pyrolysis generates the basic raw synthesis gas.

The unique effluent problem associated with liquefaction is leaks from the high-pressure operations [2000 to 3000 psig (1.3 to 2 MPa)] generally associated with liquefaction steps. Controlling materials flowing at these pressures in order to eliminate fugitive emissions and leaks is exceedingly difficult. Refinery experience has indicated that these emissions are most often found around pumps, valves, seals, and moving machinery, or during pressure letdowns, pressure releases, process shutdowns, and periodic cleaning and maintenance. The problem is compounded by the fact that liquid coal derivatives are the concentration point of many aromatic hydrocarbons, some of which are highly toxic and/or carcinogenic. An extensive list of the hydrocarbons found in coal tar and pitch may be found in ref. 8.

Sexton identified the following aromatic and aliphatic compounds from a 300-lb/day (135-kg/day) pilot plant operated in West Virginia.¹⁴

Heavy oil stream (>320° C bp)

Anthracene	Chrysene
Dihydroanthracene	Perylene
Phenanthrene	Picene
Pyrene	

Middle oil stream (260° to 320° C bp)

Dimethylnaphthalenes	Acenaphthene
Biphenyl	Fluorene

Light oil stream (<260° C bp)

Pentane	Heptane
Pentene	Heptene
Cyclopentene	Hexene
Hexane	Benzene
Methylcyclopentane	

In the light oil stream, Sexton broke the composition down into three fractions: an acidic fraction containing phenolic compounds, (2) a basic fraction containing nitrogen bases such as the primary, secondary, and tertiary nitrogen compounds, and (3) a neutral fraction containing aromatics and the high-molecular-weight aliphatic compounds. The contents of these three fractions are as follows:

Acidic (phenolic) fraction

Phenol	Indanols
Cresols	β -naphthol
Ethylphenols	Phenylphenols
Xylenols	Pyrocatechol
Propylphenols	Resorcinol
Methylethylphenol	Methylresorcinol

Basic (nitrogen bases) fraction

Primary	Secondary	Tertiary	
Aniline	Pyrrole	Pyridine	Trimethylpyridines
Toluidines	Indole	Methylpyridines	Quinoline
Ethylanilines	Methylindoles	Ethylpyridines	Methylquinolines
Dimethylanilines	Carbazole	Dimethylpyridines	Isoquinoline
Naphthalamines		Propylpyridines	Methylisoquinoline
		Methylethylpyridines	

Neutral fraction

Aromatic		Aliphatic	
Toluenes	Trimethylbenzene	Decane	Tridecane
Xylenes	Tetrahydronaphthalene	Undecane	Heptadecane
Ethylbenzenes	Naphthalene	Dodecane	Ethylcyclopentane
Propylbenzenes	Methylnaphthalenes		
Ethyltoluenes			

A recent study was conducted by the Ralph M. Parsons Company for the Office of Coal Research to create a preliminary design for a demonstration-scale plant to produce clean boiler fuels for coal.¹⁵ Environmental factors played an important role in the study. Effluents from wastewater treatment facilities in coal conversion processes draw a great deal of attention due to the high contaminant loading in process wastewater. Table 4b.2.9 gives an estimate of contaminant concentrations leaving a 10,000-lb/day (4.5-metric ton/day) (coal feed) demonstration plant in treated wastewater. The estimated total flow rate is 1960 gpm (7.42 m³/min) and the contaminant loadings in the discharge stream are compared to state standards where they are available. The inlet to the wastewater treatment facility is fed by cooling tower blowdown (making up half the total inlet flow), sanitary wastewater, boiler blowdown, treated oily water, and stripped plant sour water. All contaminants meet existing state standards, except for phenols, chromates, and zinc, for which further treatment is necessary.

Table 4b.2.9. Estimated waste bio-pond effluent concentrations for demonstration plant

Total estimated flow to bio-pond of 1060 gpm (4.01 m³/min) $\approx$ 12.8 $\times$ 10⁶ lb/day (5.8 metric tons/day) for 10,000 tons/day (9000 metric tons/day) coal feed

Constituents	Biological charge		Biological effluent		Percentage removal	State requirement (ppm)
	lb/day (kg/day)	ppm	lb/day (kg/day)	ppm		
Sulfide	1.48 (0.67)	0.12	0.06 (0.03)	0	96	
Ammonia	24 (11)	1.88	1.45 (0.66)	0.11	94	2.5
Acid oil	72 (33)	5.63	8.64 (3.91)	0.68	88	1.0
TOC	60 (27)	4.69				
BOD ₅	538 (244)	42	134.5 (61.01)	10.5	75	20
SS	660 (299)	51.6	165 (74.8)	12.9	75	25
Phenol	96 (44)	7.5	4.8 (2.2)	0.38 ^a	95	0.3
COD	1920 (871)	150	576 (261)	45	69	
Phosphate, as P	145 (66)	11.3	1.45 (0.66)	0.11	99	1.0
(pH)		6-9		6-9		5-10)
Chromate, as CrO ₄	91 (41)	7.1	91 (41)	7.1 ^a		0.05
Zinc	45 (20)	3.5	45 (20)	3.5 ^a		1.0
(Coliform organism)		15/100 ml		15/100 ml		400/100 ml)

^aFurther treatment may be required.

Source: J. B. O'Hara et al., "Environmental Factors in Coal Liquefaction Plant Design," *Symposium Proceedings: Environmental Aspects of Fuel Conversion Technology*, St. Louis, Missouri, May 1974, EPA-650/2-74-118, U.S. EPA, October 1974, Table 1, p. 177.

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4b.2.2 SAMPLING PROGRAMS AND METHODS FOR ANALYSIS OF OPERATION EFFLUENTS

4b.2.2.1 Purpose and Scope

Proper sampling procedures will be of crucial importance for the smooth operation of a coal conversion plant. Representative samples must be taken at key points for a given process. Sampling must be repeated at times such that the required information on any changes is obtained. An important consideration in sampling operations is to ensure that the concentrations of the determinants do not change between sampling and analysis. Failure to achieve these aims will render the analytical results invalid for their intended purposes. Carefully planned sampling techniques along with subsequent analytical and data handling methods will be vital to a coal conversion facility. Useful information on sampling programs is given by Wilson¹ and in Part 2 of this handbook.

4b.2.2.2 Chemical and Instrumental Methods of Analysis

Methods for ambient sampling and analysis of organic compounds, trace elements, airborne pollutants, particulates, and other pollutants are described in Sects. 2.1.3.3, 2.1.4.3, and 3.1.2. Cyanide and sulfide will be potential additional pollutants introduced during the operation of a coal conversion facility.

