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U.S. Department of Energy
Assistant Secretary for Environment
Office of Environmental Programs

December 1981

Energy

and Solid/Hazardous Waste

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Energy and Solid/Hazardous Waste

MASTER

Published December 1981

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FOREWORD

Assuring the achievement of national environmental protection goals and advising the Secretary of Energy on conformance of the Department of Energy's activities with environmental laws requires ready access to a vast and varied information base on energy technologies, environmental quality, and natural resource management. While much of this information is available in various Government documents, some is not published, and the particular sets of information relevant to energy-environment assessments come from a number of different sources.

Environmental management debates, often conducted in a hurried atmosphere, initiate an immediate requirement for new analytical information for a particular topic under consideration. When a new subject is begun, the previously developed information is filed for later reference. Information assembled in this manner is generally not available in the open literature because it takes time and resources to organize information for purposes other than environmental management decision inputs. There is usually little incentive for taking the additional time and resources to transform the information for other users or develop it in a format for additional applications.

The Environmental Handbook Series is designed to overcome the deficiencies of information utility and transfer. Each of the works in this series brings together information in format useful to both public and private sectors. It serves as a basic reference document to enrich decision making and analysis of energy and the environment both inside and outside the Government.

To accelerate the availability of these handbooks, they are issued as periodicals, with early publication of prototypes followed by prompt publication of succeeding editions, incorporating users' comments. Accordingly, your comments on the content and overall utility of these handbooks are welcomed. The development and maintenance of the environmental media information handbooks is assigned to our Regional Impacts Division.

Peter House, Director
Office of Environmental Assessments

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1. INTRODUCTION

The nation's pursuit of energy independence through the development of new energy technologies and the enhanced recovery and utilization of domestic energy resources has caused heightened concerns over potential conflicts with environmental quality. Rapid increases in domestic energy production may impose additional burdens upon the nation's air and water resources and cause changes in land use. In an attempt to identify and evaluate these potential conflicts, the Department of Energy's Assistant Secretary for Environment has instituted an environmental quality media program which provides data needed in the assessment of the potential impact of domestic energy development on air quality, water quality and availability, solid/hazardous waste management and land use. This program is designed to provide readers with a general understanding of the interaction between energy development and the four environmental media and to construct a data base from which estimates of potential future impacts can be identified and measured.

Specifically, this report addresses the past and potential future solid and hazardous waste impacts from energy development, and summarizes the major environmental legislation applicable to solid/hazardous waste generation and disposal.

The impacts of solid waste storage and disposal are far-reaching, potentially affecting air and water quality, land use, and public health. The serious attention and concern directed towards the impact of solid wastes upon the environment is relatively recent. The public has become aware not only of the enormous quantities of solid wastes that must be disposed of but also of the hazardous nature of many of these wastes. The effects of improper disposal practices in the past can take several years to surface as threats to health and the environment. Until recently, the lack of knowledge regarding the design,

operation and monitoring of disposal facilities resulted in the proliferation of unsafe disposal practices.

Solid wastes from energy technologies are expected to escalate dramatically. Present federal initiatives call for approximately two billion tons of coal to be mined by 2000. The amount of coal cleaning wastes, fly ash, and scrubber sludge to be disposed of from conventional combustion, already estimated at 66 million tons per year, will increase enormously. Of perhaps greater importance, however, is that 600 million tons of coal per year will be converted to synfuels by 2000. It is estimated that up to 90 million tons of solid waste will be generated from these conversion processes. While much of the waste streams will contain ash and scrubber sludge, these new processes will produce new types of wastes. In particular, the reducing nature of the conversion processes will produce considerable amounts of coal char, tars, and oils. These wastes could contain considerable amounts of organic chemicals that are toxic or carcinogenic.

It is evident that a direct national effort toward solving our energy problems could also lead to an environmental and health problem. This problem will be one of controlling toxic waste streams to prevent undue risk to human health and the environment. At present, many of these wastes are uncharacterized, disposal technologies have not been fully tested, and the potential environmental hazards are unclear.

This Solid Waste Report addresses solid/hazardous wastes from energy industries. Coal combustion, gasification and liquefaction, and oil shale are emphasized, although other energy technologies are considered. In Section 2, some of the major topics relating to solid/hazardous waste management are reviewed. Section 3 describes solid waste from various aspects, (such as quantity produced, hazard characteristics, waste utilization, etc.) and

Section 4 provides specific data relating to the descriptive chapters of Section 3.

The solid/hazardous waste topics section is divided into two parts: the first, relating to all energy technologies, and the second, relating to specific fuel cycle problems. The first part is divided into three subsections, where the first reviews the environmental laws affecting both the quantity of solid waste produced and the manner of solid waste management and disposal. In the first half of the 1970's, the legislative and regulatory groundwork was developed for the control of atmospheric and aqueous pollutants from most industrial, governmental, utility and private sources. The pollution controls required in the Clean Air Act and Clean Water Act have contributed to a growing solid waste problem. The second half of the 70's saw passage of the Toxic Substances Control Act (TSCA) with its explicit control of toxic chemicals, and the Resource Conservation and Recovery Act (RCRA), the law passed to specifically control solid and hazardous wastes, and to emphasize recycling of materials and energy resources.

The second subsection reviews the data gaps and limitations to our present knowledge of how to handle energy related solid and hazardous wastes. Particularly for the emerging technologies, research is needed to characterize solid wastes and identify hazardous constituents. Environmentally sound waste handling procedures must be developed, otherwise, solid wastes could constrain the commercialization of some technologies or limit the achievement of national energy goals. The difficulties in analytical methodology and impact assessment related to solid wastes are described.

Finally, this third subsection addresses the potential constraints to siting energy waste disposal facilities. Land availability is a factor, considering the large fraction of coal solid waste that will occur in urban areas. Implementation of RCRA will result in increased demand for licensed off-site facilities and will require additional environmental factors to be considered when siting energy facilities and associated disposal operations. If any energy wastes are declared hazardous, public opposition could restrict or delay the siting of hazardous waste facilities and transportation of hazardous materials.

The second part of the solid/hazardous waste topics section relates to the following specific fuel cycle problems:

- Adequate disposal of solid wastes generated from oil shale facilities is one of the major obstacles to commercialization, not only because of the enormous quantities of spent shale that must be disposed of, but because hazardous materials may be leached to ground or surface waters of the oil shale region. A major uncertainty involves the long term integrity of disposal and reclamation methods.
- The disposal technology for coal combustion wastes has been applied and tested for many years, but the huge increase in coal ash and sludge may result in a lack of available land for disposal, especially for urban facilities required to convert to coal.
- This section reviews the current debate over nuclear waste management, stressing that solutions must soon be forthcoming as existing storage capacity in temporary tanks is rapidly being depleted.
- Radioactivity in coal may present potential problems relating to the health impacts of the storage of radioactive coal wastes and the environmental risks that may result from the utilization of these wastes.

