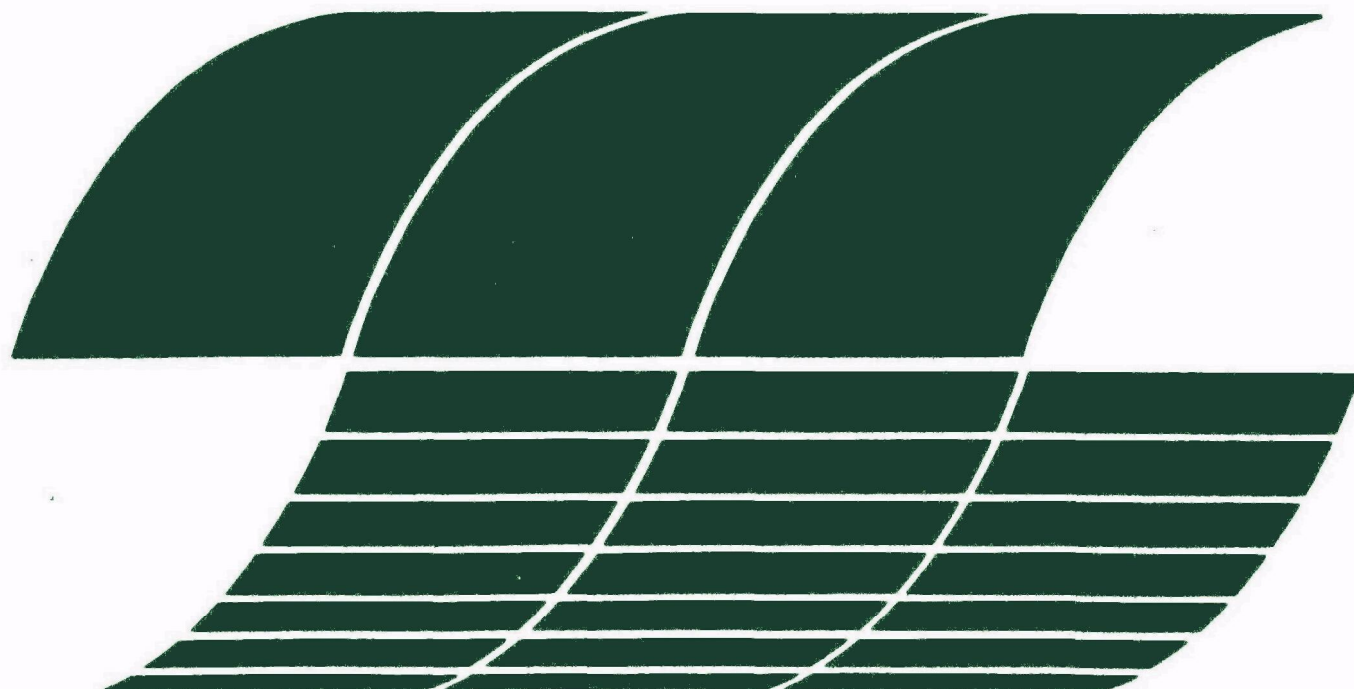




Environmental Assessment of Coal Cleaning Processes: First Annual Report; Volume II. Detailed Report

Interagency
Energy/Environment
R&D Program Report



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Environmental Assessment of Coal Cleaning Processes: First Annual Report Volume II. Detailed Report

by

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FOREWORD

Many elements and chemical compounds are known to be toxic to man and other biological species. But, our knowledge concerning the levels and conditions under which these substances are toxic is extremely limited. Little is known concerning the emission of these pollutants from industrial processes and the mechanisms by which they are transported, transformed, dispersed, or accumulated in our environment.

Portions of the Federal Clean Air Act, the Resource Conservation Recovery Act, and the Federal Water Pollution Control Act require the U.S. Environmental Protection Agency (EPA) to identify and regulate hazardous or toxic substances which result from man's industrial activities. Industrial pollutants are often identified only after harmful health or ecological effects are noted. Remedial actions are costly, the damage to human and other biological populations is often irreversible, and the persistence of some environmental contaminants may endanger future populations.

EPA's Office of Research and Development (ORD) is responsible for health and ecological research, studies concerning the transportation and fate of pollutants, and the development of technologies for controlling industrial pollutants. The Industrial Environmental Research Laboratory, an ORD organization, is responsible for development of pollution control technology and conducts a large environmental assessment program. The primary objectives of this program are:

- The development of information on the quantities of toxic pollutants emitted from various industrial processes--information needed to prioritize health and ecological research efforts.
- The identification of industrial pollutant emissions which pose a clearly evident health or ecological risk and which should be regulated.
- The evaluation and development of technologies for controlling pollution from these toxic substances.

The coal cleaning environmental assessment program has as its specific objectives the evaluation of pollution and pollution control problems which are unique to coal preparation, storage, and transportation. The coal preparation industry is a mature yet changing industry and in recent years significant achievements have been made in pollution abatement.

In focusing on the effectiveness and efficiency of coal cleaning processes as methods of reducing the total environmental impact in the use of energy derived from coal, this report describes the progress made on all facets of this program during the first year of its existence. The information derived from the studies performed will be used to evaluate the overall desirability of expanding the use of coal cleaning as a means of mitigating environmental impacts caused by the burning of coal.

ABSTRACT

Battelle's Columbus Laboratories is performing an environmental assessment of coal cleaning processes under Contract No. 68-02-2163 with the Industrial Environmental Research Laboratory [Research Triangle Park (IERL/RTP), North Carolina] of the U.S. Environmental Protection Agency (EPA). This report describes progress on this program during the first year of work. A strong base of engineering, ecological, pollution control, and cost data is being established through data gathering and systems analysis efforts.

In addition to program management, three task areas have been defined. These technically-oriented functions are: system studies, data acquisition, and general program support.

Systems studies have specifically focused on three subtasks. The development of information on coal cleaning process technology has been emphasized in the first of these subtasks, while the second has been concerned primarily with defining the technological and cost status of the control of pollutants from coal cleaning and refuse disposal operations. The third subtask relates to the establishment of criteria for meeting environmental goals. Substantial progress was made on these three subtasks and early availability of draft reports of accomplishments is anticipated. But effort on a fourth subtask designed to acquire process data was terminated to avoid duplication of the effort of another EPA contractor.

Data acquisition subtasks have been directed at the planning needed as the forerunner of the anticipated environmental field testing programs. Progress has been made in: developing and describing the overall environmental test program, developing the rationale for selection and selecting the evaluation sites, specifying the experimental testing techniques to be used, and developing the master site test plan. Based on a statistical rationale, ten unique site categories have been specified for testing; experimental techniques are based on accepted U.S. EPA and open literature methods.

General program support has consisted of: obtaining background environmental data in the vicinity of and refining a computer simulation model for use in studying the performance of the demonstration coal cleaning facility near Homer City, Pennsylvania; operating the coal cleaning information center; providing support for a sulfur emissions study for the Organization for Economic Cooperation and Development; participating in the USSR-US technical information exchange program; and studying and evaluating physical coal cleaning as an SO₂ emission control strategy. A draft report on the latter physical coal cleaning evaluation has been submitted to the Office of Air Quality Programs and Standards.

This first annual report consists of two volumes: Volume 1 - Executive Summary and Volume 2 - Detailed Report. It covers the period from July 2, 1976, through September 30, 1977.

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INTRODUCTION

This is the first annual report describing activities of Battelle's Columbus Laboratories under Contract No. 68-02-2163 for the environmental assessment of coal cleaning processes. The program is organized into three major task categories: (1) systems studies, (2) data acquisition, and (3) general program support. The program is further divided into subtasks which correspond to technical directives received from EPA. A special subtask is allocated for project management.

The following subtasks were active during the year and were designated by the three-digit numbers as indicated.

- Project Management (011)

Systems Studies

- Technology Overview (211)
- Detailed Process Descriptions (222)
- Process Data Acquisition (232)
- Develop Assessment Criteria (241)

Data Acquisition

- Develop Environmental Test Program (411)
- Select Evaluation Sites (421)
- Develop Experimental Techniques (431)
- Test Plan Development (451)

General Program Support

- Coal Cleaning Demo Planning (813)
- Coal Cleaning Information Center (821)
- OECD Support (831)
- US-USSR Information Exchange (841)
- Evaluation of Physical Coal Cleaning as an SO₂ Emission Control Strategy (851)

The activities for these various subtasks are described in sections of the "Executive Summary" and "Detailed Report" as indicated by Table 1.

In addition to completion of the ongoing tasks listed above, future activities in the remaining 21 months of the contract are planned for the following subtasks. These efforts are briefly described under "Future Efforts".

TABLE 1. RELATIONSHIP OF ORGANIZATION OF BATTELLE'S
FOR ENVIRONMENTAL ASSESSMENT OF COAL CLEANING
TO EACD* ANNUAL REPORT CATEGORIES

Category in Management Summary and Detailed Report	Subtask Number**												
	Systems			Data				General Program					
	Studies	Acquisition			Support								
	211	222	241	411	421	431	451	813	821	831	841	851	
<u>Current Process Technology Background</u>													
Process Information	x												
Status	x	x											
Schedules	x												
Priorities for Further Studies	x												
<u>Current Environmental Background</u>													
Potential Pollutants and Impacts in All Media	x	x	x										
Federal and State Standards and Criteria			x										
Other Regulatory Requirements			x										
Occupational Health/ Epidemiological Data			x										
Dose/Response Data			x										
Transport Models			x										
<u>Environmental Objectives Development</u>													
Establishment of Permissible Media Concentrations			x										
Define Emission Goals			x										
Non-Pollutant Impact Goals			x										
Bioassay Criteria			x										
Decision Criteria for Prioritizing Pollutants			x										
Methodologies Being Developed			x										
Source Analysis Models			x										
<u>Environmental Data Acquisition</u>													
Existing Data for Each Process	x												
Sampling and Analytical Techniques						x							
Test Program Development				x	x		x						
Preoperational Environ- mental Monitoring								x					
MEG Pollutant List and Recommended Additions for Consideration			x										
<u>Control Technology Assessment</u>													
Control Systems and Disposal Option Information		x											
Control Process Pollution and Impacts		x											
<u>Control Technology Development Status</u>													
(no activity)													
<u>Environmental Alternatives Analysis</u>													
Pollutant Ranking			x										
Modification of Computer Models for Evaluating Process Technology		x						x					
<u>Technology Transfer</u>													
Newsletter Status Reports									x				
Information Centers									x				
Other Reports Issued										x	x	x	

* EPA Energy Assessment and Control Division, Research Triangle Park, N.C.

** Task 232 is utilized for input to Task 222 and, thus, is not reported separately.

Systems Studies

- Pollution Control Trade-Off Studies (251)
- New Control Technologies (271)
- Revised Process Descriptions and Impact Assessments (281)
- Revised Technology Overviews (291)

Data Acquisition

- Test Support Development (441)
- Testing (461)
- Data Reporting (471)

General Program Support

(as authorized by EPA)

CURRENT PROCESS TECHNOLOGY BACKGROUND

Current coal cleaning process technology was investigated as part of Subtask 211 for a technology overview study. A draft report⁽¹⁾ on this subtask, entitled "Technology Overview of Coal Cleaning Processes and Environmental Controls", dated January, 1977, was prepared and submitted to EPA.

The overall objective of Subtask 211 was to provide a review of the objectives and U.S. methods for coal cleaning process technologies and related environmental control. The technology overview report was to provide a background against which the requirements can be established for assessment of coal cleaning technology and the control of the associated pollutants evolved from these processes and related activities.

The state of the art of coal preparation and related pollution control technology were summarized. The physical and chemical properties of coal important to coal preparation were described and the pertinent literature on washability of many U.S. coals was compiled. A technological review was provided for various coal preparation processes including size reduction, screening, physical cleaning, chemical cleaning, dewatering, drying, transportation, storage, coal handling, water handling, and solid waste handling.

The results of the technology overview study related to coal cleaning process technology are summarized in this section. Other results of Subtask 211 are summarized in the sections entitled "Current Environmental Background" and "Control Technology Assessment".

Process Information

As it comes from the mine, coal is known as run-of-mine (ROM) coal and consists of a range of sizes from chunks to small particles mixed with some dirt and rocks. In most cases, this ROM coal needs some degree of preparation to meet certain market requirements as to sizes, ash, sulfur, moisture, and heating values. Coal preparation processes as defined by this EPA study encompass all activities between the mining of coal and the end use of cleaned coal. These include coal sizing, cleaning, transportation, storage, refuse disposal, etc.

The principal coal-cleaning processes used today are oriented toward product standardization and ash reduction, with increased attention being put on sulfur reduction. Coal preparation in commercial practice is currently limited to physical processes. In a modern coal-cleaning plant, the coal is typically subjected to (1) size reduction and screening, (2) separation of coal from its impurities, and (3) dewatering and drying.

Size reduction is usually accomplished by a staged operation using a series of crushers rather than crushing to the desired size with a single crusher. Primary breaking generally reduces the raw coal to a top size of from 4 to 8 inches. The undersized materials are usually screened out prior to breaking. Primary breaking is almost entirely done by the roll-type crusher, although rotary screen-type breakers are employed to provide rough cleaning. Secondary crushing reduces the coal to top sizes of about 1-1/2 or 1-3/4 inches, and screening crushers reduce the product from the secondary crushers to the final top sizes from about 1 to 3/8 inch.

The extent of size reduction depends on the type of coal processed and the desired product characteristics. It is a well known fact that more of the impurities are liberated as the size of coal is reduced. However, because the costs of preparation rise exponentially with the amount of fines to be treated, there is an economic optimum in size reduction.

Coal is screened in either the wet or dry state to separate the various size fractions resulting from the size reduction. Screens may be stationary or moving. The screening surface may be a perforated plate, a woven wire cloth, formed bars, or nonstationary parallel bars. By far the most common screens are perforated plate and square-opening woven wire screens that shake or vibrate. The screening surfaces are usually made of high-carbon steels for larger openings and stainless steels for finer openings to provide abrasion, corrosion, and erosion resistance.

In a modern coal cleaning plant, the crushed coal is often divided into coarse, intermediate, and fine sizes, and separation of ash and pyrite from the coal is then accomplished with a variety of devices for the three individual size groupings. In coarse coal circuits, the coal is cleaned with one or a combination of gravity separation equipment such as jigs, launders, or heavy-medium vessels. The intermediate-size coals are usually cleaned with concentration tables or heavy-medium cyclones. In cleaning of fine-size coal, froth flotation or hydrocyclones are often employed.

Following the wet cleaning process, the product requires dewatering or complete drying depending on the ultimate use and transportation systems being utilized. Moisture left in the coal decreases the combustion heat available and also causes shipping and handling problems. Wet coal has a tendency to adhere to bins, chutes, railroad cars, and trucks. Additionally, in cold weather, wet coal freezes causing further handling problems. Therefore, coal-water separation is an important process for the producer as well as the buyer.

For coarse coal with particle sizes greater than 1/4 inch, the coal can be dewatered readily by natural drainage using perforated bucket elevators or dewatering screens. For fine coal, the watering is considerably more difficult and costly. Some of the fine coal will pass through the screen or bucket openings, and thus more complicated dewatering techniques are required. In addition, fine-coal surface area per unit weight is large, and hence the amount of moisture remaining on the surface per unit weight of coal is also large. Moreover, fine coals tend to pack so tightly that capillary action will hold water in the void spaces between coal particles. Consequently, fine coals usually contain relatively high moisture after mechanical dewatering and require thermal drying to obtain acceptable moisture contents.

As a result of stream pollution regulations and the coal industry's desire to improve fine coal recovery, recirculation and treatment of wash water are integral parts of the operation of a modern coal cleaning plant. In particular, closed water circuits have grown in popularity because they eliminate discharge to streams, reduce make-up water, and allow for recovery of coal. Since closing the circuit results in the build-up of slimes, it is necessary to remove a certain portion of these fine solids. Standard equipment generally applied in a closed water circuit consists of thickeners, cyclones, filters, and/or solid bowl centrifuges.

The basic principles of waste water treatment are flocculation and sedimentation. Numerous flocculation agents and a wide variety of sedimentation equipment are employed for removing the suspended solids from the washing water. Starches are probably the most commonly used flocculant in wash water treatment. Recently, many synthetic organic flocculants have been developed.

The disposal of coal cleaning plant waste is a worldwide problem of increasing magnitude. Coal refuse consists of waste coal, slate, carbonaceous and pyritic shales, and clay associated with a coal seam. It is estimated that about 25 percent of the raw coal mined is disposed of as waste. Coal refuse disposal involves two quite separate and distinct materials--a coarse refuse (+28 mesh) and a fine refuse (-28 mesh). The coarse refuse is normally disposed of in an embankment by dumping either from an aerial tramway or from trucks. The fine refuse is normally removed from the preparation plant water circuit as a thickener underflow and impounded into nearby settling ponds. Mine refuse piles across valleys have formed convenient, ready-made settling ponds for disposing of fine refuse.

Transportation of coal from the mines or preparation plants to the point of consumption is one of the most important factors affecting coal utilization because transportation costs frequently account for between one-third and one-half of the delivered price of coal. Transportation costs vary widely depending on the type of carrier, size of shipment, and distance. Transportation modes are rail, waterway, truck, pipeline, and belt conveyor. Often, more than one mode of transportation is used to convey coal from the mine to the consumer.

Storage of coal is an economic necessity in coal preparation to provide a reserve against production interruptions and also to facilitate intermittent shipment. As production and transportation capacity are increasing, coal cleaning plants require larger storage facilities to secure the maximum utilization of coal cleaning and transportation equipment. Coal is stored in huge open piles or enclosed bins and silos.

In conjunction with transportation and storage of coal, a wide variety of material handling operations is needed. These include loading and unloading, stacking and reclaiming, and transferring coal in a plant. As the amounts of coal to be handled have grown, the material handling systems have become more mechanized and equipped with more automatic and integrated control devices.

Status

Conventional Physical Coal Cleaning

Physical coal cleaning is a proven technology for upgrading raw coal by physical removal of associated impurities. In the United States, there are over 450 physical coal-cleaning plants which can handle over 400 million tons of raw coal per year. Table 2 summarizes the status of coal-cleaning plants operated in 1975.⁽²⁾ Some plants employ only one unit process, and some use a series of cleaning processes. The capacity of individual plants varies from less than 200 tons per day to more than 25,000 tons per day.

The commercial practice of coal cleaning is currently limited to the gravity methods together with minor application of froth flotation methods. Table 3 summarizes the types of processes and equipment used over the years in coal cleaning.⁽³⁾ It shows that jigging still handles the largest portion of coal-cleaning. However, dense-medium processes and concentrating tables are becoming more popular, and froth flotation is starting to play an important role.

Sulfur reduction by physical cleaning varies widely. Physical cleaning is capable of removing, on the average, about 50 percent of the pyritic sulfur and 30 percent of total sulfur. The result depends on the washability of coal, unit processes employed, and separating density.

In order to provide a systematic assessment of environmental impacts, coal preparation has been classified into four levels according to the coal sizes being washed. Coal preparation plants may be categorized into nine generic types based on coal cleaning processes employed. These levels of preparation and types of plants are summarized in Table 4 and defined in more detail as follows:

- Level 1 - Crushing and Sizing
 - Type A: Crushing for top size control with limited removal of coarse refuse and trash by scalping screen and/or rotary breaker
- Level 2 - Coarse Size Coal Beneficiation

TABLE 2. PHYSICAL COAL CLEANING PLANTS CATEGORIZED BY STATES FOR 1975⁽²⁾

State	Estimated Total Coal Production, 1000 tons	Number of Coal- Cleaning Plants	Number of Coal Cleaning Plants for Which Capacity Data Reported	Total Daily Capacity of Reporting Plants, tons	Estimated Annual Capacity of Reporting Plants, ^(a) 1000 tons	Number of Plants Using Various Cleaning Methods				
						Heavy Media Washers	Jigs	Flotation Units	Air Tables	Washing Tables
Alabama	21,425	22	10	40,600	10,150	8	10	6	1	12
Arkansas	670	1	0	-	-	1	-	-	-	1
Colorado	8,168	2	0	-	-	2	-	1	-	-
Illinois	59,251	33	20	136,775	34,195	17	20	4	1	1
Indiana	24,922	7	6	42,000	10,500	2	5	1	-	1
Kansas	568	2	2	3,800	950	-	2	-	-	-
Kentucky	146,900	70	48	245,700	61,425	43	27	16	4	20
Maryland	2,792	1	0	-	-	-	-	1	-	-
Missouri	5,035	2	1	3,500	875	-	2	-	-	-
New Mexico	9,242	1	1	6,000	1,500	1	-	1	-	-
Ohio	44,582	18	13	102,750	25,690	6	11	-	1	2
Oklahoma	2,770	2	1	550	140	1	1	-	-	-
Pennsylvania (Anthracite)	5,090	24	14	13,000	3,250	21	4	4	-	3
Pennsylvania (Bituminous)	81,950	66	50	285,010	71,255	30	19	16	20	15
Tennessee	9,295	5	4	8,520	2,130	1	1	1	2	-
Utah	6,600	6	4	23,100	5,775	2	4	2	2	-
Virginia	36,500	42	29	143,550	35,890	26	15	9	8	15
Washington	3,700	2	1	20,000	5,000	1	1	-	-	-
West Virginia	110,000	152	113	577,375	144,345	104	55	59	12	55
Wyoming	23,595	1	1	600	150	-	-	-	1	-
Total	603,055	459	318	1,652,830	413,210	266	177	121	52	125
Total (Bituminous excluding Pa. anthracite)	597,965	435	304	1,639,830	409,960	245	173	117	52	122

(a) The estimated annual-capacity values for the reporting plants were calculated from the daily-capacity values by assuming an average plant operation of 250 days per year (5 days per week for 50 weeks per year).

TABLE 3. PREPARATION OF COAL BY TYPE OF EQUIPMENT⁽³⁾

Washer Type	Yearly Percentage of Clean Coal Produced			
	1942	1952	1962	1972
Jigs	47.0	42.8	50.2	43.6
Dense-medium processes	--	13.8	25.3	31.4
Concentrating tables	2.2	1.6	11.7	13.7
Flotation	--	--	1.6	4.4
Pneumatic	14.2	8.2	6.9	4.0
Classifiers	} 29.6	8.5	2.1	1.0
Launders		5.2	2.2	1.9
Combination of methods	7.0	19.9	--	--

TABLE 4. GENERIC TYPES OF COAL PREPARATION PLANTS

Level	Plant Type	Coal Size and Unit Operation		
		Coarse (3 x 3/8 in.)	Medium (3/8 in x 28 M)	Fine (28 M x 0)
1	A	CS		
2	B	CS + J/DMV + MD		
3	C	CS + J/DMV + MD	←————— AT —————→	
3	D	CS + J/DMV + MD	←————— WT + MD —————→	
3	E	CS + J/DMV + MD	←————— DMC + MD —————→	
4	F	CS + J/DMV + MD	WT + MD	HC + MD + TD
4	G	CS + J/DMV + MD	WT + MD	F + MD + TD
4	H	CS + J/DMV + MD	DMC + MD	HC + MD + TD
4	I	CS + J/DMV + MD	DMC + MD	F + MD + TD

Legend:

Level 1 - Crushing and Sizing

Level 2 - Coarse Size Coal Beneficiation

Level 3 - Medium Size Coal Beneficiation

Level 4 - Fine Size Coal Beneficiation

CS - Crushing and Sizing Devices

J - Jigs

DMV - Dense-Medium Vessels

DMC - Dense-Medium Cyclones

AT - Air Tables

WT - Wet Concentrating Tables

HC - Hydrocyclones

F - Froth Flotation Units

MD - Mechanical Dewatering Devices

TD - Thermal Dryers

- Type B: Type A followed by dry screening at 3/8-inch and wet beneficiation of plus 3/8-inch material only with jig or dense-medium vessel. Minus 3/8-inch material is mixed with coarse product without washing. Simple mechanical dewatering for plus 3/8-inch material.
- Level 3 - Medium Size Coal Beneficiation
 - Type C: Type B plus dry beneficiation of minus 3/8-inch material with air table.
 - Type D: Type A followed by wet screening at 3/8-inch and Type B beneficiation of plus 3/8-inch material and wet beneficiation of minus 3/8-inch material with concentrating table.
 - Type E: Same as Type D except that heavy-medium cyclone is used for minus 3/8-inch material beneficiation.
 - Level 4 - Fine Size Coal Beneficiation
 - Type F: Type D followed by wet beneficiation of minus 28 mesh material with hydrocyclones. Thermal drying for fine coal product.
 - Type G: Same as Type F except that froth flotation circuit is used for minus 28 mesh material beneficiation.
 - Type H: Type E followed by wet beneficiation of minus 28 mesh material with hydrocyclone. Thermal drying for fine coal product.
 - Type I: Same as Type H except that froth flotation circuit is used for minus 28 mesh material beneficiation.

Preparation practice for steam coal lies between Levels 2 and 3, metallurgical coals are usually beneficiated through Level 4. During the past few years, however, the coal industry has undergone significant changes. First, steam coal prices tripled and metallurgical coal prices doubled from 1969 to 1974. This price structure has created a new environment for coal preparation, and the increased value of coal justifies additional capital investment in cleaning facilities to optimize yield and quality of clean

coal product. Second, environmental considerations have given impetus to the adaptation of existing coal-cleaning technology and development of new or improved technology, particularly for the removal of sulfur from coal. Consequently, it is anticipated that the majority of new coal-cleaning plants built will be in Level 4 to obtain maximum ash and sulfur removal.

The sulfur reduction which could be brought about by physical cleaning of coals from various regions of the U.S. is shown in Table 5. These values are not based on actual results of commercial coal cleaning but are estimated from the data of float-sink analysis by the U.S. Bureau of Mines.⁽⁴⁾ These data indicate hypothetical enhancement of coal quality which could be achieved by beneficiation. Actual values will vary with each installation, reflecting coal seam characteristics, mining procedures, and specific beneficiation processes selected.

An alternative strategy which could make greater utilization of coal cleaning is the multi-stream coal system (MCCS) employed by the Pennsylvania Electric Company, at Homer City, Pennsylvania.⁽⁵⁾ In the MCCS process, the ROM coal (approximately 2.7 percent sulfur) is crushed and cleaned in a dense-media cyclone circuit, yielding a product coal with 1.7 percent sulfur. The coal moves then to a second dense-media cyclone circuit which produces low-sulfur coal (0.8 percent sulfur) and medium-sulfur coal (2.2 percent sulfur). The low-sulfur coal is then used as feed for the new generating unit to meet Federal sulfur emission regulations. The medium-sulfur coal will be burned in existing boilers which are subject to less stringent state emission standards.

New Physical Coal Cleaning Processes

Physical cleaning of coal in current practice can remove only a portion of the pyritic sulfur content. The percentage that is removed by any given technique depends on the size and distribution of pyrite grains within the coal. In some cases, where the pyrite exists in large relatively discrete crystals, a high degree of separation is easily obtained. On the other hand, if the pyrite consists of small grains mixed intimately through the coal matrix, separation by physical means can be extremely difficult.

TABLE 5. SULFUR REDUCTION BY PHYSICAL COAL CLEANING^(a)

Btu Recovery, %		Level 1 Beneficiation 99	Level 2 Beneficiation 95	Level 3 Beneficiation 90	Level 4 Beneficiation 85
Pyritic Sulfur Reduction, %	Northern Appalachian	10	33	47	54
	Southern Appalachian	15	35	44	48
	Alabama	10	32	38	39
	Eastern Midwest	20	45	54	59
	Western Midwest	15	33	41	45
	Western	8	30	33	33
	U.S. Average	13	35	46	52
Total Sulfur Reduction, %	Northern Appalachian	5	20	28	33
	Southern Appalachian	2	6	9	9
	Alabama	3	9	12	12
	Eastern Midwest	6	22	29	32
	Western Midwest	5	21	25	29
	Western	2	8	11	11
	U.S. Average	6	20	25	29
lb SO ₂ Emission per 10 ⁶ Btu	Northern Appalachian	4.5	3.5	3.1	2.9
	Southern Appalachian	1.5	1.4	1.3	1.3
	Alabama	2.0	2.0	2.0	2.0
	Eastern Midwest	5.8	4.7	4.2	4.0
	Western Midwest	8.0	6.8	6.2	5.9
	Western	1.1	0.9	0.9	0.9
	U.S. Average	4.7	3.8	2.9	2.7

(a) Estimates by Bureau of Mines⁽⁴⁾ based on float-sink data for individual coal samples. Weightings based on number of coal samples, not on weight of reserves represented by each coal sample.

A number of new techniques for physical coal cleaning have been investigated to improve the pyritic sulfur removal. Among them are magnetic separation, two-stage froth flotation, oil agglomeration, heavy liquid separation, and chemical comminution. These processes are only in the experimental stage and need considerably more work to determine their full potential. A brief discussion of new processes is given in succeeding sections.

Two-Stage Froth Flotation.⁽⁶⁾ Single-stage froth flotation has long been used as a beneficiation method for fine coals usually denoted 28 mesh x 0. This process consists of agitating the finely divided coal and mineral suspension with small amounts of reagents in the presence of water and air. The reagents help to form small air bubbles which collect the hydrophobic coal particles and carry them to the surface, while the hydrophilic mineral matter is wetted by water and drawn off as tailings.

Recently, a novel two-stage froth flotation process was developed by the U.S. Bureau of Mines to remove pyrite from fine-size coals. In the first stage, coal was floated with a minimum amount of frother (methyl isobutyl carbinol) while coarse, free pyrite and other refuse are removed as tailings. In the second stage, coal was suppressed with a coal depressing agent (Aero Depressant 633), while fine-size pyrite was floated with a pyrite collector (potassium amyl xanthate).

The two-stage froth flotation process has been demonstrated in a half-ton-per-hour-capacity pilot plant. It is reported that negotiations are under way to install a full-scale prototype of 12 ton/hour capacity in an existing coal-cleaning plant. The pilot-plant data showed that up to 75 percent of pyritic sulfur could be removed from the Lower Freeport coal (minus 35 mesh) at about 60 percent of weight recovery.

Oil Agglomeration. The use of a water-immiscible liquid, usually hydrocarbons, to separate coal from the impurities is an extension of the principles employed in froth flotation. The surface of coal is preferentially wetted by the hydrocarbons while the water-wetting minerals remain suspended

in water. Hence, separation of two phases takes place and produces a clean coal containing some oil and an aqueous suspension of the refuse generally free from combustible material.

Recently, the National Research Council of Canada developed a spherical oil agglomeration process for cleaning coal fines in two steps: flocculation followed by a balling step. In the flocculation stage, a small amount of light oil (less than 5 percent) was added to a 20-30 percent coal slurry in a high-speed agitator to form micro-agglomerates. In the balling stage, a heavy, less expensive oil was added to a rotating pelletizer disc to form strong spherical balls.

It is reported that the spherical oil agglomeration process has been incorporated into the coal fine recovery circuit of a western Canadian preparation plant. The results of laboratory-batch experiments showed that about 50 percent of the pyritic sulfur was removed from the Canadian coal ground to less than 50 microns at over 90 percent Btu recovery.

High Gradient Magnetic Separation.^(8,9) A high gradient magnetic separator utilizes electromagnets to generate a magnetic field and remove mineral components, especially pyrite, from either an aqueous suspension of finely ground coal or dry powder. The separator consists of a column packed with Series 430 magnetic stainless steel wool or screens which are inserted in the base of a solenoid magnet.

General Electric Company, in conjunction with the Massachusetts Institute of Technology and Eastern Associated Coal, is attempting to establish the technical feasibility of removing inorganic sulfur from dry coal powders at commercially significant rates.

In addition, the Indiana University is currently investigating the use of high-extraction magnetic filter for the beneficiation of coal slurry containing fines below 200 mesh. A magnetic filter of 84-inch diameter can process up to 100 tons of raw coal per hour.

The utility of the process has not yet been established. Test data from the high gradient magnetic separation of dry coal powders showed that up to 57 percent of total sulfur could be removed from an eastern coal (48 mesh x 0) with the magnetic field intensity of 64 kilo oersteds at the flow velocity of 2.8 cm/sec. Laboratory tests of the Indiana University indicated that up to 93 percent of the inorganic sulfur could be removed from a coal slurry containing 90 percent of minus 325 mesh sizes with the magnetic field intensity of 20 kilo oersteds, using three passes at 30-seconds retention.

Heavy Liquid Separation.⁽¹⁰⁾ Heavy liquid separation is a practical extension of the laboratory float-sink test. The crushed raw coal is immersed in a static bath of a heavy liquid having a density intermediate between clean coal and reject. The float material is recovered as clean coal product and the sink material is rejected as refuse. The used heavy liquid is recovered completely by draining and evaporating the product coal and the reject material. The use of a heavy liquid for coal cleaning is not new. In 1936, a 50-ton/hr pilot plant was built by the du Pont Company using chlorinated hydrocarbons. However, the high costs of these heavy liquids and the toxic effects of the vapors have prohibited du Pont's commercialization of their process.

Recently, the Otisca Industries reported the development of an anhydrous heavy liquid for gravity separation of coal. The chemical composition of their liquid is presumably a fluorocarbon, with a boiling point of 24 C, a heat of evaporation of 43.1 cal/g, a specific gravity of 1.50 at 16 C. It is claimed that their process is capable of the near theoretical separation which can be obtained in the laboratory float-sink test. The data showed that about 44 percent of total sulfur was removed from 4 mm x 0 size coal at 74 percent weight recovery. The misplaced material fell in the range of 0.5 ± 0.25 percent under normal operating conditions.