Analytical procedures are constantly being modified so that the fractions they produce reflect changes in the process that created them. In a recent research report,² chromatographic procedures are outlined for a general molecular-type separation of the oils after asphaltenes and benzene insolubles have been removed by solvent extraction. The separations discussed give four classes of compounds: (1) saturates-hydroaromatics, (2) polynuclear aromatics, (3) polar hydrocarbons, and (4) asphaltenes. Further separation of the asphaltenes into acid, neutral, and base components is rather unique and may lead to new concepts of the distribution of functional groups. This distribution is rather sharp and unexpected for such a complex system as coal liquefaction products. The separation of phenols from coal liquids by thin-layer electrophoresis is also reported. This is a new approach and promises to expand the ultimate characterization of the oil and asphaltene fractions.

The reader is referred to ref. 3 for a detailed discussion of many recommended methods of analysis for solid, liquid, and gaseous effluents from a coal conversion plant. Section 4a.5 also treats this subject.

4b.2.2.2.1 Solid Samples

These samples should be analyzed for trace and minor constituents. The initial step for most trace-element analysis is ashing of the solid sample in a low-temperature ash plasma machine, with subsequent dissolution in the proper acid mixture. Due to volatility, some elements (such as mercury) will be virtually lost during the process. As a result, a duplicate sample will be needed for analysis by an appropriate analytical scheme. Elements that undergo considerable volatilization in coals include arsenic, beryllium, bismuth, cadmium, chlorine, fluorine, lead, mercury, nitrogen, selenium, sulfur, tellurium, vanadium, and zinc. Many of these are, of course, the more toxic elements, toward which environmental concern is directed. Even though the losses of each are high, all are expected to be effectively scrubbed from the product gas stream prior to methanation and recovered in various by-product or waste streams.

Some elements are retained by the ash material or are lost at low (<10%) levels during gasification of bituminous or lignite coals. These include barium, cobalt, iron, lithium, magnesium, molybdenum, nickel, potassium, samarium, silicon, sodium, and titanium. An NBS standard reference coal sample should be analyzed concurrently to ensure the accuracy of the analyses. (The reader is also referred to Sects. 2.1.4.3 and 3.1.2.)

4b.2.2.2.2 Liquid Samples

These samples include any process unit tars and oils, quench liquor, benzene, toluene, xylene, recycled wastewater, phenols, and ammonia. Some liquid samples will contain large quantities of solids and organic materials. Aqueous samples should be tested for BOD₅, COD, color, oil and grease, TOC, TS, TDS, TSS, and turbidity in the whole sample.^a Organic samples need to be analyzed for trace elements and organic constituents, specifically polynuclear aromatics. Any emulsified samples should be separated into three portions (organic, aqueous, and solid) by filtration and solvent extraction. The solid portion of the sample should be analyzed for trace and minor constituents and treated as any other solid sample. A measured portion of the organic phase of the sample should be evaporated carefully, wet-ashed, and also analyzed for trace elements. The aqueous portion of the sample will be analyzed similarly. EPA reference water samples should be analyzed concurrently to ensure the accuracy of the measurements. (The reader is also referred to Sects. 2.1.4.3 and 3.1.2.)

4b.2.2.2.3 Gaseous Samples

The entrained particulate matter in gas should be separately recovered by filtration and analyzed for trace elements using the analytical methods for solid samples discussed in the above-mentioned sections. The gases and vapors collected in the freeze-out apparatus will be combined and analyzed for trace elements, phenols, sulfur, and nitrogen. Considerable water vapor will condense and freeze from some samples, such as pretreater off-gases. The volumes of water can be reduced by preconcentration of the samples to render them more manageable for analysis, mainly by atomic absorption spectroscopy and colorimetric methods. Provisions should also be made to recover and determine the concentration of polynuclear aromatics in the effluents of all the stacks in the plant. (The reader is also referred to Sects. 2.1.3.3, 2.1.4.3, and 3.1.2.)

4b.2.2.2.4 Cyanide

Two methods⁴ are recommended by the EPA for the determination of total cyanide in various waters and wastes. A titration procedure using silver nitrate with a *p*-dimethylamine-benzal-rhodanine indicator is used for measuring concentrations of cyanide exceeding 1 mg/liter (0.2 mg/200 ml of absorbing liquid). A colorimetric procedure is used for concentrations below 1 mg/liter of cyanide and is sensitive to about 0.02 mg/liter.

Cyanide as hydrocyanic acid (HCN) is released from cyanide complexes by means of a reflux-distillation operation and absorbed in a scrubber containing sodium hydroxide solution. The cyanide ion in the absorbing solution is then determined by volumetric titration or colorimetrically.

^aBOD₅ is the five-day biological oxygen demand; COD, chemical oxygen demand; TOC, total organic carbon; TS, total solids; TDS, total dissolved solids; TSS, total suspended solids.

In the colorimetric measurement the cyanide is converted to cyanogen chloride (CNCl) by reaction with chloramine-T at a pH less than 8 without hydrolyzing to the cyanate. After the reaction is complete, color is formed on the addition of pyridine-pyrazolone or pyridine-barbituric acid reagent. The absorbance is read at 620 nm when using pyridine-pyrazolone or 578 nm for pyridine-barbituric acid. To obtain colors of comparable intensity, it is essential to have the same salt content in both the sample and the standards.

The titrimetric measurement uses a standard solution of silver nitrate to titrate cyanide in the presence of a silver-sensitive indicator. Total cyanide is defined as cyanide ion and complex cyanides converted to HCN by reaction in a reflux system of a mineral acid in the presence of cuprous ion. Samples should be preserved in plastic bottles with 2 ml of 10 *N* sodium hydroxide per liter of sample (pH $\geq$ 12) at the time of collection. Samples should be analyzed as soon as possible after collection. If storage is required, the samples should be stored in a refrigerator or in an ice chest filled with water and ice to maintain a temperature of 4°C. Oxidizing agents such as chlorine decompose most cyanides, and excess ascorbic acid is added to such samples prior to analysis. Interferences are eliminated by a distillation step. Sulfides interfere in the colorimetric and titration procedures and fatty acids interfere in the alkaline titration conditions by forming soaps.

In a single laboratory using mixed industrial and domestic waste samples at concentrations of 0.06, 0.13, 0.28, and 0.62 mg/liter CN, the standard deviations were ± 0.005 , ± 0.007 , ± 0.031 , and ± 0.094 respectively. Using similar waste samples at concentrations of 0.28 and 0.62 mg/liter CN, recoveries were 85% and 102% respectively.

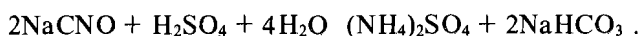
Cyanides amenable to chlorination may be determined by the two methods described above, after chlorination of a portion of the sample at a pH > 11 to decompose the cyanide. Cyanide amenable to chlorination is then calculated by difference.