Section 3 of this report is a discussion of the data presented in Section 4 and begins with an introduction to the pollutant medium or the general nature of solid wastes.

This is followed by six categories of data. The first category, Management Data, describes the Resource Conservation and Recovery Act, designed to result in "cradle to grave" regulation of all solid and hazardous wastes generated in the country. This is the basic management tool which the EPA and states will use in developing solid and hazardous waste management programs. The status of state programs is reviewed.

The second category, Residuals, summarizes the types and nature of solid wastes generated from coal utilization, oil shale processing, and other energy technologies, including geothermal, oil and gas extraction, tar sands, and nuclear power.

The third category provides figures on current and projected levels of solid waste generation and the fourth category summarizes the available information on the hazard characteristics of energy related wastes. This is followed by a review of

disposal options for various energy technologies, and engineering and environmental problems associated with long term storage and disposal.

The fifth category gives an indication of the impact of past practices, with figures on existing solid/hazardous waste disposal sites.

The last category reviews current methods of solid waste utilization. The encouragement of practices that recycle portions of energy wastes is a major undertaking under RCRA and could greatly reduce

the growing solid waste management burden.

None of the data sets contained in any of these categories are all inclusive. Rather, the data presented represents a compilation of existing data that were available at the time of this printing. New data will be added as this document is updated.

Finally, the fifth section of this report is a glossary of terms and acronyms used to describe and measure solid waste impacts of energy development.

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2. SOLID/HAZARDOUS WASTE TOPICS

This section reviews some of the major topics relating to solid/hazardous wastes from energy development. It points out the singularly complex task of solid/hazardous waste management from a number of perspectives. From a management viewpoint, difficulties arise due to the variety of environmental laws relating to energy wastes, including some which result in increased waste generation. While our national energy plan seeks to quicken the pace of domestic energy development, the major law designed for "cradle to grave" regulation of solid/hazardous wastes is only in the earliest stages of implementation. This raises serious questions as to the potential environmental constraints posed by solid/hazardous wastes to the realization of national energy goals.

The scientist faces especially difficult problems in solid waste characterization and impact assessment because of the highly site specific variables involved. This has made the establishment of generally applicable solid/hazardous waste criteria and disposal requirements a difficult undertaking.

Once the scientific groundwork has been laid, appropriate sites for the disposal of energy-related wastes must be found. Even if land meeting the physical requirements is available, public opposition can further restrict the potential disposal capacity.

GENERAL MANAGEMENT TOPICS ARISING FROM ENERGY DEVELOPMENT

When the environmental decade of the 1970's began, solid waste topics addressed the volume of residential and commercial wastes produced, health and environmental impacts of open dumps and open burning of trash, and the potential for recycling cer-

tains types of wastes which consumed non-renewable resources. The U.S. Environmental Protection Agency's (EPA) 1977 Report to Congress on Resource Recovery and Waste Reduction' took note of the passage of the Resource Conservation and Recovery Act (RCRA) in October of 1976, but the program document itself still focused on waste volume reduction, beverage container deposit legislation, and processing of mixed and separated wastes for materials and energy recovery.

EPA began to propose rulemaking actions for control of non-hazardous and hazardous wastes in February of 1978. Activity and interest have been more or less continuous since that time as all levels of government, business and industry are realizing how far reaching waste disposal practices can be on public health and the environment, as well as on economics and energy production. Public awareness and education about solid and hazardous waste problems have been heightened over the last five years by the extensive publicity received by incidents such as PCB's in Michigan, the Kepone problem in Virginia waters, and the Love Canal situation in New York.

The first half of the 1970's also saw the legislative and regulatory groundwork developed for the control of atmospheric and aqueous pollutants from most industrial, governmental, utility and private sources. The second half of the decade saw the implementation of these programs at federal, state and local government levels, the passage of the Resource Conservation and Recovery Act (RCRA) and the Toxic Substances Control Act (TSCA) in 1976 and the Surface Mining Control and Reclamation Act in 1977.

Background

Several environmental laws affect both the quantity of solid waste produced and the manner of solid waste management and

Table 2.1

Summary of Potential Regulatory Actions Impacting the Hazardous Solid Wastes from Energy Industries

Regulation	Section(s) (as applicable)	Concern	Type Control
RCRA (PL 94-580)	3	Hazardous solid wastes from energy must be prevented from entering the environment.	"Cradle to grave" regulation of hazardous wastes. Standards are set for generators, transporters, owners and operators of hazardous waste treatment, storage, and disposal facilities. Federal oversight of state hazardous waste management programs.
	4	Large volumes of simple solid wastes must be properly disposed.	Guidelines for land disposal of solid waste establish recommended procedures delineating minimum levels of performance required of any land disposal operation. Includes design and site selection criteria. Emphasis upon waste reuse.
TSCA (PL 94-469)	4-Testing of Chemicals	The process waste streams of energy technologies may contain toxic substances which present an unreasonable risk of injury to health or the environment, or there may be substantial human or environmental exposure to the chemicals. These substances must be stringently controlled.	Testing requirements: Data must be sufficient to allow a determination that the manufacture, distribution in commerce, processing, use, or disposal of such substances does or does not present an unreasonable risk to health or the environment.
	5-Premarket Notification	Emerging technologies may produce toxic substances as yet uncharacterized, or not included in the EPA inventory of existing chemicals.	Pre-manufacture notification for new chemical substances including its chemical identity, use, amount manufactured, the byproducts resulting from its manufacture, processing and disposal, and test data. The Administrator may require additional testing of the chemical or may take regulatory action, pending acquisition of additional data.
	6-Regulation of Hazardous Chemical Sub- stances and Mixtures	Same as for Sections 4 and 5.	The Administrator may prohibit or limit the manufacturing, processing, distribution in commerce, use, or disposal of a chemical substance or mixture. An order may be issued to change the manufacturing process to avoid hazardous contamination.

Table 2.1 (cont.)