Chemical Comminution.⁽¹¹⁾ The chemical comminution process is basically an improved method for pyrite liberation to enable its removal. It involves the permeation of certain low-molecular-weight compounds throughout the existing faults, pores, and other discontinuities in coal resulting in the weakening and disruption of the interlayer forces. The chemical selectivity affects the coal but not the mineral matter associated with it. The net result is the fracture of the coal, the breakage being induced selectively along the bedding planes, mineral constituents, and the mineral boundaries. The fragmented coal and unaffected mineral matter can then be separated by some conventional cleaning process. The chemicals that have been reported to have the greatest comminution ability are ammonia and methanol.

The chemical comminution of coal with ammonia has been studied by the Syracuse University Research Corporation since 1971. The bench-scale studies indicate that chemical comminution is capable of liberating more pyrite and a comparable amount of ash than mechanical crushing to same size consistency. The float-sink test for the Upper Freeport sample showed that 96.4 percent of the pyrite was removed at 1.3 specific gravity from the chemically comminuted coal, while 90 percent of the pyrite was removed from coal mechanically crushed to minus 14 mesh at the same specific gravity.

Chemical Coal Cleaning Processes

The usual concept of chemical cleaning of coal involves the treatment of coal with reagents that convert the impurities into a soluble form, usually water soluble, which can be removed by leaching. Although chemical cleaning can remove ash from coal, the low-ash product may not justify the cost of the extra step. Hence, the chemical cleaning is primarily directed at the removal of sulfur compounds in coal. Physically cleaned coal may be a preferred feed to the chemical cleaning process to reduce the chemicals and the costs.

Chemical cleaning techniques currently under development are capable of removing up to 90-95 percent of pyritic sulfur; however, only limited success has been reported in removing organic sulfur. Because costs of chemical treatments after commercialization are expected to be higher

than those of physical cleaning, chemical coal cleaning may be suitable only for low organic sulfur coals which can be utilized without stack gas scrubbing systems. Chemical cleaning is in the early stages of development, and it is estimated that a commercial plant could not be put into operation for at least 5 to 10 years. A brief discussion of chemical coal cleaning processes is given in succeeding sections.

Meyers Process.⁽¹²⁾ The Meyers process of TRW is one of the most extensively studied chemical coal cleaning processes. This process employs a chemical leach of the coal with aqueous ferric sulfate at temperatures of between 50 and 130 C. The reagent is selective for pyrite, removing 83-98 percent of the pyrite. The products of the reaction are dissolved ferrous sulfate and sulfuric acid, and precipitated free sulfur. The depleted leach solution is removed by drainage and rinsing after which it is regenerated to ferric sulfate by air oxidation. Precipitated free sulfur is washed out with an appropriate solvent (toluene or kerosene) or vaporized and recovered by condensation. The leaching rate depends on the pyrite concentration, the ratio of ferric ion to iron, temperature, and coal-particle size. It has shown that significant amounts of As, Be, Cr, Mn, Ni, Se, and Zn were removed along with the pyrite by the Meyers process. This process was claimed to be economically competitive with projected costs for flue-gas scrubbing, particularly for small installations, and a pilot plant of a 6-ton-per-day unit is being constructed with EPA sponsorship.

Ledgemont Process.⁽¹³⁾ The Ledgemont process of Kennecott Copper for removing pyrite from coal employs another hydrometallurgical technique. In this process the pulverized coal is treated at 130 C under oxygen pressure of 300 psi. The pyrite in coal is oxidized to form iron sulfate and sulfuric acid which are washed and neutralized with lime. The advantages claimed for this process are that there is no need for elemental sulfur removal, no regeneration of leachant, and almost complete removal of pyrite in two hours. Kennecott is not actively pursuing development of the process at this time.

Battelle Process.⁽¹⁴⁾ Battelle has developed an alkaline leaching process for cleaning coal known as the Battelle Hydrothermal Coal Process. It involves the heating of an aqueous slurry of 70 percent minus 200-mesh coal mixed with sodium hydroxide or a mixture of sodium hydroxide and calcium hydroxide at temperatures of 220 to 340 C in an autoclave at pressures of 350 to 2500 psi. The treated coal is separated from the leachant by centrifugation, washed and then dried to produce a solid fuel with up to 99 percent of the pyritic sulfur removed and up to 70 percent of the organic sulfur removed. It was shown that a number of potentially toxic or hazardous metals were also extracted during this treatment. The treated coal was claimed to be an improved feedstock for gasification because it was completely noncoking and easily gasified at low temperatures. Battelle is presently funded by EPA for a bench-scale investigation to pursue process improvement.

PERC Process.⁽¹⁵⁾ ERDA Pittsburgh Energy Research Center (PERC) has developed an air/water leaching process in which the aqueous coal slurry is exposed to air at 392 F and 1000 psia. It is claimed that pyritic sulfur is substantially converted to iron oxide and sulfuric acid, and it is further assumed that as much as 60 percent of the organic sulfur is removed as sulfuric acid. The carbon loss in the PERC process is claimed to be less severe than in caustic leaching at elevated temperatures or in the Ledgesmont process. A continuous, bench-scale unit is now under construction for further tests on the process.

KVB Process.⁽¹⁶⁾ The KVB process developed by KVB, Inc., consists of oxidation of the sulfur components in dry pulverized coal with gaseous NO₂ followed by a caustic washing operation to solubilize and remove sulfur compounds generated in the oxidation step. It claims to remove both mineral and organic sulfur at moderate temperature (250 F) and pressures (35 psia). Nitrogen uptake by the coal structure, however, could be a problem. Development work on the process is continuing in the laboratory, but currently there are no further demonstration plans.

Magnex Process.⁽¹⁷⁾ The Magnex process developed by Hazen Research is a totally dry process in which dry pulverized coal is exposed to iron pentacarbonyl vapor at 380 F and 40 psia. It is claimed that the iron pentacarbonyl selectively reacts with the pyrite and other mineral elements enhancing their magnetic properties.

The magnetized materials are then separated from the clean coal with use of magnetic separators. The process is limited to the removal of mineral sulfur only, and it will require grinding to liberate pyrites from the coal. The process has been investigated on a bench scale and currently is under further study in a one-ton-per-day process development unit.

Schedules

As described in the previous section, numerous commercially-sized physical coal cleaning plants are in operation (see Table 1) primarily for reduction of the ash content. The MSCC plant⁽⁵⁾ being constructed at Homer City, Pennsylvania, is the outstanding example of a planned commercial-size plant using physical coal cleaning to comply with SO₂ standards, and its schedule is described.

Acceptance tests for the interim configuration of the Homer City coal cleaning plant were successfully completed in September, 1977. This interim plant is designed to operate at a capacity of 900 T/hr of ROM coal, and the clean coal product is to be used for existing generating units No. 1 and No. 2.

Acceptance tests for the final configuration of the plant are expected to be conducted in Spring, 1978. This final plant configuration is designed to operate at a capacity of 1200 T/hr of ROM coal. The deep-cleaned coal product is to be used for generating unit No. 3 which is now being constructed, and the middling coal product is to be used for units No. 1 and No. 2.

Physical coal cleaning technology is available as described. However, chemical coal cleaning is an emerging technology. Most significant is a pilot plant planned by TRW for the Meyers Process⁽¹²⁾ and funded by

EPA. The facility will process up to 8 metric tons per day and initial operation was planned in late June/July, 1977. The first year's supply of coal is committed from the Martinka mine in West Virginia by American Electric Power.

Priorities for Further Studies

Increasing demand for coal as a primary energy source combined with the stringent regulations for sulfur dioxide emission from coal combustion results in increased pressure to expand coal preparation operations. There are still, however, many technical and/or economic uncertainties which must be overcome before extensive commercialization of coal cleaning as a method of SO₂ emission control can be realized. Major areas which require additional research, development, and demonstration activities are as follows.

- (1) The development of improved techniques for accurately predicting the cleanability of raw coals.
- (2) The development of improved techniques for quality control of coal cleaning processes to produce cleaned coal of consistent sulfur content.
- (3) The development of improved and economical techniques for liberating and removing fine-size pyrite.
- (4) The development of commercially viable techniques for removal of organic sulfur.
- (5) The development of improved methods and expanded capacity for coal transportation.
- (6) More complete determination of the environmental impacts and economic costs of coal cleaning.
- (7) The improvement of dewatering and drying techniques.

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TECHNOLOGY BACKGROUND SECTION
(pp. 1-22)

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CURRENT ENVIRONMENTAL BACKGROUND

The development of environmental assessment criteria including information relating to "Current Environmental Background" was initiated under Subtask 241. A preliminary report⁽¹⁾ on this subtask, dated April 8, 1977, was prepared and submitted to EPA.

As a result of discussions with the EPA Project Officer, the scope of this Subtask is being restricted (1) to those activities directly related to coal cleaning, handling, transportation, and storage, and (2) to a Priority I list of potential pollutants with approximately 75 entries.

Results of Subtask 241 are summarized in this section and the following section entitled "Environmental Objectives Development".

Potential Pollutants and Impacts in All Media

The universe of potential pollutants depends on the boundaries selected. Initially, the universe was taken to include the combustion of coal in coal-fired power plants and burning coal refuse piles. Under this interpretation, the myriad of organics formed by the combustion of coal in oxygen-deficient regimes (coking-type reactions) were included as representative of gob-pile burning. These numbered in the hundreds; over 800 compounds have been identified from the coking of coal. Many different pollutants have been identified as being associated with raw coal or with some segment of the coal industry. A number of lists from various sources, containing hundreds of elements and compounds, have been compiled and were presented in BCL's coal cleaning technology overview draft report.⁽²⁾ However, the original investigations by others, from which these lists were generated by Battelle, were performed by different investigators with different objectives and different approaches, so that there are major differences in the manner and format in which the results were presented. In some cases, the approach was mineralogical;

individual minerals and classes were identified. In others, where wet chemical analyses were performed, results were variously reported as oxides or in some other analytical convention, or, often, on an elemental basis. Trace element analysis results, by either emission spectrography or by spark source mass spectrography (SSMS), are reported as the element, giving no indication of the chemical form(s) present.

Thus, one of the first tasks involved the reorganization and rationalization of the overlapping lists, particularly the organic compounds. However, even after the rationalization of the list of organic compounds, many hundreds remained, only a fraction of which could be represented by "type" compounds representative of the numerous subgroups.

Re-examination of the basic problem led to the conclusion that the boundaries could and should be narrowed, to eliminate pollutants which result from coking-type reactions. Most of these compounds will be present in minute quantities, some not at all, in gases from oxidizing combustion, such as are encountered in thermal coal driers or in coal-fired power plants.

Gob-pile burning is not an intrinsic operation in coal cleaning, rather, it is symptomatic of mismanagement of refuse piles. The simple solution, which eliminates a need to consider these complex organic compounds, is prevention.

The pollutants associated with the cleaning of coal are primarily inorganic compounds associated with the ash fraction. Water will be the principal receptor of the pollutants; operations causing major emissions of air pollutants are infrequent in the cleaning of coal. Largest air emissions will include fugitive dust from coal handling and transfers and particulates and combustion products from coal driers.

As the investigation progressed, it became clear that it would be advantageous to develop a relatively small list of pollutants of most interest for the first-phase effort. The original goal was a list of 50 or less; as the list was created it seemed advisable to slightly exceed this number, and the final list contains about 75 entries.

For the first phase, a logical criterion for selection was to define Priority I pollutants as those which already have been identified as pollutants of concern and whose presence in finite concentrations in coal cleaning

processes is known or suspected. The chemical substances on this list were drawn from a number of sources, including:

- EPA criteria pollutants for air
- Pollutants identified by effluent guidelines for coal mining and coal preparation
- Substances included in EPA "Quality Criteria for Water"
- Toxic and hazardous pollutants listed by EPA which may be associated with coal cleaning.

In addition to these specific pollutants, a number of more general non-chemical pollutants and aggregated pollutant parameters were included in the list. The proposed list, shown in Table 6, includes 49 elements and 23 chemical substances or aggregated pollutant parameters. The selection of elements was based on a number of factors, including their recognition by EPA as pollutants to be regulated, their elemental group, their abundance in coal, and the availability of information on toxicity, abundance, fractionation factors, etc.

The elements selected and their relationship to the rest of those in the periodic table are shown in Figure 1; the omitted elements are shaded. The following elemental groups, or portions thereof, were omitted:

- | | |
|---|-----------------------------------|
| • Hydrogen | Not applicable |
| • Group IIIB, except lanthanum which will represent the group | Low abundance; low toxicity |
| • Group VIIIA, fixed gases | Not applicable |
| • Group VIII, all precious metals | Low abundance; low toxicity |
| • All lanthanides, except lanthanum | Low abundance; low toxicity |
| • All actinides, except uranium and thorium | Not applicable |
| • All other radioactive elements, i.e., technetium, radium | Not applicable; low abundance |
| • All elements above 57, except mercury, lead, uranium, and thorium | Low abundance; little information |

TABLE 6. PROPOSED PRIORITY I POLLUTANTS
FOR COAL CLEANING PROCESSES

Elements	Specific Pollutant Limitations**							Groupings	Specific Pollutant Limitations**						
	A	B	C	D	E	F	G		A	B	C	D	E	F	G
Aluminum								Alkalinity							X
Antimony		X						Ammonia		X					X
Arsenic		X			X		X	Cyanide		X			X	X	X
Barium		X			X		X	Chlorides					X		
Beryllium			X				X	Nitrates					X		X
Boron		X					X	Sulfides							
Bromine		X						Sulfates					X		
Cadmium					X	X	X	SO _x		X	X				
Calcium		X						NO _x		X	X				
Carbon								Total Suspended Solids (TSS)							
Cerium								Total Dissolved Solids (TDS)					X		
Cesium								Chemical Oxygen Demand							
Chlorine		X					X	Total Suspended Particulates (TSP)		X			X		
Chromium		X*			X		X	Carbon Dioxide			X				
Cobalt		X*						Carbon Monoxide		X	X				
Copper		X*					X	Hydrocarbons		X					
Fluorine		X						Photochemical Oxidants		X					
Gallium								Oil and Grease							X
Germanium								Phenols			X		X		X
Indium								Organic Sulfur Compounds							
Iodine		X						Organic Nitrogen Compounds							
Iron					X		X	Polycyclic Organic Materials (POM's)							
Lanthanum								Carbon Chloroform Extract (CCE)					X		
Lead					X		X								
Lithium															
Magnesium															
Manganese		X			X		X								
Mercury			X		X	X	X								
Molybdenum		X													
Nickel		X					X								
Niobium															
Nitrogen															
Oxygen															
Phosphorus							X								
Potassium															
Rubidium															
Selenium					X		X								
Silicon															
Sodium															
Strontium															
Sulfur															
Tellurium		X													
Thorium															
Tin															
Titanium		X													
Uranium		X													
Vanadium		X													
Zinc		X			X		X								
Zirconium		X													

* Column headings are defined as follows:

- A. National Primary and Secondary Ambient Air Quality Standards
- B. OSHA Standards for Workroom Air Contaminants
- C. National Emission Standards for Hazardous Air Pollutants
- D. New Stationary Source Performance Standards (Coal Preparation Plants)
- E. Drinking Water Regulations (EPA and PHS)
- F. EPA Toxic Pollutant Effluent Standards (Proposed)
- G. EPA Water Quality Criteria (Proposed-not regulations)

** Metal fume standard.

GROUP IA																		VIII																	
IA																		VIII																	
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FIGURE 1. ILLUSTRATION OF RELATIONSHIP OF ELEMENTS SELECTED FOR PRIORITY I POLLUTANT LIST TO THOSE OMITTED

While the selection rules may be somewhat arbitrary, the elements selected are judged to include those of greatest priority. Other elements and substances not listed are regarded as more appropriate for a lower priority. Some of the 49 elements may drop out later, on the basis of insignificant abundance or lack of sufficient information for analysis and evaluation.

The remaining 23 entries on the proposed Priority I list comprise a number of substances, e.g., sulfur dioxide, defined statutorily as a criteria air pollutant, or aggregated pollutant parameters, e.g., total suspended solids (TSS), also defined as a pollutant in effluent guidelines. Since many pollutants of the latter type are variable and undefinable mixtures, there may be insufficient information to permit their treatment in a rigorous fashion.

Table 5 also indicates where existing and proposed standards and criteria are judged to have application to coal cleaning processes, based on Cleland and Kingsbury's recent draft report of key Federal regulations.⁽³⁾ The last column (G) indicates water quality criteria recently issued by EPA⁽⁴⁾ which will achieve the status of regulations when they are ultimately adopted by the states as part of their implementation plan.

Although the Priority I list satisfies the requirement of a manageable list containing the important pollutants expected from coal cleaning processes, there appeared to be a need for an even more abbreviated list suitable for preliminary testing of some of the concepts and approaches to environmental assessment. To meet this need, an abbreviated "short list" has been proposed, which includes the following chemical pollutants:

Arsenic	Manganese
Beryllium	Selenium
Cadmium	Sulfate sulfur
Iron	Sulfur dioxide
Mercury	Nitrate nitrogen
Lead	Nitrogen oxides

This list, which includes both air and water pollutants, will be used to evaluate chemical and physical transport models, as well as estimated emissions and permissible concentrations.

Following completion of the compilation of the data base on Priority I pollutants, it is recommended that a Priority II list of pollutants be selected for further consideration. These are, by definition, of lesser importance and concern, on the basis of today's knowledge of estimated environmental concentrations and estimated permissible concentrations. Such a list may include part or all of the pollutants initially identified as being in the universe of potential pollutants.

Analysis of these Priority II pollutants probably will result in the upgrading of a few to the lower end of the Priority I group, with the rest assigned to the category of unimportant pollutants.

It will not be possible to analyze Priority II pollutants in time for inclusion in the draft final report on Task 241 scheduled for January, 1978. A preliminary evaluation of Priority II pollutants probably could be accomplished by July, 1978.

Estimation of Emission Concentrations

The various lists of potential pollutants described above identify those pollutants which may be of concern, providing that they are present above some yet undefined environmental concentration. Thus, the amounts of these substances in the coal and their distribution through the coal cleaning and utilization processes is one of the important factors in an environmental assessment.

Coal cleaning offers the possibility of controlling potentially harmful emissions resulting from the combustion of large tonnages of coal, by removing the pollutants prior to combustion. Heretofore, attention has been focused on sulfur removal by cleaning, with little attention paid to the minor and trace elements. This is now changing, as evidenced by the Priority I list of pollutants for this investigation.

In order to evaluate the effect of coal cleaning on removal of potentially harmful major, minor, and trace elements in coal, it is necessary to determine fractionation factors, i.e., the distribution of these elements from raw coal into their respective components in cleaned coal, refuse, and effluent

discharges. The fractionation factors may be estimated, in some cases from experimental data for raw coal, cleaned coal, particulate emissions, and refuse. When relevant experimental data are not available, it may be possible to predict fractionation factors from theoretical considerations.

Prediction of fractionation factors for trace elements in coal is extremely difficult because the form in which they exist in coal is unknown. A principal source of empirical data on fractionation factors for coal cleaning (washing) has been studies by the Illinois State Geological Survey.^(5,6) Where experimental fractionation factors are absent, the approach of Zubovic⁽⁷⁾ is being used. He postulated that trace metals are present in the organic phase as chelated metal-organic complexes, with complex formation favored for metal ions with a high ionic charge: ion radius ratio. The existence of such complex formation is supported by experimental data.

There appears to be a similar correlation between the fractionation factor and the ionic potential. As was shown in the April, 1977 draft report on the development of environmental assessment criteria, fractionation factors tend to increase as ionic potentials increase.⁽¹⁾ However, in its present state of development, the approach is crude, but it can provide approximate ranges of fractionation factors for many trace elements.

"Fractionation factors" are also available from Klein, et al.,⁽⁸⁾ and others, for the partitioning of elements upon combustion in a boiler. These can be used to estimate losses to the atmosphere from the thermal drying of cleaned coal. Using estimated material balances and a simple computer model, several exploratory simulations have been performed. This work is to be continued and expanded as more and better data become available. These values of emission concentrations are required as input to dispersion models to permit the calculation of ground level concentrations (GLC) for air pollutants and surface water concentrations for water pollutants.

Environmental Impacts to Biota and Man

Pollutants from coal cleaning processes are released as airborne gases and particulates, waterborne ions and compounds (including dissolved and suspended substances), and elements and compounds associated with solid refuse piles. The ecological impacts of these pollutants are broken down in

the following review according to their effects on human health, aquatic biota, terrestrial biota, and entire ecosystems.

Human Health. Many pollutants associated with coal cleaning and burning are toxic to humans. Although air pollutants probably pose the greatest health hazard, the quantity of these emissions can be drastically reduced by prevention of refuse pile fires. Air pollutants, in addition to their primary direct toxic effects, are known to cause secondary effects by aggravating existing disease conditions. However, the quantity of certain pollutants, such as heavy metals, may also be of great concern in the water effluents, due to the potential for leaching these toxic trace elements from coal refuse and storage piles.

Air pollutants such as sulfur dioxide, nitrogen dioxide, and carbon monoxide (all of which are emitted from thermal driers and burning refuse piles) are known stressors on the cardiopulmonary system. Sulfur dioxide irritation of the nose and throat, for example, occurs at exposure concentrations of about 6-12 ppm by volume in air.⁽⁹⁾ Long-term exposures to sulfur dioxide have been reported to result in nasopharyngitis, chronic bronchitis, and changes in the mucosa of the upper respiratory tract.⁽¹⁰⁾ Inhalation of sulfur dioxide causes a local reaction in the respiratory tract with histopathological changes in the epithelium of the trachea, bronchi, and elastic lung tissue.

Mixtures of sulfur dioxide and aerosols often have a greater effect than is seen when the two components act independently. This synergism occurs with increased frequency in humid air as sulfur dioxide dissolves in the vapor in the air and forms aerosols of soluble salts and acids. The tiny droplets carry the sulfur dioxide more deeply into the respiratory tract than would occur with sulfur dioxide alone.^(9,11) It has been shown, however, that any synergism between sulfur dioxide and particulates or aerosols in terms of potentiation of an irritant effect depends on the chemical nature of the particle.

Reports are cited that verify increased rates of lower respiratory illness resulting from exposure to nitrogen dioxide (NO₂) at low concentrations. Both ozone and NO₂ can cause increased airway resistance with as little as

1.6 ppm NO₂ exposure for 15 minutes.⁽⁹⁾ Stokinger and Coffin⁽¹²⁾ indicate that the reported acute effects of NO₂ and/or of associated oxides of nitrogen range from odor, nose and eye irritation, pulmonary congestion and edema, and obliterative bronchiolitis and pneumonitis to death. Chronic pulmonary fibrosis and emphysema have been shown to develop in persons who have undergone chronic, intermittent exposure to NO₂ in the range of 10 to 40 ppm. Henkin⁽¹¹⁾ indicates that changes in sensory perception are the most sensitive indicators of the presence of NO₂. Exposure to low concentrations of NO₂, 0.075 ppm, may also impair dark adaptation.

The clinically recognized acute effects resulting from the inhalation of ozone include dislike of its pungent odor; dryness of mucous membrane of the mouth, nose, and throat; changes in visual acuity; severe irritation of the eyes; headaches; functional derangements of the lung; and pulmonary congestion and edema.^(12,13)

Particulates and aerosols produce adverse health effects in humans. Inorganic mists such as sulfuric acid produce symptoms of irritation or tickling of the upper respiratory tract as well as sneezing and coughing.^(11,12)

The chemical nature of particulates determines their toxicity.⁽¹⁴⁾ Toxic elements such as lead, cadmium, vanadium, and nickel tend to concentrate in the smaller, respirable particles. Besides irritation, particulate deposition can also impair oxygen transfer in the lungs. Fine particulates are capable of adsorbing significant quantities of toxic gases such as sulfur dioxide and hydrogen chloride, thereby leading to potentially severe synergistic effects when inhaled.

Man requires certain nutrients in relatively large quantities for life processes but metals are needed to a much lesser extent. Those metals which man requires in substantial amounts and to which he has a rather wide tolerance include iron, sodium, and potassium. Those which are required in much smaller amounts and are narrowly tolerated include copper, manganese, and cobalt. Many elements (e.g., Ca, Mg, K, Na, Fe, Mn, Cu, Zn, Co, Mo, and Ni) are known micronutrients which are clearly essential for normal biochemical functions.⁽¹⁵⁾

Those elements which do not, on the other hand, have a known essential role in the life process and are toxic even at low levels include many

of the minor and trace elements such as cadmium, mercury, lead, selenium, and chromium. Many toxic elements (trace metals) are associated with aerosols and particulates. Effects produced by trace metals associated with aerosols and particulates are:

- Beryllium--irritation of the mucous membranes of the eyes and upper respiratory tract
- Cadmium--disturbances in conditioned reflex activity
- Manganese--destruction of ganglion cells of the basal ganglia; perivascular degeneration in the striatum and pallidum and to a lesser extent in the frontal and parietal cortex
- Mercury--acute toxicity manifested by renal and gastrointestinal changes; chronic toxicity indicated by neurological changes (anxiety, anorexia, insomnia, etc.)
- Arsenic--neurological symptoms such as pain in the limbs, headache, convulsions, muscular weakness, and loss of consciousness indicate acute toxicity. Chronic toxicity manifested by numbness, burning, tingling, or itching followed by gross tremors with muscle atrophy and paralysis.

Aquatic Biota

Of the wide variety of toxic chemicals that are known to be associated with coal and coal preparation activities, the trace metals are of great environmental significance. Trace metals are often introduced into aquatic ecosystems as byproducts of acid mine drainage residues. Trace metals are highly toxic to aquatic organisms, especially fish. Some of the trace metals and related trace elements are also highly bioaccumulative.

Several investigators have reported that trace metals (e.g., cadmium, copper, zinc) inhibit photosynthesis, respiration, and growth in various genera of freshwater algae (e.g., Chlorella, Anabaena, Selenastrum).^(16,17,18) Some of the aquatic macrophytes (plant life visible with the naked eye) are able to concentrate such metals from water without deleterious effects.⁽¹⁷⁾ There are also reports of trace metals (e.g., zinc) acting alone to stimulate growth in aquatic plants and then acting synergistically with other metals to inhibit aquatic plant growth.⁽¹⁹⁾

Lead, iron, nickel, zinc, copper, cobalt, tin, manganese, cadmium, and chromium are among the trace metals which exert toxic effects on various freshwater invertebrates (protozoa, flatworms, mollusks, crustaceans).^(17,20-23) Some of the toxic effects include reproductive impairment, growth reduction, and reduced survival times. Clubb, et al.,⁽²¹⁾ have reported a synergism between dissolved oxygen and cadmium toxicity in five species of stoneflies. Cadmium toxicity was found to increase with increasing levels of dissolved oxygen.

Manganese, zinc, and copper were found to be bioaccumulative in freshwater mussels. Copper concentrations were highest in the digestive glands and zinc and manganese were highest in gill tissue. The accumulation of lead in benthic invertebrates and fishes was shown to be a function of habitat and niche. Lead was discriminated against in food chain transfers such that detritus feeders and herbivores contained higher lead concentrations than did carnivores.⁽¹⁷⁾

Metal toxicity to fishes varies with pH, temperature, chemical species, and water hardness. Some of the effects of trace metals such as mercury, cadmium, zinc and copper on various freshwater fishes include reduction of growth, of survival times, and of reproductive capacity. Behavioral responses, e.g., avoidance reactions, are modified in some cases under chronic exposure to sublethal metal concentrations.^(16,17,19)

The drainage of acid waters from coal storage and refuse piles poses a serious threat to the aquatic environment because of the ensuing change in pH. Some organisms which live in waters receiving acid mine drainage are able to survive while others are completely intolerant. Overall, the effects of acid drainage on aquatic communities include a reduction in diversity and density of organisms and a dominance by pollution-tolerant organisms. Recovery is

sometimes shown by the establishment of communities with a large number of species most of which are represented by relatively few individuals. Butler, et al.,⁽²⁴⁾ studied the effects of acid mine drainage on fish populations in several watersheds in Pennsylvania. These authors concluded that total acidity, pH, and probably heavy metals are all involved in the toxic action of acid mine drainage on fish populations. Concurrent readings of a pH as high as 4.5 and a total acidity as low as 15 ppm were sufficient to account for the complete loss of fish populations at about 90 percent of the sampling stations which were devoid of fishes.

Some of the ways in which suspended solids affect aquatic biota are:

- (1) Mechanical or abrasive action (i.e., clogging or irritational)
- (2) Blanketing action or sedimentation
- (3) Loss of light penetration
- (4) Availability as a surface for growth of microorganisms
- (5) Adsorption and/or absorption of various chemicals
- (6) Change in temperature fluctuations.⁽²⁰⁾

These ecological effects can severely affect aquatic biota by endangering the integrity of community structure. For example, the integrity of the community structure of algae and protozoa could be seriously interfered with by any reduction in the penetration of visible radiation into aquatic ecosystems (due to increases in suspended solids) which would restrict or prohibit the growth of photosynthetic organisms. Predator-prey relationships (i.e., zooplankton grazing on phytoplankton) might change, resulting in abnormal increases or decreases of individuals, thereby causing an upset in the population balance and stability.⁽²⁰⁾

Terrestrial Biota. Vegetation is stressed or killed by a variety of gases and particulate matter. These pollutants may enter the leaf directly from the air or be taken in by the roots from the soil. Foliar markings are used by experts to determine air pollution effects on vegetation. Treshow⁽²⁵⁾ listed four basic types of markings which are symptomatic of air pollutants:

- (1) Necrosis and bleaching of intercostal or leaf margins
- (2) Glazing or silvering of leaf surface, particularly the under surface
- (3) Chlorosis or loss of chlorophyll
- (4) Flecking or stippling on upper leaf surface.

Table 7 gives symptoms shown by vegetation from effects of a variety of air pollutants. These pollutants create stresses on vegetation which can cause reduced growth or death. The effect of the pollutant may be a result of:

- (1) The concentration of the pollutant under consideration
- (2) Its combined effect with other pollutants
- (3) Its combined effect with other stressors such as temperature, nutrients, light, humidity, etc.⁽²⁵⁾

Pathways of the pollutants associated with coal cleaning and burning to terrestrial animals include:

- (1) Inhalation of gases, aerosols, and particulates
- (2) Ingestion of contaminated water
- (3) Ingestion of vegetation covered with particulates and/or vegetation which has absorbed pollutants from the soil
- (4) Ingestion of contaminated animals
- (5) Absorption of pollutants through the eyes or skin.

Caution must be used in assessing the effects of pollutants on terrestrial animals, since much of the available information on effects involves the investigation of single pollutant effects on laboratory animals. Much more research is needed on the synergistic effects of the combination of pollutants released from coal cleaning and burning on terrestrial animals.⁽²⁶⁾

TABLE 7. POLLUTANT EFFECTS ON VEGETATION⁽²⁵⁾

Pollutant	Symptoms	Maturity of leaf affected	Part of leaf affected	Injury threshold		
				ppm (vol)	$\mu\text{g}/\text{m}^3$	Sustained exposure
Sulfur dioxide	Bleached spots, bleached areas between veins, chlorosis; insect injury, winter and drought conditions may show similar markings	Middle-aged most sensitive; oldest least sensitive	Mesophyll cells	0.3	785	8 hours
Ozone	Fleck, stipple, bleached spotting, pigmentation; conifer needle tips become brown and necrotic	Oldest most sensitive; youngest least sensitive	Palisade or spongy parenchyma in leaves with no palisade	0.03	59	4 hours
Peroxyacetyl-nitrate (PAN)	Glazing, silvering, or bronzing on lower surface of leaves	Youngest most sensitive	Spongy cells	0.01	50	6 hours
Nitrogen dioxide	Irregular, white or brown collapsed lesions on intercostal tissue and near leaf margin	Middle-aged leaves most sensitive	Mesophyll cells	2.5	4700	4 hours
Hydrogen fluoride	Tip and margin burn, dwarfing, leaf abscission; narrow brown-red band separates necrotic from green tissue; fungal disease, cold and high temperatures, drought, and wind may show similar markings; suture red spot on peach fruit	Youngest leaves most sensitive	Epidermis and mesophyll cells	0.1 (ppb)	0.08	5 weeks
Ethylene	Sepal withering, leaf abnormalities; flower dropping, and failure of leaf to open properly; abscission; water stress may produce similar markings	Young leaves recover; older leaves do not recover fully	All	0.05	58	6 hours
Chlorine	Bleaching between veins, tip and margin burn, leaf abscission; marking often similar to that of ozone	Mature leaves most sensitive	Epidermis and mesophyll cells	0.10	290	2 hours
Ammonia	"Cooked" green appearance becoming brown or green on drying; over-all blackening on some species	Mature leaves most sensitive	Complete tissue	~ 20	~ 14,000	4 hours
Hydrogen chloride	Acid-type necrotic lesion; tipburn on fir needles; leaf margin necrosis on broad leaves	Oldest leaves most sensitive	Epidermis and mesophyll cells	~ 5-10	~ 11,200	2 hours
Mercury	Chlorosis and abscission; brown spotting; yellowing of veins	Oldest leaves most sensitive	Epidermis and mesophyll cells	< 1	< 8,200	1-2 days
Hydrogen sulfide	Basal and marginal scorching	Youngest leaves most affected		20	28,000	5 hours
2,4-Dichlorophenoxyacetic acid (2-4D)	Scalloped margins, swollen stems, yellow-green mottling or stippling, suture red spot (2,4,5-T); epinasty	Youngest leaves most affected	Epidermis	< 1	< 9,050	2 hours
Sulfuric acid	Necrotic spots on upper surface similar to caustic or acidic compounds; high humidity needed	All	All	—	—	—

Both sulfur dioxide and sulfuric acid irritate the respiratory system. However, levels much higher than normal air pollutant levels are required to cause death in laboratory animals.⁽²⁷⁾ Sulfur dioxide is absorbed in the upper airways, and very little penetrates deep into the lungs unless it is sorbed on small particulates.^(25,27) Feeding of SO₂-damaged alfalfa to cows had little effect, but swine exposed to several different levels of SO₂ concentrations showed eye irritation, salivation, nasal secretion, altered respiration, hemorrhage, emphysema, and pulmonary fibrosis.⁽²⁸⁾

Airborne fluorides cause more worldwide damage to domestic animals than any other air pollutant. Fluoride intoxication of animals may result from inhalation or ingestion of fluorine-contaminated vegetation. Among farm animals, cattle are most susceptible to fluorosis followed in descending order of susceptibility by sheep, horses, swine, rabbits, and poultry. Chronic symptoms associated with fluorosis include dental lesions, skeletal changes, lethargy, emaciation, poor health, and sometimes poor reproductive efficiency.⁽²⁸⁾

Nitrogen dioxide is about four times more toxic to animals than nitric oxide.⁽²⁹⁾ Increasing concentrations of NO₂ can cause pulmonary congestion, edema, obliterative bronchiolitis, pneumonitis, and eventual death.⁽²⁵⁾ Concentrations greater than 100 ppm are lethal to most animal species.⁽²⁹⁾

Terrestrial animals are subjected to a variety of toxic trace elements in the vicinity of coal burning facilities. These elements are either relatively volatile (i.e., Be, F, As, Se, Cd, Pb, and Hg)⁽²⁶⁾ and/or they are preferentially concentrated on the surface of fly ash particles (i.e., Be, Ca, Cr, K, Li, Mn, Na, P, Pb, S, Tl, V, and Zn).⁽³⁰⁾ Of these elements, it is fairly well established that As, Be, Cd, Cr, Mn, Ni, Pb, Sb, Se, Tl, V, and Zn are particularly toxic. Effects of these toxic trace elements include organ system injury, carcinogenicity, genetic and neonatal toxicity, and immunological injury.⁽²⁶⁾

Ecosystems. Ecosystems are the basic fundamental units of "nature" in which the organisms and nonliving environment are interrelated. These dynamic units may be conceived and studied in a variety of sizes, such as a small pond, a large lake, or a tract of forest. Generally, the larger and more diverse ecosystems are more stable and more independent of adjacent systems.⁽³¹⁾

Stickel⁽³²⁾ has reviewed the three basic effects of pollutants on ecosystems, as follows:

- (1) Continued contamination of an area results in an increasing loss of species. These simplified communities are often less stable and more subject to wide fluctuations than communities with a large number of species.
- (2) Some species are much more sensitive to a given pollutant than other species. Thus, only the hardy, more broadly adaptable species are able to survive. In the case of vegetation, the larger plant species, which have broad leaf areas, are usually more vulnerable to pollutants. This vulnerability could ultimately result in a forest being changed to a stand of grass or sedge. Thus, animal species which require forest habitats for survival are also lost from the polluted region.
- (3) When the larger plants die there is also a loss in organic matter and in the total inventory of nutrient elements held in the system. These nutrients are lost through erosion and leaching, and are not quickly replaced.