A recent trend in determination of cyanide in wastes involves the application of a cyanide-ion-selective electrode.⁵ Where applicable, this technique is attractive because of its simplicity, directness, and speed. The method can tolerate up to 100 ppm of sulfide in the sample and, incidentally, detects sulfide down to 0.05 ppm. The range of the method is 0.03 to 100 ppm cyanide, and a single determination can be completed in about 3 min. A precision of $\pm 5\%$ and recoveries of 90% to 100% are routinely achieved. Thiocyanates, thiosulfates, ferrocyanides, and ferricyanides up to 100 ppm do not interfere.

Variations of the above methods are described in detail in a recent book.⁶

4b.2.2.2.5 Cyanate

Cyanate (CNO) is an intermediate in the decomposition of cyanide. Cyanate is unstable at neutral or low pH; therefore, samples should be stabilized as soon as collected by the addition of sodium hydroxide to pH > 12 . Residual chlorine should be removed by the addition of ascorbic acid. A method⁶ which has been successfully used on natural waters and wastes is based on the fact that cyanate hydrolyzes to ammonia when heated at low pH:



The ammonia concentration must be determined on one portion of the sample before acidification. The ammonia content before and after hydrolysis of cyanate may be measured by the direct nesslerization or phenate methods (see ref. 6, Sects. 418B and 418C) or by the ammonia-ion selective electrode using the standard addition technique. The detection limit is 1 to 2 mg/liter

cyanate. Metal ions may interfere by forming colored complexes or precipitating. The addition of EDTA overcomes these interferences. Metal precipitates do not interfere with the ion-selective electrode method. Organic nitrogenous compounds may hydrolyze to ammonia upon acidification. To minimize this interference, control acidification and heating closely. No data on the precision or accuracy of this method are available.

A direct method⁷ for the determination of cyanate has been described. The cyanate solution was acidified by addition of excess 1 *M* sulfuric acid and boiled to cause hydrolysis of the cyanate to ammonia and remove cyanides. If metallic impurities were present then distillation of ammonia was necessary: Ammonia was distilled by the addition of 1 *N* sodium hydroxide to make the solution basic. The ammonia was absorbed in 0.01 *N* sulfuric acid. A yellow color was developed by adding gum arabic solution and Nessler's reagent. The concentration of cyanate in the original solution was determined by measuring the percent transmission of light in a photoelectric colorimeter using a 465-m μ optical filter.

4b.2.2.2.6 Sulfide and Sulfite

The EPA recommends methods⁴ for the determination of sulfide and sulfite in various water and industrial wastes. In the method for sulfides, acid insoluble sulfides are not measured. Copper sulfide is the only common sulfide in this class. Sulfides are stripped from the acidified sample with an inert gas and collected in a zinc acetate solution. Excess iodine added to the zinc sulfide suspension reacts with the sulfide under acidic conditions. Thiosulfate is used to measure unreacted iodine to indicate the quantity of iodine consumed by sulfide. Reduced sulfur compounds such as sulfite, thiosulfate, and hydrosulfite which decompose in acid may yield erratic results. Also, volatile iodine-consuming substances will give high results. Samples must be taken with a minimum of aeration. Sulfide may be volatilized by aeration and any oxygen inadvertently added to the sample may convert the sulfide to an unmeasurable form. If the sample is not preserved with zinc acetate, the analysis must be started immediately. Similarly, the measurement of dissolved sulfides must also be commenced immediately. This method is suitable for the measurement of sulfide in concentrations above 1 mg/liter.

For the determination of sulfite an acidified sample containing an indicator is titrated with a standard potassium iodide-iodate titrant to a faint permanent blue end point. The temperature of the sample must be below 50° C. Care must be taken to allow as little contact with air as possible. For example, do not filter the sample and keep the buret tip below the surface of the sample. Other oxidizable substances, such as organic compounds, ferrous iron, and sulfide are positive interferences. Nitrite gives a negative interference by oxidizing sulfite when the sample is acidified; this is corrected by either using a proprietary indicator which eliminates nitrite or by adding sulfamic acid. Copper and possibly other heavy metals catalyze the oxidation of sulfite; EDTA is used to complex metals. A blank must be run. The minimum detectable limit is 2 to 3 mg/liter SO₃.

The precision and accuracy for the determination of sulfide and sulfite have not been established. For a general discussion and full details of these methods consult ref. 6.

REFERENCES FOR SECTION 4b.2.2

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2. F. K. Schweighardt, *Chromatographic Characterization of Coal Liquefaction Products*, PERC/RI-77/3, 1977.

3. M. Attari, M. Mensinger, and J. Pau, *Initial Environmental Test Plan for Source Assessment of Coal Gasification*, EPA-600/2-76-259, 1976, pp. 41-73.
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6. American Public Health Association, Inc., *Standard Methods for the Examination of Water and Wastewater*, 14th ed., pp. 361-381, 1975.
7. E. J. Serfass, R. F. Muraca, and D. G. Gardner, *The Colorimetric Determination of Cyanates in Effluents*, Lehigh University, Ohio River Valley Sanitation Commission, Cincinnati, Ohio, 1952.

4b.2.3 MONITORING FOR PHYSICAL-CHEMICAL IMPACTS ON THE TERRESTRIAL ENVIRONMENT (SOILS)

This section addresses the physical-chemical effects of plant operations on soils. Later sections are devoted to the effects on drainage (Sect. 4b.2.4.1) and terrestrial ecology (Sect. 4b.3.1). Continuity with the preconstruction and construction monitoring programs discussed in Sects. 2.1.1 and 3.1.3 is important.

No further visual disturbance or compaction of soil is anticipated during postconstruction plant operations. Therefore, low-altitude aerial photographs are not required for monitoring impacts on soils during the operation of the plant.

Because effluents from the process, landfills, and holding facilities may alter the soil chemistry, it will be necessary to take soil samples and field test for pH, salinity, and toxic materials as described in Sects. 2.1.1.2.2 through 2.1.1.2.4. Samples should be randomly selected as specified in Sect. 2.1.1.3 for baseline sampling rather than spot collected as in monitoring during the construction phase. Chemical methods for analysis are described in Sects. 2.1.4.3, 3.1.2, and 4b.2.2.2.

4b.2.4 MONITORING FOR PHYSICAL-CHEMICAL IMPACTS ON THE AQUATIC ENVIRONMENT

4b.2.4.1 Hydrologic Monitoring of Surface Water

4b.2.4.1.1 Impact of Operation on Surface Water

The flow characteristics of surface water impacted by the operation of a coal conversion plant are the current patterns and the water use patterns. Since little or no outfall of liquid discharge is anticipated due to the legislated mandate to achieve zero discharge, the impact of a plant on the flow characteristics will be generated by the intake. When the plant is operational, the water intake structure will alter the current and change the nature of sediment transport. In alluvial rivers, meanders or changes in aquatic habitats can result. Facilities that are sited near surface water with critical low flow periods may cause water availability problems downstream.