Regulation	Section(s) (as applicable)	Concern	Type Control
	7-Record Keeping & Reporting	Many information gaps exist regarding the types, amounts, & effects of potentially toxic substances produced by the various energy technologies.	Each person who manufactures or proposes to manufacture a chemical substance must maintain records & submit reports, including existing information on environmental and health effects, exposure data, and information on the manner & method of disposal of chemical substance. A manufacturer must immediately inform the Administrator of any information regarding the existence of a substantial health or environmental risk posed by a chemical substance.
SMCRA (PL 95-87)	5	Ground and surface water contamination from mine wastes. Reclamation of spoil piles.	Environmentally sound disposal reclamation, required for mining permit.
FWPCA (FL 92-500) and CWA (FL 95-217)	Subtitle III	Priority pollutants from emerging technologies. Waste-water discharges must be stringently controlled.	BAT and total recycle. These processes produce additional solid wastes.
CAA (PL 95-95)		Stringent control of criteria pollutants and NESHAPS (Sec. 112).	ESP, scrubbers, etc. These will produce additional solid wastes.
SDWA (PL 93-523)		Wastes from energy process will cause ground water pollution.	RCRA type controls, requirement of permits for any deep well injections.
UICA (PL 95-190)			

Source: Chiu, S.Y., et al., *Problems Associated with Energy Solid Wastes, Draft*, Argonne and Brookhaven National Laboratories (August 1980).

disposal. The regulations of greatest significance have been or are being promulgated under the:

- Resource Conservation and Recovery Act
- Toxic Substances Control Act
- Clean Air Act
- Federal Water Pollution Control Act, as amended by the Clean Water Act of 1977
- Safe Drinking Water Act and Underground Injection Control Act
- Surface Mining Control and Reclamation Act.

The Clean Air Act and Clean Water Act are of interest because the controls they require produce solid wastes, while the Surface Mining Control and Reclamation Act and Safe Drinking Water Act contain provisions addressing solid waste disposal. Of greater importance are the Toxic Substances Control Act, with its explicit control of toxic chemicals, and the Resource Conservation and Recovery Act, the law passed to specifically control solid and hazardous wastes. These laws are summarized in Table 2.1. This general discussion does not address nuclear radioactive wastes, which is a fuel specific waste topic discussed in the second part of this section.

Clean Air Act (CAA) Amendments of 1977 (PL 95-95)

Increasingly stringent air pollution control requirements have led to a growing solid waste burden. The 1970 Federal Clean Air Act Amendments established a common framework for federal, state, and local governments to work together for the control of air pollutants and achievement of cleaner air.

Important implications for solid waste are the emission limitations imposed by state and national emission standards for criteria pollutants, which affect the quantity of solid waste produced. State regulations control emissions of particulates and sulfur dioxide (SO₂) from both old and new industrial and utility boilers. The extent of control varies from state to state. All states require particulate control, the ash becoming solid waste. In some states SO₂ regulations may be stringent enough to require scrubbers, adding to solid waste, whereas in other states they can be met by burning low sulfur coal.

Federal emission standards for new boilers over 250 MBtu/hr capacity were promulgated in June 1979. These standards

restrict the quantity of particulate emissions to 0.03 lb/10⁶ Btu heat input. This will require up to 99 percent control; virtually all ash in the coal will appear as solid waste. The SO₂ regulations are on a sliding scale and limit emissions to 1.2 lb/10⁶ Btu and 90 percent removal or 0.6 lb/10⁶ Btu and 70 percent removal. In all cases some degree of scrubbing will be required, greatly increasing the quantities of solid waste produced.

The amount of air pollution control (APC) sludge generated by electric utilities in 1977, the year the Clean Air Act Amendments were signed, was 40 million dry metric tons;² a drastic increase within our decade. Oil refining is another energy activity whose air pollution controls produce large quantities of solid waste. The figures for this industry are 3.5 million tons of sludge in 1977 and 4.3 million tons in 1987, and this industry is the tenth largest producer of APC sludge.²

Federal Water Pollution Control Act (FWPCA) PL 92-500 As Amended by the Clean Water Act (CWA) PL 95-217

These acts are aimed at restoring and maintaining the integrity of the nation's waters. They direct EPA to develop and enforce standards for waste discharges into navigable waters and publicly owned wastewater treatment plants. The recent amendments require Best Available Technology (BAT) for 129 pollutants (Consent Decree pollutants). Many of these pollutants are found in energy systems' waste streams. Control of these streams will create sludge that will require some form of disposal.

Of the 12 largest wastewater sludge generating industries during the period 1967-77, petroleum refining is the only energy-related industry and ranks twelfth. In 1967, refineries produced 700,000 dry tons of wastewater sludge; in 1977, 900,000 tons; and are expected to produce 1.3-1.8 million dry tons in 1987.²

Safe Drinking Water Act (SDWA) PL 93-523 and Underground Injection Control Act (UICA) PL 95-190

SDWA provides a program for the protection of public drinking water. It does this by requiring the development of national drinking water standards to protect health and provides for the enforcement of such standards.

Section 1424(e) of the Act allows EPA to designate an aquifer which is the sole or principal source of drinking water for an area which, if contaminated, would create a significant public health hazard as a sole source aquifer (See Table 4.9). Under Section 1442 of SDWA, a study of the nature and extent of the impact on underground drinking water sources of ponds, pools, lagoons, pits and other surface impoundments will be performed. This assessment, which involves an inventory of surface impoundments, will be coordinated with the RCRA inventory and will be used as a screening device to establish priorities for the RCRA inventory and the application of RCRA regulatory provisions so that the worst drinking water problems may be addressed first.

The Underground Injection Control Act will require permits for any deep well injection of wastes; these wastes may be liquid, but under RCRA definitions, are considered solid wastes due to their containment. UICA was designed as a permitting program to protect the nation's aquifers from degradation, and may reduce the practice of underground injection as a method of disposing of energy-related wastes.

Surface Mining Control and Reclamation Act (SMCRA) PL 95-87

The overall objective of SMCRA is to protect the environment from the adverse effects of surface coal mining operations. The Act provides for reclamation of the mined areas to a condition capable of supporting the uses that were available prior to mining or to higher or better uses. It requires the Secretary of Interior to establish standards and criteria regulating the design, location, construction, operation, maintenance, enlargement, modification, removal, and abandonment of new and existing coal mine wastes, tailings, coal processing wastes, or other liquid and solid wastes. Section 508 of the Act requires submission for federal/state approval of a reclamation plan as part of a request for the mining permit. Section 515 of the Act requires that the reclamation effort insure that all debris, acid forming materials, toxic materials or materials constituting a free hazard are treated or burned and compacted or otherwise disposed of in a manner designed to prevent contamination of ground and surface waters.

Toxic Substances Control Act (TSCA) PL 94-469

This legislation is directed toward protecting the environment and public health from exposure to toxic chemicals. TSCA authorizes EPA to require that companies test chemical substances or mixtures manufactured or processed by the company. Section 5 requires submission of notice and testing data to EPA before manufacture of any new chemical substance for a significant new use. Section 8 requires EPA to require record-keeping and requires EPA to require record-keeping and reports and also requires companies to immediately report adverse information.