Although these three effects apply mainly to plant communities, they have many parallels in animal communities.

Federal and State Standards and Criteria

One of the subtasks under Task 241 was to investigate Federal and state regulations governing pollution resulting from activities associated with coal cleaning, transportation, storage, and handling. Detailed results of this study were reported in the April 8, 1977 preliminary report on the development of environmental assessment criteria.⁽¹⁾ In summary, the following Federal Acts were determined to constitute the principal regulatory authority:

- Clean Air Act Amendments of 1970*
- Federal Water Pollution Control Act Amendments of 1972

State regulations are generally written or amended to incorporate the provisions of the Federal laws. In some cases, state regulations are more stringent than are the Federal regulations. Whatever the case, however, states are usually required to submit implementation plans, for approval, to the appropriate Federal agency outlining how Federal standards will be met, and specifying a reasonable time frame for implementing those standards.

The major Federal regulations which are applicable to coal activities as related to environmental pollution are concerned with air and water pollution control. In addition, health standards for the workplace environment have been promulgated to regulate exposure to various airborne contaminants.

Air Pollution Regulations

Federal. The U.S. Environmental Protection Agency has set primary and secondary ambient air quality standards which regulate pollutant levels in order to, respectively, protect human health and public welfare (property and plant and animal life).

Most of the air pollutants associated with coal processes are generated mainly from coal combustion and include sulfur oxides, nitrogen oxides, and total suspended particulates.

In accordance with Section III of the Clean Air Act, the U.S. Environmental Protection Agency has promulgated standards for emissions from new stationary sources. Since these standards are based on emissions, the owner/operator may use any control system, but the standard must be achieved without the privilege of variances or exemptions.

The promulgated Federal standards of performance for new and modified coal preparation plants and handling facilities (e.g., barge-loading facilities) regulate particulate emissions from those facilities processing more than 200 tons per day of bituminous coal. The standards stipulate the maximum permissible particulate emission levels in g/dscm and percent opacity.

* These have been substantially modified by the Clean Air Act Amendments of 1977 (enacted August 7, 1977).

The U.S. Environmental Protection Agency is only responsible for setting new source emission limitations. Federal regulations require states to develop new source review procedures thereby ensuring that new sources do not violate national ambient air quality standards (NAAQS).

Wherever air quality is already better than NAAQS, Federal regulations do not permit states to allow significant deterioration of the present air quality. The U.S. EPA has established a specified increment in air quality which cannot be exceeded by any new source or combination of new sources within the impact area. Land use classes or zones are required to be established which designate the amount of development allowable in certain regions.

The Mining Enforcement and Safety Administration (MESA) of the U.S. Department of the Interior has set health standards for those individuals working in surface work areas of underground and surface coal mines. The definition of surface coal mine and surface work areas of an underground mine includes "surface areas of land and all structures, facilities,...used in...the work of preparing the coal so extracted, and includes custom coal preparation facilities". Health standards for these surface work areas, which include coal cleaning facilities, have been set for: (1) respirable dust, and (2) any other airborne contaminants with threshold limit values (as adopted by the American Conference of Governmental Industrial Hygienists).

State. Although the EPA promulgates national ambient air quality standards (NAAQS), states have the privilege of establishing more standards. Thirty-three states and the District of Columbia have ambient air quality standards for one or more pollutants that are more stringent than the NAAQS. Ten of the 19 states with coal preparation plants have ambient air quality standards (AAQS) that are more stringent than the Federal standards.

Since the concentrations of nitrogen oxides and other pollutants other than sulfur oxides and particulates, for which there are AAQS, are only marginally related to the quality of coal prepared or burned, emphasis has been placed on the standards for sulfur dioxide and particulate matter (total suspended particulates). Those states with more stringent AAQS are Alaska, Arizona,

California, Connecticut, Colorado, Delaware, Florida, Georgia, Hawaii, Indiana, Kentucky, Louisiana, Maine, Maryland, Minnesota, Mississippi, Missouri, Montana, Nevada, New Hampshire, New Mexico, New York, North Carolina, North Dakota, Ohio, Oregon, South Dakota, Tennessee, Vermont, Washington, West Virginia, Wisconsin, and Wyoming.

States are required to develop state implementation plans (SIP's) which, on approval by the U.S. EPA, specify how the NAAQS or their own state standards, if more stringent, will be achieved within three years of the promulgation of the SIP's. The SIP's cover existing source limits and, where applicable, new source limits. These plans employ different regulatory means for controlling pollutants from fuel-burning equipment. SIP's exist for sulfur dioxide, total suspended particulates and nitrogen dioxide.

In terms of new source performance standards, all new sources must conform to emission limits set by the U.S. EPA, but states are required to develop new source review procedures. Such procedures must be conducted and ensure that all new sources constructed do not violate NAAQS even if it involves facility resiting or a total denial of a permit to construct a facility.

Water Pollution Regulations

Federal. Federal control of water pollution sources associated with coal production, preparation, and consumption is achieved through the issuance of permits to each discharger which contain the limits on the effluents discharged. Effluent guidelines are presently based on the best practicable control technology currently available and must be based on the best available technology economically achievable by 1983, except where modified requirements are in order, pursuant to Section 301(c) of the Federal Water Pollution Control Act (FWPCA). Effluent guidelines are also being issued for new sources. These new source performance standards, as mandated by the FWPCA's Section 306, are intended to be the most stringent standards applied.

In 1976,⁽³³⁾ the Environmental Protection Agency established effluent guidelines and standards for existing coal preparation sources which are attainable by the application of the best practicable control technology currently available.⁽³⁴⁾ These regulations specified no discharge of pollutants from

coal preparation plants; controlled discharges were permitted from the coal storage, refuse storage and preparation plant ancillary area subcategory of sources.

At the time of preparation of the draft report, proposed effluent guidelines for existing coal preparation sources based on the best available technology economically achievable (BAT) had been proposed, along with proposed standards of performance for new sources.⁽³⁵⁾

Subsequently, revised BAT effluent guidelines for existing sources have been promulgated,⁽³⁶⁾ which combined coal preparation plants and ancillary operations into one subcategory, eliminated the requirement of no discharge of pollutants for coal preparation plants, and also established slightly different limitations for plants with acidic and alkaline discharges. Final regulations for BAT effluent limitations have not yet been promulgated.

Very recently, standards of performance for new sources have been proposed.⁽³⁷⁾ While ambient air standards are set at the Federal level, ambient water quality standards are primarily a state responsibility. Federal water quality standards presently cover only public (community) water supplies. Maximum contaminant levels in public water supplies have been set for the following contaminants that are associated with coal and coal activities: arsenic, barium, cadmium, chromium, fluoride, lead, mercury, nitrate, selenium, and silver.

Federal water quality criteria have recently been revised and expanded, since the issuance of Battelle's preliminary report.⁽¹⁾ These criteria were presented in "Quality Criteria for Water".⁽⁴⁾ While these criteria do not have direct regulatory use, they do form the basis for judgement by the states in implementing state water quality regulations. They are being utilized in developing estimated permissible concentrations (EPC's) for the pollutants listed.

State. Water pollution control enforcement is based on effluent standards rather than stream quality, and plant outfalls must be within certain

limits prescribed for each industry. State control of water pollution sources associated with coal preparation is achieved through the issuance of permits independently or under the National Pollutant Discharge Elimination System (NPDES). The permits, which contain limits on the effluents discharged, are issued to each discharger. The objective of such control systems is to achieve or maintain specified ambient water quality standards which are primarily a state responsibility. The Federal laws are intended to aid the achievement of state standards. The U.S. EPA, however, retains the authority to veto state plans.

Since Federal and state laws have the same goals, the Federal Water Pollution Control Act Amendments (Public Law 92-500) provide for the reduction of duplicate laws by delegating permit issuance authority to the states. Delegation of authority takes place when a state demonstrates that it has legal authority and resources to operate the program as envisioned by that Federal law. The States of Colorado, Indiana, Kansas, Maryland, Missouri, Montana, North Dakota, Ohio, Virginia, Washington, and Wyoming are delegated NPDES-issuing states. The effluent limitations vary among the delegated and nondelegated states.

Solid Waste Disposal Regulations

Federal. Solid wastes generated from coal preparation are generally subject to land disposal. Federal guidelines for land disposal of solid wastes, accepted or excluded, are nonspecific in terms of definite quantities which can or cannot be disposed of. Pursuant to Section 211 of the amended Solid Waste Disposal Act, the guidelines are mandatory for Federal agencies and are recommended to state, interstate, regional and local governmental agencies for use in their solid waste disposal activities.

All facets (from location to operation) pertaining to land disposal sites are covered by requirements to conform to the most stringent standards applicable to water quality established in accordance with or effective under the provisions of the Federal Water Pollution Control Act. Leachate collection and treatment systems are required at disposal sites where it would be necessary to protect ground and surface water resources.

Provisions of the Solid Waste Disposal Act were significantly modified by the passage October 21, 1976, of the comprehensive Resource Conservation and Recovery Act (RCRA) of 1976 (P.L. 94-580). Since from 90 days to two years was provided for consummation of many of the actions called for by the Act, the exact direction which the Act will take is not yet clear. Some of the general provisions of the Act are:

- The U.S. Environmental Protection Agency has to issue guidelines within one year for defining sanitary landfills as the only acceptable land disposal alternative which can be implemented; open dumps are to be prohibited.
- Within one year EPA shall develop and publish suggested guidelines for solid waste management.
- Within eighteen months EPA shall promulgate criteria for identifying hazardous waste, standards for generators, transporters, and for treatment, storage, and disposal of hazardous wastes.
- Permit programs are to be managed by the states but under minimum guidelines to be provided by EPA.
- Each regulation promulgated shall be reviewed and, where necessary, revised not less frequently than every three years.

The indications are that coal refuse (and combustion ash) will not be classified as hazardous wastes, which would avoid the most restrictive provisions of the Act. Due to the lengthy time involved in fully implementing the Act, the details of its application to coal cleaning cannot yet be ascertained.

The Geological Survey of the U.S. Department of the Interior also has established regulations for the disposal of waste from coal preparation and handling operations on the surface of land associated with underground mining:

"The operator shall...dispose of all waste resulting from...preparation of coal in a manner designed to minimize, control, or prevent air and water pollution and hazards of ignition and combustion".

"Mine" in the regulation is defined as underground or surface excavation and the surface or underground support facilities that contribute directly or

indirectly to coal mining, preparation, and handling. How these regulations will interact with the RCRA provisions is uncertain.

State. A few states have solid waste disposal regulations directly applicable to coal preparation or consumption. The various states have general regulations covering solid waste management, solid waste disposal, and solid waste disposal areas (landfills, snaitary landfills, etc.). Locations of these disposal areas are to be such that there is the least possibility of contamination of surface or ground waters. Presumably, the provisions of the Resource Conservation and Recovery Act of 1976 will allow definitive guidelines to be drawn up by each state for the storage and disposal of solid wastes, including those generated from coal preparation and consumption.

Other Regulatory Requirements

Regulations are ever-changing, and the discussion of them in Battelle's April, 1977 preliminary report⁽¹⁾ is already out of date. Some of the changes were alluded to in the previous section; further comments may be in order.

Air Pollution Regulations

The Clean Air Act Amendments of 1977, enacted August 7, 1977, have significantly modified the Clean Air Act Amendments of 1970, as amended June, 1974; some of these modifications will interact with coal cleaning.

One of the most important is the amendment of Section 111, covering new source standards of performance, from the previous basis of an absolute limitation on criteria pollutants (e.g., 1.2 lb SO₂/10⁶ Btu) for fossil-fuel-fired stationary sources to a combination of a maximum emission limitation and a percentage reduction in emissions from the level which would have resulted from the use of fuels not subject to treatment prior to combustion. Any cleaning

of the fuel after extraction and prior to combustion may be credited toward compliance with the above standards of performance.

The actual values to be achieved have not yet been specified, and are currently under consideration to evaluate technical and economic constraints. There are indications that limitations on SO₂ may fall in the range of a 90 percent reduction with maximum emissions not to exceed 1.2 lb SO₂/10⁶ Btu. It is probable that a lower emission limit of 0.2 lb SO₂/10⁶ Btu below which the percentage reduction provision will not be required will be promulgated. Although reductions in allowable emissions of NO_x and particulates are also probable, these should have only a minor impact on the cleaning of coal. The revised standards of performance are to be promulgated not later than August 7, 1978.

Depending somewhat upon the SO₂ regulations finally promulgated, these amendments are likely to influence significantly the role of coal cleaning in the utilization of coal. They may preclude the use of coal cleaning as the sole method of SO₂ control for new utility boilers. However, in some instances, such as non-attainment areas, coal cleaning and scrubbing may be required to meet regulations more stringent than those for New Source Performance Standards.

The atmospheric emission of several hazardous air pollutants found in coal (beryllium and mercury) is already regulated. The establishment of regulations governing arsenic emissions is now under consideration, with a decision anticipated early in 1978. Other hazardous pollutants under consideration include polycyclic organic matter (POM) and lead, with uncertain decision dates. Except for POM's, emissions of the other hazardous pollutants mentioned above, in concentrations likely to be affected by the standards, are expected to be emitted only from sources other than fossil fuel combustion.

Water Pollution Regulations

There have been no major new Federal acts affecting water pollution since the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500). New regulations have, however, been proposed under this Act which will affect coal cleaning plants. Recently proposed New Source Performance Standards⁽³⁷⁾ would permit the continued discharge of process wastewater from coal cleaning plants which recycle waste water (adopted in April, 1977 as a revision⁽³⁶⁾ of the original effluent guidelines limitations⁽³⁴⁾).

Slightly different limitations are proposed for acidic and alkaline discharges, in that there are no limitations on manganese for alkaline discharges. Proposed limits for total iron are 3.5 and 3.0 mg/l (daily maximum and 30-day average, respectively). These are considerably lower than the 0 analogous 7.0 and 3.5 mg/l limits established for existing sources.

The establishment of effluent limitations for approximately 129 toxic pollutants is under investigation; most of these are organic compounds which are not expected to be present at significant concentrations in effluents from coal cleaning plants.

Similarly, nearly 100 toxic substances are being evaluated relative to the establishment of Federal water quality criteria. If any of these are adopted they would affect primarily state regulations. This program is not yet sufficiently advanced to predict the nature and extent of impacts upon coal cleaning.

Solid Waste Disposal Regulations

A number of the components of the Resource Conservation and Recovery Act of 1976 (RCRA) will affect coal cleaning operations, in ways not yet determinable, since up to a couple of years will be required to fully implement the provisions of the Act. Like its predecessor, the Solid Waste Disposal Act, RCRA will leave the promulgation of governing regulations and their enforcement to the individual states; there will not be specific Federal limitations. The Federal role is to consist of financial and technical assistance and leadership in the development, demonstration, and application of new and improved methods of waste management.

As noted in the previous section, the U.S. EPA is mandated to develop, within one year (i.e., by October 21, 1977) criteria for sanitary landfills, and suggested guidelines for solid waste management. Within eighteen months numerous criteria for identifying, transporting, treatment, and disposal of hazardous wastes are to be promulgated. Criteria for defining hazardous wastes are now under development but have not yet been published.

Section 8002 of the Act calls for a detailed and comprehensive study on solid wastes from active and abandoned surface and underground mines, the scope of which will presumably include coal preparation. The report of the study (no publication date is specified) shall include recommendations for Federal and non-Federal actions concerning environmental effects. The findings of this study may influence disposal procedures for coal refuse.

Occupational Health/Epidemiological Data

In assessing the potential health effects of toxic pollutants, occupational health and epidemiological data are summarized in the form of Threshold Limit Values (TLV's) for acute short term exposure to those major and minor elements which are found in coal and coal ash. Since TLV's are one of the best sources of toxicological data for humans in regard to industrial pollutants in air, they were used in the calculation of estimated permissible air concentrations which will not produce harmful effects as a result of continuous long term exposure. The TLV's have been developed by the American Conference of Governmental Industrial Hygienists⁽³⁸⁾ and are based on animal toxicology data and on measured effects produced on humans working in a specific atmosphere. No attempt has been made to summarize any other industry-related health or epidemiological literature.

TLV's were found for only 37 of the 80 elements known to occur in coal and coal ash (Table 8). These values permitted the calculation of estimated permissible concentrations (EPC's) in air for those 37 elements using the formula developed by Handy and Schindler.⁽³⁹⁾ The use of the EPC values in determining the need for control development is described later in this report.

Dose/Response Data

Dose/response data for use in calculating estimated permissible water concentrations (EPC for water) were obtained from the National Institute for Occupational Safety and Health (NIOSH) registry,⁽⁴⁰⁾ which lists the toxic effects of a large number of chemical substances. In order to calculate the EPC for water using the formula developed by Handy and Schindler⁽³⁹⁾, it was

TABLE 8. ESTIMATED PERMISSIBLE AIR CONCENTRATIONS
FOR ELEMENTS FOUND IN COAL AND COAL ASH

Elements Found in Coal or Coal Ash	TLV ^(a) mg/m ³	Estimated Permissible Concentration ^(b) , mg/m ³	Carcinogenic or Teratogenic Elements ^(c)
<u>Major Elements</u>			
Aluminum	-	-	
Calcium	-	-	
Carbon (Black)	3.5	8.33×10^{-3}	
Hydrogen	-	-	
Iron (Soluble salts)	1.0	2.38×10^{-3}	
Magnesium	-	-	
Nitrogen	-	-	
Oxygen	-	-	
Potassium	-	-	
Silicon	-	-	
Sodium	-	-	
Sulfur	-	-	
<u>Minor and Trace Elements</u>			
Antimony	0.5	1.19×10^{-3}	
Arsenic	0.5	1.19×10^{-3}	
Barium (Soluble compounds)	0.5	1.19×10^{-3}	
Beryllium	0.002	4.76×10^{-6}	Car.
Bismuth	-	-	
Boron	-	-	
Bromine	0.7	1.67×10^{-3}	
Cadmium	0.05	0.12×10^{-3}	Car.
Cerium	-	-	
Cesium	-	-	
Chlorine	3	7.14×10^{-3}	
Chromium (Salts)	0.5	1.19×10^{-3}	Car.
Cobalt (Metal dust & fumes)	0.1	0.24×10^{-3}	
Copper (Fume)	0.2	0.48×10^{-3}	
Dysprosium	-	-	
Erbium	-	-	
Europium	-	-	
Fluorine	2	4.76×10^{-3}	
Gadolinium	-	-	
Gallium	-	-	
Germanium	-	-	

TABLE 8. (Continued)

Elements Found in Coal or Coal Ash	TLV ^(a) mg/m ³	Estimated Permissible ^(b) , Concentration mg/m ³	Carcinogenic or Teratogenic Elements ^(c)
<u>Minor and Trace Elements (continued)</u>			
Gold	-	-	
Hafnium	0.5	1.19×10^{-3}	
Holmium	-	-	
Indium	-	-	
Iodine	1	2.38×10^{-3}	
Iridium	-	-	
Lanthanum	-	-	
Lead	0.15	0.36×10^{-3}	$Pb_3(PO_4)_2$: Car. Ter.
Lithium	0.025	0.06×10^{-3}	
Lutetium	-	-	
Manganese	5.0	11.9×10^{-3}	
Mercury	0.05	0.12×10^{-3}	
Molybdenum (Soluble comp.)	5.0	11.9×10^{-3}	
Neodymium	-	-	
Nickel	1.0	2.38×10^{-3}	Car.
Niobium	-	-	
Osmium	0.002	4.76×10^{-6}	
Palladium	-	-	$PdCl_2$: Car.
Phosphorus	0.1	0.24×10^{-3}	
Platinum (Soluble salts)	0.002	4.76×10^{-6}	
Polonium	-	-	
Praeseodymium	-	-	
Radium	-	-	
Rhenium	-	-	
Rhodium (Soluble salts)	0.001	2.38×10^{-6}	$RhCl_3$: Car.
Rubidium	-	-	
Ruthenium	-	-	
Samarium	-	-	
Scandium	-	-	
Selenium	0.2	0.48×10^{-3}	
Silver	0.01	0.02×10^{-3}	
Strontium	-	-	
Tantalum	5.0	11.9×10^{-3}	
Tellurium	0.1	0.24×10^{-3}	
Terbium	-	-	
Thallium (Soluble comp.)	0.1	0.24×10^{-3}	
Thorium	-	-	
Thulium	-	-	
Tin (Organic compounds)	0.1	0.24×10^{-3}	

TABLE 8. (Continued)

Elements Found in Coal or Coal Ash	TLV ^(a) mg/m ³	Estimated Permissible ^(b) , Concentration mg/m ³	Carcinogenic or Teratogenic Elements ^(c)
Minor and Trace Elements (continued)			
Titanium	-	-	
Tungsten (Soluble comp.)	1.0	2.38×10^{-3}	
Uranium	0.2	0.48×10^{-3}	
Vanadium (Fume)	0.05	0.12×10^{-3}	
Ytterbium	-	-	
Yttrium	1.0	2.38×10^{-3}	
Zinc	1.0	2.38×10^{-3}	
Zirconium	5.0	11.9×10^{-3}	

(a) Threshold Limit Values from American Conference Governmental Industrial Hygienists for short term (acute) exposures.⁽³⁸⁾

(b) Estimated Permissible Concentrations for continuous long term (chronic) exposure computed by formula: $EPC = 2.38 \times 10^{-3} \times TLV$, as by Handy and Schindler.⁽³⁹⁾

(c) From NIOSH Registry (Fairchild).⁽⁴⁰⁾

necessary to know either the LD₅₀* or LD₁₀** value for oral ingestion of a given pollutant by rats. However, these values were available for only 3 of the 80 elements (antimony, cobalt, and indium) known to occur in coal or coal ash which were reviewed to calculate permissible air concentrations.

Obviously, formulae for calculation of an EPC will have to be modified to use other types of dose/response data, if an EPC is desired for all of the potential pollutants from coal cleaning processes. This effort has been initiated at Battelle and is discussed in a later section of this report. However, for several pollutants known to occur in coal there are no dose/response data in the NIOSH registry.⁽⁴⁰⁾ In these cases, the dose/response value for such an element can only be approximated by extrapolation from known values for elements with similar chemical behavior.

Some additional dose/response data were reviewed during an analysis of the ecological effects of pollutants from coal cleaning. The four major headings considered in this review were human health, aquatic biota, terrestrial biota, and ecosystems. Although the primary emphasis was on effects, some information on doses causing these effects were reviewed and are presented in another section of this report.

Transport Models

Pollutants emitted from coal cleaning processes can both accumulate and disperse, in both a physical and a biological sense, depending upon the characteristics of the pollutant and the environmental compartment. Activity was initiated recently to develop simplified models for both the physical and biological transport of key pollutants. These key pollutants are various forms of sulfur, nitrogen, manganese, arsenic, cadmium, mercury, lead, iron, beryllium, and selenium. These ten elements are all on the Priority I list and are very significant. Application to other elements on the Priority I list is postponed pending the outcome of this activity. The approaches being undertaken are briefly described in the following.

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- * LD₅₀ - Lethal Dose Fifty. The calculated dose of a pollutant which can be expected to cause the death of 50 percent of an experimental animal species population by any route other than inhalation.⁽⁴⁰⁾
 - ** LD₁₀ - Lethal Dose Low. The lowest dose of a pollutant, other than LD₅₀, reported to have caused the death of humans or animals by any route other than inhalation over any time period and by any number of individual portions.⁽⁴⁰⁾

Atmospheric Transport Models

The concentration of key pollutants in the flue gas and the thermal drier atmospheric discharge will provide input for calculations of atmospheric dispersion to yield ground level concentrations. The basic purpose of the dispersion calculation is to provide an estimate of the dilution factor which, when divided into the stack emission concentrations, will yield ground level concentration.

Two basic models are required, depending on whether the pollutant is associated with large or small particles, where 100 microns is a typical dividing point. Large particles tend to deposit on surfaces close-in such that the air concentration is depleted as distance from the stack increases. The concentration of smaller particles is reduced only by dispersion.

Simplified dispersion models, as typified by that presented by Turner⁽⁴¹⁾ are available to consider stack height and diameter, stack gas temperature and exit velocity, and ambient air temperature and wind speed. Calculations would be performed for different weather categories. Multiple sources can be considered to include the effects of more than one stack if distance between stacks is large enough to merit this refinement.

The large particle deposition model requires only the deposition factor, wind speed, and effective stack height. Deposition factors are available in the literature and various wind speeds of interest will be used.

Output consists of ground level concentrations and deposition rates as a function of position (usually distance downwind) for pollutants associated with small particles and large particles, respectively.

Aquatic Transport Models

For the estimation of surface water concentrations, the concentrations of pollutants and the flows of waste water discharges are required as input. Emission sources to be considered will include the waste water discharge from coal cleaning, runoff and percolation from coal and refuse storage piles, as

well as from ash ponds at coal cleaning plants and from coal storage piles at user plants.

Sedimentation in settling basins can be allowed for by use of deposition coefficients, leaving a concentration in the water column. This water is then further diluted by dispersion and additional sedimentation in streams, etc. Simplified dispersion models using point sources of pollutants will be used. These models provide a correlation of dispersion coefficient with flow velocity and stream configuration so that reasonable approximations for surface water concentrations associated either with a specific facility or with a generalized case can be calculated for average flows, low flows, and high flows. USGS flow data, precipitation data, and watershed areas can be used for estimates of flow velocities at various flow stages of interest. Sedimentation is incorporated by the use of deposition factors relating sedimentation rate to concentration of the pollutant in the water body. Output will consist of sedimentation rate and concentration in water as a function of position (normally distance downstream) for each case. Cases of interest will include various flow stages anticipated.

Transport Through Porous Media

The leaching of key pollutants from coal and refuse piles and other sources will provide an additional source of water pollution. Water flow, permeability, and leachability data are needed to develop a model. Simple one-dimensional column models are anticipated. Flow of water through a bed of soil or other similar porous materials will leach pollutants from the bed. These overall leaching rates can be estimated using simplified mass transfer models. Cases of interest may include coal piles, refuse piles, pond bottoms, etc.

Ecological Transport

After a pollutant reaches the biological environment (animals and plants), a variety of metabolic processes can alter the concentration and form of the pollutant before it reaches the site within the body where it has an effect and/or before a pollutant-carrying organism is eaten by an animal (including man). Thus, models are needed to estimate the transport or redis-

tribution and fate of pollutants within an ecosystem. Simplified linear compartmental models with transfer from one compartment to another governed by a transfer coefficient will be used. A hypothetical temperate deciduous forest ecosystem (typically found in northern Appalachian and other regions) will be the case of most emphasis. The ecosystem will be divided into terrestrial and aquatic components, with functional groups being specific for each component (i.e., primary producers, herbivores, omnivores, carnivores, and decomposers).

Output from the physical models (e.g., ground level and water concentrations) as well as mode of entry into the system and the chemical form of the pollutants are needed as input.

Approach

Literature is currently being searched for specific data on the physical and biological transport of the key pollutants. Simplified model runs using estimated emission concentrations for the key pollutants from hypothetical Type B and Type I coal cleaning plants will be performed. This output will assist in the interpretation of environmental impact of such facilities and serve as trial runs for later more extensive analysis.

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ENVIRONMENTAL OBJECTIVES DEVELOPMENT

The development of environmental objectives is being undertaken as part of Subtask 241. Results of Subtask 241 are summarized in this section and the previous section entitled "Current Environmental Background".

Establishment of Permissible Media Concentrations

Establishment of permissible media concentrations of pollutants is needed for pollution control development guidance, e.g., for setting pollutant emission goals. Pollutant emission goals can, of course, be set on the basis of best practicable technology, but from a health/ecological viewpoint, such standards have the potential of being either too lax or unnecessarily restrictive.

In view of the state of the art, which is still in the class of an emerging technology, the permissible media concentrations are designated as "estimated permissible concentrations" (EPC's), and they are regarded only as estimates, subject to later revision as more data become available.

Since a multimedia approach is being taken to the environmental assessment of coal cleaning, estimated permissible concentrations are needed for all three media--air, water, and land, and these will be integral parts of the multimedia environmental goals (MEG's), which are to be established. EPC's will be especially germane for the homogenous media air and water, which man and biota utilize directly. Because of the heterogenous nature of soils, and the fact that, normally, there must be at least one transfer before a soil pollutant impacts man, determination of EPC's for soil will prove to be a difficult task.

The establishment of EPC's is recognized as a critical area central to the entire environmental assessment. Unfortunately, there is no accepted method for setting EPC's. A number of approaches have been suggested, based on various manipulations of TLV, LD₅₀, LD₁₀ values, etc. Many of the original experimental data are in a form not directly usable, and methods for inter-conversion and extrapolation are lacking. For these and other reasons, the methods used have not been rigorous, and without exception, are open to criticism on one or more counts.

Early in the BCL program some attempts were made to compile EPC's for air and water,⁽¹⁾ using basically the approach of Handy and Schindler.⁽²⁾ These attempts were subsequently abandoned (a) to avoid duplicating the effort which Research Triangle Institute is undertaking to estimate MEG's for several hundred compounds, using available data and correlations, and, (b) because it was deemed more fruitful for BCL to investigate and develop, if possible, improved methodologies for deriving EPC's from health/ecological data. These efforts are discussed in a later section on "Methodologies Being Developed".

Define Emission Goals

As noted in the preceding section, emission goals can be set on the basis of health/ecological impacts or upon the basis of available pollution control technology. Data for the first method are still being awaited, and will depend upon the prior establishment of permissible environmental concentrations.

Preliminary data for pollution control technology capabilities and costs have been assembled under Subtask 222, and a preliminary report has recently been issued.⁽³⁾ However, more comprehensive data on coal characteristics and coal cleaning process parameters will be needed before technology related emission goals can be set with confidence; it would be premature to attempt this at the present time.

Non-Pollutant Impact Goals

No work is in progress under the coal cleaning program on nonpollutant impact goals. However, Battelle is working on establishing EPC's (and MEG's) for several non-chemical pollutants and non-pollutant factors under Contract No. 68-02-2138⁽⁴⁾ for assessment of the environmental impact of fluidized-bed combustion processes; some of the findings of this investigation may also be applicable to coal cleaning where the same pollutants or factors are involved.