The temperature characteristics of surface water can be changed by plant operation. Increases in temperature can arise from the modifications that are made to the bank or shoreline and the alteration of flow characteristics in backwater regions. Decreases in temperature can result from changes in the flow characteristics and increases in turbidity.

Because of the changes in the flow characteristics and in the land use patterns, erosion and sedimentation are likely to change during operation. Local changes near the intake structure are a certainty, causing possible silt accumulation or undermining of the structure. Further changes in erosion patterns can result from fugitive runoff from the plant site. Changes in erosion and sedimentation are detected by bed sampling and water quality investigations.

4b.2.4.1.2 Monitoring Program

The monitoring program for operation must have as its core the continuation of portions of the baseline monitoring program. A continuation of the monitoring techniques used at the originally selected monitoring points cannot be overstressed. Additions to the monitoring program that were made during the construction phase should be continued during the initial period of operation in order to observe any long-term effects. Other additions to the monitoring program may be required to reflect site-specific conditions and to determine operating conditions. These additions may be suggested in the environmental impact statement (EIS).

The necessary flow characteristics to be monitored during operation are the intake flow rates and the velocity of the fluid at the intake structure. The intake flow rate should be monitored for quantity of fluid withdrawn and the temporal variations in withdrawal rates. A continuous monitoring of this parameter should be included in the intake conduit and should be conducted using a flow meter and thermograph display. A digital recorder can be used for data collection for easier data analysis. The fluid velocity at the intake structure should be determined around the entire circumference of the structure so as to determine any nonuniformity in current patterns. This determination should be made during fully operating conditions. During this determination, additional data regarding stage, temperature, current patterns, and sedimentation in the neighboring surface waters should be collected.

Monitoring of temperature characteristics requires little change except for site-specific inclusions recommended in the EIS. Operating characteristics can be typified by adding one fixed, continuous monitoring thermistor (or other temperature sensor) at the intake port.

Erosion and sedimentation characteristics should be monitored by the procedures used for baseline monitoring (described in Sect. 2.1.2.3.5) with the inclusion of one sampling location at the intake site. Stream bed samples should be made at least once every month for the first full year of operation to detect local changes at the intake site. Close attention should also be paid to the water quality tests for suspended solids at the intake site. Since the intake site is the first location that is likely to show the effects of changes in sedimentation, accuracy in data gathering is important.

4b.2.4.1.3 Indicators of Impacts During Initial Startup

Possible indicators of unanticipated impacts should be carefully watched for during the initial startup period. The flow characteristics of the surface water often are the easiest to examine for any unexpected impact. Evidence of changes in the flow are most obvious near or at the intake structure. Unexpected change in surface patterns (rapids, upwelling, vortices, foam, trash) are indicators of possible significant impacts. In neighboring backwaters, the collection of trash or the presence of calm waters that were previously rapidly flowing can indicate a change of habitat or increased temperature. The presence of unexpected change in the flow requires additional monitoring if a threat to the intake structure or aquatic environment is likely. A possible threat to the intake structure would be chipping of concrete that might threaten the structural integrity.

The presence of deadwater may be the first indicator of an unexpected elevation in the temperature of surface water. Later indicators of such an increase include the presence of dead fish and changes in odor and color. If any of these are evident, the monitoring program should be modified to gather additional information on temperature changes.

Indications of increased sedimentation and erosion will be visible near the intake or at the intake itself. Additional indicators include the deterioration of the bank or shoreline and a change of color in the water. Increased erosion is of special concern due to the fugitive emissions which may be transported with the runoff.

4b.2.4.1.4 Future Revision

It is beyond the scope of this handbook to explicitly outline the review procedure for a coal conversion plant, but as the plant operating characteristics become understood a reduction in the monitoring effort is appropriate. Effects to the hydrological environment do not have a long time lag before the impacts are felt except for some impacts due to sedimentation. After a period of one year of full operation a critical review should be able to compare the measured impacts with the predicted impacts with some confidence. A favorable comparison would suggest a reduction in all three of the hydrological areas: flow characterization, thermal characterization, and erosion and sedimentation characterization. The upstream site for flow measurement and sediment measurement might be abandoned. Sufficient flow data would only require stage data and intake data, except for unusual river events. Sediment data gathering frequency might be reduced to quarterly or semiannually. Sufficient temperature data might include only the intake temperature. Periodic visual inspection of the surface water for unusual changes would probably be sufficient for the remaining hydrological features. Site-specific requirements must be considered, however, prior to any significant reduction in the monitoring effort.

4b.2.4.2 Surface Water Quality Monitoring

When a coal conversion plant begins operation, water quality monitoring objectives will shift to

1. verifying impacts of operating the facility predicted by the EIS
2. detecting unforeseen impacts
3. determining the effectiveness of waste handling and waste disposal systems
4. providing guidance in designing measures for mitigating any unacceptable impacts.

Generally, operational monitoring should maintain continuity with baseline monitoring so that valid "before and after" comparisons can be made. The operational monitoring program must also be coordinated with any related research efforts, especially research on transport mechanisms, toxicological properties, metabolic transformations, and pathways of degradation of materials which might be released into the environment. Where possible, results of such research should be integrated into operational monitoring.

4b.2.4.2.1 Sampling Effort

Initially, there should be relatively frequent monitoring of the quality of runoff, storm drainage, and leachate from coal piles and the plant. Such monitoring should be done during or shortly after precipitation, especially after heavy rainfall. If there are serious water quality problems associated with drainage, these can be identified so that control and mitigation measures can be implemented.

During operations, sampling of water in the receiving environment should continue on a routine basis. After the first few years of operation, monitoring of in-plant waste streams will likely also become routine. Sampling frequency may well be defined by regulatory guidelines. During this period intensive monitoring should accompany changes in plant operation or feedstock, accidents, spills, and other inauspicious events (e.g., fishkills or unusual weather).

After several years, operational-phase monitoring personnel should have considerable experience with the site. This may allow eventual streamlining of the monitoring program by reducing the sampling frequency at less sensitive locations.

4b.2.4.2.2 Parameters

The anticipated impacts will be the primary determinant of which parameters are monitored during the operational phase. Impacts of operating a coal conversion plant are discussed generally in Sect. 2.1.2.4.2. The EIS for the plant will consider the specific impacts expected, based on the details of the process being used, the design, site layout, and the abiotic and biotic characteristics of the local environment. The EIS should also define the major uncertainties and include recommendations regarding the operational monitoring program.

When the coal conversion demonstration plant first begins operation, real effluent streams from the plant, storage areas, etc. should be completely characterized after waste treatment. Also, by this time DOE research and development work on environmental impacts of coal conversion process effluents may have determined parameter priority for the monitoring programs. It is very probable that the list of parameters included in the baseline program and continued through construction will be increased rather than decreased. More refined and extensive monitoring of organic compounds may be recommended. Early determinations of the scope of operational monitoring of surface water quality should therefore be flexible. At this time, it is only possible to suggest that the parameters included in the operational phase program be at least those listed in Table 2.1.6 (Sect. 2.1.2.4.2).