Section 6 allows EPA to regulate and ban if necessary, the manufacture, processing, distribution in commerce, or disposal of chemical substances and mixtures on the basis of unreasonable risk to human health or the environment. The regulation or banning of a substance is, however, based on unreasonable risk which is so great as to outweigh the benefits of the chemical "using the least burdensome requirements."

One important TSCA regulation affecting energy industries relates to the use and disposal of polychlorinated biphenyls (PCBs). Specifically, "within six months of the effective date of this Act (TSCA) the Administrator shall promulgate rules to:

- prescribe methods for the disposal of polychlorinated biphenyls, and
- require polychlorinated biphenyls to be marked with clear and adequate warnings and instructions with respect to their processing, distribution in commerce, use or disposal with respect to any combination of such activities."

As a result of this directive, specific disposal mechanisms were set down for these regulations.⁵ Incineration required specific combustion criteria such as a two second dwell time for all PCB containing liquids at 1200 °C and 3 percent excess oxygen in the stack gas operating at a 99 percent combustion efficiency. Monitoring criteria for incineration were developed with recordkeeping and reporting procedures. Chemical waste landfills also were required to meet specific technical standards.

In many ways the thrust of the PCB disposal rule is similar to those being developed under RCRA. Thus, "the Agency made a tentative decision to merge the TSCA PCB rules in the final RCRA regula-

tions.”⁶ This task has not yet been completed as both rules are lengthy and complicated and must be carefully coordinated to avoid regulatory loopholes and disruption of the ongoing TSCA PCB control program. EPA expects to complete the task of integrating the RCRA regulations and TSCA PCB rules by the fall of 1980.⁶

Resource Conservation and Recovery Act of 1976 (RCRA)

RCRA encourages the conservation and recovery of materials and energy from wastes through a number of mechanisms. Subtitle D of the Act advocates state and regional solid waste planning which maximizes the utilization of valuable resources and encourages resource conservation. Solid wastes must be utilized for resource recovery or be disposed of in sanitary landfills or in some other environmentally sound manner. Guidelines have been published facilitating the identification and development of regional solid waste planning areas. Such regional planning is essential to the development of cost-intensive resource and energy recovery plans.

Because RCRA is the major avenue for federal management of solid/hazardous wastes, its requirements pertaining to all forms of solid and hazardous wastes are discussed in more detail in the Data Management part of Section 3. Energy related wastes are currently in a state of uncertainty with respect to the severity of disposal requirements that will be applied to them. RCRA regulations promulgated thus far focus almost entirely on municipal solid waste programs for collection and disposal of residential and commercial wastes, and on industries which deal with manufacturing or processing that involves hazardous chemicals. Energy-related solid hazardous waste streams were included in one set of proposal regulations, but concerted congressional opposition moved them to the non-hazardous category for at least two years.

That disposal of solid wastes from energy technologies will be an engineering problem is evidenced by the estimates of solid wastes to be generated in the future (Table 2.2). Estimates of solid waste production project a significant increase in energy-related solid wastes, from 58 million tons (MT) in 1976 to 134 MT in 1995.⁷

Data Gaps and Limitations

Uncertainties about how to handle energy related solid wastes result from in-

adequate information on waste stream volumes and characteristics; applicability of existing environmental control technologies to these waste streams; environmental, public and occupational health effects of wastes; recycling or reutilization technologies; and market potential for wastes that can be recycled.

Research needs for emerging technologies are especially pressing. The President's Energy Plan for increased coal utilization entails several changes in the energy supply profile of the U.S. Unless adequate waste handling procedures are developed along with research on the nature of these wastes, progress of some commercial areas could be very slow.

Solid Waste Characterization

Solid wastes from energy technologies are noted for the variation in their composition as well as their volume. Existing data on these characteristics and on the factors that affect them are far too sparse to allow adequate understanding of their impacts or development of control technologies for them. This is due, at least in part, to the historical order in which environmental control technologies have developed (air, water, then solid wastes), and in part to the rapid increase in the types and volumes of waste which must be dealt with in Table 2.2.

The basic waste characteristics that must be identified include: quantities, physical characteristics, trace elements, trace organics, radioactivity, toxicity, and mutagenicity.

Coal Conversion Wastes

The importance of obtaining basic information was emphasized at an April, 1979 workshop held on solid waste research and development need for emerging coal technologies:

“Due in part to RCRA, specific challenges may be raised as to the legal environmental acceptability and viability of the demonstration and commercial sized coal liquefaction and coal gasification facilities in the near to medium term future.”⁸

At this workshop, sponsored by the American Society of Civil Engineers and the Electric Power Research Institute, solid waste research and development needs were recommended which fall into three categories: solid waste characterization; reuse, recycling and utilization; en-

Table 2.2

Estimated Solid Wastes from Energy Related Activities (10⁶ tons)¹

Waste	1976	1985	1990	1995
Conventional Coal Boiler				
Utility - Ash	58.0	71.0	105.0	134.0
Lime/Limestone				
Scrubber Sludge	0.8	5.0	30.0	51.0
Industrial - Ash	7.0	24.0	33.0	46.0
Coal Gasification				
Coal Cleaning		0.2	0.7	1.8
Gasifier Ash		2.0	7.0	18.0
Boiler Ash		0.2	0.7	1.7
Boiler FGD Sludge		0.04	0.15	0.4
Biosludge		0.08	0.3	0.7
Acid Gas Clean-up		0.003	0.01	0.02
Spent Catalysts		N/A	N/A	N/A
Tar and Oil Sludges		N/A	N/A	N/A
Coal Liquefaction				
Coal Cleaning		2.0	2.0	18.0
Liquefaction Waste		0.9	0.9	8.0
(Chars, Ash, Filter Cake)				
Boiler Ash		0.025	0.025	0.2
Boiler FGD Sludge		0.03	0.03	0.3
Biosludge		0.09	0.09	0.8
Spent Catalysts		N/A	N/A	N/A
Acid Gas Clean Up		N/A	N/A	N/A
Tar and Oil Sludges		N/A	N/A	N/A
Oil Shale				
Raw Shale Dust		0.5	0.9	4.0
Spent Shale		19.5	39.0	173.0
Spent Shale Dust		0.04	0.08	0.35
Arsenic Waste		0.0002	0.0005	0.002
Nuclear				
High Level Waste (10 ⁶ × ft ³)	0.007	0.02	0.03	0.04
Low Level Waste (10 ⁶ × ft ³)	229.0	716.0	1030.0	1380.0
Utility coal (mmtons)	448.0	733.0	1066.0	1377.0
Industrial coal (mmtons)	62.0	212.0	289.0	404.0
Coal-derived gas (BCF)		88.4	313.4	786.0
Coal-derived oil (mmBls)		11.0	11.0	93.7
Oil shale (mmBls)		18.25	36.5	162.4
Nuclear (BKWH)	191.0	597.0	857.0	1151.0

Notes: 1976 figures from Monthly Energy Review, DOE/EIA publication.