Bioassay Criteria

Normal toxicological data (e.g., TLV's and LD50's) form the basis for establishing permissible concentrations in air and water media for individual substances. However, these data do not provide a basis for accounting for synergistic and antagonistic interactions between pollutants in complex mixtures, such as are encountered in effluents from coal cleaning and other energy processes. To better evaluate the characteristics of such complex mixtures, a new bioassay protocol is being developed⁽⁵⁾ under the EPA/ERL Fluidized-Bed Combustion Program (Contract No. 68-02-2138). This protocol may be used to assess the relative toxicity of an effluent by some combination of nine biological tests. Three of the nine biological tests (microbial mutagenicity, cytotoxicity, and rodent acute toxicity) are designed to address potential human health effects. The other six biological tests for ecological toxicity assessment are as follows:

- freshwater algal assay
- acute static bioassays with freshwater fish and Daphnia
- bioassay with unicellular marine algae
- static bioassays with marine animals
- stress ethylene plant response
- soil-litter microcosm tests.

These tests provide a direct measure of toxicity and mutagenicity for which there are few available data.

This bioassay method will be utilized for the coal cleaning program to assess samples from test sites. Its use will also be considered in the development of estimated permissible environmental concentrations and emission goals.

The Level 1 screening techniques described in the bioassay procedures manual⁽⁵⁾ are recommended by the Industrial Environmental Research Laboratory (IERL-RTP) as part of a framework for prioritizing waste streams according to their relative toxicity. The biological screening techniques are designed to complement the chemical and physical procedures described in another IERL-RTP manual by Hamersma, et al.⁽⁶⁾.

Results of these biological screening tests should be considered along with the results from chemical and physical procedures to prioritize effluent streams for more detailed (Level 2 or 3) environmental assessments.

Decision Criteria for Prioritizing Pollutants

A simple but logical basis for evaluating the importance of a pollutant is to compare the concentration in which it is present in the environment to the maximum concentration which presents no hazard to man or environmental biota on a continuous long-term basis.

The environmental concentration is a function of the quantity of pollutant emitted from the source, the extent of its dispersion or transformation in the environment, and the degree of transfer between compartments. The environmental concentration of a pollutant may be defined in several ways. For an air pollutant it may be the ground level concentration (GLC) associated with a given pollutant concentration emitted from a stack. The corresponding aqueous concentration might be the surface water concentration (SWC) reached at the edge of the discharge mixing zone. In order to calculate either of the above environmental concentrations, site-specific information on the physical situation must be known or assumed in order to apply the appropriate dilution factors.

The ratio of the estimated environmental concentration to the estimated permissible concentration can serve as the basis of a rating technique for prioritizing sources, pollutants, and emission or control problems, and this concept is incorporated into the source analysis model (SAM) approach being investigated by another contractor. Very preliminary attempts to apply the concept to the coal cleaning environmental assessment proved ineffective, primarily because the data needed to make the comparisons are not yet available. Sufficient emissions data and dilution factors are available to satisfactorily approximate environmental concentrations. The critical lack, as noted elsewhere in this report, is permissible concentration data.

In the absence of rigorous criteria for prioritization, decision criteria to date have been subjective and based on general knowledge of the identity of the pollutants of most concern and their emission rates. One important external decision criterion has been the need to restrict preliminary

considerations to a small, manageable number of pollutants, rather than the whole population of potential pollutants.

Methodologies Being Developed

It was noted in preceding sections that there is a critical need for a sound and rigorous method for converting toxicological and epidemiological data to estimated permissible environmental concentrations, which does not depend upon a number of arbitrary or unsupportable assumptions.

Battelle's Columbus Laboratories is investigating this challenging problem under Subtask 241, with the goal of developing an improved methodology over those currently available. Achievement of the ultimate goal may be beyond the reach of the current program, but it is anticipated that significant progress will be made.

Two specific areas of achievement are (a) review of formulae for estimating permissible concentrations, and (b) development of rationale for extrapolation from animals to man and other organisms.

Numerous formulae for estimating permissible concentrations have been identified and reviewed. The following references are typical of this effort: Stokinger and Woodward⁽⁷⁾; International Commission on Radiological Protection⁽⁸⁾; Dawson et al.,⁽⁹⁾; American Conference of Governmental Industrial Hygienists⁽¹⁰⁾; Handy and Schindler⁽²⁾; and Kingsbury⁽¹⁾. Each formula is reviewed according to the format: (a) situation or purpose of equation, (b) the equation with explanation of all parts, and (c) rationale for biologically-based portions of quantitative relationships. We have concluded that a formula qualifies as "best" when it is (a) simple, (b) appropriate for mixtures, (c) utilizes LD₅₀, TLV or other quantitative toxicological measurements, (d) incorporates knowledge of target species, target organs and biological half-life, (e) considers chemical state of pollutant mixtures, and (f) has a supporting rationale for the use of safety or adjustment factors.

The second problem area arises in attempting to extrapolate toxicity data from animals to man. The raw data encompasses a wide variety of test animals and toxicant administration procedures, and methods are needed to interconvert these data and to extrapolate them to man.

A review of 15 articles, including Kleiber^(12,13); Freireich, et al.⁽¹⁴⁾; Anderson and Weber⁽¹⁵⁾; and Goldsmith, et al.⁽¹⁶⁾, shows there are two basic methods for extrapolating toxicity responses from animals to man. In Method I, responses of numerous species of various sizes to one toxicant are identified; the response of various species untested by the same toxicant is projected with the relationship

$$Y = aW^b ,$$

where

Y = a response

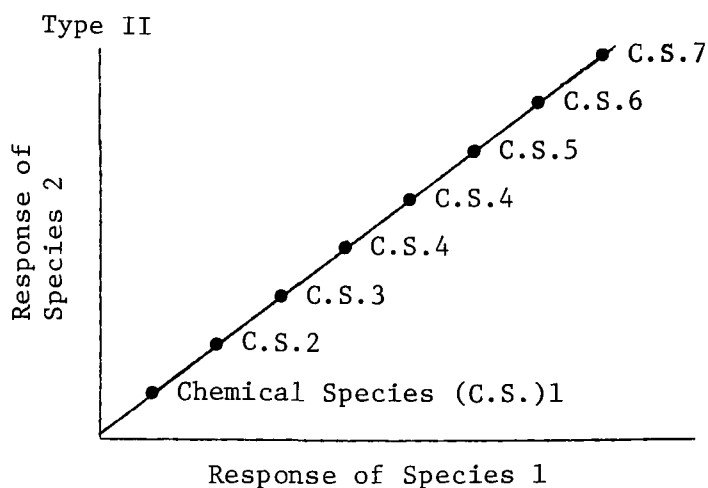
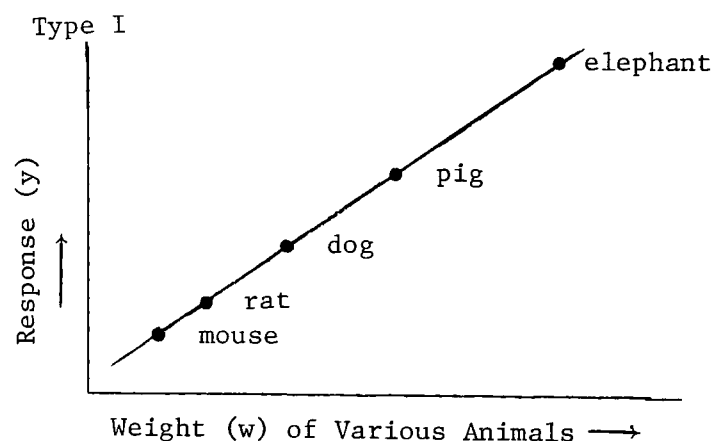
a = a constant (derived from regression of W, Y data)

W = organisms' weight

b = a constant (derived from regression of W, Y data).

In Method II, one equation deals with responses of many different toxicants on one animal species; extrapolation proceeds from one animal species to another.

Briefly, these methods are shown pictorially with non-linear scales as follows:



Battelle plans to use these approaches along with the "best" formulae to further develop estimated permissible concentrations of selected substances to humans, other organisms, and ecological systems around coal cleaning facilities.

Source Analysis Models

The source analysis model (SAM) basically involves the utilization of normalized hazard factors determined by computing the ratio of concentration of a pollutant in a stream to the goal concentration from the MEG analysis. This approach is being investigated by another contractor, and no work on it is being conducted at Battelle's Columbus Laboratories.

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OBJECTIVES DEVELOPMENT SECTION
(pp. 63-69)

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ENVIRONMENTAL DATA ACQUISITION

Existing Process Data

Published environmental data from coal cleaning processes are essentially nonexistent. The following discussion, resulting primarily from Task 222, briefly characterizes the kinds of data that are anticipated and the variations expected from simple physical to complex physical to chemical cleaning.

Physical Coal Cleaning

The pollutants generated from coal preparation plants include those contained in solid waste, contaminated water, particulates, and gaseous emissions. The nature and quantity of pollutants resulting from coal preparation facilities vary significantly depending upon characteristics of coal treated, coal cleaning technology utilized, pollution control technology employed, and geological, hydrological, and meteorological conditions where the preparation plant is located. For a given type of coal, two important factors affecting the environmental consequences of coal preparation are the coal sizes being treated and the unit operations employed. As the coal sizes become smaller, in general, coal preparation requires more sophisticated processes and becomes susceptible to producing more environmental pollution.

Coal preparation has been classified into four levels according to the coal sizes being washed and then categorized into nine generic types of plants based on coal cleaning processes employed as indicated in Table 4 of "Current Process Technology Background".

Chemical coal cleaning processes constitute another type of plant but the technologies are still in the development and testing stages. The nine physical cleaning plant types represent the majority of coal preparation facilities throughout the United States, and each type is expected to produce different environmental consequences of coal preparation although there are many similarities.

Thus, a spectrum of potential pollutants will yield a wide variety of kinds of environmental data. The most simple preparation plant consisting of only crushing and sizing will have solid waste consisting of coarse rock and tramp iron, air pollution of coal dust and dust from refuse piles, and water pollution from surface run-off around the facility. As washing or cleaning circuits are added, a quantity of contaminated process water is then present. Even though raw water is impounded and treated, effluents are acid or alkaline, and contain suspended solids, dissolved solids, iron, ammonia, and sulfates. Sludge and coarse refuse are added to the solid waste. Addition of dense media cyclones or other dense media treatments will result in a small amount of an additive, usually magnetite, being present in both the waste water and solid waste. Washing of fine coal results in a fine refuse addition to the solid waste. Use of froth flotation introduces more additives to both solid waste and waste water as chemical reagents are used in the flotation process. They may be grouped into two major classes: first, the residual organic and inorganic reagents added deliberately to the flotation circuit, and second, the metal ions and complexes contributed to the aqueous phase due to dissolution by some of the flotation reagents. No quantitative data are available to show pollutant emissions associated with froth flotation processing of coal, but, the amounts of flotation reagents used in the process are very small and are kept at a minimum not only because of economics but also to avoid the detrimental effects of excess reagents.

The cleaned fine coal that has resulted from a wet process must be dried. Thermal driers normally take coal that has been partially dewatered by mechanical means and remove as much of the remaining water as may be required by a specific market. Emissions from thermal driers include particulates from the coal being dried and particulates in the form of fly ash from the coal-fired furnace that supplies the drying gases. Gaseous emissions from thermal dryers include carbon monoxide, carbon dioxide, hydrocarbons, sulfur dioxide, and oxides of nitrogen--all furnace combustion products.

Chemical Coal Cleaning

In the chemical cleaning of coal, the dissolution of sulfur and ash minerals would be accomplished using acid, alkaline, and oxidation reaction methods. Potential pollutants from chemical coal cleaning may include unreacted chemical agents, by-products of chemical reactions, and contaminated process water as well as many of the wastes, particularly solids, that might be expected from physical coal cleaning, a logical first step in any integrated cleaning facility. Because chemical coal cleaning processes are still in the development stage, however, very few data on the environmental impact of chemical cleaning are available.

Air pollutants can originate from perhaps two or three types of sources associated with a chemical cleaning process. The type of source about which the least is known would be process vents. Although the pollutants in the vent gases would be controlled by scrubbers or by thermal or catalytic combustors, some residuals might be expected. For example, a positively identified air emission stream from the Meyers process emanates from a gas scrubber vent as a stream containing 90 percent oxygen, 10 percent sulfur dioxide, plus (unspecified) volatile organic compounds.

Another source of air pollutants would be that from combustion operations designed to provide for addition of reaction heat. The provision for reaction heat may be necessary for the Meyers process, for example. Fortunately, the air pollutants from combustion operations and their control are well understood and should prove no problem.

The final source for air pollutants would be from thermal dryers. For the most part, the air emissions would be similar to those produced by thermal dryers used in physical coal cleaning operations, and similarly controllable.

In chemical cleaning, potential air pollutants from the coal are converted to water soluble salts. Thus, the process water contains high concentrations of dissolved salts. In addition, the process water may contain other inorganic and organic materials. For the Meyers process, for example, special care should be taken for the organic solvent (e.g., light naphtha)

used in sulfur removal section. Naphtha has a measurable solubility in water and can appear in the purge stream. The buildup of organic impurities in the recycled organic solvent and trace elements in the process water stream may be potentially hazardous. Other liquid wastes from the Meyers process may include sulfuric acid, wetting agents, and agents to control foaming.

In addition to any physical cleaning wastes, as previously noted, the solid wastes from chemical coal cleaning will include solid reaction products and sludges produced by the neutralization of scrubber waters and process waters. These waste (or by-product) reaction products and sludges may contain organic materials used in the process or dissolved or vaporized from the coal. Trace element concentrations, too, may be many times higher than in the untreated coal or even its ash.

In the Meyers process, for example, large quantities of iron sulfates (mixed ferrous and ferric) are produced as a by-product. Also produced are gypsum, from the neutralization of the sulfuric acid which is not recycled, and elemental sulfur. Although their quantitative levels have not been established, many trace elements from the mineral constituents in the coal will also be present in the solid wastes produced because the trace elements will be dissolved and reprecipitated in the process. Organic wetting and antifoaming agents and other organic materials (such as naphtha) used in the process or perhaps dissolved from the coal may also be present in the solid wastes.

It should be concluded that compositions of the many waste streams by chemical coal cleaning processes need to be quantized.

Sampling and Analytical Techniques

Objectives

Task 431 of this contract was established to evaluate applicable methods of sampling and analyses for the purpose of assessing the environmental effects of coal cleaning plants. The steps to be followed in achieving this objective include:

- The application of sampling methods which are appropriate to anticipated pollutants from various media
- Recommend accepted or new methods of preservation, storage, transfer and preparation of samples for analyses
- Indicate the analytical methods which possess the desired detection and sensitivity limits for the expected pollutants at the required levels of characterization
- Evaluate the assessment strategy of the phased versus the direct approach in regard to convenience, cost, and utility
- Complete writeup of the overall desired or recommended procedures of sampling and analysis.

Development of Experimental Techniques

The phased approach for determining the extent of pollution potential of a process is divided into three consecutive levels of effort. Level I is used as a survey tool to identify existing broad problems and to evaluate the possible adverse environmental effects of effluents. As such, representative sampling is not required and analytical results within a factor of ± 2 or 3 are acceptable. Level II is an extensive qualitative, semiquantitative program that is intended to identify specific substances that exist in effluent streams having significant environmental effects. Level III is a quantitative study of the effects of process variables on the emission of specific substances which Level II identified as causes of environmental effects.

An alternative to the phased strategy is the direct approach. This approach requires quantitative analyses of one set of representative samples. This is essentially a Level II procedure and assumes that prior knowledge is available as to the nature of emissions of the technology being investigated. To avoid repeated sampling trips to any one plant, Battelle recommends the direct approach with the assumption that it will be less costly to over-sample

on a single visit than to make a second visit. The result is that samples may be taken at Level II intensity but screened at Level I and followed up with Level II analysis as needed. This level of sampling will be justified because we will have some prior knowledge of the effluents of a plant.

Existing methods for collection, preservation, transport, preparation, and analysis of known or anticipated effluents from coal cleaning processes have been surveyed and appropriate methods have been compiled. These are summarized in Table 9.

Sampling, Sample Preservation, and Transport. The sampling for chemical analyses for this assessment will deal only with the source materials of and the carriers for pollutants as contrasted to in-process sampling. The sources of pollutants are noted to be raw coal, refuse and ash areas, holding ponds, and process chemicals. The carriers of the pollutants are air, water, and sediments. Pollutant sinks such as vegetation, soils, aquatic biota, and terrestrial mammals are believed to be best assayed for ecological contamination in a Level III monitoring program where effects can be observed over periods of time. Some of these samples will be taken and preserved for possible future analysis.

Solid samples such as coal, ash, and refuse are taken by grab sampling with a core tube or from a conveyor belt. These are stored in air-tight plastic bags or plastic-lined metal containers.

Grab samples of water are taken by dipping or by use of a Van Dorn or equivalent sampler. Preservatives can be added immediately.

Atmospheric pollutants include both gas vapors and particulates. Gaseous emissions come from thermal drying of clean coal and combustion of coal in thermal driers while particulate sources are crushers and screens, refuse and coal piles, transfer points, ash from thermal driers, and vehicular dust. Particulates are collected on glass fiber filter pads by hi-vol samplers and by Andersen impactors which are placed downwind of the plant. Gaseous emissions are collected either by adsorption by an XAD-2 resin for C₇-C₁₂ organic compounds or by admission into evacuated vessels for inorganic and C₁-C₆ organic compounds. Preservation measures are designed to reduce pickup of moisture by particulates, stable biological activity and prevent photochemical reactions.

TABLE 9. SUGGESTED SCHEME FOR ANALYTICAL CHARACTERIZATION OF COAL CLEANING PROCESSES

Media	Sample	Measurement	Sampling Technique	Preservation(a)	Sample Preparation	Analytical Method(b)	Method Reference (e)
Atmospheric	Particulate	weight	Hi-Vol, 8"x10" glass filter	Store in sealed plastic		Gravimetric	
		available elements	Hi-Vol, 8"x10" glass filter	Store in sealed plastic	Acid extract	SSMS	
		Hg	Hi-Vol, 8"x10" glass filter	Store in sealed plastic	Acid extract	AAS	
		SO ₄	Hi-Vol, 8"x10" glass filter	Store in sealed plastic	Water extract	IC	(3)
		NO ₃	Hi-Vol, 8"x10" glass filter	Store in sealed plastic	Water extract	ISE	(4)
		Cl ⁻	Hi-Vol, 8"x10" glass filter	Store in sealed plastic	Water extract	ISE	(4)
		NH ₄ ⁺	Hi-Vol, 8"x10" glass filter	Store in sealed plastic	Water extract	ISE	(4)
		Bioassay	Hi-Vol, 8"x10" glass filter	Store in sealed plastic	Solid and water extract	Cytotoxicity, mutagenicity	(5)
		Organics	Hi-Vol, 8"x10" glass filter	Store in sealed plastic	Pentane solvent extraction	GC, IR, LC (8 fractions); IR, GMS	(1,6,7)
		Particle size	Andersen Impactor	Glass Bottles	None	Gravimetric	--
		Particle morphology	Andersen Impactor	Glass Bottles	None	LM, SEM, TEM	(8)
	Gaseous	C ₁ -C ₆	Evacuated glass bulb	Glass	None	GC-FID (on-site)	(6,7)
		C ₇ -C ₁₂	Adsorption-XAD-2	Cap and Refrigerate	Methylene chloride extract	GC, IR, LC (8 fractions); IR, GMS	(1)
		Metals	XAD-2 cartridge	Cap and Refrigerate	Parr Bomb	SSMS	
		Bioassay	XAD-2 Cartridge	Cap and Refrigerate	Pentane extract	Cytotoxicity, mutagenicity	(5)
		H ₂ S	Gas bag	(Store in dark to reduce photochemical reactions)	None	GC-FPD	(1)
		COS	Gas bag	(Store in dark to reduce photochemical reactions)	None	GC-FPD	(1)

TABLE 9. (Continued)

Media	Sample	Measurement	Sampling Technique	Preservation (a)	Sample Preparation	Analytical Method (b)	Method Reference (e)
	Gaseous (Continued)	CS ₂	Gas bag	(Store in dark to reduce photochemical reactions)	None	GC-FPD	(1)
		CO	Gas bag	(Store in dark to reduce photochemical reactions)	None	GC-TC	(1)
		CO ₂	Gas bag	(Store in dark to reduce photochemical reactions)	None	GC-TC	(1)
		CN	Gas bag	(Store in dark to reduce photochemical reactions)	None	GC-TC	(1)
		NH ₃	Gas bag	(Store in dark to reduce photochemical reactions)	None	GC-TC	(1)
		NO _x	Gas bag	(Store in dark to reduce photochemical reactions)	None	Chemiluminescence	(1,9)
		SO _x		(Store in dark to reduce photochemical reactions)	None	GC-FPD	(1)
Aquatic	Water	Total elements	Grab	P or G, HNO ₃ to pH <2(2)	Dry for residue & briquette	SSMS	
		Hg	Grab	P or G, HNO ₃ to pH <2(2)	Reduce & amalgamate with Ag	AAS	
		Acidity	--	P or G, Cool, 4° C	on site	Hach kit, or equivalent	(10)
		Alkalinity	--	P or G, Cool, 4°C	on site	Hach kit, or equivalent	(10)
		BOD	--	P or G, Cool, 4°C		5 day incubation	(4)
		COD	--	P or G, H ₂ SO ₄ to pH ₂		Dichromate oxidation	(4)
		Chloride	--	P or G, Cool 4°C	on site	Hach kit, or equivalent	(10)

TABLE 9. (Continued)

Media	Sample	Measurement	Sampling Technique	Preservation(a)	Sample Preparation	Analytical Method(b)	Method Reference (e)
80	Water (Continued)	O ₂	--	G	on site	Portable oxygen probe (or Winkler method)	--
		Hardness	--	F or G, Cool to 4°C	on site	Hach kit, or equivalent	(10)
		MBAS	--	P or G, Cool to 4°C		Colorimetric	(4)
		Total N	--	P or G, H ₂ SO ₄ to pH<2, Cool 4°C	oxidize	Kjeldahl + NO ₃	(4)
		Total organic C	--	Glass, H ₂ SO ₄ to pH <2, Cool 4°C		Beckman instrument or equivalent	(4)
		pH	--	P, G, Cool to 4°C	on site	Portable pH meter or pH paper	--
		Phenols	Grab	G, H ₃ PO ₄ to pH<4, 1 gr CuSO ₄ /l, Cool to 4°C	Distillation	Colorimetric	(4)
		Total P	--	P or G, H ₂ SO ₄ to pH<2, Cool 4°C	Oxidation	Colorimetric	(4)
		Total residue	--	F or G, Cool to 4°C	Evaporation	Gravimetric	(4)
		Conductance	--	P or G, Cool to 4°C	on site	Portable meter	--
		Total S	--	P or G, 2 cc zinc ace- tate; Cool to 4°C	oxidize to sulfate	IC	(3)
		Temperature	--	P or G	on site	thermometer	--
		Organics	--	H ₂ SO ₄ to pH<2 Cool 4°C	methylene chloride ext	LC (8 fractions)	(1)
		Bioassay	--		None	Cytotoxicity, mutagenicity	(5)
Solids	Coal	Total elements	Grab	Plastic Bag	Parr Bomb	SSMS	
		Hg	--	Plastic Bag	Parr Bomb	AAS	
		Total sulfur	--	Plastic Bag	Direct	Eschka, grav.	(11)

TABLE 9. (Continued)

Media	Sample	Measurement	Sampling Technique	Preservation (b)	Sample Preparation	Analytical Method (b)	Method Reference (e)
81	Refuse	Total elements	Grab	Plastic Bag	Direct	SSMS	
		Hg	Grab	Plastic Bag	Direct	AAS	
		Available elements	Grab	--	Water leach	SSMS	
		Available Organics	Grab	--	Methylene chloride ext	GC, LC/IR-GMS	(1)
		Bioassay	--	--	Water leach grind solid	Cytotoxicity, mutagenicity	(5)
		Acidity	--	--	Water leach	(see methods for water)	(see water references)
		Alkalinity	--	--	Water leach	(see methods for water)	(see water references)
		COD	--	--	Water leach	(see methods for water)	(see water references)
		Chloride	--	--	Water leach	(see methods for water)	(see water references)
		CN	--	--	Water leach	(see methods for water)	(see water references)
		Total N	--	--	Water leach	(see methods for water)	(see water references)
		Organic Carbon	--	--	Water leach	(see methods for water)	(see water references)
		pH	--	--	Water leach	(see methods for water)	(see water references)
		Phenols	--	--	Water leach	(see methods for water)	(see water references)
		Total P	--	--	Water leach	(see methods for water)	(see water references)
		Total residue	--	--	Water leach	(see methods for water)	(see water references)
		Total S	--	--			
		Total S	--	--	Water leach	(see methods for water)	(see water references)

(a) P- Plastic, G - Glass

(b) SSMS - Spark Source mass spectrometry; AAS-Atomic Absorption Spectrometry; IC-Ion Chromatography; ISE-Ion selective Electrode; LM-Light Microscope; SEM-Scanning Electron Microscopy; TEM-Transmission Electron Microscopy; GC-Gas Chromatography; IR-Infrared Spectroscopy; LC-Liquid Chromatography; GMS-Gas Mass Spectrometry; FID-Flame Ionization Detector; TC-Thermal Conductivity Detection; FPD-Flame Photometric Detection

(c) References are given at the conclusion of this section of the report.

Sample Preparation. Each kind of instrumental analysis has its set of operating ranges and conditions which requires that samples from whatever source they come must be prepared for that analytical method. In general, this requires samples, whether air, water, or solid, to be brought into solution by dissolution or extraction with appropriate solvents for chemical analysis or bioassay or dried for gravimetric or spectrometric analysis. Combustible solids such as coal will be burned and the residues taken up in nitric acid.

Chemical Analyses. Level I chemical analyses are performed by methods with low detection limits. The methods listed in Table 8 are sufficiently sensitive to identify potential pollution problems without accurately measuring the pollutant concentrations. Inorganic elements in solids and liquids will be analyzed by spark source mass spectrometry; inorganic gases and low molecular weight organic compounds (C₁-C₆) will be analyzed by gas chromatography; and higher molecular weight organic compounds (C₇-C₁₂) will be resolved for functional groups and typed by solvent separation and analyzed by gas chromatography, infrared spectroscopy, and gas mass spectrometry. Some analyses can be performed on site with reagent test kits (Hach or equivalent). Mercury is a special case of an inorganic element for which atomic absorption spectrometry is the accepted method of analysis even for Level I.

Bioassays. Level I bioassays are based on the exposure of organisms to whole samples to estimate the potential adverse health and ecological effects. Sensitive aquatic organisms are exposed to various levels of liquid effluents to determine toxicity levels of the pollutants. Leachates from solids can also be tested in this manner.

Gaseous samples are tested by the plant stress ethylene test in which plants (soybeans) are exposed to the gaseous emissions for varying lengths of time after which they are enclosed in plastic bags and the evolution of ethylene by the plants monitored for several days.

Test Development Program

The test program was developed under Subtask 411 to provide overall guidance for the field program, identify sources of coal cleaning pollutants, and select the ecological compartments to be evaluated for the environmental effects of those pollutants. The test program is described in Battelle's draft report⁽¹²⁾ of September 30, 1977.

The largest single source of potential pollution from coal cleaning is solid waste. Potential impacts of solid waste include air, water, and land pollution; safety hazards; and ecological and esthetic impacts. These solids include soluble and suspendable materials which can produce acid run-off, toxic solutions, and silted waterways. The greatest adverse biological impact of solid wastes occurs as water pollution. Acid run-off and leachate are products of reactions with the pyrite present in the refuse pile, and it can leach into the groundwater as well as drain into surface waters. Solid wastes can also contribute to air pollution in the forms of blowing dust and smoke and gases from burning piles.

Polluted water can come from the preparation plant washing processes as well as the solid waste run-off. Acid waters dissolve metals and mineral salts which they contact. Lime treatment to decrease the acidity can create highly alkaline waters with the precipitation of calcium carbonate and metal salts which may affect aquatic organisms. Silts and suspended solids cause changes in aquatic habitats.

Air pollution results from the dusts and particulate matter that come from the mechanical and thermal processes in the preparation plants as well as the gases, odors, and particulates from burning refuse and coal piles. The biggest source of particulates is thermal drying. A number of toxic trace elements and gases have been identified in emissions from thermal driers.

Although it is quite localized, noise is another form of air pollution which originates in the crushers, screens, conveyors, and other parts of the coal cleaning plant.

The field test program is designed to assess the severity of these environmental pollutants and the effectiveness of pollution controls. To accomplish this, a well planned test program must be carried out to test,

sample, and analyze wastes, effluents, and emissions from coal cleaning plants which have been selected to be representative of the coal cleaning processes and the environmental settings in which these plants are located. The procedure for selecting these test sites and the general test plan development are discussed briefly below.

Site Selection Procedure

To support the study of coal cleaning and pollution control technologies, Battelle will make field visits, measure environmental factors, and take samples of process streams for subsequent laboratory analysis. A site selection scheme has been developed to permit the study of as many variables as possible with a limited number of field trips.

Four unique and important variables were selected for study. These variables which are expected to have the greatest influence on the kinds of pollution controls needed for coal cleaning operations are neutralization potential (N), pyritic sulfur (S), annual precipitation (R), and process technology (T).

Based on the low (0) and high (1) potential pollution levels for each of these variables as shown in Table 10, 16 types of site categories are possible. Six of these site categories are excluded from further consideration because they are nonexistent, e.g., low rainfall which occurs in the western U.S. is not consistent with high sulfur or acid conditions. A basic statistical rationale for identifying sampling sequences for factorial designs may be stated as follows:

- Early in the sampling sequence, sample those site categories that permit the "main effect" of each classification variable to be investigated; next include those site categories that permit investigations of the "interaction effect" associated with two classification variables, then three classification variables, etc.

This rationale is based on the assumption that the most desired information is that associated with the main effects of single variables. After obtaining

TABLE 10. CLASSIFICATION VARIABLES AND ASSOCIATED
LEVELS USED TO DEFINE SITE CATEGORIES

Variable	Low Level (0)	High Level (1)
N (Neutralization potential)	pH \geq 7.5*	pH \leq 6.0*
S (Pyritic sulfur)	\leq 1.0%	\geq 3.0%
R (Average annual rainfall)	\leq 15 in/yr	\geq 25 in/yr
T (Coal cleaning process technology)	Plant Type A&B [#]	Plant Type F thru I [#]

* pH of soil in the receiving environment. As defined, low level of N actually refers to a low pollution potential which is, in fact, a high ability to neutralize acid streams.

[#] See Table 4 in "Current Process Technology Background" for definitions of plant types.

information on the effect of each classification variable, the next priority is then associated with information on the combined effects of two classification variables, etc.

Table 11 shows the recommended sequential sampling design for the ten remaining coal cleaning plant categories. One site from each site category is to be sampled in the sequence from 1 to 10, as shown in Column 2, with site category 1, defined as (1111), sampled first and site category 10, defined as (0000), sampled last. The sampling may be terminated after sampling the first four site categories (Option C), after sampling the first eight site categories (Option B), or after sampling all ten site categories (Option A).

Once the existing coal cleaning plants have been classified into these site categories, the next step of the selection process is that of selecting specific sites within each site category. The specific sites are intended to yield the maximum information concerning coal cleaning impacts upon environments from a given number of sites. The selection of specific sites is to be accomplished by applying constraints or defining specific needs. Published information, telephone contact, and site visits will be used to provide information on candidate sites. Constraints which will be imposed in making the final site selections are shown in Table 12. These constraints will be applied in the order shown.

Test Plan Development

The master test plan and the site-specific test plans are intended to ensure that the testing is performed effectively with regard to costs, schedules, and data requirements. This activity is designated as Subtask 451. The objectives dictate that the test planning subtask be a coordinated activity involving several other subtasks. Determination of data requirements comes about in part through interaction with the systems studies task (200 series) since one of the functions of that task is to identify data gaps in the coal cleaning literature. Development of realistic testing cost estimates and schedules requires participation of the key test personnel. Test

TABLE 11. RECOMMENDED SEQUENTIAL SAMPLING DESIGN
FOR COAL CLEANING PLANTS

Group Number	Site Category ⁽¹⁾	Site Characteristics (N, S, R, T) ⁽²⁾	Geographic Regions ⁽³⁾
1	1	(1111)	NA
	2	(1110)	NA
	3	(1011)	NA
	4	(0111)	MW
2	5	(1010)	NA
	6	(0110)	NA
	7	(0011)	MW, SA
	8	(0010)	MW, SA
3	9	(0001)	W
	10	(0000)	W

- (1) One site from each site category is to be sampled in the sequence from 1 through 10, with site category 1, defined as (1111), sampled first and site category 10, defined as (0000), sampled last. The sampling may be terminated after sampling 4 site categories (Option C), 8 site categories (Option B), or 10 site categories (Option A).
- (2) See Table 10 for definitions of low (0) and high (1) levels for neutralization potential, N, pyritic sulfur, S, average annual rainfall, R, and coal cleaning process technology, T. The combination (1010), for example, denotes a site category with N and R at level 1 and S and T at level 0.
- (3) Geographic regions associated with the site categories are denoted by Northern Appalachian (NA), Southern Appalachian (SA), Midwestern (MW), and Western (W).

TABLE 12. PRIORITIZED CONSTRAINTS USED IN SPECIFIC
SITE SELECTION PROCEDURES

Constraints
<u>Essential</u>
(1) Best practicable pollution control technology
(2) Plant management cooperation
<u>Needed</u>
(1) Two ages of refuse piles
(2) Plant capacity greater than the mean of the site category
(3) Baseline data available
<u>Desired</u>
(1) Minimal coal industries in area
(2) Nonmixed refuse piles
(3) Homogeneous coal source

planning personnel are involved in the site selection process described in the preceding section to ensure that selected sites are physically reasonable for sampling purposes.