4b.2.4.2.3 Sampling Locations

As the coal conversion plant begins operations, monitoring should continue at the locations established in previous stages. In addition, however, monitoring should begin at some new locations. The various waste streams should be monitored: for example, drainage from coal storage piles, coal ash slurry, sludge from the water treatment/recycling facility, storm drainage from the plant, and water and sediments from treatment ponds or holding ponds. Information about the substances found in these waste streams should be evaluated carefully. The actual content of the waste streams should be compared with the content predicted in the EIS, since any differences found may require modifications of the operational monitoring program. Detailed information regarding monitoring of waste streams can be found in Part 4a of this handbook and in the EPA's *Handbook for Monitoring Industrial Wastewater*.¹

In the receiving environment, sampling should continue at the previously established locations. If sampling locations were poorly chosen originally or if they have become unsuitable due to construction activities or other reasons, these problems should have been remedied during the construction phase (see Sect. 3.1.4.3.4).

4b.2.4.3 Hydrogeologic Monitoring

The monitoring of groundwater during operation may require additions to the monitoring program previously established. These additions should be included in the findings of the EIS. They are intended to provide monitoring data that will determine the extent of predicted impacts, determine the effectiveness of waste handling systems, provide data for the design of appropriate mitigating measures, and detect any unforeseen impacts. These purposes may result in additions to the monitoring program beyond those recommended in the EIS because of unforeseen impacts. Continuation of the baseline and construction monitoring programs cannot be overstressed because of the need for an accurate comparison with operational monitoring data and because of the need for a determination of long-term construction impacts. Due to the uncertainties in the nature of the process effluents it is essential that operational monitoring be as flexible as possible in order to adjust to the early findings on plant performance. This flexibility will require close cooperation with other monitoring personnel to design and implement an effective and appropriate monitoring program.

4b.2.4.3.1 Groundwater Hydrology

During operation, the determination of construction impacts on the hydrogeologic environment may be incomplete due to the length of time required for hydrogeologic events to occur. Thus, construction monitoring should continue through the operational phase to ensure the completeness of monitoring. Plant operational monitoring should recognize that variations in hydrogeology may be the result of construction. Therefore, the plant operational monitoring program should be directed towards separating the impacts of operation from the impacts of construction.

Reductions in the monitoring program should be considered reasonable only if there is confidence in the future capabilities of the program to detect impacts on the groundwater regime and if there is no data anomaly.

4b.2.4.3.2 Groundwater Quality

When plant operation begins, the impacts of construction on groundwater quality will not immediately cease. Therefore it is important that the construction-phase monitoring program for

groundwater quality be continued during operation. Additions to the monitoring program may be recommended in the EIS. Due to the uncertainties associated with the effluents of plant processes, any additions made to the monitoring program should be flexible so that analysis of plant performance and any results gained during operational monitoring can be included.

Parameters

The parameters monitored during operation should include those monitored prior to and during construction and those based on effluent characteristics. Specific additions to the organic parameters measured should be anticipated. Monitoring for these additional parameters should be based on their mobility characteristics and their associated toxicities. Parameters to be monitored may vary with different locations at the site if the compositions of the waste ponds and solids' storage areas are considerably different. Variations in concentrations and compositions of the effluent streams underscore the need for flexibility in the operational monitoring program.

Frequency

The frequency of monitoring should be increased in some zones during operation. In the areas immediately surrounding waste ponds and solids' storage areas, monitoring should be at least monthly. Monitoring after major precipitation events in the vadose zone can provide data on the chemical character of precipitation runoff, whereas monitoring of waste ponds during dry periods in the vadose zone can provide data on pond seepage. Anomalies in the data should suggest that the sampling frequency be increased to separate long-term trends from short-term fluctuations. Monitoring beneath appropriately designed waste ponds² can provide data on pond seepage and pond overflow which will aid in the impact analysis of plant operation. After two years of plant operation, a reduction in monitoring frequency for less-sensitive locations should be considered. Reduction should be recommended only if the variation in concentrations at a specific location is small and shows little data scattering.

Location

The number of locations for groundwater sampling should be increased during operation to detect contaminants and define their concentrations. Table 4b.2.10 lists locations where groundwater samples should be collected and their minimum recommended frequencies. All measurements taken should be compared with the water quality samples collected from the control well drilled during the synoptic survey. In some site-specific cases, definition of the hydrogeologic environment may require several control wells. Methods for collection of groundwater samples are discussed in refs. 3 and 4. It should be emphasized that Table 4b.2.10 represents a minimum of monitoring, with additions based on the findings of the EIS and monitoring program experience. Fewer sampling locations should be considered only after several years of monitoring when an extensive log of data is available for comparison. The considerable experience with the site may suggest that some insensitive locations not used for control purposes be eliminated.

REFERENCES FOR SECTION 4b.2.4

1. U.S. Environmental Protection Agency, *Handbook for Monitoring Industrial Wastewater*, Technology Transfer Program, Washington, D.C., 1973.

Table 4b.2.10. Minimum recommended locations and frequencies for groundwater quality monitoring

Groundwater zone	Location	Number of samples	Sampling frequency
Land surface	Wastewater ponds	1 or 2 per pond	Monthly
	Solid wastes	1 or 2 per storage area	Monthly or quarterly
	Stored solids	1 or 2 per storage area	Quarterly
Vadose zone	Under each waste pond	1 hole every 5 to 10 ft of depth of unsaturated zone	Monthly ^a
	Under each solid-waste storage area	1 hole every 5 to 10 ft of depth of unsaturated zone	Monthly ^a
	Under each solid-waste disposal area	1 hole every 5 to 10 ft of depth of unsaturated zone	Monthly ^a
	Near waste ponds	5 to 10 holes, every 5 to 10 ft in depth	Monthly ^a
	Near solid-waste storage areas	5 holes, every 5 to 10 ft in depth	Monthly ^a
	Near solid-waste disposal areas	5 to 10 holes, every 5 to 10 ft in depth	Monthly ^a
Saturated zone	Control wells	1 up-gradient of each potential contamination site, 1 for each aquifer	Monthly to quarterly
	Down-gradient of ponds, solid-waste storage areas, solid-waste disposal areas	2 to 5 for each waste site, 1 sample from each aquifer	Monthly to quarterly

^aSee text for additional considerations.

2. D. K. Todd et al., *Monitoring Groundwater Quality: Monitoring Methodology*, EPA-600/4-76-026, 1976.

3. L. G. Everett et al., *Monitoring Groundwater Quality: Methods and Costs*, EPA-600/4-76-023, 1976.

4. E. Brown, M. W. Skongstad, and M. J. Fishmann, "Methods for Collection and Analysis of Water Samples for Dissolved Minerals and Gases," *Techniques of Water-Resources Investigations of the United States Geological Survey*, 1970, Book 5, Chap. A1.