Future years from U.S. DOE/EIA Annual Report to Congress 1978, Volume 3, supplement 1, DOE/EIA-0173/3-S1.

Assumptions are from Series C - Medium supply, medium demand and medium costs.

¹Solid waste figures are based on the following energy consumption and production figures:

Source: Crowther, M.A. and S.C. Morris, *Draft OTI White Paper on Environmental Aspects of Energy Related Solid Wastes*, Brookhaven National Laboratory (June, 1980).

environmental effects: system design, monitoring, and disposal. The summary of the workshop recommendations is presented in Table 2.3.

Table 2.4 lists very briefly the data needs for the Lurgi coal gasification process.⁹ It shows very clearly the lack of data on all

waste streams except for the FGD sludges. Almost totally lacking for all Lurgi and many other gasification and liquefaction streams are data on the type and concentration of organic substances, trace elements, and hazardous and ecological properties. For some streams no data are available on

quantities and characteristics primarily due to the nonexistence of such streams (e.g., combined plant effluent) in existing gasification plants or the proprietary nature of the data (if any such data indeed exists).⁹

Oil Shale

Environmental impacts of oil shale development have been a subject of considerable controversy, and shale solid/hazardous waste problems are the focus of many of the questions. Specific needs include the following:

- *Mining Technology.* Experts are needed to acquire data for the safe design of disposal piles and, where open pit mining is done, the stability of the pit walls. Waste piles from oil shale mining and processing are expected to be two or three times higher than existing dumps, and the depth of pits may exceed that of

the largest existing open-pit mines. Accordingly, because of the intrinsically greater hazards, present methods of calculating safe slopes and stable configurations should be sharpened and refined.¹⁰

- *Liquid Wastes.* Laboratory research and experiments on a pilot scale are needed to determine the practicality and effectiveness of various strategies for controlling liquid wastes from oil-shale processing. Of these, the control of leachate from in situ retorts appears to be difficult, costly, and uncertain, and procedures for upgrading the large quantities of retort water from in situ retorting are unresolved. A goal of such investigations should be reuse of retort water.
- *Other Solid Wastes.* A number of the waste streams with which EPA must deal

Table 2.3

Summary of Recommendations from Workshop on Solid Waste R&D Needs for Emerging Coal Technologies

Session I: Solid Waste Characterization

1. Evaluate Waste Characteristics

Session II: Reuse, Recycle, Utilization

2. Develop Design Parameters for Handling, Processing and Storage of Solid Waste
3. Identify Characteristics of Secondary Waste Streams
4. Conduct Market Feasibility Study
5. Evaluate Institutional Barriers to Reuse/Recycling of Coal Wastes
6. Investigate Existing Transportation Infrastructure
7. Recommend Practices for Soil Application of Coal Conversion Wastes
8. Recommend Practices for Use of Coal Conversion Residues as Livestock Feed Additives
9. Develop Priorities for Advanced Testing
10. Develop Total System Descriptions
11. Co-Disposal of FGD or FBC Sludges with Coal Cleaning Wastes
12. Evaluate Resource Recovery Options to Reduce U.S.A. Dependence on Foreign Supplies
13. Determine Material Handling Constraints
14. Temperature Impacts on Treatment of Coal Cleaning Gasification and Liquefaction Residues

Session III: Environmental Effects: System Design, Monitoring, and Disposal

15. Review Case Studies of Utility Waste Disposal
 16. Develop Literature Base for Environmental Effects
 17. Evaluate Constraints on Plant Siting Due to Waste Disposal
 18. Determine Occupational Health Concerns from Emerging Coal Technologies
 19. Determine Economic Impact of RCRA on Utility Industry
 20. Generic Environmental Impact Assessment for FBC Systems
 21. Develop Monitoring System for Disposal Site Evaluation
 22. Determine Treatment Options for Solid Wastes from Coal Gasification and Liquefaction Installations
 23. Evaluate Liner Materials
-

Source: Proceedings of the ASCE Power Research Council Workshop, *Solid Waste Research and Development Needs for Emerging Coal Technologies*, for the Electric Power Research Institute, San Diego, California, (April, 1979).

Table 2.4

Data Needs Relating to Lurgi Coal Gasification Solid Waste Stream Characteristics and Control Technology Capabilities

Waste Stream	Waste Characteristics	Control Technology Capabilities
Coal fines, dust and refuse	No data available on characteristics and quantities for a Lurgi SNG plant (these wastes would be coal- and site-specific). Some data available from other industries (e.g., electrical utility and coking).	Control technologies (e.g., disposal in ponds/landfills) should be applicable. Effectiveness for containment and costs not evaluated.
Gasifier and boiler ash	No data available on quenched gasifier ash (including its hazardous characteristics). Limited data available on elemental composition and leaching potential of the unquenched gasifier ash for certain coals (not including those proposed for use in U.S. Lurgi plants). Boiler ash characteristics would not be unique to Lurgi, except when Lurgi process water is used for ash quenching.	Control technologies requirements dependent on forthcoming RCRA regulations; if these wastes are classified as "hazardous," existing controls used in utility industry may not be adequate and more effective controls (e.g., containment in secure landfills, lined ponds, fixation, etc.) may be required. Design criteria would have to be developed for these more stringent controls.
Spent catalysts and methanation guards	No characterization data (including hazardous characteristics) available on spent shift and methanation catalysts and methanation guards for Lurgi plants; very limited gross characterization available on spent methanation catalyst from pilot scale tests in connection with other gasification processes.	Control technologies used or proposed under RCRA for use in other industries (resource recovery, encapsulation and/or disposal in secure landfills) should be applicable. Although catalyst manufacturers/reclaimers may have costs and effectiveness data on these controls, such data are not publicly available.
Tarry/oily sludges	No data available on quantities and characteristics (including hazardous properties).	Control technologies used or proposed under RCRA for use in other industries (e.g., energy recovery, disposal in secure landfills) should be applicable; cost and effectiveness of these controls not defined.
Biosludges	No data available on quantities and characteristics (including hazardous properties).	Same as for tarry/oily sludges.
Inorganic solids and sludges (FGD wastes)	Data available on composition and handling/disposal characteristics (compactability, permeability, leachability) for FGD sludges from utility industry. Characteristics of FGD wastes are coal- and process-specific.	Same as for gasifier and boiler ash.