To date, progress in test plan development has primarily involved key test personnel input to the master test plan. Specialists in hydrology, structural geology, water chemistry, air pollution measurement, air pollution modelling, aquatic and terrestrial biota, and noise measurement have identified for their respective disciplines those test elements which will be site-independent. These common elements are being integrated into a master test plan. Approximately 15 percent of the work on the master test plan is complete.

The site-specific test plans are, at the time of this writing, awaiting selection of the first site. In development of specific site test plans, coordination with the systems studies task will be especially important in determining data requirements.

Preoperational Environmental Monitoring

Homer City, Pennsylvania

A major environmental monitoring evaluation has been completed for the U.S. Environmental Protection Agency in a study area containing an advanced physical coal cleaning facility, presently in the final stages of construction at the Homer City (Pennsylvania) electric generating complex. The Homer City generating complex is jointly owned by Pennsylvania Electric Company (Penelec), a subsidiary of General Public Utilities Corporation (GPU), and New York State Electric and Gas Corporation (NYSEG). Because of the technically advanced nature of the new coal cleaning facility, the U.S. EPA has arranged for the collection and analysis of data, to enable an evaluation to be performed of the effectiveness and cost of physical coal cleaning techniques in controlling pollutants, principally sulfur and its compounds, currently being emitted by power generation facilities. The primary objective of this environmental monitoring in the study area surrounding the Homer City coal cleaning plant was to obtain background information on environmental conditions prior to the operation of the coal cleaning plant.

Homer City Coal Cleaning and Generating Complex. The Homer City station is part of an integrated power complex which includes coal mines; coal cleaning, storage, and transport facilities; power-generation facilities; and waste disposal facilities as illustrated by Figure 2. Coal used at the Homer City station comes from two dedicated mines located at the site, as well as coal hauled by truck from other mines. The Helvetia and Helen mines are both deep mines which obtain coal from the Upper Freeport seam and have life expectancies of approximately 50 and 30 years, respectively. Both mines will deliver crushed coal to the new coal cleaning plant by conveyor. The coal cleaning plant or MCCS will receive about 24 percent of its coal from the Helen mine, 52 percent from the Helvetia mine, and about 24 percent from coal trucked to the complex from nearby mines. Cleaned coal will leave the cleaning plant in two streams, one with low and the other with medium sulfur content for use in the Homer City station boilers. The

Coal Sources

Helen Mine
Helvetia Mine
Trucked In

Coal Preparation

Crushers & Breakers at Mines
Multi-stream Coal Cleaning
Plant

Coal Storage

Active Pile
Reserve Pile

Power Units

#1 } medium sulfur
#2 } coal
#3 low sulfur coal

Solid Waste

Refuse Disposal Area (from MCCS)
Ash Disposal Area (from power plant)
Boney Piles (from mines)

Liquid Waste Ponds

Refuse Leachate Ponds (2)
Ash Leachate Pond (1)
Coal Pile Runoff Ponds (3)
Bottom Ash Desilting Pond (4)
Emergency Holding Pond (1)

Water Treatment Facilities

Leachate Water
Industrial Waste
Cooling Tower Makeup
Boiler Feedwater
Sewage Treatment (2)

Streams Receiving Runoff and/or Effluent

Cherry Run
Blacklick Creek
Two Lick Creek

FIGURE 2. HOMER CITY POWER COMPLEX

existing power units, numbers 1 and 2, will use the higher sulfur content coal and the deep cleaned coal will be burned in the new power unit, number 3.

Solid refuse from coal mining, cleaning and burning will eventually be deposited in the three different types of disposal areas indicated in Figure 3. Refuse from the cleaning plant and sludge from the emergency holding pond will be stored in a newly created refuse disposal area. Both the Helen and Helvetia mines will continue to dump their mine waste, including high-ash coal or "bone" coal, in the boney piles near each mine shaft. The ash disposal area is the third type of area for solid refuse. It receives sludge dredged from the two coal pile run-off desilting ponds which receive a slurry of bottom ash and pulverizer reject. Finally, fly ash captured by the electrostatic precipitators is trucked from fly ash storage silos to the ash disposal area.

Liquid wastes from coal mining, cleaning, and burning are clarified and/or treated by several different methods prior to discharge into tributaries of Blacklick and Two Lick Creek as indicated in Figure 4. A proposed 4,000 gpm capacity plant will treat leachate water with calcium oxide pellets and aeration before release into an unnamed tributary of Blacklick Creek. Water entering this new plant will be pumped from leachate settling ponds at the ash and cleaning plant refuse disposal areas. In addition, mine drainage from the two mines at the complex will also be treated at this new facility. In the event of an emergency, slurry from the cleaning plant will be discharged into a seven-million-gallon emergency holding pond, which also receives storm run-off and spillage from around the MCCS. Two 135-foot-diameter static thickeners will clarify water in the holding pond and return it to the cleaning plant.

Storm run-off from the coal storage area is diverted in ditches to two desilting ponds where the suspended solids are permitted to settle. Caustic is fed at the inlets to these ponds for neutralization and removal

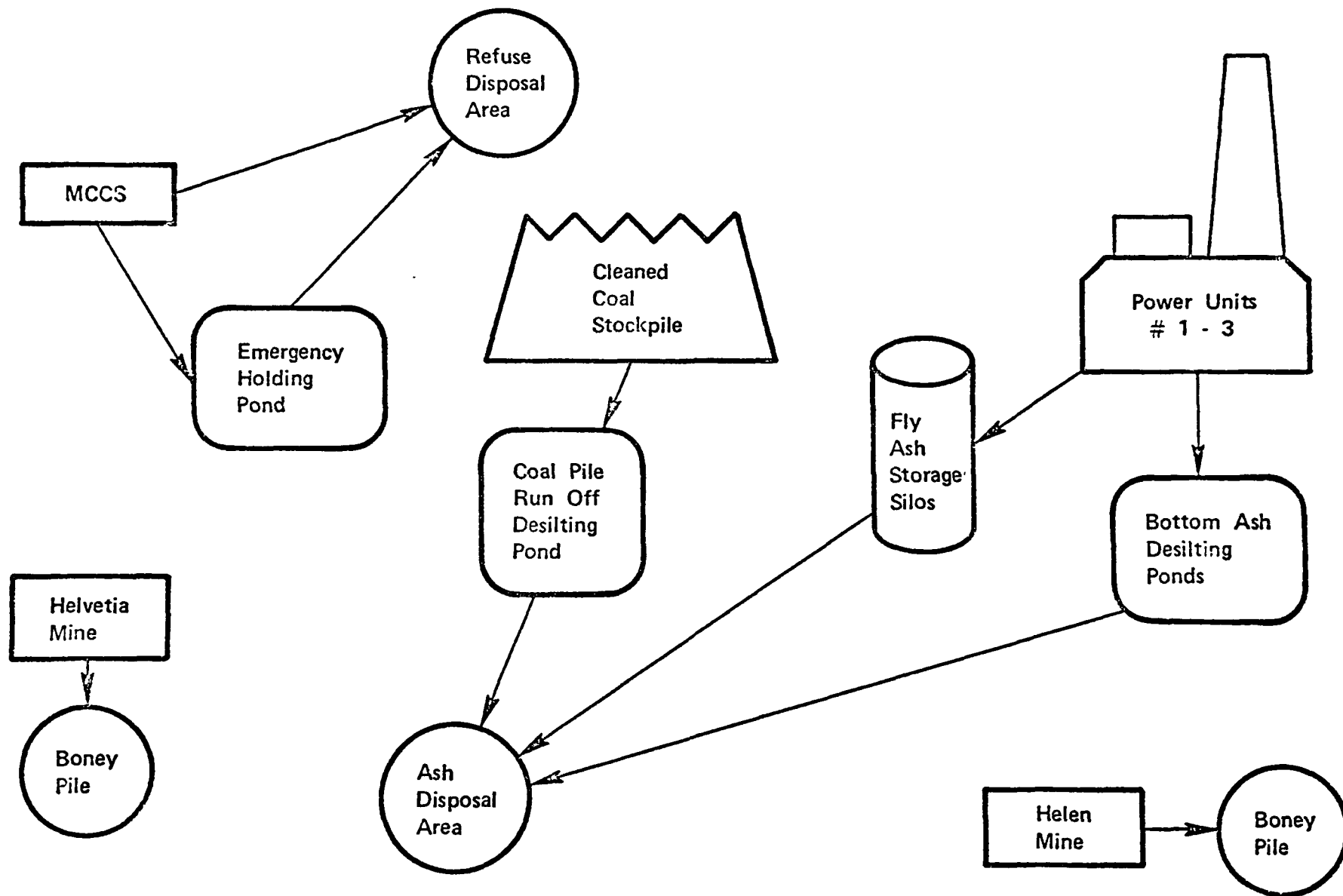


FIGURE 3. DISPOSAL AREAS FOR SOLID REFUSE FROM COAL MINING, CLEANING, AND BURNING

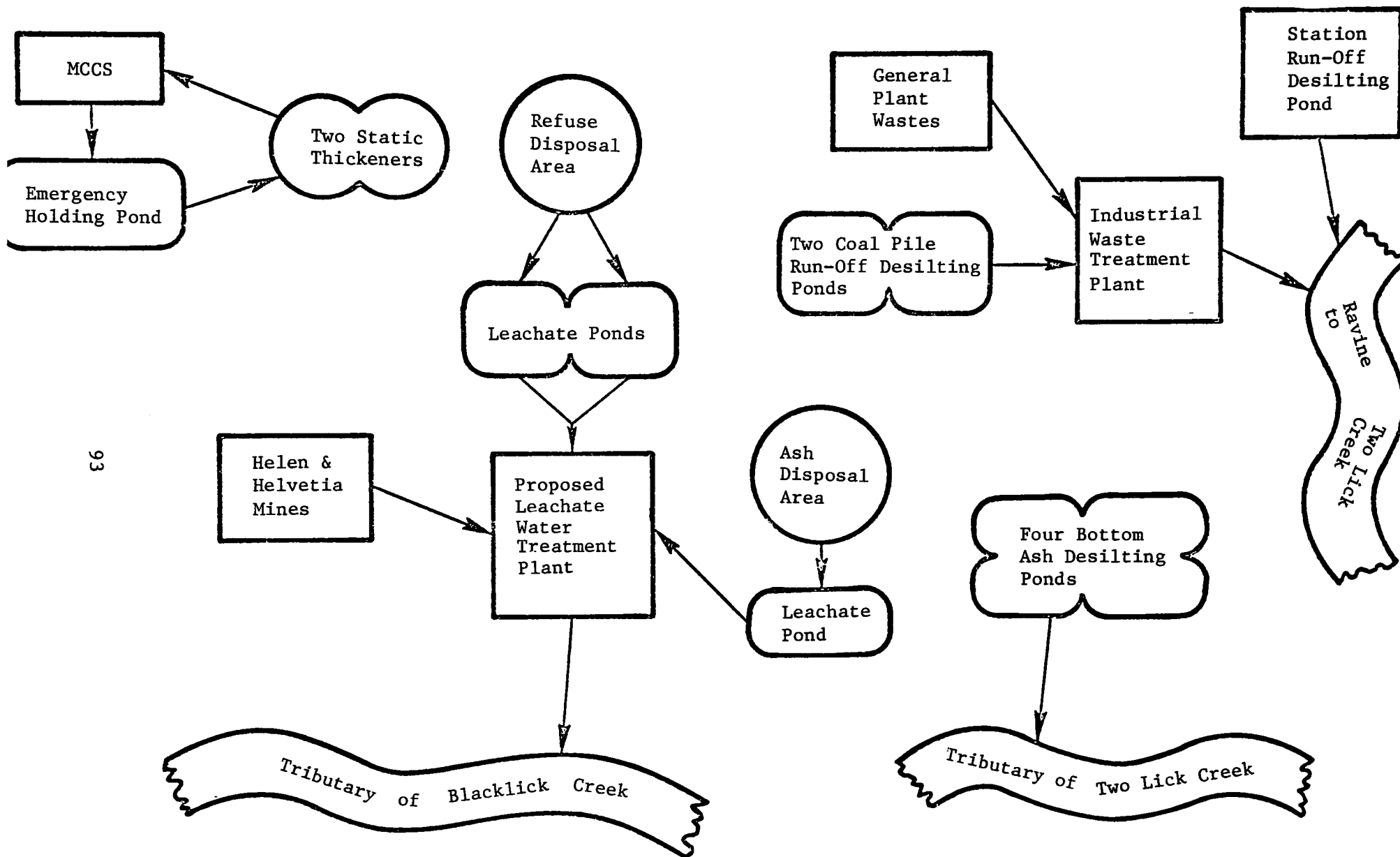


FIGURE 4. LIQUID REFUSE FROM COAL MINING, CLEANING, AND BURNING

of iron. Average flows from these ponds are pumped to the industrial waste treatment plant and eventually discharged in a ravine leading to Two Lick Creek.

Storm run-off from roof and paved surface drains at the power station leads to a desilting pond after oil from the oil handling area has been removed by a concrete oil separator-skimmer tank. Average flows from this pond pass through an underdrain filter system before release into a ravine. Sluice water, containing bottom ash and pulverizer reject, is discharged into clay-lined settling ponds. Two of the four ponds used for this purpose are in operation while sludge collected in the other pair of bottom ash settling ponds is removed. Some clarified effluent from these ponds is recycled for ash sluicing and the remaining effluent is discharged into a tributary of Two Lick Creek.

General plant wastes not directly in contact with coal are also treated at the industrial waste treatment plant. These wastes include boiler blowdown water, furnace bottom-seal water, vacuum seal water, and floor washing. This plant waste water, coal storage-pile drainage, and some ash sluice water are neutralized by the addition of lime and then subjected to air agitation. Prior to discharge into a ravine the water is allowed to settle for removal of suspended solids. Sanitary wastes are treated in two package sewage treatment plants sized for 5,000 and 12,000 gallons per day. After chlorination to 1-2 ppm residual, the effluent flows into a ravine which discharges into Two Lick Creek.

Monitoring Protocol. Nine general environmental evaluation areas at the Homer City complex listed in Figure 5 have been examined for a variety of abiotic factors that involve sampling and analysis of fugitive dusts, surface and groundwaters, and refuse. One or more of (1) minor and trace elements, (2) sulfur, (3) waste water characteristics, (4) stream flow, and (5) particulates were determined. A brief selected example of the sampling performed in the environmental evaluation study area is shown diagrammatically in Figure 6 for the cleaning plant refuse disposal area. The 13 sampling sites are indicated by the numbers in circles. Samples of the major input and output streams to this disposal area include solid refuse from the cleaning plant, sludge from the emergency holding pond,

1. Bottom and Fly Ash Disposal Area
2. Cleaning Plant Refuse Disposal Area
3. Treatment Plant for Leachate Water
4. Emergency Holding Pond for Cleaning Plant
5. Airborne Dust from Coal and Refuse Transport
and Storage
6. Streams and Underground Aquifers With Potential to
Receive Pollution
7. Coal Pile Run-Off Desilting Ponds
8. Desilting Pond for Plant Facilities Storm Run-Off
9. Ash Sluice Water Desilting Ponds

FIGURE 5. ABIOTIC ENVIRONMENTAL EVALUATION AREAS

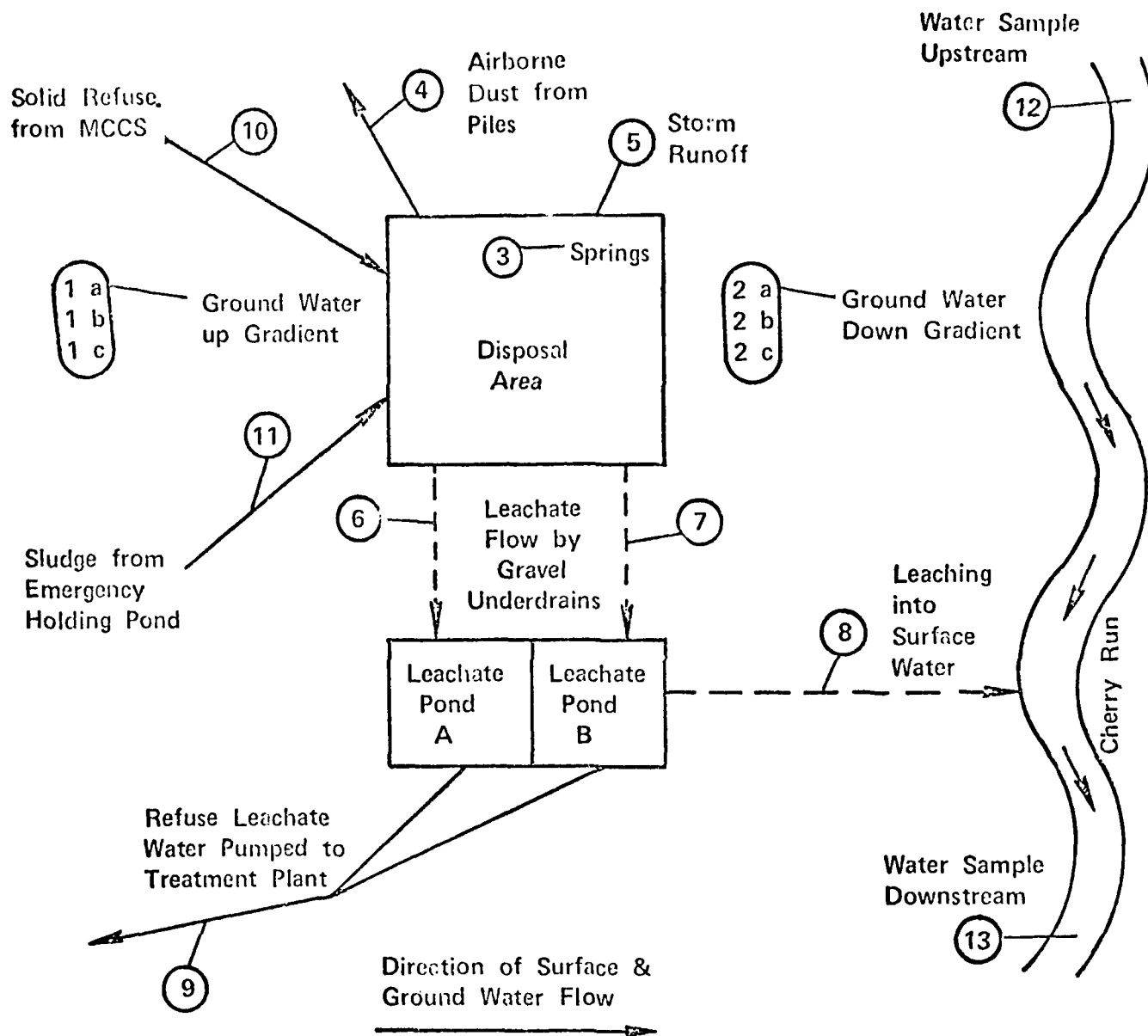


FIGURE 6. SAMPLING SITES AT CLEANING PLANT REFUSE DISPOSAL AREA

and leachate water pumped to the treatment plant. In addition, the potential for leaching of pollutants into the surface and groundwater were examined. Water samples and flow rates from the aquifer lying under the disposal area were obtained both up and down gradient from the disposal area by a series of piezometers. These samples were analyzed to determine differences in concentrations of pollutants caused by leaching from the disposal area. Similarly, storm run-off diverted around the disposal area and surface water flowing downgradient from the leachate ponds were sampled and their pollutant levels compared. Water samples from springs in the disposal area and leachate flow in the gravel underdrains have been compared. Finally, water and sediment samples and flow rates were obtained at sites upstream and downstream from the reach of Cherry Run likely to receive leachate from the refuse disposal area.

The other environmental evaluation areas noted in Figure 5 have been sampled in a manner similar to the refuse disposal area, with appropriate modifications for differences in direction of water flow, distance to other potential sources of pollution, and differences in construction of the facility.

Accepted sampling and analysis techniques have been documented for most of the components of each of the five environmental parameters listed earlier. Some additional techniques have been recommended by Battelle. The Illinois Geological Survey recommended analysis techniques for 33 of the minor and trace elements likely to be found in particulate samples. Waste water characteristics including sulfur analysis methods have followed those recommended by EPA in the Federal Register. Stream flow may be determined by several different methods depending on the circumstances, but the most widely used method was the current meter (pygmy meter). Groundwater flows were determined from piezometer observations. Fugitive dust particulate samples were weighed, analyzed for minor and trace elements, and mass concentrations calculated.

A computer simulation model was developed to predict the zones of fugitive dust fallout and the predicted rates of dispersion of the fallout. This model will be further refined and utilized in Battelle's national coal cleaning testing program.

General Results

The studies performed in December 1976, and April 1977, included assessments of water quality, sediments (both surface and groundwater) fugitive dust, and aquatic and terrestrial biota. Three separate campaigns were performed for water quality, sediments, fugitive dust and aquatic biota. A single survey was performed of the terrestrial biota.

Aspects of water quality were measured at 41 sampling locations on eight streams within the study area as shown in Figure 7. Overall water quality ranges from fair to poor; the low level of quality is due to aqueous discharges from existing facilities. Although water quality is generally poor in the vicinity of facility operations and outfalls, within a short distance downstream, because of inherent buffering and dilution capacities of the stream quality improves. As would be expected in a coal region lithology, the streams had quantitative levels of forms of iron, manganese, sulfur, and calcium, high enough to be of concern. In addition, oil sheens were present during all sampling periods conducted in the common ravine area.

Conclusions

- (1) The groundwater quality as measured and as recorded in the literature is quite marginal to being unfit for human and some animal consumption. The stream sediments of the area are heavily laden with metallic compounds. But, the streams have a high level of oxygen and, if it were not for the pH extremes and suspended solids, the streams could begin a rather rapid recovery as the chemical character of the stream returned to background values for that region.

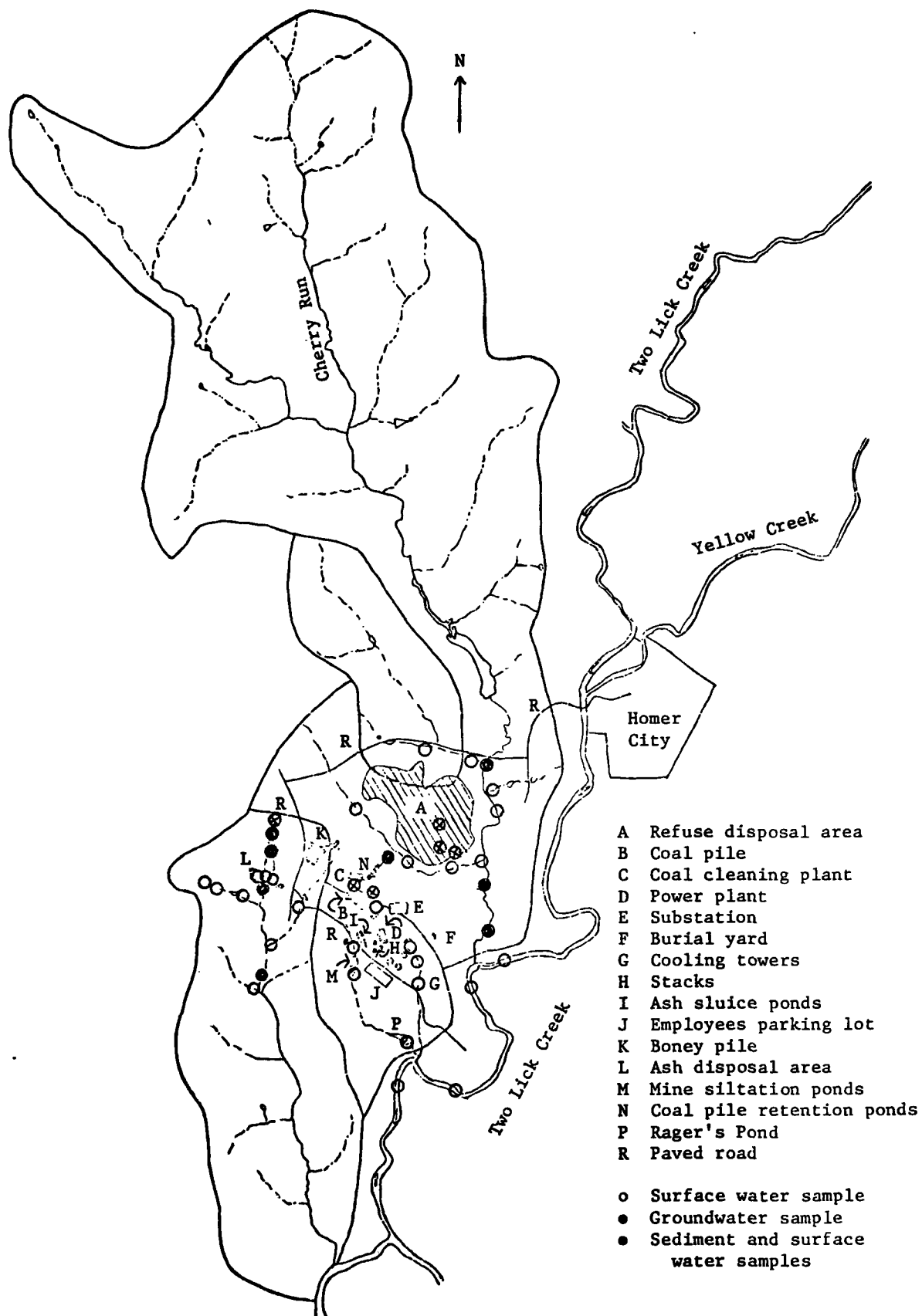


FIGURE 7. WATER QUALITY SAMPLING LOCATIONS

- (2) In assessing the quality of aquatic life, it was found that Cherry Run's tributary North of the coal cleaning refuse area, now under construction, has good overall biological quality. Similarly, the upstream portion tributary south of the refuse was judged to be of good aquatic quality.

Cherry Run was evaluated as having fair biological quality based on the number of species of fish inhabiting this stream. However, the quality of the biological community inhabiting Cherry Run has been affected by both plant and mining operations in the area. Low standing crops of benthic macroinvertebrates and fishes clearly demonstrate this perturbation.

The remaining streams, Wier's Run, Rager's Pond tributary, Common Ravine and the downstream portion of the tributary south of the disposal area were all considered to have poor biological quality. Two Lick Creek was not rated because of the small number of samples collected in this study.

- (3) A wide range of particulate loadings were found in the vicinity of the coal cleaning plant (under construction). The heaviest mass loadings occurred at stations located 200 meters downwind of the coal cleaning plant/coal pile. At stations 2000 meters downwind the levels dropped to those typical of an agrarian region. The stations that were within 1000 meters of the site had a distinct diurnal loading phase. In the daytime the mass weights were 50 percent higher than the contiguous nighttime values. The extent of obvious and significant impact was found to exist to about 1200 meters downwind. The snow cover assisted in determining the fugitive dust impact area. The overall average of the coal particle sizes at all stations was measured to be between 20 and

70 microns in diameter. The average ash size at all stations was in the 5 to 20 micron range. Coal was the predominant material deposited on the hi-volume and "Anderson" filters.

Trace element concentrations by chemical species was not found to be directly related to the variance of mass weights. The average trace element concentrations were higher at 12-hour sampling sites than the 24-hour sampling sites. The 12-hour sites were generally 500 meters downwind of the coal cleaning plant site. Southwest winds prevailed at the site for 70 percent of the time during the 3 sampling campaigns. These southwest winds generated the highest level of particulate loadings as compared with the other major wind directions. The lowest fugitive dust values were captured under a north-west wind.

To support this fugitive monitoring activity a multiple source fugitive dust dispersion model was developed. It was field calibrated to the results and source conditions at the Homer City Coal Cleaning Plant. It is probably that this model will continue to function well at other coal handling and storage facilities. The utility of this model, besides being able to predict dispersion levels with distance and meteorologic conditions, is that it is a valuable tool in choosing the optimum air sampling receptor locations.

The fugitive dust chemical analysis revealed that there is uncombusted coal dust at distances of 2000 meters downwind of the coal cleaning plant site; this dust exhibits higher levels of lead, cadmium, arsenic and mercury than is present in the whole coals analysis.

Cadmium and lead values are several orders of magnitude higher than the whole coal analysis. Beryllium and vanadium were not found in the coal dusts; but these are quite evident in the source coals.

- (4) The terrestrial habitats of the off site properties are quite diverse and provide good to excellent habitats for animal populations when compared to the current land use common to that region. The area does not exhibit suitable conditions for water bird habitats. Due to the accumulation of particulate matter in the neighboring 1 mile area it is expected that the plant biota there soon will begin to show signs of stress.

The current design and construction of the refuse disposal facility covers most of the important potential environmental problems in coal refuse disposal, such as slope stability, erosion and leachate control. The actual construction, however, as it existed in the field as of April 21, 1977, may not completely control the migration of the heavy metal laden leachate. This is principally due to the excavation of the main leachate collection line into an unconsolidated sandstone saddle bench that surfaces on the site. The second major problem with the site, as of the above date, was the construction of a refuse area storm drain trunk line at a lower vertical displacement than the leachate collection pond elevation in the first lift area. This may permit the surface run-off leachates to by-pass the leachate collection pond and treatment system.

MEG Pollutant List and Recommended Additions for Consideration

No work has been performed under the coal cleaning program on derivation of MEG's for chemical pollutants. However, Battelle is working on establishing EPC's (and MEG's) for several nonchemical pollutants and non-pollutant factors (such as noise) under Contract No. 68-02-2138⁽¹³⁾ for assessment of the environmental impact of fluidized-bed combustion processes. The findings concerning EPC's will be applicable to the coal cleaning program where the same pollutants or factors are involved.

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DATA ACQUISITION SECTION
(pp. 72-102)

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CONTROL TECHNOLOGY ASSESSMENT

An assessment of pollution control technology for coal cleaning processes was initiated as part of Subtask 222. A preliminary report⁽¹⁾ on this subtask, dated June, 1977, was prepared and submitted to EPA. The results of this study, with respect to control technology for air pollution, water pollution, and solid waste, are summarized in this section.

The information in this section applies mostly to the EPA outline subheading entitled "Control Systems and Disposal Option Information and Design Principles Application". A brief general commentary is supplied for "Control Process Pollution and Impacts" illustrating major points. No work has been done yet on this program with respect to the other subheadings in the EPA outline under "Control Technology Assessment".

Preliminary information relating to costs is included in this section rather than in "Environmental Alternatives Analysis" because the Battelle program has not yet progressed to the stage of comparing alternatives.

Control Systems and Disposal Option Information

Air Pollution Control Technology

An evaluation was made of the various air pollution control technologies to determine their applicability for treating emissions from coal cleaning processes. Major factors considered in the evaluation of each control technology are performance, operational constraints and limitations, and costs. Based on this evaluation, cost estimates are given for the most applicable control technologies for controlling major emissions for two different sizes of coal cleaning plants: 500 and 1000 tons per hour (tph).

Several types of air pollution control devices are available for application to coal cleaning operations. The choice of the control device depends on the type of pollutant (particulate or gaseous), the properties of the pollutant (such as size, density, and shape for particulates, and equilibrium solubility, reactivity, and adsorptivity for gases), and the properties of the conveying medium (such as density, temperature, and velocity). Particulate control devices may be broadly classified as dry inertial collectors

(gravity settlers and cyclones), filters, wet scrubbers, and electrostatic precipitators. Control devices for the removal of gases or vapors involve adsorption or absorption in a variety of contacting devices. Table 13 provides a general outline of the mechanisms and types of equipment in common use today for the removal of the two basic air pollutant types.

Considerations in the Evaluation of Control Equipment. Five major sources of air pollution were identified for coal cleaning processes; they are

- Crushing and sizing
- Pneumatic cleaning
- Thermal drying
- Coal storage, transportation, and handling operations
- Coal waste disposal areas.

In general, the fugitive emissions from coal storage, transportation and handling operations, and solid waste disposal areas are not amenable to treatment by air pollution control devices. The practical way of controlling these fugitive emissions is prevention and, therefore, only the first three sources are considered in this section.

Several factors must be considered in the evaluation of equipment for controlling the air emissions from coal cleaning processes. Important factors are:

- (1) Characteristics of air emissions and operational constraints
- (2) Control efficiency
- (3) Capital and operating costs.

The air emissions from each of these three sources vary somewhat, but certain generalizations can be made as to their characteristics. Typically, the crushing and sizing operations produce dry, small particulates (0.5 to 6.0 microns) at ambient temperature. The quantity of dust generated depends on the coal type, moisture level, and type of sizing and screening operations. In the pneumatic cleaning operations, large volumes of dry particulates (~120 gr/dscf) are generated with particle sizes up to 100 mesh. The thermal drying

TABLE 13. CLASSIFICATION OF EMISSION CONTROL EQUIPMENT⁽²⁾

Control of Particulates	Control of Gases and Odors
Dry Inertial Collectors	Dry Adsorbers
Gravity Settling Chambers	Wet Absorbers
Cyclones	
Fabric Filters	
Electrostatic Precipitators	
Wet Inertial Scrubbers	
Impingement	
Centrifugal	
Venturi	
Self-Induced	

operations produce high volumes of particulate emissions (50 to 200 gr/dscf) at high moisture levels and temperatures above 200 F. Combustion gases containing SO₂, NO_x, and CO, produced from the coal fuel, also accompany the particulates. These emission characteristics dictate to a significant degree the type of technology most applicable for their control. Factors such as temperature, humidity, particle size distribution, loading, and the potential for an explosion pose operational constraints on the control equipment.

The promulgated Federal standards of performance for new and modified coal preparation plants, processing more than 200 tons per day, limit particulate emissions as follows:

- Not in excess of 0.070 g/dscm (0.031 gr/dscf) and 20 percent opacity for thermal driers
- Not in excess of 0.04 g/dscm (0.018 gr/dscf) for pneumatic coal cleaning equipment
- Not in excess of 20 percent opacity (approximately 0.1 gr/dscf) for coal handling and storage equipment.