4b.2.5 ATMOSPHERIC MONITORING

4b.2.5.1 Monitoring Program

In describing the preconstruction monitoring approach, we tried to anticipate the atmospheric effluents from a coal conversion plant. Since it is possible that some of these may already exist in the local environment, preconstruction monitoring affords the opportunity to measure the existing concentration. By comparison of these data with operational data one can determine, qualitatively, if the plant has introduced new pollutants and, quantitatively, the added loading due to the plant.

The actual procedures adopted at each monitoring station during operation should differ very little from those described in the preconstruction part of this handbook. One possible difference, however, may be higher levels of some pollutants during operation than during preconstruction, thereby requiring different instruments. For example, ambient levels of CO during the preconstruction phase may be such that commercially available gas chromatographic equipment should be used. However, if higher levels of CO are present during construction, nondispersive infrared techniques may be more appropriate.

Meteorological monitoring should continue during plant operation, and the location of observation stations should be based on the same criteria used during preconstruction. If station locations were originally chosen with some idea of the plant layout in mind, these same locations should suffice during construction.

4b.2.5.2 Location of Monitoring Stations

One air quality monitoring station will probably suffice in the preconstruction phase, but at least two are recommended during the operational phase. Based on the prevailing wind direction, one station should be located upwind and the other downwind of the plant. If the direction of the prevailing wind is not well defined or if it has a seasonal variation, further study and consultation with DOE will be required. Having an "upwind" and a "downwind" station allows a mass of air to be monitored before and after it passes the coal conversion plant. Thus, pollutants in the air sampled at the downwind location which were not detected at the upwind location can be identified as having come from the plant.

The upwind station should be located about 10 building heights upwind from the plant boundary ("building height" refers to the tallest building in the complex). The location of the downwind observation station will depend on the effective height of the emissions. If the emissions are likely to be at ground level or from the roofs of normal sized industrial buildings, a location one to two times the upwind distance should suffice. However, for stack emissions or for lower level emissions likely to be buoyant and/or to have considerable upward momentum, a location farther downwind might be necessary. When final design parameters are available, the point where the maximum ground-level concentration occurs for elevated plumes should be calculated with the help of the meteorological parameters obtained in the preconstruction monitoring. If pollutants are being emitted at various heights, it may be necessary to have more than one downwind monitoring station.

4b.3 Biota

4b.3.1 TERRESTRIAL ECOLOGY

4b.3.1.1 Purpose and Scope

The purpose of the operational-phase monitoring program is to determine the effects of the operating coal conversion plant on the terrestrial biota. This will be accomplished by a continuation of the analytical monitoring program of the preconstruction period (Sect. 2.2.1.3). This program is intended to reveal the fate of toxic coal conversion plant effluents in the biotic environment and to detect the effects of these effluents on the functioning of the biotic community for a broad array of possible facilities and ecosystems. Site-specific problems may call for additional specific monitoring programs or modification of the programs described. These site-specific problems will be described in the environmental impact statement (EIS) for the project.

4b.3.1.2 Monitoring Program

The analytical monitoring program should be carried out for at least three years after the one-year startup period. The plot locations, sampling periods, and sampling methods should not be changed from those used for baseline monitoring during the preconstruction and construction periods. This continuity is essential for statistical analysis of the data collected.

After three years of operational-phase monitoring, analysis of the data may allow conclusions to be reached about the nature of project impacts, which would allow modification of the monitoring program design. Four aspects of the monitoring program may be modified: (1) sampling intensity, (2) sampling frequency, (3) scope of the program, and (4) continuation of a particular monitoring activity.

The necessary sampling intensity should have been established during the preconstruction program on the basis of the level of error variance and the sensitivity desired. However, the specified level of sensitivity may be changed on the basis of newly acquired knowledge of the dynamics of the receiving system in response to stress changes in the statistical model (e.g., discovery of a significant covariant), or changes in relevant regulations (e.g., public health standards for food contamination).

Examination of the acquired data may indicate that sampling is being carried out more or less frequently than is necessary to detect trends in the parameters of interest. For example, leaves that have been collected seasonally for chemical analysis may only need to be collected yearly once seasonal patterns of accumulation are established.

The appearance of an environmental impact of a coal conversion plant may lead to expansion of the monitoring program to confirm the impact, determine its extent, or more closely specify its character. New monitoring activities might include analysis of tissues from a greater variety of

species, histological or microchemical analysis of tissues, lysimetry, studies of reproduction and other life history parameters, and soil respirometry. In addition, experimental toxicology programs (e.g., fumigation and feeding experiments or microcosm studies) may be needed to elucidate toxicant effects. The literature should be consulted regarding the results of experimental investigations of the effects of coal conversion waste products on the environment.

Eventually, individual monitoring activities may be terminated. The key to this decision is knowledge of the distribution and rate of accumulation of toxic substances in the environment. Monitoring of ecosystem function and stress responses may be terminated if the chemical analysis of air, soil, water, and biological materials indicates that an approximate equilibrium has been achieved between input and loss of the toxic substances of interest or that input of such substances is so small as to be negligible. Substances which have a high affinity for biological materials and are slowly degraded (chlorinated hydrocarbons are the classic example) may require a long-term monitoring program. Alternately, project effects may be demonstrated which cannot be attributed to any of the monitored plant effluents. In this case the number of effluents monitored may have to be increased. Finally, the monitoring program may be modified to accommodate changes in the project or in the receiving system (e.g., reclassification of a species as threatened or endangered would require that its population size and distribution in the plant area be monitored).

The conclusion of the monitoring program is a decision as to the significance of the environmental impacts detected by the monitoring program. To some extent decisions concerning significance should be made during the design of the monitoring program. For example, if the sampling intensity is designed to detect changes in primary productivity greater than 25% of the mean, then a presumption has been made that changes smaller than this are insignificant. Beyond this level of resolution, decisions concerning significance should be based on ecological and statutory considerations.

4b.3.2 AQUATIC ECOLOGY

4b.3.2.1 Purpose and Scope

To design an efficient monitoring program to measure pollutant interactions with receiving system aquatic biota, the pollutant vectors, their modes of dispersion and transport, and their interactions with receiving system biota should be known. Since source terms for environmental impacts from coal conversion technologies are currently tentative, operational monitoring should address a broader range of potential ecological effects than might normally be addressed when effluents and their impacts are well characterized. As developed in the baseline monitoring section, the approach should be to monitor functionally important habitats and species in a food-web context in those areas expected to receive impacts.

Operational-phase monitoring will initially entail a continuation of the baseline program and appropriate aspects of construction monitoring as modified by the EIS synthesis, by DOE review, and by new information from research and development efforts. Continuity with the baseline program is important because it allows direct comparisons of before-after data at control and impacted sampling areas. Only the general form of the operational monitoring program for aquatic ecology is presented here since most of it will be site-specific.