Source: Ghassemi, M., K. Crawford and S. Quinlivan, *Environmental Assessment Report: Lurgi Coal Gasification Systems for SNG*, TRW Environmental Engineering Division for U.S. EPA, EPA-600/7-79-120, (May, 1979).

are ranked, on the basis of the very limited data available, as to their potential harmful effects on health and the environment (Table 4.59, Section 4, Effects). The waste streams which are somewhat analogous to coal and oil shale waste streams (e.g., petroleum refining, iron, steel, coke scrubber sludge) were deemed toxic due to the presence of one or more of the following chemicals: arsenic, cadmium, chromium, lead, cyanide, phenolics, and fuel aromatics (naphthalene). A comparison of solid waste and leachates from these industries and energy industries point out the following possible areas of energy waste regulation. Coke plant phenolics are on the order of 10 parts per million (ppm). Lurgi and SRC-I waste streams are 3500 and 45,000, respectively. Petroleum Refining (DAF) has chromium values of 260 ppm. Values for bottom ash (270 ppm), fly ash (300 ppm), synthane bottom ash (240 ppm), FBC spent bed (450 ppm) and Lurgi wastes (590 ppm) are all within this range. These values were for solids and not leachate. However, these regulated wastes were considered hazardous in the toxic category rather than the Extraction Procedure toxic category relating to leachate composition. Thus, no leachate tests may be necessary. Creosote wastes are considered hazardous in part due to the presence (0.2 ppm) of benzo(a) pyrene. Coal tar has concentrations up to 2 ppm. Tars are by-products, in particular, found in coal liquefaction and gasification wastes.¹¹

Analytical Methodology

The potential presence of hazardous compounds in energy wastes and the consequent potential for release of these substances in the environment are the cause of current public concern. A major difficulty in determining waste stream composition and monitoring lies in the analytical techniques for identifying and quantifying these pollutants.

In recent years considerable work has been funded by DOE, EPA and other agencies to develop sampling and analytical protocols for the determination of pollutants in energy process/waste streams. These protocols cover many but not all of the substances that are expected to be present in energy related process/waste streams. Some modifications may be required for applica-

tion of these protocols to specific conditions encountered in the plants.⁹

The instrumentation and procedures required for analysis of many of the substances of concern are often expensive and time consuming. The numbers of waste streams needing analysis and the numbers of substances requiring analysis in each waste stream make the task of developing reliable data a formidable one. It is essential, however, that reliable analytical methodologies and statistically valid analytical data be developed as expeditiously as possible.

Residuals Definition

The problems of assessing the solid waste impacts of energy technologies are among the most difficult faced by the environmental assessment analyst. Unlike the air and water sectors, there are no relatively simple generic models that can translate residuals into ambient concentrations that provide a quantitative basis for impact assessment. Moreover, even the definition of solid waste residuals is a difficult task: whereas the stoichiometry of combustion processes is sufficiently well understood to allow definition of, say, SO₂, particulate, and NO_x air emissions with some precision, characterization of sludge characteristics and the determination of its leaching properties is subject to considerable uncertainty.¹⁵

To illustrate some of the difficulties of residuals definition, consider, for example, the question of SO₂ air emissions. Because the regulatory requirements are specified directly in terms of pounds of SO₂ per 10⁶ Btu heat input, SO₂ emissions can be specified solely on the basis of heat content of the coal and plant heat rate. The only impact of any FGD system is a slight change in plant heat rate: one may simply assume that a utility will choose that system which meets the standard at least cost, and which system is assumed does not significantly affect the final result. *Per contra*, consider the question of solid waste residuals from the same conventional coal combustion system. Here the chemical and physical characteristics of the sludge are dependent on the particular FGD system and sludge fixation process chosen.

Modeling of Residuals

The basic premise of the more advanced techniques used to generate residuals is that there is sufficient information to be able to

predict output residuals as a function of input fuel characteristics and process configuration. The method used by Brookhaven National Laboratory (BNL) characterizes all coal-based facility input and output streams by a 45 element vector which focuses on trace metals, radionuclides and dissolved solids species (see Section 4, Residuals and Loadings). Organic components cannot be treated in the same rigorous fashion because of lack of data, and they are omitted from this and most models.

Given the high variability of trace element contents within even major coal provinces, BNL defines 7 major coal types associated with average trace metal characterizations. For each major coal type, a series of sulfur content classes is defined; for the moment, all sulfur classes within a major coal category are assumed to have the same trace element composition.⁵

The residuals generation program calls on a library of subroutines for calculation of solid waste residuals. Each routine models a major type of coal utilization—conventional combustion, fluidized bed combustion, liquefaction, etc.—using a mass balance approach. Within each major utilization category, a number of options are available: in the case of conventional combustion, for example, seven different types of FGD system precipitator combustions can be modeled, and three different types of boilers.³

A detailed description of the individual models under development by BNL can be found by consulting this reference, but a brief review of the first of the modules, for conventional coal combustion, is pertinent here. A mass vector of coal inputs is split into four output vectors representing the bottom ash, fly ash, FGD waste and stack effluent streams. In addition to the mass vector input, the requisite SO₂ removal level, precipitator efficiency, boiler, and FGD options are supplied to the routine. Each input/output vector is denominated in terms of mass. Information in terms of other units, such as pounds of pollutant per 10⁶ Btu fuel input, are calculated externally to the routines, in the main residuals generation program. And, as noted previously, merging of the residuals stream—such as the merging of ash and FGD waste streams that is frequently encountered in practice—is also accomplished outside of these subroutines.¹⁵

It should be noted that the make-up water (in the case of wet ash handling

systems and lime and limestone in the case of FGD systems can themselves be important contributors to trace element concentrations in the residuals stream. The coal combustion modules include consideration of trace elements in lime/limestone scrubbing agents.¹⁵

The output of this model produces country or plant level detail and includes bottom ash, fly ash, FGD waste, and stack emissions streams denominated in tons, stack emissions denominated in lbs/10⁶ Btu of fuel input, and a total solid waste stream (sum of bottom ash, fly ash, and FGD waste) that would be indicative of the frequently encountered joint ash/FGD disposal option. For the solid waste streams, a series of tables denominated in concentration (ppm) are also included. These six tables are repeated for the country as a whole, giving federal and regional detail.¹⁵

Control Alternatives and Impact Assessment

At the present time there are no specific controls for most coal conversion or other emerging technology wastes. Table 2.3 also describes the control technology status for a number of Lurgi coal gasification solid wastes. Because of the lack of detailed information on waste characteristics and control technology capabilities, all options cannot be compared.