Some states have established standards more stringent than the above; in some cases the presence of a visible dust plume is all but prohibited. To meet these standards, the control equipment must either be highly efficient over a wide range of particle sizes or operate in conjunction with another control device and be selectively efficient for a specific range of particle sizes.

An important consideration in the evaluation of applicable control equipment is the capital and operating cost. The installed costs vary significantly with equipment types; and operating costs, depending on utility, raw material, and maintenance requirements, can also vary substantially, making some types of capital intensive equipment with low operating costs appear relatively attractive when capitalized over the life of the equipment.

Particulate Control Devices.

Dry Inertial Collectors. Dry inertial collection systems utilize either gravitational or inertial forces to separate the particulates from the gas stream. The collection systems are characterized by moderate removal efficiencies, low energy requirements, low capital and operating costs, and an

ability to accommodate high inlet dust loadings and operate at high temperatures. For applications at coal cleaning plants, the inertial collectors are used primarily as scalping units or precleaners to remove the major volume of particulates from pneumatic cleaner and thermal drier off-gases. To meet the particulate emission standards, they are generally followed by more efficient removal devices, such as high-energy scrubbers or filters.

Gravity settling chambers are among the simplest and oldest known methods for particulate collection. The chamber consists of a large rectangular, horizontal or vertical duct with a sufficiently large cross-sectional area to reduce the velocity of the gas to below that of the terminal settling velocity of the dust particles. The bottom of the chamber is equipped with a hopper or collection chamber to collect the settled dust particles.

Gravity chambers are low in capital and maintenance cost, produce a low pressure drop, and have no temperature or pressure limitations beyond those of the materials of construction. They do, however, have large space requirements and low removal efficiencies for particles smaller than 75 microns diameter at the typical design space velocity of 1 fps.⁽³⁾ Because of their poor performance gravity chambers are not commonly utilized at coal cleaning plants for treating any of the major emission sources.

Cyclones are the most widely used devices for particulate control. Their simplicity of design, ease of operation, and low maintenance make them one of the more trouble-free particulate collectors available.

Cyclones may be fabricated from a number of materials, and can be used to collect particles over a broad range of pressures and temperatures (from ambient to above 2000 F). They can also accommodate high inlet dust concentrations, well in excess of 200 gr/dscf, and demonstrate increased removal efficiency with increasing inlet particle concentration. Moreover, cyclones are relatively compact, and can handle high volumetric flow rates, e.g., a 4-inch-diameter cyclone can handle 100 to 150 scfm of air.⁽³⁾

The major disadvantage of cyclones is their somewhat low collection efficiency, particularly with particles smaller than 10 microns. Typical efficiency ranges for conventional and high efficiency cyclones are shown in Table 14. Because of its moderately high removal efficiency for large size particles, coupled with its capacity to accommodate high dust loadings (above 3 grains/scf) and, in effect, fractionate a poly-dispersed dust stream, the

TABLE 14. TYPICAL EFFICIENCY RANGES FOR CYCLONE COLLECTORS⁽³⁾

Size Range (microns)	Efficiency, percent	
	Conventional Cyclone	High Efficiency Cyclone
5	NA*	50-80
5-20	50-80	80-95
15-20	80-95	95-99
40	95-99	95-99

* NA = Not Available

cyclone has become a common choice for reclaiming coal dust discharged from pneumatic cleaners and thermal driers on coal preparation plants. When utilized as primary reclaiming devices, cyclones are regarded as integral components of the pneumatic cleaner or thermal drier and are not considered, from a cost standpoint, to be emission control equipment.

Cyclones have no moving parts and are usually very reliable. The major operational problems are erosion and corrosion, plugging of the dust outlet or a build-up of cake on the walls.

Fabric Filters. Fabric or bag filters are regarded as one of the simplest and most reliable high efficiency dry collector devices, being capable of 99.9 percent removal of submicron size particles. They are suitable for a wide variety of dry particulate removal applications, and depending on the type of fabric selected, are resistant to chemical and mechanical rigors, and are operable at moderately high temperatures.

The most common fabric filter device consists of several long, cylindrical bags, enclosed in a sealed vessel with a gas inlet and outlet, and a dust collection hopper and discharge valve. Gas, contaminated with dust, is passed through the fabric filter medium from either the inside or the outside of the bag. The particulate matter impinges on and adheres to the filter medium and is thus removed from the gas stream.

Basically, two fundamental types of filter system are used, depending on the type of filter medium and method of cleaning. The first type utilizes a woven fabric filter bag, where the dust, which is usually collected on the inside face of the fabric, builds up a thin cake which helps augment the filtering action. As time passes and the dust cake continues to build, the pressure drop increases to a point where it must be reduced to prevent a loss of system capacity or bag rupture. The entire filter unit is temporarily shut down and the filter bags mechanically shaken to dislodge the dust, or a compartmented section of the filter is isolated from the gas stream and cleaned mechanically or with air. The woven fabric filter operates with a design volumetric capacity of 2 to 3 cfm/sq ft filter area and 4 to 8 inches of water pressure drop. Filter efficiencies range from 99.0 to 99.9+ percent for dust particles down to the submicron size range.

The second filter type utilizes a felted fabric where the dust particles penetrate but do not pass through the fabric due to the constricted tortuous path. These filters are cleaned continuously by intermittently subjecting individual bags to a reverse jet or pulse while the remainder of the bags continue filtering. The felted-fabric, continuously cleaned filters are designed to accommodate 6 to 12 cfm/sq ft of filter area. They are capable of handling higher dust loads and operate with more constant filter resistance than the woven fabric filters.

Several different types of filtering media are available for fabric filters depending on the application. The predominant factors in the selection of the media type are thermal endurance, resistance to chemicals, and cost.

Fabric filters have several features that make them attractive as particulate collectors, namely (1) very high removal efficiencies over a wide range of particle sizes, (2) simplicity of operation, (3) relative compactness, (4) no water requirements or creation of water disposal problems, and (5) moderate operating pressure drops. These features make them a common choice for collectors for dust control systems for crushing and sizing operations and backup systems for cyclones on air tables.

The filters do, however, suffer from several operational restrictions. The temperature at which they can operate is limited to 550-600 F for periodically cleaned filters and 250 F for continuously cleaned filters. This limitation minimizes their applicability for flue gas or drier gas treatment.

Moreover, the moisture in the gas must be low to avoid condensation and/or bag plugging by the filter cake.

Electrostatic Precipitators. The electrostatic precipitator consists of a chamber housing a series of high-voltage electrodes and a series of grounded electrodes and collectors. The precipitation process involves charging the airborne particles with ions in the electrical field produced between the two series of electrodes and driving them onto the collector surface from where they are removed by washing, vibrating, or rapping. The dislodged particles fall from the surface into a hopper from which they are subsequently removed for disposal.

The principal advantages of electrostatic precipitators are collection efficiencies in excess of 99 percent for particles smaller than 20 microns in diameter, low gas-phase pressure loss, and relatively low total power consumption compared to other systems operating with comparable collection efficiency. The major disadvantage, however, in dust removal applications for coal cleaning plants, is the explosive nature of a coal dust-air mixture and the danger imposed by the charged field in the precipitator. This danger precludes the use of electrostatic precipitators for any of the coal dust control applications.

Wet Inertial Scrubbers. Wet scrubbers or collectors utilize a liquid, generally water, to assist in removing the dust particles from the gas stream. The major features that make wet collectors popular dust control devices are their high removal efficiencies, ability to remove gaseous pollutants, tolerance of moisture in the gas, and relatively low capital costs. Some disadvantages inherent with wet collectors in general are (1) the captured particulate is in the liquid state and sometimes presents a water or waste disposal problem, (2) the scrubber internals are subject to plugging and corrosion, (3) the scrubbed gas is saturated with the liquid vapor, and (4) the energy requirements for some units are high, resulting in higher operating costs than for some dry collectors. Several different types of wet collectors are used for particulate control; some of the more common are impingement, centrifugal, venturi, and self-induced spray scrubbers.

Impingement scrubbers consist of cylindrical or rectangular chambers into which water is introduced through one or more spray nozzles. The gas usually flows upward through the chamber where it contacts the water spray and passes through a series of baffles or a packed bed and finally through a centrifugal drum or chevron type mist eliminator to knock out entrained water droplets before venting. Gas velocities are on the order of 10 to 12 fps through the scrubber and water consumption is in the range of 1/2 to 2 gallons per 1000 cu ft of gas. Pressure drops range from 1/2 to 8 inches of water.⁽⁴⁾

The impingement separator is more suitable for removing particulate material 5 microns and larger, as removal efficiencies are shown to be 97, 92, and 85 percent, for 5-, 2-, and 1-micron particles, respectively. In addition to the moderate removal efficiencies, the impingement separator is subject to plugging.

Centrifugal scrubbers consist of a cylindrical vessel equipped with spray nozzles and one or more stages of directional or centrifugal vanes. The gas stream enters the bottom of the vessel where centrifugal motion is imparted and where it is initially wetted to remove the larger particles. After passing up through the directional vanes at a velocity of 6 to 8 fps and one or more washing stages, the gas is directed through the mist eliminator and out the top of the scrubber. Water requirements are typically 2 to 10 gallons per 1000 cu ft of gas and pressure drops are usually 1-1/2 to 3 inches water gage. Removal efficiencies for smaller particles are relatively low at only 90 percent for 5-micron particles.

In the venturi scrubber, scrubbing water is introduced normal to the direction of gas flow, at, or upstream of, the constriction of the venturi, where it is atomized and conducted with the gas stream into a centrifugal separation chamber. The atomizing action helps induce contact of the water with the particulates which are subsequently separated from the carrier gas in the separation chamber. Approximately 3 to 10 gallons of water are required per 1000 cu ft of gas.

The removal efficiency of the venturi varies with the power input and can be increased to 99+ percent for submicron particles. As a result of the high removal efficiencies attainable with venturi scrubbers, they have

found common application in coal cleaning plants as dust collectors for the grinding and sizing, pneumatic cleaning, and thermal drying operations. (5)

The self-induced scrubber consists of a vertical cylindrical vessel consisting of baffle plates and various constrictions and one or more standing water levels. The gas stream is directed around or through the constrictions to increase its velocity and then made to impinge upon the surface of the scrubbing liquor. Removal efficiencies of self-induced scrubbers are lower than those for venturi scrubbers and are less than 90 percent for particulates 2 microns in size. Water requirements are lower than for most other types of wet scrubbers at 1/4 to 1 gallon per 1000 cu ft of gas and pressure drops are moderate at 3 to 6 inches of water.

Evaluation of Particulate Collection Devices. The information compiled in the preceding discussion is assembled in tabular form to permit an easier comparison and evaluation of the various types of particulate removal equipment for their application in coal cleaning operations. Table 15 outlines the operating constraints and removal efficiencies for each of the different equipment types.

Based on the characteristics outlined for the three major emissions from coal cleaning unit operations, and the performance evaluation of the control equipment, those equipment types most appropriate as control equipment for each major emission may be selected. The selections are presented in Table 16.

Gaseous Removal and/or Collection Devices. Gaseous removal and/or collection devices are designed to extract specific gaseous compounds from a carrier gas stream. Although not practiced to date, the major potential application for gaseous removal devices in coal cleaning operations is for the removal of SO₂ from thermal drier off-gases. To this end, two major types of gaseous removal processes, dry adsorption and wet absorption, can be considered for controlling sulfur dioxide emissions. Both processes have achieved commercial status in flue gas desulfurization for utility and industrial boilers. They are not, however, efficient dust removal devices,

TABLE 15. DUST COLLECTOR CHARACTERISTICS AND APPLICATION CHART⁽⁸⁾

Dust Collector	Particle Size	Dust Load	Operating Temperature, F	Operating Efficiency	Space Requirement	Remarks
Louver Settling Chamber	30 microns and up	Medium to heavy	Up to 1,500	45% for 30 microns to 99% on flyash	Medium	No moving parts. Will handle heavy surge. Coarse sizes can cause excessive wear. Good as a scalping unit.
Low-efficiency Cyclone	20 microns and up (200 mesh is ideal)	Light to heavy	Up to 1,500	75% on all plus 325 mesh	Needs considerable space.	Usually placed out of doors because of bulk.
High-efficiency Cyclone	1 micron and up	Very light to very heavy	Up to 1,500	95% on plus 10 micron feed	Small and compact.	No moving parts. Best on plus 20 micron sizes. Good for classifying.
Wet Scrubbers (Spray tower and other scrubber types)	All	Light to heavy	Up to 1,500	80% in 1 to 10 micron range	Small and compact.	Can handle heavy dust loads.
Fabric Filters (unit frame, bag and reverse-jet types)	Minus 200 mesh	Light to medium	Cotton: 175 Wool: 225 Dacron: 275 Fiber-glass: 550	Up to 100% in 10 micron range	Small to medium.	Excessive moisture will blind fabric. Good on fumes.
Venturi Scrubber	All	Light to heavy	Up to 1,500	99%+ in 1 to 10 micron range	Small and compact.	Requires high water supply, up to 1,000 cfm.
Electrostatic Precipitator	Very fine	Light to medium	Up to 550	90 to 100	Small to medium.	Most efficient system for handling extremely fine dust and fumes. Not suitable for use on explosive mixtures.

TABLE 16. SUMMARY OF APPLICATIONS FOR PARTICULATE
CONTROL EQUIPMENT

Emission Source	Typical Characteristics of Dust	Appropriate Control
Crushing and Sizing Operations	Dry, submicron up to about 6 microns in size; light dust load, ambient temperature	Cloth filters or high-energy wet scrubbers
Pneumatic Cleaners	Dry, submicron up to 48 mesh in size, heavy dust load (>100 gr/dscf), ambient temperature	Primary cyclone-(a) cloth filter or primary cyclone- high-energy wet scrubber
Thermal Dryer	High humidity, submicron up to about 100 microns in size, heavy loadings up to 200 gr/ dscf, temperature 200 to 250 F.	Primary cyclone-(a) high efficiency wet scrubber

(a) Not considered as emission control equipment but rather as pneumatic cleaner or thermal drier process equipment utilized to recover coal.

and to meet particulate control regulations must be used in conjunction with or preceded by a high-efficiency wet scrubber.

Dry Adsorbers. Removal of sulfur dioxide from flue gas or drier off-gas may be accomplished by either molecular sieves or carbon adsorption. Unfortunately, molecular sieves have a greater affinity for water than for SO_2 , and since water in flue gas or drier off-gas is present in considerably greater concentrations than SO_2 , the sieve is rendered essentially ineffective unless preceded by a drying device, i.e., another sieve.

The most practical adsorbent for SO_2 from coal-processing-related gas streams is activated carbon which has been demonstrated to be an effective adsorbent of SO_2 at temperatures of less than 300 F. Two primary drawbacks, however, to a carbon-based system are the limited capacity and low gas velocity requirements. The sorbent capacity is generally only about 2 to 10 percent sulfur by weight and the rate of adsorption of SO_2 on carbon is limited to the rate of SO_2 diffusion into the pores. Thus, large quantities of adsorbent must be used and gas velocities must be limited to 1 to 4 feet per second.

Adsorption is a high-initial-cost process which can vary from \$7 to \$13 per cfm for installed carbon steel units without regeneration to \$14 to \$25 per cfm with regeneration.⁽⁹⁾ Operating costs consist of the blower power requirements and regeneration or adsorbent make-up costs and can run \$0.60 to \$1.20 per 1000 cfm-yr.

Wet Absorbers. Absorption is regarded as the most developed method for removing SO_2 from flue gases, and to date, several hundred various commercial-size installations have been applied worldwide to utility and industrial boilers.

Several different types of absorption equipment are utilized to effect contact of the gas with the scrubbing slurry; some of the more common types are spray towers, venturi scrubbers, and marble bed scrubbers. A variety of different aqueous solutions are also utilized to capture the SO_2 . They may be classified into four different categories: slurry solutions, clear solutions, weak acid solutions, and organic liquids. The most developed systems to date are those utilizing slurry solutions in spray towers or venturi scrubbers.

Slurry solutions involve the use of a 5 to 15 percent lime or limestone slurry to absorb SO_2 . The spent absorbent, CaCO_3 and CaSO_4 , is transferred to a disposal facility and discarded as waste. Removal efficiencies range from 70 to 90 percent of the SO_2 in the inlet gas.⁽¹⁰⁾

The attractive feature of the lime/limestone-based scrubbing system is that the low cost of the absorbent eliminates the need for regeneration facilities. But, alternately, provisions must be made to dispose of the CaSO_3 and CaSO_4 waste, reheat the flue gas, if necessary, and grind the limestone.

Estimated Plant Costs. Based on the emission characteristics and equipment costs compiled in the preceding sections, an estimate can be made of the costs for air pollution control technology for each of the three emission sources.

These costs are presented as installed capital costs and operating costs for hypothetical 500 and 1000 tph coal cleaning plants with the following levels of treatment:

Crushing and Sizing Plant (Level 1)

Medium Size Coal Beneficiation Plant with Air Tables (Level 3)

Fine Size Coal Beneficiation Plant with Thermal Drying (Level 4)

A more detailed description of each plant and its characteristic emissions is provided in "Current Process Technology Background". This preliminary cost analysis was limited to the above three cleaning levels because they each contain at least one of the three major emission sources described earlier.

As summarized in Table 17, for some plants more than one particulate control device is applicable; in this case, cost estimates are prepared for each type of treatment. For the Type F plant, an additional cost was included to account for flue gas desulfurization on the thermal drier. This preliminary analysis is given as an example. Other alternatives will be appraised for sulfur control for thermal driers, e.g., firing with cleaned coal in some cases. Limestone scrubbing was selected as the basis for the cost estimate due to its more developed status.

The summary of the estimated installed and operating costs for each pollution control system are presented in Table 17.

TABLE 17. ESTIMATED COSTS OF AIR POLLUTION CONTROL
EQUIPMENT FOR COAL CLEANING PLANTS

Plant Type and Emission	Applicable Control Equipment	Installed Cost of Control Equipment, Dollars (1977)/tph		Annual Operating Cost of Control Equipment, (a) cents/ton	
		500 tons/hr	1000 tons/hr	500 tons/hr	1000 tons/hr
Type C,F,G,H, or I (Level 1): Dust from crushing and sizing operation	Dust enclosures with dry bag collectors	52	36	0.2	0.1
	Dust enclosures with high-efficiency wet scrubbers	30	20	0.2	0.2
Type C (Level 3): Air tables operating on medium-size coal	Primary cyclones followed by dry bag collectors	400	360	2.8	2.8
	Primary cyclones followed by high-efficiency wet scrubbers	220	200	10.0	9.7
Type F,G,H, or I (Level 4): Thermal dryers associated with fine size coal beneficiation	Primary cyclones with high effec- iency wet scrub- bers	270	250	12.5	12.2
	Primary cyclones with high-effic- iency wet scrub- bers followed by limestone scrub- bing	9450	9250	93.8	93.8

(a) Excludes capitalization, depreciation, and interest. Based on 180 (2-shift) days.

Additional Information Required. To more accurately determine pollution control costs for the different plants, the equipment capital and operating cost information should be better quantified. In addition to more accurate modular costs, information is also needed on instrumentation and control, installation, power, and maintenance costs.

Furthermore, to more effectively assess the possible environmental problems associated with disposing of the collected particulate wastes generated from the crushing and sizing operations, information is being sought on the characteristics of the wastes. Knowledge of the composition, leachability and chemical activity of the wastes would be helpful in determining any potential environmental complications with their disposal as well as alternative handling or disposal procedures.

Water Pollution Control Technology

Process and scrubbing water effluents from coal cleaning operations contain two types of pollutants: suspended materials (solid or liquid) and dissolved substances. The technology available for removing suspended materials from the water includes mechanical dewatering, sedimentation, and flotation. Dissolved substances can be removed from water or converted to less objectionable forms by neutralization, adsorption, ion exchange, reverse osmosis, freezing, or biological treatment. Table 18 lists the methodology currently in use or contemplated for use in treating coal cleaning waste water.

Before assessing the applicability of these classes of technology to various coal cleaning waste streams, a brief description of each class is presented. Information relevant to this assessment includes removal efficiency, and operational constraints. Potential water treatment technologies are then matched with significant emission sources. Each source/technology pair is evaluated with respect to anticipated performance, and capital and operating costs for typical coal cleaning plant configurations.

TABLE 18. CLASSIFICATION OF WATER TREATMENT TECHNOLOGIES

Control of Suspended Materials	Control of Dissolved Materials
Mechanical Dewatering	Neutralization
Centrifuges	
Filters	
Sedimentation	
Settling Ponds	
Sedimentation Tanks (Thickeners)	
Flocculation	

Control of Suspended Materials. Suspended solids may be removed from liquid streams by mechanical dewatering methods, sedimentation, or flotation. Each of these methods produces a solid material which may be processed further in the coal cleaning plant, in the case of a coal-rich material, or disposed of as solid waste.

Mechanical Dewatering. Mechanical dewatering devices applicable for removing solid materials from water include centrifuges and various kinds of filters.

A centrifuge is a device which rapidly rotates a solids-containing stream in order that centrifugal force can separate the solid and liquid fractions.

The perforated basket centrifuges use centrifugal force to filter water through perforated sides, while removing trapped solids from the base of the cone. The solid bowl centrifuge has a helical conveyor inside a truncated conical solid bowl, both of which rotate at slightly different speeds. The solids are removed at the apex end of the bowl by the helical conveyor, while the water exits at the base of the cone (the lip of the bowl). Perforated basket machines require at least a 40 percent solids feed, while solid bowl centrifuges can handle more dilute slurries.

None of the centrifuges completely remove fine suspended materials from water. As a water treatment device, a centrifuge is useful for roughing purposes and would be followed by sedimentation, filtration, or some other finishing method. The centrifuge has found application, however, as a dewatering device for the land-destined thickener underflow.

Vacuum filters are used in the dewatering of fine coal products and fine refuse from wastewater. Although a drum type of vacuum filter is available, only the disc type will be addressed in this report as it has been the traditional choice in coal cleaning plants.

The disc type vacuum filter consists of a number of discs arranged along a single axis with the assembly sitting in a rectangular chamber. As the discs rotate, a vacuum pump pulls water and suspended solids through the submerged portion of the screen fabric discs. As the cake rises from the water, the air pressure within the disc is maintained at slightly above atmospheric pressure to loosen the cake from the fabric. A scraper and conveyor system finally remove the cake from the screen surface before the fresh filtering surface is submerged again.

Standard models of disc-type vacuum filters range in disc diameter from 4 to 12 feet and in surface area from 20 to 2400 square feet.

Granular media filter's may either be gravity or pressure filters. Pressure filters are generally used in smaller plants where package units are economical or where the additional pressure in the effluent can replace a pump(s) downstream.⁽¹²⁾ In either case, the bed of granular filter medium has a depth of 18 to 30 inches. The influent water filters up or down through the bed under the force of pressure or gravity respectively. When the filter capacity drops to a given level as a result of loading of the medium, the load is shifted to another filter(s) while the bed is backwashed in preparation for another cycle.

Filter media available for use include silica sand (most common), crushed anthracite, diatomaceous earth, perlite, and activated carbon. Two or more of these media may be combined (layered) for a multimedia bed, or a gradation of particle sizes of one material may be used; all of the possible combinations of media and particle sizes produce different filtering characteristics with a given waste water.

Sedimentation. Sedimentation processes allow suspended materials to settle to the bottom of a vessel and incorporate means for continually removing settled solids and supernatant liquor separately. Systems classified under sedimentation include settling ponds or lagoons and various configurations of sedimentation tanks.

A settling pond or lagoon is the simplest and largest capacity approach to sedimentation. It consists simply of routing wastewater with or without flocculants to an excavated area. Suspended solids settle out in the lagoon, and the supernatant is continuously decanted either to a stream, with or without additional treatment, or back to the plant. When the depth of the sediment in the lagoon reaches a predetermined level, the solids are dredged or otherwise removed to a disposal area. Depending on the permeability of the ground and the nature of the wastewater, a lagoon may or may not have to be lined with clay, concrete, limestone, or other material.

Advantages of lagoons include low maintenance, no daily sludge disposal problem, and flexibility with respect to flow rates.⁽¹³⁾

Thickeners are available in a variety of configurations, including rectangular, square, round, and inverted pyramidal.⁽¹²⁾ Flow through the pyramidal unit is upward, with sludge pumped continuously from the apex (bottom) and clarified effluent overflowing at the top. Round thickeners use radial horizontal flow and rectangular units use parallel horizontal flow; the horizontal flow types all have sloping bottoms, with continuous sediment removal at the lowest point.

Thickener size varies between 35 and 200 feet in diameter for round units, with depth of 7 to 15 feet. Rectangular units as long as 300 feet with length-to-width ratios of 3:1 to 5:1 exist. Bottom slopes range from 1 degree to 8 degrees.⁽¹⁴⁾

Filtration and sedimentation can be improved by the addition of flocculants. Among commonly used additives are alum, lime, iron salts, sulfuric acid, starches, and polymers. Although polymers are the most expensive, on a per unit basis, they are used in very small concentrations and work very well.

Control of Dissolved Materials. The most common pollution problem of dissolved substances in wastewater is pH control. For coal cleaning wastewater, and drainage from coal and refuse piles, the problem is usually acidity, so an alkaline additive is needed; lime is the preferred reagent for this purpose.

In an acid waste stream from a plant, lime is added to neutralize the wastewater. The CaSO_4 or other insoluble precipitate which is formed is removed in a thickener or other solids-removing device and disposed of as a solid waste.

Applicability of Wastewater Treatment Processes to Coal Cleaning Process Waste Streams. In this section each potentially applicable treatment process is matched with each type of water stream from the nine generic types of coal cleaning plants and evaluated with respect to anticipated performance. Capital and operating costs (including depreciation and interest on capital) for typical water pollution control facilities are documented in Table 19 for three types of plants. In addition to the nine plant types, the storage, transportation, and handling of coal, which are common to all types of plants, are evaluated.

In generating the treatment costs, it was assumed that all water treatment is performed to satisfy environmental constraints. Actually, much of the treatment, particularly dewatering, is an integral operation in the coal cleaning process. Thus, all or a portion of the costs cited may be attributed to process requirements rather than environmental requirements.

Since the use of a closed water circuit is a viable alternative to treatment and release of wastewater, much of the water treatment will be aimed at upgrading the wastewater to render it suitable for process use.

In the absence of information on the actual treatment flows, the process water flow characteristics of each plant type have been used to estimate the capital and operating costs for process water treatment. These cost estimates probably represent some extreme maximum resulting from an overestimate of the size of the treatment facility required, from an overestimate of the flow rates, and from lack of knowledge about number of operating hours per year (for the treatment facility).

TABLE 19. ESTIMATED COSTS OF WATER POLLUTION CONTROL EQUIPMENT FOR
SELECTED 1000 TPH COAL CLEANING PLANTS

Plant Type	Effluent	Quantity, gpm	Applicable Control Equipment	Installed Cost of Control Equipment, (1977 Dollars)	Annual Operating Cost of Control Equipment ^(b) cents/ton
Crushing and Sizing with Dry Screening and Wet Beneficiation	Process Water	3,450			
	Flow-				
	Suspended Solids		Radial flow thickener lagoon, or	345,000 108,000	0.8 0.6
	Dissolved Solids		froth flotation Absorption-activated carbon treatment	33,000 1,700,000 ^(a)	0.7-1.4 2.0
Crushing and Sizing with Wet Screening and Wet Beneficiation	Process Water	7,650			
	Flow-				
	Suspended Solids		Mechanical dewatering- hydroclones,	150,000	1.4
			microscreens, or	230,000	1.0
			pressure filters	310,000	1.8
Fine Size Coal Beneficiation with Hydroclones and Thermal Drying	Process Water	9,250			
	Flow-				
	Suspended Solids		Radial flow thickener or lagoon	560,000 180,000	1.3 0.9

(a) Adsorption is not presently used to treat coal cleaning process water, and would not be necessary for treating the recirculating process water for any plant with a closed water circuit.

(b) Including depreciation and interest on capital.

Information on wastewater treatment costs will be refined for the final report on pollution control technology for coal cleaning processes. The final report will also discuss the allocation of waste treatment costs relating to process and environmental requirements.

Type A Preparation Plant. The coal cleaning plants described as Type A perform crushing and sizing operations only. Since the operations are performed dry, there are no process water streams in the plant.

Type B Preparation Plant. A Type B coal cleaning plant is a Type A plant followed by dry screening at 3/8-inch and wet beneficiation of plus 3/8-inch material only, with jig or heavy medium vessel. Mechanical dewatering is performed on the plus 3/8-inch product. The minus 3/8-inch material is mixed with the coarse product. The untreated process water contains TSS, TDS, alkalinity, iron, manganese and some metals.

Since the process water stream in a Type B plant is the result of mechanical dewatering, further mechanical dewatering probably would not be sufficient to remove the remaining suspended solids from the stream. A lagoon or thickener would most likely be the method of choice for removal of suspended solids from the process water. In either case, alum, or some other flocculant, would be added to decrease settling time, since coal particles are rarely readily settleable without flocculants. Both thickeners and lagoons produce a solid waste stream (the thickener continuously, the lagoon intermittently) which must be either disposed of or in some cases reprocessed for use as a fine, clean coal.

The pH of coal cleaning plant process water is routinely maintained between 7.3 and 8.1 for those processes recycling the process water. Water recirculation or pollution control needs therefore should not require any further neutralization.

Type C Preparation Plant. A Type C coal cleaning plant is a Type B plant with an air table circuit added to clean minus 3/8-inch coal. No difference in process water quantity or quality is expected between Types B and C. Thus, identical treatment technology should be applicable.

Type D Preparation Plant. A Type D plant is a Type A plant followed by wet screening at 3/8-inch, and Type B beneficiation of plus 3/8-inch material. It includes wet concentrating table beneficiation of minus 3/8-inch material, mechanical dewatering of plus 28-mesh product, and discard of minus 28-mesh. The process water is expected to contain higher concentrations of suspended solids than plant Types B and C, and the quantity of water flow is expected to be considerably greater due to concentrating table requirements. The process water flow is 7650 gpm for a 1000 tph plant.

Thickeners, lagoons, and froth flotation would be applicable treatments for Type D plant water, as they are for Type B.

With a closed water circuit, only the process pH control should be necessary.

Type E Preparation Plant. A Type E coal cleaning plant is the same as a Type D plant, with the concentrating tables replaced by heavy medium cyclones. The quantity of process water in the Type E plant (10,200 gpm for a 1000 tph plant) is greater than for a Type D plant (7,650 gpm for a 1000 tph plant). In addition to the constituents in Type D plant wastewater, magnetite particles will be present as suspended solids in Type E plant wastewater, but the applicable treatment processes should be similar to those used for a Type D plant.

Type F Preparation Plant. A Type F coal cleaning plant is the same as a Type D plant except that the Type F plant includes wet beneficiation of minus 28-mesh material with hydrocyclones and thermal drying of minus 28-mesh product. The process water flow is approximately 9,250 gpm for a 1000 tph plant, which is greater than that for a Type D plant, but suspended solids content should be lower for a Type F and comparable to a Type B plant. Thus the same water treatment methods used for a Type B plant should be applicable to Type F.

Type G Preparation Plant. A Type G coal cleaning plant is the same as a Type D plant except that the Type G plant includes froth flotation for minus 28-mesh, and thermal drying of minus 28-mesh product. The process water flow is approximately 7750 gpm for a 1000 tph plant, which is intermediate between plant Types D and F. Suspended solids content should be about the same as for a Type F plant. Flotation reagents in the water may constitute an additional problem in a closed water circuit or wastewater stream.

Applicable treatment methods should be essentially the same as for a Type F plant, for all pollutants except flotation reagents. These reagents, however, are not expected to build up in the water circuit, since they are probably removed with the coal or waste solids. The reagents which leave the plant in this way are potential water pollution problems in coal and refuse runoff or potential air pollutants in thermal driers. Some residual flotation reagents may also leave the plant in any treated wastewater streams.

Type H Preparation Plant. A Type H coal cleaning plant is the same as a Type E plant, except that the Type H plant includes wet beneficiation of minus 28-mesh coal with hydrocyclones, and thermal drying of minus 28-mesh product. The process water flow is approximately 11,450 gpm for a 1000 tph plant, which is greater than for a Type E plant, but suspended solids content should be lower for the Type H plant and comparable to a Type B plant. Thus, treatment methods useful in a Type B plant should be applicable to a Type H plant.

Type I Preparation Plant. A Type I coal cleaning plant is the same as a Type E plant, except that the Type I plant includes froth flotation for minus 28-mesh, and thermal drying of minus 28-mesh product. The process water flow is approximately 9,950 gpm for a 1000 tph plant which is intermediate between plant Types E and H. Suspended solids content should be about the same as for a Type H plant. Flotation reagents in the water may constitute an additional hazard, as in the case of a Type G plant. The water treatment methods useful for Type G plants should also be applicable to Type I plants.

Coal Transportation, Storage, and Handling. The major type of water pollution arising from the transportation, storage, and handling of coal is leachate from coal storage piles which is in general very much like acid mine drainage.

All forms of treatment for the leachate are preceded by a collection pond of some kind. The collection pond would also serve the function of a settling pond or lagoon, removing most of the suspended solids. Certain other treatment, such as lime neutralization, may take place in the pond itself. Subsequent treatment would take place downstream before the water is released to a stream or used in the plant.

No further treatment for suspended solids should be necessary after the collection pond. The acidity and much of the metals content of the water would be removed by lime neutralization in the collection pond.