Certain aspects of the current state of the art of environmental monitoring also necessitate this general approach. For example, performance criteria for receiving systems as ecological entities are currently being studied in applied environmental research and the results are anticipated to be available for application at coal conversion demonstration plants during their operational phase. Inputs from current applied ecology research efforts should markedly upgrade the cost-effectiveness and quality of operational environmental monitoring programs as conceived to date.

4b.3.2.2 Components of Operational Monitoring Program

4b.3.2.2.1 Field Sampling Program Design

Continuity with baseline monitoring program

Continuity with the baseline monitoring effort (Sect. 2.2.2.3) is inherent in the early stages of the operational monitoring program. Generally, the initial sampling procedures, methods, and stations should be the same as those used in the baseline monitoring program as modified by the EIS, or by results from research and development efforts.

Spatial considerations

Operational-phase monitoring should consider point source effluent locations (if any), nonpoint source effluent areas (e.g., contaminated surface runoff), water intake structures, and comparison areas as used in the baseline sampling program. Pollutant transport and dispersion relationships and other criteria such as movement of aquatic organisms should be used to define the spatial limits of sampling. The contractor should implement all site-specific considerations used in the baseline analytical monitoring program (Sect. 2.2.2.3.3), as modified by the EIS synthesis and research and development efforts, at each of the above sites if applicable to the plant design (e.g., point source release of aqueous effluents). Near- and far-field impacted areas should be included. Nonpoint source contamination of groundwaters (e.g., leaching from storage ponds) that enter surface receiving waters should be considered.

Statistical sampling design

For each predicted impact and for general ecosystem performance monitoring, the contractor should develop a statistical sampling program. Where practical, it is desirable to detect a level of impact within limits imposed by the field sampling error (evident from baseline sampling) and the level of impact that has been determined or chosen to be significant (e.g., 25% of the baseline level of production of some biological component). The particular impact detection level should be derived from ecological, statutory, or other considerations, and it should be used to calculate the intensity of sampling necessary to adequately monitor for the predicted impact. The intensity of sampling should also be commensurate with the degree of impact expected and the importance of the impact to the essential functioning of the receiving ecosystem. Other aspects of statistical sampling design should follow guidelines discussed in Sect. 2.2.2 of this handbook and standard guides.¹

4b.3.2.2.2 Monitoring of Aquatic Biota

Aquatic biota in potentially impacted and in comparison areas should be monitored as in the baseline program (Sect. 2.2.2.3) with modifications given in the EIS or by DOE. Spatial and temporal uses of important biotic habitat by the important functional components of the receiving system biota should continue to be emphasized.

Modifications to the baseline program may be necessary to verify impact predictions and to concentrate monitoring in those areas (habitats) and for those target organisms or biotic communities that are predicted to receive significant impact. This will be especially true as detailed information on the environmental effects of coal conversion effluents and accurate predictions of environmental impacts develop.

4b.3.2.2.3 Ecosystem Performance Measurements

Functional process rate measurements should be included in the operational-phase monitoring program to augment the data collected on aquatic biota. As stated in the baseline monitoring section, it is important to perceive converging lines of evidence to accurately define environmental impacts on an ecosystem level. Aggregate response variables of the important functional components of the receiving system will be measured in both control and impacted areas as discussed in Sect. 2.2.2.3.3.

4b.3.2.2.4 Bioaccumulation of Toxic Substances

The operational monitoring effort should address the potential for chemicals released from the coal conversion plant to be bioaccumulated in the receiving system, resulting in disruption of biotic functions or leading to ingestion of toxic substances by man through consumption of aquatic organisms. As bioaccumulation pathways of toxic coal conversion effluents or biocidal agents used in plant operation through aquatic food webs become better known, it is anticipated that indicator species or indicator communities can be efficiently used to monitor site-specific rates of bioaccumulation. These studies will be compared with the normal chemical body burden analysis (Sect. 2.2.2) and will be designed to use sampling frequencies and sampling intensities commensurate with the intensity of the expected problem. Target organisms of functional importance or of commercial or recreational importance should be especially considered.

4b.3.2.2.5 Entrainment and Impingement Mortality

Although water consumption or use by coal conversion processes is expected to be low compared with other energy technologies, the location of facilities near surface water supplies experiencing large seasonal flow variations may necessitate a consideration of the entrainment and impingement effects on the aquatic system biota. For instance, impingement problems of fish may occur during seasonal stress periods (e.g., winter cold) or during periods of behavioral changes (e.g., increased swimming activity) correlated with physical-chemical changes in the habitat.

Potential entrainment and impingement impacts will be evaluated in the EIS on the basis of the location and design characteristics of intake structures, the seasonal flow data for the surface water to be used, the nature of the aquatic system biota, their persistence near the intake structures, the percentage of the total flow that will be drawn into the coal conversion plant, and other site-specific considerations. In many cases, the percentage of flow used will be insignificant compared with the total flow of the receiving system and monitoring may only consist of a periodic check.

4b.3.2.3 Modification of Operational Monitoring Program

The operational monitoring program should continue the essential elements of the baseline program as modified by research and development and site-specific EIS synthesis until predicted impacts are evaluated or until uncertain environmental effects are found to be insignificant. Since there will always be an uncertainty associated with the analysis of environmental impact significance, the operational-phase monitoring program should not be discontinued altogether. However, where an adequate time series of operational monitoring data does not demonstrate significant impacts as defined within the constraints of impact assessment error, those sections of the operational monitoring program should be reduced or deleted.

It is anticipated that the initial period of the operational monitoring program should continue for about the first three years of plant operation. DOE should be consulted to determine which startup events should be monitored and the desired monitoring intensity. A three-year monitoring period, following a one-year startup, is justified according to the minimum observation period needed to show permanent changes in age structures of fish populations or to perceive permanent shifts in benthic macroinvertebrate community composition if impacts are not acute in nature. The actual monitoring period will depend on a number of variables, including the rates of pollution migration through the receiving ecosystem, the scale of the resultant impacts, and statutory requirements. At the end of the initial operational monitoring effort, a thorough evaluation of the utility of the individual elements of the monitoring program should be undertaken by DOE, and modifications to the operational program should be implemented according to the impacts observed and the long-term needs of the operational monitoring program as discussed below.

The operational monitoring effort has a number of different long-term purposes. Fulfillment of statutory requirements for protection and enhancement of the environment of the receiving system without degradation is an obvious need. Monitoring at this level will generally entail checks to ensure that concentrations of chemicals do not reach levels toxic enough to result in loss of organisms in the receiving system. The general state of the receiving system over time is also included in statutory requirements. Functional process variables should be important determinants of the state of the receiving system.