Degree of Hazard/Special Wastes

One of the most actively discussed and least agreed upon topics surrounding solid waste regulation deals with methodology for definition of hazardous wastes and the degree of stringency of disposal requirements for wastes of varying hazard levels.

The demand for consideration of the degree of hazard of a waste in establishing waste handling requirements has been voiced by many sectors of American industry and by states which already have such schemes in their solid or hazardous waste management programs. Proponents for a degree of hazard scheme contend that it would allow development of the most cost-effective and environmentally sound means of disposing of solid wastes from coal conversion facilities. Only wastes posing the highest risk would be subject to the most stringent and costly standards for disposal. Less hazardous streams would be regulated less stringently. Transportation

costs would be reduced as less waste would have to be taken to authorized hazardous waste sites. In addition, facilities for handling less hazardous wastes would be easier to develop than hazardous waste sites have been traditionally.¹²

Multimedia Environmental Goals (MEGs)

Very few coal combustion or coal conversion solid wastes have been tested according to recommended EPA procedures for definition of hazardous wastes. In addition, air, water, and solid waste levels have not been identified for many of the toxic compounds detected in these wastes. In an attempt to respond to this lack of guidance without the Research Triangle Institute, under the direction of EPA's Industrial Environmental Research Laboratory, developed the (MEG's) system.

MEG's are levels of significant contaminants or degradents (in ambient air, water, or land or in emissions of effluents conveyed to the ambient media) that are judged to be (1) appropriate for preventing certain negative effects in the surrounding populations or ecosystems, or (2) representative of the control limits achievable through technology. The system was originally designed to aid EPA in environmental assessments of synthetic fuels facilities but was expanded to be a broad spectrum assessment tool.¹³

The MEGs system and EPA's reliance on it has come under fire from several sectors of the energy industry. Nevertheless, it represents the most comprehensive attempt thus far to assess the potential risks of commercialization of systhetic fuels technologies.

Modeling/Impacts Assessment Methodology

Even if an accurate characterization of leachates were possible, a determination of whether or not there is a significant impact is beset with further difficulties and uncertainties. The complexities of leachate transport through soils makes it extremely difficult to estimate in quantitative terms the likely impact, except in the situation where highly detailed and site specific groundwater movement models can be applied. Furthermore, the sight-specific analysis would need to determine if the waste required complete containment, impervious lining, site stability, etc.

Other questions that must be addressed for an impact assessment include:

- What is the cost of meeting given regulatory requirements (with respect to air and water as well as solid waste regulations)?
- What is the quantity and quality of leachates potentially generated in the least cost system that meet regulatory requirements (from which follows the potential for environmental damage in the event of a failure of an engineered system—e.g., a break in the containment system)?
- What is the implication of a unit change in a particular regulatory requirement, both in terms of cost and change in leachate character?
- What is the impact of the introduction of a new technology (FBC, a new FGD system, etc)?¹⁵

From these general considerations, a number of specific design criteria for a solid waste impact methodology can be derived.

In the solid waste assessment area, the application of generic impact models is therefore extremely difficult. Even if relatively simple models of leachate transport and groundwater movement were available, considerable computational and data resources would be required. Although such models might mathematically be quite similar to air diffusion/dispersion models, determination of boundary conditions is quite different, and much more complex in the case of leachate transport. Furthermore, whereas air emissions can be assumed to be fairly constant over a time for a given facility (especially the large emissions sources that are likely to be base-loaded), leachate releases will in general be related to precipitation events in a non-linear fashion. Moreover, the trace metal concentration in the leachate over some interval will be a function not only of the precipitation events in that same interval, but may also be a function of how much of the particular trace element has already been leached out.¹⁵

Level of Model Disaggregation

One of the more important considerations in the overall design of the methodology concerns the level of disaggregation at which computations are made. In general, as in all environmental analysis, it is desirable to be as specific about location as possible, a point already made previously. And for an accurate assessment of solid waste impacts, one needs almost site level detail. Yet the latter is clearly out of the question for national assessment.¹⁵

While such a level of disaggregation may thus be desirable, there are certain disadvantages, primarily that of computational complexity. The use of, say, statewide averages, rather than a county-by-county enumeration of facilities, residuals, and impacts, would obviously imply a much simpler computational algorithm. However, additional effort is essential to establish credibility in the following areas.¹⁵

- Many of the processes that determine trace metal stack (and hence also solid waste emissions) are non-linear. Selective reconcentration of certain heavy metals in the precipitator, for example, are non-linear functions of overall particulate removal. Estimation of state level residuals, based on an average coal and an average pollution control configuration, will necessarily lead to error.
- While the specification of air emissions is almost entirely a function of the State Implementation Plan (SIP) or New Source Performance Standards (NSPS), and may be constant, in the case of the revised NSPS, over wide ranges of sulfur inputs, the situation with regard to solid wastes is quite different. It makes a great deal of difference whether an FGD system removes 70 percent SO_2 from a coal of 1 percent sulfur, as opposed to 90 percent SO_2 from a coal of 3 percent sulfur. Even though the air emissions are 0.6 lb/10⁶ Btu in both cases, 4 times as much FGD sludge would be produced in the 90 percent scrubbing case as in the 70 percent case.
- Even in the absence of nonlinearity of residuals generation, spatial averaging can lead to misestimation of residuals. Application of average SIPs may lead to error if the spatial distribution of energy growth has not the same spatial distribution of relative magnitudes of the individual SIPs.
- Model validation. Because a state statistic is built up on county or plant level computations, and because the report writers provide this basic level of information to the analyst, the credibility and accuracy of a set of computations is more easily ascertained. Even if the plant level information is not used, the ability to show the environmental analyst, who must subsequently use the information provided to him by the computer analyst, how the numbers that are used have been derived proves to be of some importance to a smooth process of assessment.¹⁵

Siting Topics Related to Energy Solid/Hazardous Waste Disposal

Current national policy centers upon increased utilization of domestic energy sources versus reliance upon imported oil and gas. This goal is to be largely accomplished through directives and programs laid out in the Powerplant and Industrial Fuel Use Act of 1978 (PIFUA), and Senate Bill 932 (S.932).

PIFUA contains three statutory prohibitions which discourage the use of natural gas and petroleum:¹⁶

- New electric powerplants cannot be constructed with the capacity of using natural gas or petroleum as their primary fuels.
- Existing electric powerplants are prohibited from using natural gas after January 1, 1990, and are in the interim prohibited from increasing their proportional use of natural gas above historic levels.
- For new major fuel burning installations (MFBIs), all boilers are prohibited from using natural gas or petroleum as their primary energy source.