Coal Waste Disposal Areas. The drainage from coal refuse storage areas is very much like acid mine drainage and drainage from coal storage piles. The leachate from coal refuse areas is usually mixed with any drainage from the mine before treatment. The same treatment methods used for coal storage pile leachate would apply to refuse area drainage and mine drainage. Since the refuse contains much more inorganic matter than coal, the refuse area drainage should have somewhat higher concentrations of acid, iron, and other acid-soluble minerals. Thus, the treatment system for refuse pile leachate should be of higher capacity than that for coal storage pile leachate.

Items Requiring More Information. Much of the information presented in this report is based on preliminary information and estimates. Many of these approximations will be replaced by more exact information in the final report. Contacts are being made with plant operators and vendors to obtain more detailed capital and operating costs of control equipment, especially as applied to the specific plant types. More information is being acquired on disposal of waste streams produced by ion exchange and reverse osmosis treatments. This data acquisition task will eventually be able to provide detailed information on performance of control equipment, and actual pollutant

concentrations in raw and treated water streams. In addition, the proportions of treated and untreated process water will be determined, making it possible to estimate actual pollution control costs more accurately.

Solid Waste Control Technology

Properties of Physical Coal Preparation Refuse. Coal preparation refuse can be expected to contain all of the inorganic substances found in the raw coal. An important constituent of coal preparation refuse is sulfur. Physical coal preparation removes primarily the inorganic sulfur forms, pyrite and marcasite. These may be present in quantities from less than 0.1 percent to as much as 7.1 percent by weight.⁽¹⁶⁾ The presence of these sulfur compounds has important implications for acid generation from the refuse.

Other trace elements found in coal refuse are not uniformly distributed. Some elements, particularly Ge, Be, and B, have been found to concentrate in the organic fraction of coal and, therefore, are not likely to be as abundant in the refuse. A second group of trace metals, including Hg, Zr, Zn, Cd, As, Pb, Mn, Mo, Si, Al, Ca, and Fe, tends to concentrate in the mineral matter and therefore in the refuse.

Particle sizes and size distributions, specific gravity, and in-place density of the coal preparation refuse seem to be similar to ordinary non-cohesive (sandy) soils.

Potential Problems from Land Disposal of Coal Preparation Refuse.

Generally, the problems caused by land disposal of coal waste fall into these categories: aesthetics, blowing dust and debris, gas generation, fire potential, erosion, leachate, and final land use.

The potential aesthetic impact is largely site-dependent. Good disposal practice would have the working area of the disposal facility held to a minimum and other areas kept vegetated until needed and revegetated upon completion.

The refuse generated by a coal preparation plant contains considerable quantities of fine particles, leading to potentially serious fugitive

dust problems. Site selection is partly the solution to this problem. The orientation of the valley with respect to prevailing winds should be considered. . . . A crusting agent may be employed to prevent water infiltration and fugitive dust from refuse piles.⁽¹⁷⁾

Gas generation within the refuse has not been identified in research so far as a potential problem. However, as there still remains a considerable amount of organic matter in the refuse, fire resulting from spontaneous combustion in the refuse banks is a matter of concern. Compacting the coal preparation refuse piles will minimize air circulation and reduce the likelihood of fire. In addition, sealing the pile, either with an occasional soil covering or with a crusting agent, also may reduce the fire potential.⁽¹⁷⁾

Particle sizes are such that the refuse is particularly susceptible to erosion. Diversion ditches to minimize flow of water over the refuse surface, as well as siltation basins to capture eroded material, are essential. The supernatant liquid (leachate) from the siltation basin should be monitored for high pH, sulfate, calcium, total dissolved solids, and heavy metals before being discharged to the environment. Treatment of this liquid may be necessary. . . .

Because of the heavy metals concentration in coals, the leachate from the refuse can be expected to be high in metal ions. This is especially true if the leachate is acidic, as most of the metallic minerals are quite soluble in acid.

It is possible to minimize leachate production from a disposal facility by (1) diverting away all surface drainage, (2) applying a cover material to prevent infiltration of rainfall, (3) grading to promote rapid run-off (but not so rapid as to create excessive erosion), (4) minimizing the open (working) area, and (5) applying a vegetative cover upon completion of an area. In most cases, a naturally impermeable soil, or in some cases a synthetic liner, is used to prevent infiltration of the leachate into the ground and eventually the groundwater. An underdrain system is needed to gather the leachate and carry it to a leachate treatment system. Leachate treatment will probably consist of lime neutralization and settling. As well as improving pH, lime treatment also will remove large quantities of metal ions, which are relatively much less soluble at higher pH levels. However, additional physical or chemical treatment may be required.

Present and Future Limitations Imposed by State and Federal Laws.

The Resource Conservation and Recovery Act of 1976 (RCRA) was signed into law on October 21, 1976. The law authorizes financial and technical assistance to state, regional, and local agencies to develop comprehensive programs for environmentally disposing of solid waste, including both hazardous and non-hazardous waste. Coal preparation refuse clearly falls under the laws definition of solid wastes.

Primary enforcement responsibility will be delegated to the states. Minimum criteria for acceptable state programs must be developed by U.S. EPA by October, 1977. These criteria will include appropriate methods and degrees of control of solid waste disposal facilities to protect public health and welfare, protect quality of groundwater and surface water from leachate, protect surface waters from run-off, and provide for safety and aesthetics.⁽¹⁸⁾

The U.S. EPA is to establish criteria for determining specifically which materials fall into the category of hazardous wastes. The hazardous waste criteria presently being considered are flammability, corrosiveness, "reactivity", radioactivity, toxicity, and potential for bioaccumulation, persistence, and potential for causing disease.⁽¹⁹⁾ Any material found to meet the criteria established for any of these hazard classifications will be considered a hazardous waste.⁽²⁰⁾

For wastes which may contain soluble hazardous constituents, the leachate from those wastes will be tested against the hazardous waste criteria. The leachate will be generated using a standardized technique now being developed. If the leachate is found to be hazardous, the solid material it was derived from will be considered hazardous. For coal refuse, the criterion most applicable will be toxicity, principally due to the heavy metal ion concentrations expected to be in the leachate. Other criteria such as pH and sulfate ion concentration may be important as well.

If the refuse, by virtue of its leachate, is not considered hazardous, standard sanitary landfill practice, as outlined by Federal guidelines and enforced by the states, will apply.

In 1974, U.S. EPA issued guidelines to be applied to Federal disposal facilities and which were recommended for use by the states. These guidelines are still highly relevant and, with some updating regarding leachate collection and treatment, may be used as a basis for the guidelines required by RCRA.⁽²¹⁾

Site selection will be of primary importance. A refuse disposal site should have adequate isolation, through physical barriers or by distance, so as not to create a nuisance by virtue of noise, dust, or traffic, to nearby residences. The site should be oriented to the prevailing wind in such a way as to minimize blowing dust. A thorough hydrogeologic investigation will be required to determine the depth of soil, groundwater, and geologic strata underlying the site. Water pollution can be prevented by locating the site away from lakes, streams, wells, and other water sources; avoiding sites where subsurface strata will allow leachate to reach water sources, e.g., fractured limestone and sandstone; providing good surface water diversion and site drainage to minimize infiltration of water into the fill area; tightly compacting the residue; collecting and treating leachate if necessary; and never depositing residue directly into groundwater or surface water. As coal preparation refuse does not present most of the problems associated with garbage, daily cover may not be required.

If coal preparation refuse is found, by leachate testing as described previously, to be hazardous, there probably will be only a few additional requirements. The principal changes will be in the management/permit system and in the degree of leachate control needed. Periodic reports to the responsible state will be required. Furthermore, a permit will be required from either U.S. EPA or the state for each hazardous waste disposal facility. These requirements fall into the category of "added paperwork" and do not affect the design or operation of a facility. In addition to the leachate collection and treatment described earlier, a liner may be required to assure that no leachate is allowed to escape the site.

Monitoring wells are certain to be required for a hazardous waste site. These will have to be installed upgradient and downgradient to detect changes in groundwater quality. Contingency plans will have to be made a part of the permit process in case leakage should occur and in case any other accident or spill should occur.

Coarse Refuse Disposal. Coarse refuse is considered to be refuse larger than 28 mesh. It is generated by all levels of coal preparation (Types A-I). There have been four major methods of coarse refuse disposal. The method selected depends upon topography, economics, regulations, and other factors.

The four common disposal methods are:

- (1) Valley-fill dumps
- (2) Side-hill dumps
- (3) Cross-valley fill
- (4) Waste piles.

With the methods above, refuse is generally transported and placed by aerial trams, conveyors, or trucks. These transporting/dumping techniques lead to very loose, unstable fills, which in turn lead to refuse bank fires, acid generation, erosion, and slope failures. Present day engineering demands careful compaction, usually by means of bulldozers at the dump site. Furthermore, the Buffalo Creek disaster in 1972 has led to legislation and engineering improvements which have reduced the numbers of impounding cross-valley fills.

Fine Refuse Disposal. Fine refuse is considered to be refuse smaller than 28 mesh. It is generated by Level 3 and 4 preparation plants (Types D-I). Fine refuse occurs as the thickener underflow and may contain 75 percent moisture. Therefore, handling of fine refuse is generally done hydraulically, by pumping the slurry from the preparation plant to a disposal area. Direct disposal of the fine slurry into streams is no longer practiced. Disposal of fine refuse will be by slurry impoundment, dewatering, or underground disposal.

Earth or coarse refuse is often used to build dams or dikes to impound fine refuse slurries. The particular type of impoundment is related to topography and many times to the method used for coarse refuse disposal. Types of impoundments parallel the coarse refuse methods. These impoundments usually serve multiple functions--to provide for collection and storage of water and to remove, by settling, the suspended solids from the fine refuse slurry. Impoundment disposal is a convenient and relatively inexpensive way of disposing of fine coal refuse.

The National Dam Safety Act, Public Law 92-367, was passed shortly after one of these slurry impoundments, the Buffalo Creek dam at Saunders, West Virginia, failed, causing heavy loss of lives and property. The act was intended to greatly improve the engineering of refuse embankments which are intended to, or which might, impound water. The result of this Act has been economic pressure on the coal industry to eliminate slurry ponding. Therefore, the next two methods have received increased attention.

Fine refuse slurries may be dewatered, allowing the resulting fine solids to be disposed of together with the coarse refuse fraction. There are four categories of dewatering methods available for potential application.

- Mechanical dewatering is done by filtration and by centrifuge, with the addition of flocculants. (The addition of flocculants to the refuse may affect its mechanical properties in a land disposal facility, its leaching characteristics, and its utility for other purposes.)
- Thermal dewatering is accomplished with driers or incinerators.
- In situ dewatering usually involves placing layers of fine refuse slurry alternately with layers of coarse refuse, allowing the moisture to drain. Another technique, electrokinetic densification, has not yet been applied to surface disposal of fine refuse but has been successfully used for years to dewater fine-grained soils in a variety of construction projects.
- Chemical solidification of the fine refuse involves addition of chemicals to produce a solid material with substantial strength, while allowing the moisture to be freed.

Returning coal refuse to underground mines has long been practiced in Europe. A study done in 1975 for the National Science Foundation showed that disposal of coal refuse in underground mines is technically, but not economically, feasible in most cases.

Dewatering and handling of fine refuse may be made more difficult in the future. This is due to the smaller particle sizes created by a number of new techniques being investigated to improve pyritic sulfur removal from coal. These techniques include magnetic separation, electrophoretic separation, electrostatic separation, and 2-stage froth flotation.

Secondary Pollution and Other Problems from Waste Disposal. Air pollution may result from blowing dust and from refuse bank fires. Both of these sources are controllable.

Leachate and surface drainage will result from coal refuse disposal in most parts of the country. Both can be collected and treated. U.S. EPA has published effluent standards for new and existing coal refuse areas. Table 20 shows those standards for new sources.

TABLE 20. EFFLUENT STANDARDS FOR NEW COAL REFUSE AREAS

Effluent Characteristics	Daily Maximum	30-Day Average
Total suspended solids, mg/l	70	35
Iron, total, mg/l	3.5	3.0
Manganese, total, mg/l	4.0	2.0
pH	6-9	6-9

Reclamation of Waste Disposal Area. It is estimated that the coal waste piles and impoundments accumulated between 1930 and 1971 in the United States cover approximately 225,000 acres of land.⁽²³⁾ The most positive approach to preventing pollution from disposal areas is probably reclamation. Refuse piles are very similar to spoil banks and thus reclamation of refuse piles can be achieved through similar procedures to those practiced for the reclamation of mine spoil banks.

The reclamation procedures can be divided into these steps:

Contouring. Contouring involves shaping the surface of waste disposal areas to achieve some predetermined objectives. The top surface of an area is sloped to conform with the surrounding countryside. Terraces are often used to control water run-off. Bulldozers are generally used to spread and compact the refuse, and some compaction is done by the refuse hauling vehicles.

In most cases, it is necessary to add a soil capable of supporting plant growth. Twelve or eighteen inches of fine soil or topsoil cover is capable of supporting vegetation.

Conditioning. Conditioning of the soil is essential on some coal wastes prior to attempts at revegetation. Salinity, pH, and nutrient content are among the most important factors which must be improved. Agents which have been demonstrated to increase pH are lime, crushed limestone, and fly ash. Nutrients may be added by standard fertilizers or along with sewage sludge used for pH control.

Revegetation. In areas studied by the Bureau of Mines, grasses combined with legumes gave the best results. Mulches are used after planting or during planting to protect the seed and soil from drying.

Costs of Disposal and Reclamation. The Bureau of Mines studied the costs of refuse disposal and reclamation for nine coal waste disposal projects. The results disclosed that refuse disposal costs ranged from 13 to 29 cents per ton-mile, spreading and compacting ranged from 4 to 28 cents per ton, and soil covering and planting ranged from \$1,070 to \$2,319 per acre.⁽²⁴⁾ These costs did not include the cost of installing or operating leachate collection or surface drainage collection and treatment facilities.

A report done by the Institute of Mining and Minerals Research at the University of Kentucky stated that coal refuse disposal costs ranged from \$0.50 to \$1.00 per ton, although specific disposal methods were not described.⁽²⁵⁾

Waste Utilization. Because the potential pollution problems associated with refuse disposal are so great and because coal refuse offers significant combustion heat content and other mineral values, serious consideration is being given to its utilization as a raw material. The coal industry and the government are developing new uses and reexamining earlier uses for coal refuse.

Landfill. Refuse can be used as landfill for a variety of construction purposes. One coal mine in West Virginia has converted a refuse pile into useful real estate. The Bureau of Mines has reported that refuse sites have been used for housing and small industrial development.⁽²⁴⁾

Road Construction. Coal refuse has been used extensively in Britain as a road base and for embankments. Adequate compaction is considered to be the main factor in successful utilization, and composition is of secondary significance. Refuse has successfully competed with conventional aggregates on an economic basis.⁽²⁶⁾

Building Materials. Coal refuse can be used as a raw feed in cement-making to replace the clay fraction. The refuse provides the silica and alumina required for the preparation of Portland cement clinker. Coal refuse also is being used in the manufacture of brick. Coal refuse is also used in the manufacture of lightweight aggregates for the building industry.⁽²⁶⁾

Sulfur Compounds. A U.S. patent⁽²⁷⁾ reveals that coal refuse containing pyrite could be used to produce elemental sulfur and pelletized coherent calcium carbonate.

Heat. Since coal refuse still contains a significant combustion heat content, it can be used as a fuel. It has great potential for application in the thermal drying of fines.

Metals. Work done by the Institute of Mining and Minerals Research of the University of Kentucky showed that aluminum and the transition metals exist in coal refuse piles in sufficient quantities to be of economic interest.⁽²⁸⁾

Additional Data Needs. Further data are needed on the relative proportions and total amounts of fine waste that are being dewatered and disposed of with the coarse refuse, as opposed to being disposed of in slurry ponds. An idea of the trends in the proportion would also be helpful.

Costs should be updated to include the costs of constructing and operating leachate and surface drainage collection and treatment systems and the costs associated with combined coarse and fine disposal.

More data are needed on leachate characteristics of both the fine and coarse waste, particularly as to heavy metal concentrations, as these are expected to be the determining factor in deciding whether coal refuse is or is not hazardous. More data are also needed on the physical characteristics of the refuse, especially of dewatered fine refuse.

Control Process Pollution and Impacts

No contractual activity was performed by Battelle-Columbus in this specific area. The following two sections provide a general commentary relating to pollution and impacts resulting from air and water pollution control. No significant pollution results from any of the solid waste control measures.

Air Pollution Control

Air pollution control equipment on coal cleaning plants captures particulates and gases that are destined for the atmosphere and transforms them to solids or sludges. The disposition of the solids and their potential for environmental impact is determined by the type of control equipment, the type of coal cleaning equipment the control equipment is installed on, and the process configuration of the coal cleaning plant.

Particulate control equipment functions principally as gathering devices, transforming the airborne particulates into dry solids or sludges and add no additional, or secondary, pollutants to the solid stream. The collected solid, depending on the coal cleaning process configuration, is either combined with the product coal stream as with control equipment on pneumatic cleaners or some thermal driers, or combined and disposed of with the coal refuse. As the quantity of captured particulate represents only a small fraction of the coal refuse, no additional environmental impact is expected beyond that attributed to the coal refuse itself.

Some gaseous control equipment, specifically that for SO₂ control, can generate sludges. The most common SO₂ control systems, those using lime or limestone, generate a calcium sulfite or calcium sulfate sludge. The sludge waste is unfortunately of little commercial value and must be disposed of. The most environmentally sound methods for sludge disposal are landfilling of chemically fixed sludge and disposal of untreated sludge in ponds lined with an impervious material such as clay, plastic, or rubber. However, calcium sulfite presents a significant land use problem. Sulfites tend to crystallize into small, thin platelets which settle to a loose bulky structure that may occlude a relatively large amount of water. The sludge is difficult to compress and dewater, and conversion to a suitable landfill presents an expensive and formidable problem. Ponds on the other hand require a large, suitable disposal site close to the plant and may not only be structurally unstable but aesthetically objectionable.

Water Pollution Control

Wastewater treatment equipment designed for removing suspended solids from coal cleaning plant process water are essentially gathering devices serving to remove suspended particles from the water stream and collect them in a solid or sludge form. No additives other than flocculants are generally introduced into the wastewater, and the collected solids are either combined with the coal product and sold or are disposed of with the coal refuse. The composition of the produced solid waste is generically the same as that of the coal refuse and it would not be expected to add to the environmental impact beyond that to be attributed to the coal refuse itself.

Wastewater treatment equipment designed for the control of dissolved solids, typically pH control, results in the addition of a small amount of calcium sulfate to the solid wastes. Calcium sulfate is relatively innocuous, insoluble, and would not be expected to add to an might even result in a slight reduction of, the environmental impact of the coal refuse.

REFERENCES FOR CONTROL
TECHNOLOGY ASSESSMENT SECTION
(pp. 104-139)

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ENVIRONMENTAL ALTERNATIVES ANALYSIS

Environmental alternatives analysis is one of the most important requirements in environmental impact assessment. However, it is also one of the last activities undertaken in a program. Hence, Battelle's activity in the first year in this area was limited to a preliminary pollutant ranking (Subtask 241) and the modification of a computer model for evaluating process technology (a segment of Subtasks 222 and 813).

Pollutant Ranking

When the initial group of approximately 1000 potential pollutants from coal cleaning processes was identified, it was recognized that all were not of equal importance and that priorities had to be established. However, it was also recognized that attempts to rank them serially in order would be a meaningless academic exercise. Thus, ranking efforts have sought only to classify pollutants by priority groups. As described in an earlier section, a Priority I group of about 75 pollutants regarded as most important was selected as given by Table 6 in "Current Environmental Background". The basis of selection of pollutants, which was not a rigorous one, reflected such factors as toxicity, abundance, classification as a named hazardous substance, and appearance in environmental standards.

For purposes of developing and testing an environmental assessment methodology on actual substances, a "short Priority I list" of 12 pollutants was drawn from the Priority I group as discussed in "Potential Pollutants and Impacts in all Media" under the major heading "Current Environmental Background". However, no particular ranking significance is attached to this list. Twelve was a convenient number to test, and the pollutants selected possess a spread of characteristics desirable for testing. They do rank among the most important pollutants and will rank high on any list of pollutants from coal. Prioritization of pollutants, on a group basis, can be carried further as more data on emissions and estimated permissible concentrations are developed.

Modification of Computer Models for
Evaluating Process Technology

This work consisted of a modeling effort related to existing computer programs in the area of coal preparation simulation. The purpose was to review and modify this software to (1) aid in the evaluation of an advanced coal cleaning facility being constructed at Homer City, Pennsylvania, and (2) use in trade-off studies later in the Coal Cleaning Program. Four computer programs were surveyed:

- (1) A U.S. Bureau of Mines coal preparation plant simulation model, version 4 (CPSM4), described in Gottfried, Jacobsen, and Vaillant.⁽¹⁾
- (2) A program to perform complete coal washability and froth flotation calculations and to automatically plot all washability curves, described in Humphreys, Leonard, and Buttermore.⁽²⁾
- (3) Coal cleaning programs described by PEDCo-Environmental, Inc. described in Isaacs.⁽³⁾
- (4) A computer simulation model for coal preparation plant design and control, described in Walters.⁽⁴⁾

Each of these programs contained unique features which hopefully will be available at some future date in a single program. However, only the coal preparation plant simulation model was sufficiently flexible to be directly usable in the evaluation of the Homer City Plant. This program was, therefore, selected for modification.

The original purpose for the modeling effort at the Bureau of Mines that resulted in the construction of program CPSM4 was to give the user the ability to simulate 'the performance of...configurations representative of actual preparation plants'. The key word in the above purpose is representative. The program was not originally designed to simulate actual plant conditions. Rather, its role was to give users the ability to examine a representative picture of some configuration as it might impact on a given type of coal.

Such analysis is important and valuable for the various design tasks which might precede the actual construction of a plant or, more importantly, which might precede the very decision to build a plant.

With this purpose in mind, the authors of the program made every effort to derive algorithms and generalized coefficients which would give good generalizations of the behavior of the various types of equipment listed in Figure 8. These algorithms included generalized distribution curves, classification functions, selection for breakage functions, breakage distributions, and others, all of which are discussed in detail in Goodman.⁽⁵⁾ This work was very well formulated and programmed in the original version of the program. It is a major asset to the design effort and all of it has been maintained in the present version of the program, though in slightly different form.

The goal of this research effort was not to simulate a representative configuration; rather it was to simulate a particular plant - the Homer City plant. Actual design curves describing the expected performance of units of equipment in the plant were available. Eventually, actual performance curves will also be made available after the plant becomes operational. The goal set for the program was to generate results which agreed as closely as possible with the material balance prepared by the design team for the plant. To achieve this goal it was necessary to modify the program to deal not just with generalized descriptions of equipment behavior but also with particular descriptions - those used by the designers in preparing the material balance. This basic modification was the purpose of the modeling effort which resulted in the version of CPSM4 described herein.

Modifications Made to Program

The major goal of the initial modification effort was to restructure CPSM4 so that it could be used in the evaluation of an actual coal cleaning plant. In this context the term could be used was taken to have two levels of

<u>Unit Operation</u>	<u>Equipment Type</u>
Blending	Stream blender
Splitting	Stream splitter
Screening	Dry upper screen
	Dry lower screen
	Wet upper screen
	Wet lower screen
Single-stage washing	Concentrating table
	Dense medium vessel
	Dense medium cyclone
	Hydrocyclone
	Single-stage Baum jig
Two-stage washing	Classifying cyclone
	Two-stage Baum jig
Froth flotation	Froth flotation cell
Rotary breaking	Rotary breaker
Crushing	Primary multiple roll crusher
	Primary gyratory/jaw crusher
	Primary single roll crusher
	Primary cage mill crusher
	Secondary multiple roll crusher
	Secondary gyratory/jaw crusher
	Secondary single roll crusher
	Secondary cage mill crusher

FIGURE 8. UNIT OPERATIONS SIMULATED

a provision was added allowing the program to accept Btu data classified both by size and specific gravity; a capability was added to circumvent the generalized distribution curves with actual curves; and various other miscellaneous changes were made. At the end of this phase another review meeting was held. At this meeting it was agreed that the present version of the program seemed capable of representing the plant, and plans were made to make some data modifications and to do extensive sensitivity runs.

The fourth phase effort for the program modifications started at the beginning of the task and was completed with the preparation of a user handbook by Goodman.⁽⁵⁾ Its purpose was to fully describe and document the program and its logic so that it could be used as an effective and understandable tool. Initially, a basic description of the mathematical approach to the program was written and reviewed, then a detailed user handbook and program description was written and distributed to the following along with a program deck and sample data deck:

- (1) Pennsylvania Electric Company, Johnstown, Pennsylvania
- (2) New York State Electric and Gas Corporation, Binghamton,
New York
- (3) Versar, Incorporated, Springfield, Maryland
- (4) U.S. Bureau of Mines, Pittsburgh, Pennsylvania.

To date no serious problems have been reported by any of the above in their attempts to make CPSM4 operational on their computers.

The fifth phase effort is not yet completed. Its purpose is to modify CPSM4 to provide a tool to

- (1) Evaluate effects of coal and equipment variables
on circuit and plant performances, and
- (2) Compare alternative coal cleaning systems with
respect to environmental impact, energy recovery,
and cost.

Within this phase there are two major thrusts. The first is to incorporate the calculation of costs into the program. At this point in time, a basic set of cost estimation routines have been written and are being tested. In addition, a working paper describing the overall approach has been distributed for review and comment.

The other thrust involves expanding the list of unit operations within CPSM4 so that it can simulate not just coal preparation plants, but also entire coal processing systems from mine to end-use. The types of processes being studied include

- (1) Mechanical dewatering
- (2) Sedimentation
- (3) Dissolved materials control
- (4) Particulate control
- (5) Gaseous removal and/or collection
- (6) Storage, handling, and transportation
- (7) Thermal drying
- (8) End uses.

At this point in time, alternative approaches to simulating the above processes are being examined. No actual implementations of these processes in CPSM4 have begun.

Simulation of Homer City Plant

To date three input decks which relate to the Homer City plant have been prepared, run, and reviewed. These are as follows:

- (1) The initial plant configuration (for power plant Units #1 and #2)
- (2) The final plant configuration (for power plant Units #1, #2, and #3)
- (3) The material balance flowsheet.

By far the most important of these is the material balance flowsheet run. Figure 9 shows the configuration and the results of the original material balance prepared. Table 21 gives a comparison of results from CPSM4 with that original material balance. The two results are quite close.

TABLE 21. COMPARISON OF RESULTS FROM PROGRAM CPSM4 WITH ACTUAL
MATERIAL BALANCE - Prepared for Homer City Plant,
Units 1, 2, and 3

Flow Stream	% of Feed		% Ash		% Sulfur		Btu/lb		SO ₂ /MMBtu	
	Actual	CPSM4	Actual	CPSM4	Actual	CPSM4	Actual	CPSM4	Actual	CPSM4
1	100.0	100.0	24.0	24.0	2.65	2.65	11,442	11,452	4.64	4.63
2	15.5	15.5	45.7	45.7	2.90	2.90	7,599	7,596	7.64	7.64
3	84.5	84.5	20.0	20.0	2.60	2.61	12,145	12,160	4.28	4.29
4	7.9	8.1	19.8	21.6	2.02	2.07	12,187	11,881	3.32	3.49
5	7.6	7.4	72.8	72.1	3.81	3.80	2,809	2,932	27.14	25.94
6	34.8	34.7	27.1	27.1	2.92	2.93	10,898	10,899	5.36	5.37
7	49.8	49.8	15.0	15.0	2.38	2.38	13,019	13,040	3.66	3.66
8	9.3	9.5	4.2	4.3	1.00	1.01	14,970	14,944	1.34	1.36
9	25.5	25.2	35.4	35.7	3.62	3.64	9,421	9,377	7.68	7.77
10	4.0	4.1	4.2	4.3	1.00	1.01	14,970	14,944	1.34	1.36
11	5.3	5.4	4.2	4.3	1.00	1.01	14,970	14,944	1.34	1.36
12	42.8	42.8	14.7	14.6	2.40	2.38	13,071	13,118	3.68	3.63
13	7.0	7.0	17.0	17.7	2.29	2.42	12,702	12,561	3.60	3.85
14	23.8	21.8	5.1	2.6	1.11	.85	14,804	15,243	1.50	1.11
15	19.0	20.9	25.5	27.1	4.01	3.98	10,906	10,904	7.36	7.29
20	16.1	17.4	19.3	19.7	2.84	2.86	12,272	12,211	4.62	4.68
19	2.9	3.6	67.7	62.7	10.48	9.37	3,371	4,594	62.16	40.78
22	19.5	19.6	2.5	2.5	0.85	0.85	15,262	15,254	1.12	1.11
23	4.3	2.2	17.0	3.2	2.29	0.86	12,702	15,141	3.60	1.13
28	16.9	16.9	19.1	19.7	2.03	2.10	12,309	12,202	3.30	3.45
29	8.6	8.3	67.6	67.9	6.75	6.76	3,729	3,663	36.22	36.94
30	19.1	19.4	69.7	68.5	6.15	6.11	3,367	3,555	36.54	34.38
31	56.2	55.6	17.8	17.9	2.24	2.24	12,549	12,523	3.56	3.58
32	24.8	25.0	2.8	2.9	0.88	0.88	15,200	15,187	1.16	1.16

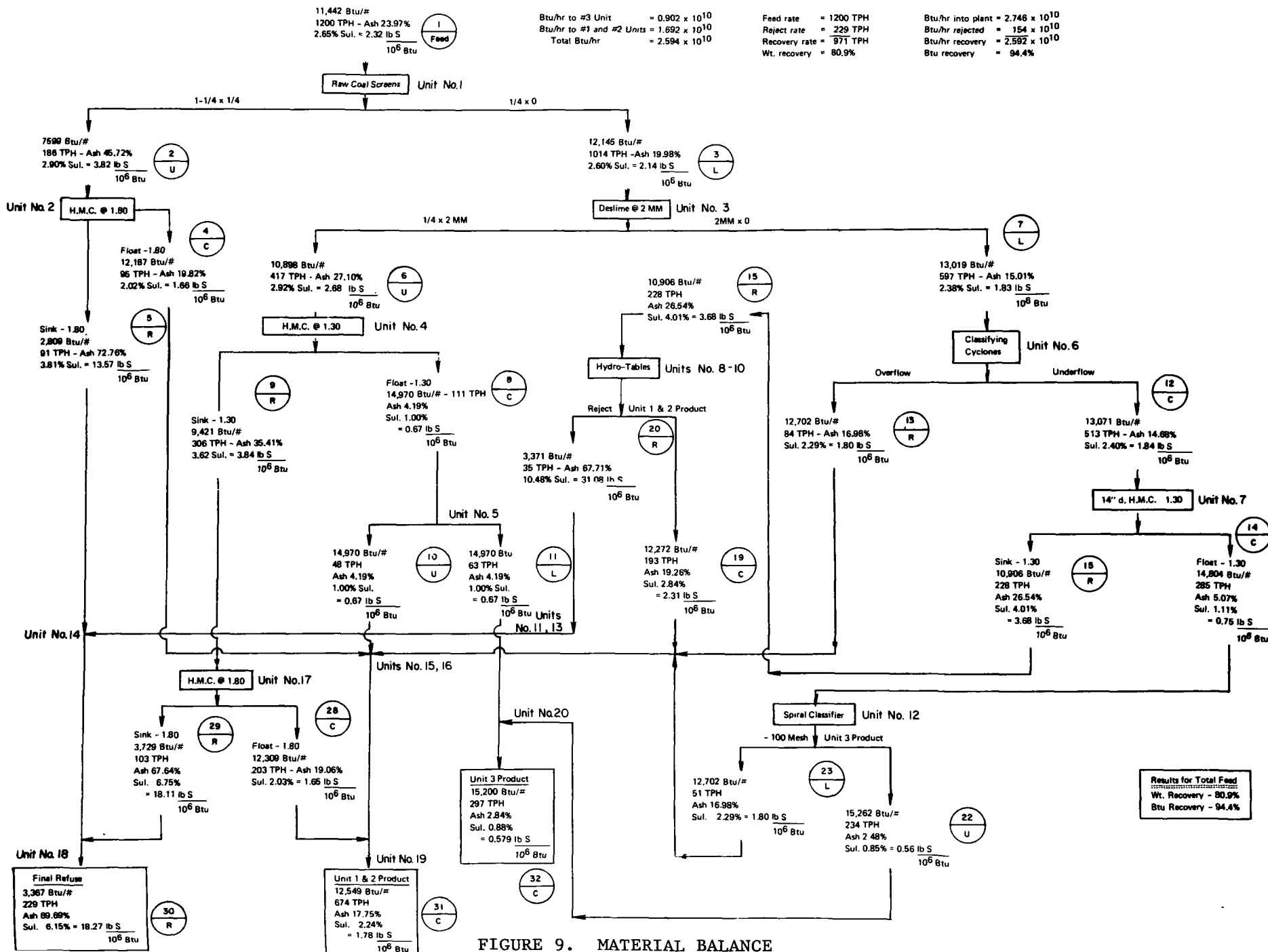


FIGURE 9. MATERIAL BALANCE

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(pp. 142-150)

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TECHNOLOGY TRANSFER

Contractual activities performed by Battelle-Columbus in this area consist of (1) preparation of the Monthly Current Events Summary and a quarterly Coal Cleaning Review, (2) the implementation, development, and operation of a Coal Cleaning Information Center (CCIC), (3) support to the Organization for Economic Cooperation and Development (OECD), (4) US-USSR information exchange, and (5) evaluation of physical coal cleaning as an SO₂ emission control strategy. The first two activities are described under "Newsletter Status Reports" and "Information Centers", respectively. The last three activities are described under "Other Reports".