In addition to statutory requirements there is the need to monitor for long-term chronic pollution impacts on the receiving system biota. It may be initially found from laboratory research and development efforts that chronic-level pollutant effects from coal conversion technologies

cannot be separated in the short term from background noise. Site-specific synergistic or antagonistic pollutant interactions may also warrant long-term monitoring to develop a data base adequate to assess the level of impact. The long-term operational monitoring program should function to detect impacts as well as to monitor those that are predicted. It is also recognized that time constraints on monitoring of long-term impacts will be imposed by the length of operation of a particular facility.

Impacts that have been determined to be significant should be included in the long-term monitoring effort. Monitoring efforts for these impacts can usually be fine tuned according to the degree of understanding of the cause-effect relationships. The effectiveness of mitigating measures should also be monitored over the long term.

In summary, the long-term operational monitoring program should include only those target organisms, biotic communities, or functional process rates which have been perceived to suffer significant impacts or which will be used as indicators of pollution events or the health of the receiving ecosystem. The date at which a minimum set of parameters of proven utility is developed is indeterminant at this time and must evolve with the long-term environmental assessment programs.

REFERENCE FOR SECTION 4b.3.2

1. Battelle Pacific Northwest Laboratories, *Environmental Impact Monitoring of Nuclear Power Plants. Source Book of Monitoring Methods*, vol. 2, 1975.

4b.4 Socioeconomic Impacts

4b.4.1 INTRODUCTION

The monitoring of socioeconomic impacts is likely to require less effort during the operational phase of the project than during the preceding phases. This decline in the need for monitoring may be attributed to several factors. First, the overall impacts that are either directly or indirectly attributable to the plant will probably be less severe during this phase of the project. Excess demands will have declined somewhat as labor, materials, and service requirements are reduced following completion of the construction effort. Also, supplies of these goods will increase as a sufficient amount of time elapses for capacity adjustments to occur and as local entrepreneurs and public officials become convinced of the financial viability of required capital investments. The net result of these occurrences is a tendency toward a state of equilibrium between the demands for and supplies of crucial goods and services (both public and private). Shortages begin to disappear and prices return to equilibrium levels. In addition to this probable decrease in adverse social and economic impacts, the basic problem of identifying plant-related effects becomes increasingly difficult during the operational phase. As the length of time between the prediction and the observation increases, the influence of unforeseen exogenous events becomes more important and the difficulty of tracing the source of forecasting errors rises. Therefore, both the need for monitoring and the potential benefit from monitoring decline considerably during the operational phase. As a result, less effort should be expended in monitoring during the operational phase than in the preconstruction and construction phases.

Nevertheless, the rate of improvement in and the final level of services reached, as well as changes in population and employment, should be observed in the operational phase. To accomplish this, the same basic types of monitoring information needed in the construction phase should be gathered in the operational phase. The principal information categories are: (1) descriptions of the employment, population, and land-use changes resulting from the plant operation; (2) descriptions of the wages, taxes, and purchases generated by plant operation; and (3) descriptions of the impacts of these population, employment, and fiscal changes on various aspects of community infrastructure such as housing, schools, transportation, etc.

4b.4.2 POPULATION AND EMPLOYMENT CHANGES

Monitoring of population and employment changes resulting from plant operation should be done in the same way as construction-phase monitoring (Sect. 3.3.2). A few questions about satisfaction with local services and/or the general quality of life might also be added to the survey questions suggested for the construction stage. If the resources are available, questions about changes in the quality of life might also be asked of long-term residents who lived in the community before the plant was located there.

4b.4.3 ECONOMIC IMPACTS

The operational-phase monitoring of economic impacts should follow the procedures that were outlined for construction-phase monitoring (Sect. 3.3.3). The wages and taxes paid and materials purchased should be determined and compared with the levels predicted during the preconstruction monitoring effort. Secondary influences can only be inferred, but gross discrepancies between predicted and observed values can be identified and the source of the error determined. Since local supply sources are likely to engage in capacity adjustments during this period, some effort might be made to identify expansions in local supply capabilities.

4b.4.4 INFRASTRUCTURE IMPACTS

The monitoring of socioeconomic impacts on the local infrastructure during the operational phase of the project should be carried out in a similar fashion to the monitoring effort carried out during the construction phase (Sect. 3.3.4). Specific areas that should be monitored are described below.

4b.4.4.1 Housing

The housing market should reach an equilibrium state in the operations phase. Evaluation of the state of the housing market can be accomplished by the techniques suggested in Sect. 3.3.4.1.

4b.4.4.2 Health Care

If a plant is located in a rural area, demands for health care may not be met even in the operations phase. Attracting physicians to rural areas is problematic with or without a plant. The ratios of population to various types of health care personnel are indicators of the adequacy of health care. Hospital occupancy rates and numbers of emergency room visits are also indicators of the level of health care.

4b.4.4.3 Transportation

In contrast to the construction phase, long-distance commuting by plant workers will be uncommon during the operations phase. Deliveries of materials and equipment also will probably place less demand on the transportation system during operations. But deliveries of large amounts of coal will usually begin in the operations phase. Railroad or barge will often be the method of coal delivery. The impacts of increased use of these transport systems should be monitored during the operation of the plant. The methods of monitoring traffic impacts suggested in Sect. 3.3.4.3 can also be used if it seems necessary.

4b.4.4.4 Education

Monitoring during the early part of the operational phase will be useful in verifying incremental enrollment projections made during the preconstruction monitoring effort and in pinpointing areas in which permanent capacity adjustments are required. Information similar to that requested for construction-phase monitoring should be obtained (Sect. 3.3.4.4).

4b.4.4.5 Police and Fire Protection

The purpose of operational-phase monitoring here is not to verify previous predictions, per se; rather, the effort is intended to serve as a check against unforeseen adverse impacts. Consequently, an examination of performance-related measures should be carried out (e.g., average response time, crime rates, etc.). Mitigative actions should be initiated if the observed conditions deteriorate below acceptable standards.

4b.4.4.6 Recreation

Operational-phase monitoring of recreational facilities should be carried out to identify areas experiencing significant overcrowding. The basic effort should follow that described in Sect. 3.3.4.6.

4b.4.4.7 Historic and Archaeological Sites

Historic and archaeological sites should have been identified in the preconstruction phase. Plans for their protection, or for the recovery of materials, should have been implemented in the construction stage. In the operational stage, monitoring for indirect impacts (e.g., visual impacts, noise) should be all that is required.

4b.4.4.8 Solid Waste Disposal

Operational-phase monitoring should describe capacity adjustments made in the local solid waste disposal system and identify any areas in which expansion is required. Contact with local officials should be maintained for such information.

4b.4.4.9 Water Supply and Wastewater Treatment

The same three basic aspects of the water supply and wastewater treatment facilities that were described for the construction-phase monitoring effort should be monitored during the operational phase (Sect. 3.3.4.9).

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