Monthly Current Events Summary

The first issue of the Monthly Current Events Summary was included in the monthly progress report for June, 1977. Subsequent issues of the Summary have been included in the progress reports for July, August, and September, 1977. It is planned that the preparation of the Monthly Current Events Summary will continue throughout the current contract period.

In brief, the Monthly Current Events Summary covers the following topics.

- (1) Calendar of meetings and short courses
- (2) Annotated literature citations
- (3) Organizational news
- (4) New contract awards
- (5) Requests for proposals
- (6) Topics of general interest

Numerous journals, newsletters, reports, and other publications are reviewed on a continuing basis to identify items of interest for inclusion in the summary. It is planned that the calendar of meetings and short courses and selected items from topics 2 through 6 above will be utilized as input to the Coal Cleaning Review (published quarterly).

Coal Cleaning Review

The Fall, 1977, issue of the Coal Cleaning Review (the first issue) is scheduled for completion by October 31, 1977.

The Coal Cleaning Review will provide descriptions of current research results and new developments in (a) coal cleaning processes, (b) related environmental effects, and (c) applicable pollution control technology. It is expected that each review will contain several articles which pertain to these three topics. In addition, the latest calendar of meetings and short courses from the Monthly Current Events Summary and pertinent items from various sections of all issues of the Summary during the quarter will be included in the Coal Cleaning Review.

Information Centers

Coal Cleaning Information Center (CCIC)

The Coal Cleaning Information Center (CCIC) was implemented in September, 1976. The most important functions and services of the CCIC and the work accomplished during the past 13 months are summarized in the following sections.

Data Base Development. Among the first tasks in establishing the CCIC was that of data base development, which has been accomplished during the past 13 months through the following activities.

- The searching of commercial- and government-operated data bases to identify citations of interest to the coal cleaning program
- The screening of multiple information sources to identify items of interest to the coal cleaning program

- The acquisition of articles and reports that were identified through the screening process or which have been brought to the attention of the CCIC by project personnel
- The logging of new articles and reports, the assignment of accession numbers, and the typing of a title card and an input processing form for each item
- The review of each item being processed and the selection of index terms for later use in computer searching
- The keypunching onto tape, for each item being processed, all information from the input processing forms and all index terms which were selected
- The processing of tape into the CCIC computer data base through the use of a computer program especially prepared for this operation.

Contacting Organizations Conducting Ongoing Research. Searches of the SSIE (Smithsonian Science Information Exchange) data base and one of the ERDA/RECON data bases provided the material necessary for one of the important activities of the CCIC during the past 13 months. The computer printouts from these data base searches contained summary information of ongoing research projects of interest to the coal cleaning program.

Telephone and letter contacts have been made with many of the organizations conducting ongoing research to determine if research reports are available to CCIC. A number of research reports have been obtained through these contacts and, in a number of instances, Battelle has been placed on the distribution for reports which are scheduled for publication in the future.

Document Storage and Retrieval. Data base storage has been accomplished through the processing into the computer of appropriate bibliographic data and index terms for each item selected. As of September 30, 1977, there had been approximately 900 items processed into the CCIC data base. The actual hard copies of these 900 items are stored in the CCIC in accession number order by year of processing.

The identification and retrieval of items of interest are accomplished in two steps, i.e.:

- (1) A search of the CCIC data base is conducted via remote terminal. The search is made through the use of appropriate index terms and all pertinent citations are printed from the computer tapes.
- (2) The computer printout lists all citations identified through the computer search as being pertinent. An examination of the printout will identify the most important items and the hard copy of these can be ordered from the CCIC holdings by referring to the accession numbers listed on the printout.

Preparation of User Guide for Data Base Searching. In May, 1977, a CCIC On-Line User Guide was prepared. This guide was prepared to instruct the user in how to search the CCIC data base.

Detailed information was provided the user on log-in procedures, query build-up, display of CCIC records, off-line printing, retrieval/display aids and log-out procedures. In addition, tables were included on searchable fields and output fields. An appendix included a Tymshare/Tymnet communications network (including Tymnet telephone numbers) and an abbreviated instruction page on the use of the CCIC data base.

After completion of the user guide, CCIC user names and passwords were established for data base searching. Six user names and passwords were forwarded to the EPA Project Officer and two user names and passwords were retained for use by BCL project personnel. It is expected that the EPA Project Officer will allocate CCIC user names and passwords for use within EPA and to selected EPA contractors who would find it helpful to search the CCIC holdings.

Coordination and Preparation of Monthly and Quarterly Newsletters.

Monthly Current Events Summary. The monthly Current Events Summary was initiated in June, 1977, and the first issue was included in the monthly progress report for June, 1977. A more detailed description of the Monthly Current Events Summary can be found in the section entitled "Newsletter Status Reports".

Coal Cleaning Environmental Review. The preparation of the first issue of the Coal Cleaning Environmental Review was started in September, 1977, for publication as the Autumn, 1977, issue. Further details on the Coal Cleaning Environmental Review can be found in the section entitled "Newsletter Status Reports".

Other Reports Issued

Letter Report on "Desulfurization of Coal" for OECD

A letter report, dated May 20, 1977, on "Desulfurization of Coal" was prepared and submitted to the Organization for Economic Cooperation and Development, Paris, France, for use in preparing a report for its 24 member countries on "Clean Fuel Supply".

In December, 1976, Battelle participated in a workshop on coal desulfurization organized by OECD and held in Paris. The purpose of this workshop was to initiate the preparation of a draft report on coal desulfurization in western Europe and the United States.

Battelle's letter report was reviewed by the EPA Project Officer prior to submission to OECD. The first draft of the OECD report on "Clean Fuel Supply" was distributed for comments on September 8, 1977. Information was provided in Battelle's May 20, 1977, letter report with respect to the following six topics.

- (1) Description of technologies available for desulfurization of coal which can be used between now and 1985

- (2) Estimates of capital and operating costs versus plant capacity and quantity of sulfur removal for these technologies for the U.S.
- (3) Estimates of the time frame to construct and shakedown coal desulfurization plants
- (4) Estimates of the quantity of coal now being desulfurized in the United States and the quantity of sulfur being removed
- (5) Estimates of the quantity of coal which could be desulfurized in the United States and the quantity of sulfur that would be removed in 1985
- (6) Constraints preventing or delaying the use of coal desulfurization technologies.

US-USSR Information Exchange

The exchange of information on coal utilization with the USSR began about three years ago, shortly after the signing of the environmental agreement. The information which has been exchanged has been in two general areas--coal preparation and the use of coal in complex advanced energy generation systems.

Until the most recent meeting, the coal preparation activities have been concerned primarily with the use of flotation for the removal of pyritic sulfur. The transfer of that activity to the Energy Agreement led to a shift in emphasis on coal preparation at the July, 1977, meeting in Moscow. The activities now will focus upon the environmental consequences of coal preparation. It has been proposed that the initial activities be to conduct a bilateral symposium on "Discharges and Controls for Coal Beneficiation Plants".

The USA and USSR delegations have met on two occasions during the past year to pursue the exchange of information on the utilization of coal in complex advanced energy generation systems--in the U.S. during December, 1976, and in the USSR during July, 1977. The principal activity during both meetings was the exchange of technical material which will be used in a joint report which will be issued in 1978. The delegations will meet in November, 1977, and twice in 1978 to finalize the joint report.

Evaluation of Physical Coal Cleaning as an SO₂ Emission Control Strategy

This effort has had two related but separate components. The first objective was to provide a report to the Office of Air Quality Planning and Standards (OAQPS) incorporating technical information on coal cleaning needed by OAQPS in its evaluation of possible revisions in the New Source Performance Standards (NSPS) for SO₂ from utility boilers. The second component involves a much broader effort to determine the technological, environmental, institutional, economic, and social factors which affect the adoption by industries of physical coal cleaning (PCC) as an SO₂ emission control strategy, and to analyze optional initiatives designed to overcome barriers to PCC commercialization.

Report to OAQPS. The objectives of this portion of the task were: to define available coal supplies by location and sulfur content for raw and for physically-cleaned coal, to assess the impact of sulfur variability and averaging times for determination of compliance on coal availability, to assess the impact for alternative standards for utility boilers on coal markets and supplies, and to describe existing and emerging technologies to abate SO₂ emissions from coal burning. A draft report was submitted June 30, 1977, and a revised draft was completed October 14, 1977.

The analysis of coal availability under selected alternative NSPS and control technique options was conducted in terms of years of coal availability assuming a constant utility demand. This is a useful way of showing the effects of various NSPS and other factors on coal availability. The utility demand for coal in 1985 was arbitrarily selected for this purpose. Projections of coal use to 1985 are based on utility planning. While these projections are not expected to be precise, they are more soundly based than longer-range projections. If the utility coal use growth rate were essentially constant, the 1985 projected demand would represent the average demand over the next two decades. Changes in the demand rate chosen would affect the years of availability (a higher demand would result in fewer years of coal availability), but such changes would not affect the conclusions with respect to the availability of raw coal or cleaned coal to meet selected NSPS.

Federal Power Commission projections of coal demand for coal-fired utility boilers call for 715 million kkg (788 million short tons) in 1985. Given this projected utility demand for coal, the availability was determined for various alternative NSPS and, for comparison, for the case of no emission standards. The availability of coal which could meet the various NSPS with coal cleaning together with flue gas desulfurization (FGD) also was determined.

The bounded solution to this analysis was obtained by using:

- (1) The projected annual demand-pull of coal, by all the coal-fired electric utilities (existing and new) scheduled for 1985 operation;
- (2) The annual coal demand by the potential utility candidates for conversion from oil and gas to coal;
- (3) The demonstrated recoverable coal reserve base;
- (4) The potential cleanability of the reserve base;
- (5) Assumptions regarding the effectiveness of FGD applied to the combustion products from cleaned coal, and
- (6) Assumptions regarding the variability of sulfur in coal.

Summaries of the results of the analysis are displayed in the form of bar charts in Figure 10, in which sulfur variability is not considered, and in Figure 11, in which sulfur variability effects are included. The bar chart is an effective means of conveying the effects of emission regulations and techniques for compliance on the coal availability throughout the United States.

The nature of the information presented in Figure 10 may be illustrated by reference to the four bars for the entire United States. If there were no emission standards, the demonstrated recoverable coal reserve base could supply the utility demand for 330 years if consumed at the projected 1985 rate. For a NSPS of $0.52 \text{ kg SO}_2/\text{GJ}$ ($1.2 \text{ lb SO}_2/10^6 \text{ Btu}$), raw coal availability drops to 46 years. Physical cleaning to the level noted increases the availability to 79 years. If FGD and PCC were applied, the availability becomes 326 years. This is almost the equivalent of the raw coal recoverable reserve. This simply means that there is a small amount of coal which could

FIGURE 10.

COAL AVAILABILITY BAR CHART

STATUS OF THE AVAILABILITY OF COAL TO MEET THE NSPS OPTIONS
FOR ALL COAL-FIRED UTILITIES OPERATING IN 1985 (EXISTING PLUS NEW)
RAW AND PREPARED COAL WITH AND WITHOUT FLUE GAS DESULFURIZATION (FGD)

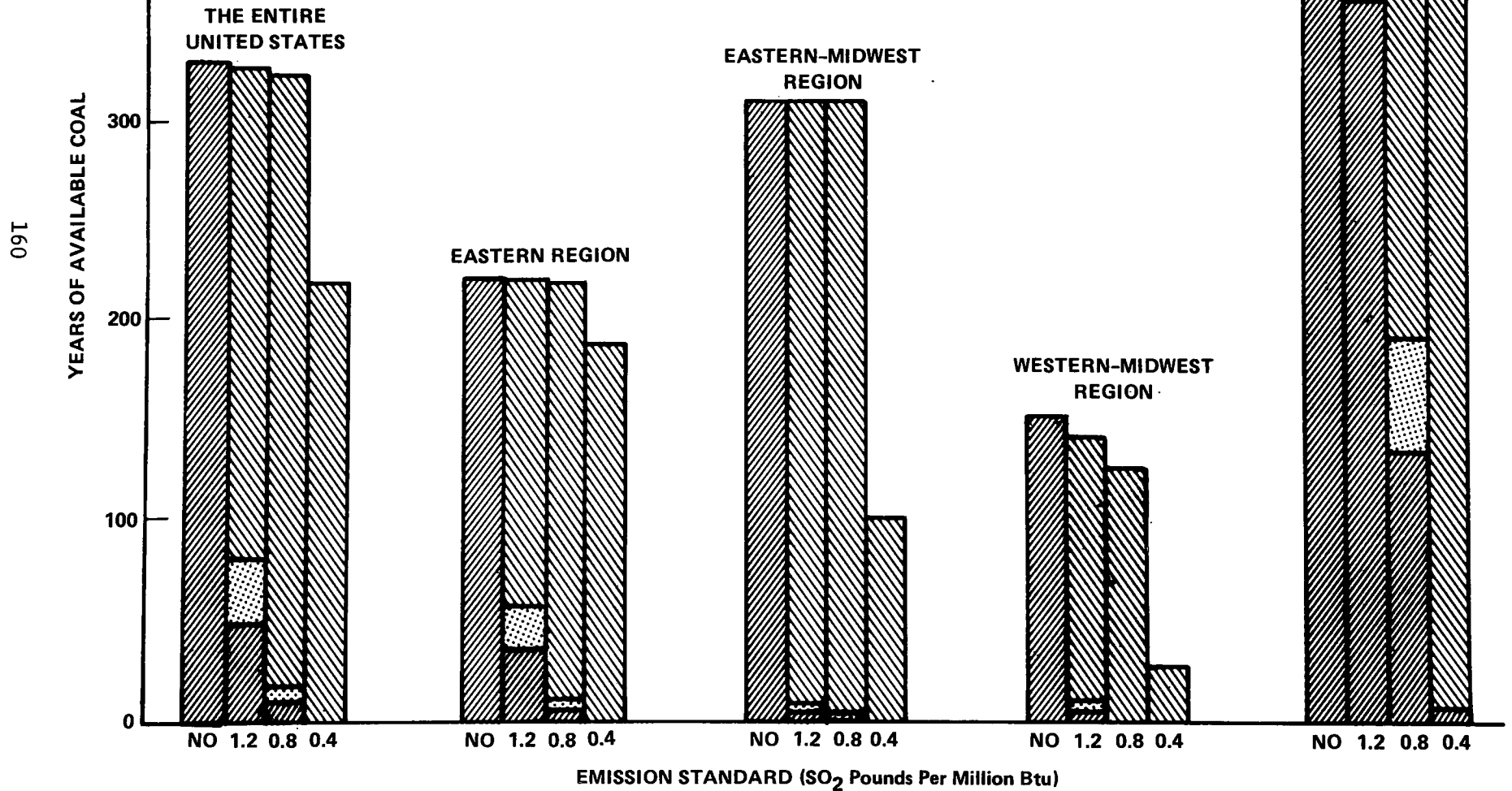
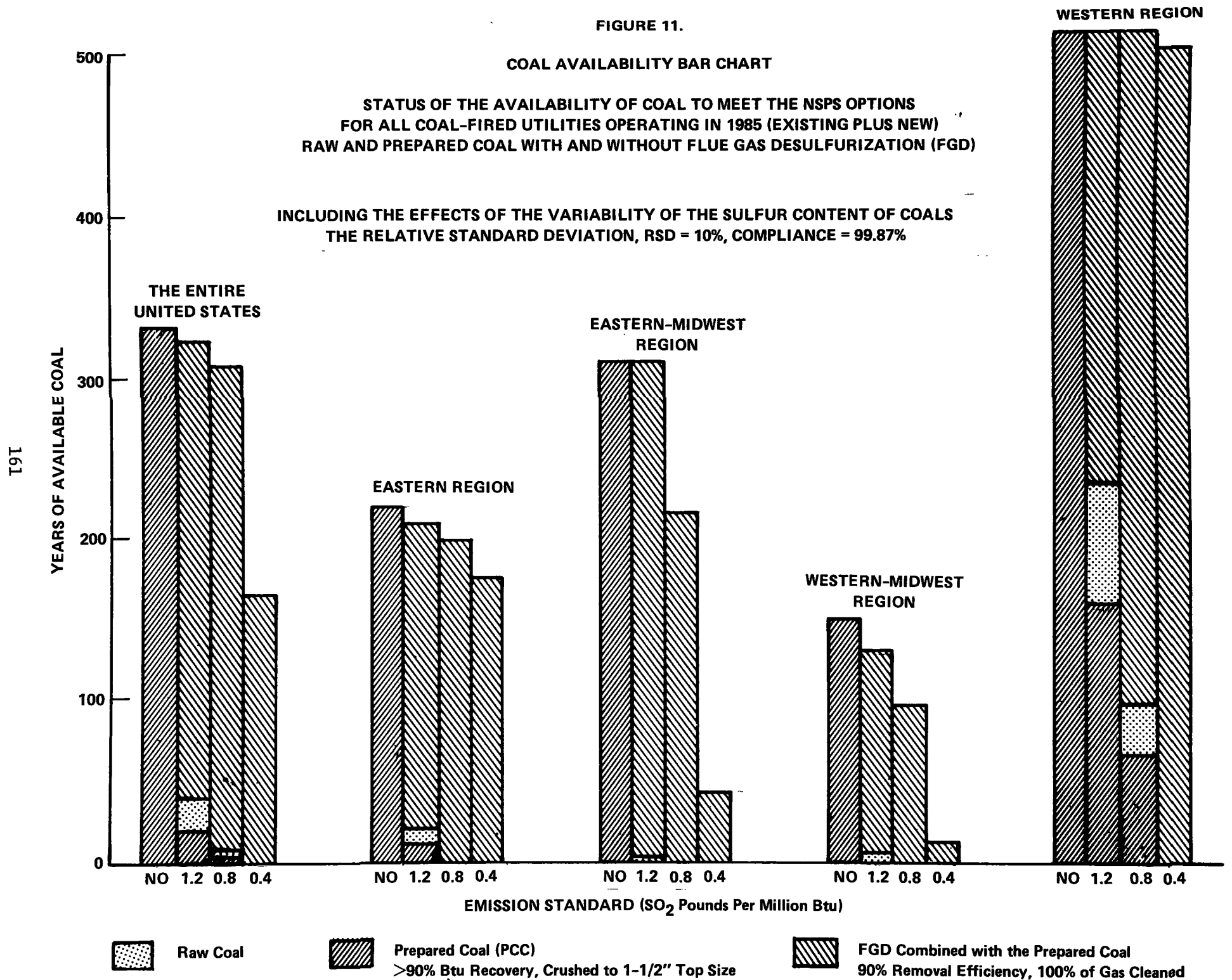


FIGURE 11.



not meet a 0.52 kg/GJ (1.2 lb SO₂/10⁶ Btu) standard on a long-term averaging basis even with PCC and FGD applied. For the optional 0.34 kg/GJ (0.8 lb SO₂/10⁶ Btu) NSPS, raw coal and PCC coal availability both drop still further. Essentially no raw coal or coal which could be sufficiently cleaned is available for the optional 0.17 kg SO₂/GJ (0.4 lb SO₂/10⁶ Btu) NSPS, and the availability drops to 218 years even if both PCC and FGD control techniques were applied. A regional breakdown also is presented in Figure 10. For each region the available coal in the region is compared with the projected 1985 utility demand for coal in the same region.

All of the information presented in Figure 10 is based on average sulfur values. Consideration of the effect of sulfur variability was incorporated in the analysis as summarized in Figure 11. The net effect of requiring short-time averaging in determining compliance with a stated emission limit is to reduce the availability of raw coal, and of cleaned coal as can be seen by comparing Figure 11 with Figure 10.

The summary results of Figures 10 and 11 indicate the following conclusions:

- (1) PCC alone will be of limited value in meeting optional NSPS for utilities.
- (2) FGD or other control techniques with comparable sulfur-removal effectiveness will be required, if more stringent SO₂ emission standards are imposed.
- (3) If the practicality of coal distribution from one region to another region were ignored, and if it were assumed that the coal reserves were available for use anywhere in the United States, compliance with more stringent regulations would still be impossible without FGD or comparable control techniques.
- (4) Since the potential for conversion from oil and gas to coal would increase the demand-pull for coal by only 6 percent, this by itself would only cause a ripple effect in the coal availability results.

Initiatives Study. The second portion of the effort is directed toward the identification of barriers to PCC commercialization and initiatives for overcoming these barriers. The study involves: assembly of information on coal supply, demand, reserves, and cleanability; review of coal cleaning technology and costs; comparative analysis of alternative sulfur removal options; review of environmental impacts of alternative sulfur removal strategies; summary of air quality factors and emission control strategies; identification of barriers; identification of initiative alternatives; assessment of environmental, energy, and economic trade-offs; and impact assessment.

Work is proceeding in all of these areas, however, completed results are not available at this time. An interim progress report was submitted in September, 1977, which included progress reports on the several areas under study with respect to barriers and initiatives. A draft final report will be issued in March, 1978.

FUTURE EFFORTS

The following sections briefly describe Battelle's currently authorized and/or planned efforts for the remainder of the contract period ending June 30, 1979.

Current Process Technology Background

Technology Overview - Subtask 211

The draft report entitled "Technology Overview of Coal Cleaning Processes and Environmental Controls" will be revised to include information on economics of coal cleaning, potential of coal cleaning technology for meeting state implementation plans and regulations, limitations of washability data, and other topics to be determined by EPA.

Revised Technology Overview - Subtask 291

The final report entitled "Technology Overview of Coal Cleaning Processes and Environmental Controls", prepared on Subtask 211, will be revised approximately during the last half year of the program to include updated information obtained from both the outputs of other Subtasks of this program and a continuing review of the literature.

Current Environmental Background

Develop Assessment Criteria - Subtask 241

Little further effort is anticipated on identifying additional potential pollutants; however, some effort will be made in characterizing the mode of occurrence and transformations of pollutants already identified.

An updated summary of pollution control regulations related to coal cleaning processes will be prepared. This effort will involve revising Appendix A to Battelle's April 8, 1977, preliminary report on "Development of Environmental Assessment Criteria" to include new regulations proposed and promulgated since the report was submitted.

The extent of further investigation and compilation of health/epidemiological literature and dose/response data will depend upon the results of the methodology development for estimated permissible concentrations. It is expected that primary reliance will be on the MEG and MATE compilations, with only limited investigation of a few specific substances, where additional data may be needed.

Work on transport models will be continued and expanded; this will include physical transport (including initial dispersion) and biological transport. Initially, the models will be delineated for the 12 pollutants on the "short Priority I list". The results from these efforts can be used to extend the modeling to additional pollutants in the Priority I group.

Environmental Objectives Development

Develop Assessment Criteria - Subtask 241

The principal objective continues to be to develop an improved methodology for estimating permissible environmental concentrations of pollutants acceptable for the health and well-being of man on the basis of a long-term continuous exposure. Various approaches to estimating permissible concentrations on the basis of toxicological data have been proposed, but none of these appears to be adequate. Also necessary to this effort is a parallel development of improved methods for interconverting and extrapolating a wide variety of animal test results to man for use when the usual LD₅₀ values for the rat are absent.

It is clear from the work to date that development or synthesis of the "best" method of extrapolation will be a difficult and complex task, and perhaps one that cannot be completed during the present task investigation. However, it is expected that the methodology presently being used can be significantly improved.

Environmental Data Acquisition

Development of Environmental Test Plan - Subtask 411

The report on this subtask has been submitted for review and all that remains to be done is final revision following receipt of comments.

Selection of Evaluation Sites - Subtask 421

Upon approval of the site selection scheme, coal cleaning plants will be classified into site categories. Information will be gathered on plant characteristics from literature, government agencies, and site visits to make site selections. Information on selected sites will be submitted for site approval before field work begins. A total of ten sites will be recommended as a prioritized list.

Development of Experimental Techniques - Subtask 431

Future effort on Subtask 431 will be to provide detail on those experimental procedures to be implemented at the site investigations. The detail will consist of work descriptions of procedures or reference to well-known standards, flow charts showing the sequence of how samples may be divided, and diagrams of equipment where appropriate. Quality assurance and control aspects of Level I sampling and analysis will be addressed. Inadequacies in current practices of sampling and analysis, such as in the determination of leachable materials in refuse piles, will be indicated and discussed.

Test Support Development - Subtask 441

Appropriate equipment and instruments will be acquired as needed to conduct the field and laboratory samplings and analyses in the field test program.

Test Plan Development - Subtask 451

A master test plan, which is now being prepared, and which will encompass the general requirements for testing all selected sites and coal cleaning processes will be submitted. As individual evaluation sites are selected, specific test plans will be prepared to add the details of sampling location, kinds of samples, etc. that are unique to each site.

Testing - Subtask 461

As test sites are selected and approved, the field testing program will be implemented. Sampling, testing, and laboratory analyses will be carried out in accordance with the test plans prepared in Subtask 451 and the analytical procedures outlined in Subtask 431. Testing is expected to begin in the Fall of 1977 on sites of highest priority.

Data Reporting - Subtask 471

Data will be compiled, analyzed, and reported for each test site as the programs at that site are completed.

Control Technology Assessment

Detailed Process Descriptions - Subtask 222*

In an effort to secure the previously defined additional information, required to prepare the final report on "Pollution Control Technology for Coal

* Process Data Acquisition - Subtask 232 provides input data for this subtask and is not reported separately.

Cleaning Processes", visits are being conducted to vendors of pollution control equipment, engineering consulting firms, and selected coal cleaning plants. The types of information to be obtained from these visits and other sources are summarized as follows:

- Dust emissions from transfer points (loading and unloading) and access roads.
- Characteristics of process water from different types of coal cleaning plants including total suspended solids, pH, chemical composition, and particle size distribution.
- Detailed material balances and performance characteristics, including secondary pollution potential, for existing pollution control equipment or processes, e.g., ponds, thickeners, filters, scrubbers, and cyclones.
- Detailed information on capital and operating costs of pollution control equipment including costs for power, water, labor, space, and material requirements.
- Detailed capability and adaptability of new pollution control equipment or processes.
- Process flow diagrams for treatment of runoff from refuse and storage piles.

New Control Technology Studies - Subtask 271

Studies will be undertaken to generate preliminary conceptual designs for improved pollution control systems for coal cleaning processes. This task will utilize results from other subtasks including 211 (Technology Overview), 222 (Detailed Process Descriptions), 232 (Process Data Acquisition), 241 (Development of Assessment Criteria), 251 (Trade-Off Studies), and 461 (Testing).

Conceptual designs of control systems for air pollution, water pollution, and solid waste will be developed. Advanced control technology will

be examined for possible application to various types of coal cleaning processes. The major emphasis will be on control technology for physical coal cleaning processes, although control technology applicable to chemical coal cleaning processes also will be addressed. Preliminary consideration will be given to pollution control for biological coal cleaning processes.

Control Technology Development Status

Battelle-Columbus has no planned contractual activities in this area.

Environmental Alternatives Analysis

Detailed Process Descriptions - Subtask 222

Existing computer programs will be modified for utilization in performing pollution control trade-off studies on Subtask 251. The major effort in this area will involve further modifications to the U.S. Bureau of Mines Coal Preparation Simulation Model Version 4 (CPSM4), as previously modified by Battelle for use in evaluating the advanced coal cleaning facility at Homer City, Pennsylvania.

The primary types of computer program modifications to be accomplished for the trade-off studies include providing the capability of (1) modeling additional equipment types and/or operations, primarily related to pollution control, coal handling, and end use, (2) analyzing capital and operating costs for various configurations of coal cleaning plants including pollution control systems, and (3) comparing alternative coal cleaning systems, including various pollution control options, with respect to environmental impact, energy recovery, and cost.

Pollution Control Trade-Off Studies - Subtask 251

Studies will be performed to establish cost and performance trade-offs associated with various pollution control techniques for coal cleaning processes (CCP). These studies will be used to identify the pollution control

equipment and configurations which provide systems for minimal environmental impact and/or minimal cost in coal cleaning plants.

Using information on existing and projected Federal and state regulations for the control of pollutants from CCP, an assessment will be made of the costs (energy and economic) and effectiveness of both existing and recently developed applicable pollution control technologies. Capital and operating costs, equipment life, maintenance requirements and performance will be evaluated for each technology. This information will be integrated to construct a cost-performance profile as a function of size for the various control technologies.

Revised Process Descriptions and Impact Assessments - Subtask 281

A detailed review will be made of information pertaining to performance and costs of pollution control technology. Results from other subtasks, including 251 (Pollution Control Trade-Off Studies), will be utilized to revise and update process descriptions in the report entitled "Pollution Control Technology for Coal Cleaning Processes", originally prepared on Subtask 222. Emphasis will be placed on the relative advantages and disadvantages of each control technology and the trade-offs related to environmental impact, costs, and energy utilization.

A comprehensive assessment of the environmental consequences of coal cleaning processes will be provided. This environmental assessment will be based on the assessment criteria developed on Subtask 241 and the field test results from Subtask 461.

Technology Transfer

Coal Cleaning Information Center - Subtask 821

Newsletter Status Reports. It is planned that the preparation of both the Monthly Current Events Summary and the Coal Cleaning Review (Quarterly) will continue throughout the current contract period. Primary emphasis on the Monthly Current Events Summary will be to include greater coverage through the review of additional sources of information.

Inputs to the Coal Cleaning Review will be solicited from other EPA contractors who are performing research under the EPA coal cleaning program. These inputs from other organizations should result in a newsletter much broader in scope than that which was originally envisioned.

Information Centers. It is anticipated that the routine operations of data base development, document storage and retrieval, and the contacting of organizations conducting ongoing research, will continue throughout the current contract period for the Coal Cleaning Information Center (CCIC). By June 30, 1979, it is estimated that the CCIC data base will contain approximately 1,800 items of interest to the coal cleaning program.

In addition to the continuation of routine operations of CCIC during future months, there is the possibility that two additional assignments will be assumed by the CCIC. These new assignments, which were described within the draft of Technical Directive (TD) No. C2-2 (822), dated May 18, 1977, are as follows:

Annotated Bibliography. If funding is available in future months, it is possible that annotated bibliographies will be prepared for the EPA. It is planned that these bibliographies will be printed from the CCIC data base in alphabetical order by personal or corporate author.

In order to accomplish this task, considerably effort will be required in adding selected annotations to the existing bibliographic information within the CCIC data base and in making quarterly updates as suggested in the May 18, 1977, TD. It will also be necessary to revise the present CCIC computer program so that the annotated bibliographies can be printed in the manner desired.

Reference Services. When resources are available, the service of both manual and computer searches of the CCIC data base as well as computer searches of commercial- and government-operated data bases can be made available to EPA and to selected EPA contractors.

Remote terminal access to the CCIC data base is already possible by EPA and EPA contractors as described in the CCIC On-Line User Guide. Assignments to perform searches of commercial- and government-operated data bases could be accepted by CCIC if directed by EPA.

Coal Cleaning Demo Planning - Subtask 813

The U.S. Bureau of Mines CPSM4 program, as modified by Battelle, will be used in the evaluation of the Homer City coal cleaning plant. The following types of tasks are envisioned in this effort.

- (1) Adjust the equipment specifications for the Homer City configurations as input to program CPSM4 to obtain agreement with experimental results obtained during the plant performance testing and any process characterization studies which might be performed.
- (2) Using data obtained from equipment performance tests which will be conducted to measure the sensitivity of that performance to coal properties and operating variables, further adjust program CPSM4 and/or its input data to achieve agreement with these results.
- (3) Perform trade-off studies using CPSM4 to identify changes in operating conditions and coal blends which will maximize Btu recovery and pyritic sulfur removal and which can be used to operate the plant for extended periods of time.
- (4) Incorporate changes into CPSM4 which would allow the program to estimate detailed coal washability data given only a limited number of experimental data values (probably about 20 points).
- (5) Using a newly developed cost model within CPSM4 and available cost data, incorporate a cost component into the trade-off studies.

US-USSR Information Exchange - Subtask 841

Meetings of US-USSR delegations are anticipated in November, 1977, and twice during 1978 to finalize a joint report on the utilization of coal in complex advanced energy generation systems.

Evaluation of Physical Coal Cleaning as
an SO₂ Emission Control Strategy - Subtask 851

Work on this task is scheduled to be completed with revision of the draft report on "Initiatives Study" due December, 1977. Some discussions have been conducted regarding additional modeling work required after completion of this effort, however, no work has been directed, and none has been incorporated in future planning at this time.

Symposium on Coal Cleaning to Achieve
Energy and Environmental Goals - Subtask 861

A symposium on the environmental aspects of coal preparation will be planned and held.

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16. ABSTRACT The report gives results of the first year's work on an environmental assessment of coal cleaning processes. A strong base of engineering, ecological, pollution control, and cost data is being established through data gathering and systems analysis efforts. In addition to program management, three task areas are defined: system studies, data acquisition, and general program support. Early availability is anticipated for draft reports of progress for three subtasks: (a) developing information on on coal cleaning process technology; (b) defining the technological and cost status of the control of pollutants from coal cleaning and refusal disposal; and (c) establishing criteria for meeting environmental goals. (A fourth subtask, acquiring process data, was terminated to avoid duplication.) Progress has been made on data acquisition subtasks, aimed at the planning needed as the forerunner of the anticipated environmental field testing program: (a) developing and describing the overall environmental test program; (b) developing the rationale for selection and selecting the evaluation sites; (c) specifying the experimental testing techniques to be used; and (d) developing the master site test plan. (Ten site categories have been specified for testing.) General program support includes: (a) obtaining background environmental data, and (b) operating a coal cleaning information center.			
17. KEY WORDS AND DOCUMENT ANALYSIS			
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