PIFUA limits exemptions, placing the burden of justifying an exemption with the facility. The Act also employs a streamlined procedure for ordering existing facilities to convert to coal.

The first phase of S. 932 establishes a twenty billion dollar, five-year synthetic fuels development program to be managed by a new federal Synthetic Fuel Corporation. The Corporation will provide the financial assistance to promote a synfuels production capability of 500,000 bbl/d by 1987 and 2 million bbl/d by 1992. Indirect coal gasification and liquefaction, surface oil shale retorting, and fuels from biomass are considered most readily available for commercial coal use, while direct coal liquefaction and in situ oil retorting are among the emerging technologies.¹⁷

Utilization of these energy sources on a scale envisioned by the National Energy Plan will generate large quantities of solid waste which must be disposed of. The siting constraints posed by energy solid wastes to the fulfillment of national energy goals can be seen in three ways:

1. Land Availability. Emerging technologies (oil shale and synfuels) can incorporate land for waste disposal as part of management and growth planning. The disposal technology for coal combustion wastes has been in place for

many years, yet future widespread conversions from oil and gas to coal and increases in new coal-fired plants will generate enormous increases in coal ash and FGD sludge, raising questions as to land availability near the plant or marked increases in transportation costs to available land. These economic burdens are especially important in siting urban power generation facilities.

2. Regulatory. RCRA further limits waste disposal facility siting alternatives by prohibiting disposal in environmentally sensitive areas or over sole source aquifers.
3. Public opposition. Oil refining wastes are the only non-nuclear energy wastes that have been officially designated as hazardous. However, some other energy wastes may contain toxic or hazardous substances. Public fear of, and resistance to, hazardous waste disposal is steadily increasing, and exhibits itself in restrictive zoning, court actions, and legislative bans and moratoriums on the siting of new disposal facilities. Industry and regulatory credibility has been weakened by disclosure of mismanaged or illegally operated hazardous waste sites. At this time, public opposition and the lack of adequate disposal capacity appears to be the major obstacle to the siting of hazardous waste disposal facilities.

This report examines the constraints to siting energy waste disposal facilities, including the physical availability of land, regulatory criteria, and public opposition. Potential mitigation measures are reviewed.

Land Availability

In an analysis of environmental trends and impacts resulting from implementation of the President's Second National Energy Plan, it is estimated that by the year 2000 the synthetic fuels industry will account for 68-74 percent of the total energy-related solid waste.¹⁸ Over 90 percent of these wastes would result from activity in oil shale production.¹⁹ The oil shale resource, however, is centered in a largely undeveloped, distinct geographical area. Constraints to siting solid waste disposal facilities relate more to technological and regulatory uncertainties. Oil shale and the other synthetic fuel technologies are in the early stages of commercialization, which allows considerations of the physical requirements for disposal to be incorporated

into the initial planning and siting of facilities.

It is for this reason that the problem of land availability relates primarily to coal use in the electric utility and industrial sector. Of particular concern is the large fraction of coal solid wastes, especially in the industrial sector, that will occur in urban areas. At smaller industrial facilities, which account for the bulk of the potential coal use increment, land availability and the economics of sludge transportation will be critical problems. This topic is developed in detail in this report's discussion of specific fuel cycle problems.

Management Constraints

The magnitude of the siting problem is largely related to the impact of the Resource Conservation and Recovery Act of 1976 (RCRA). RCRA regulates the disposal of solid wastes by establishing minimum design and siting criteria, establishing standards and issuing permits for the operation of hazardous waste disposal facilities. The stringency of the regulations depends upon whether or not a waste is classified as hazardous.

RCRA contains a number of provisions governing land disposal of non-hazardous solid wastes, and has proposed criteria defining what will be treated as environmentally adequate solid waste disposal facilities. These proposed rules will generally severely constrain the siting of facilities in environmentally sensitive areas. Sensitive areas include wetlands, flood plains, permafrost areas, critical habitats of endangered species, and recharge zones of sole source aquifers.

Most of these will not restrict the large utilities and synfuels plants because it is increasingly difficult to site plants in such areas. However, about 65 percent of existing industrial waste disposal sites are located in environmentally sensitive areas.¹⁹ The two items which impact most severely with regard to site selection criteria are the 100-year flood plains and the coastal high hazard areas. Floodplains are favored locations for siting inland utility plants, and industrial facilities are concentrated along major waterways and in coastal areas.

It is possible that many industrial disposal sites will have to be abandoned, and new sites outside of urban areas found as more disposal sites come under the scrutiny of RCRA through the initiation of EPA's open dump inventory. A report

prepared for EPA by Fred C. Hart Associates reported that 75 percent of all landfill sites are in areas "particularly susceptible to contamination problems"—in wetlands, on floodplains, and over major aquifers.²⁰

For those energy facilities deemed to be generating hazardous wastes, the problem of adequate disposal capability is even more severe. EPA estimates that when RCRA is implemented 50 to 60 additional sites for commercial use will be needed nationally for proper hazardous waste handling, treatment, and disposal.²¹ This is probably underestimated, because a switch from on-site to off-site disposal is likely, as companies decide against incurring the expense of upgrading on-site facilities.

Public Opposition and Mitigation of Siting Problems

Public opposition to siting facilities is a major constraint to expanding disposal capacity and is likely to increase in the future, as new requirements for public participation in the permitting process are implemented. Reports from states with hazardous waste management facility permitting systems indicate increasing difficulty in permitting new facilities due to local opposition.²¹

Many approaches to overcoming public opposition have been suggested, including the siting of facilities on public land and preemption of local government approval authority. EPA's Office of Solid Waste and its internal task force on hazardous waste facilities siting are exploring the use of incentives and compensation payment plans as part of the negotiation process. EPA, commenting on public opposition, stated that "... active and visible public participation, based on intense public education efforts, in the development of hazardous waste programs at state and local levels should help to build positive attitudes."²²

While efforts to reduce waste volumes are desirable, they cannot alleviate the capacity problem. Most importantly, the states must take an active role as arbiters in the siting process for new or expanded facilities.

EPA guidelines for developing and implementing State solid waste management plans should facilitate the development of comprehensive, effective state programs. This is a necessary prerequisite to the development of environmentally safe

facilities, and should help to mitigate the problem of public opposition.

SPECIFIC FUEL CYCLE PROBLEMS

The following is a discussion of topics pertaining to specific fuel cycle problems. The choice of topics was based upon those energy technologies which are emerging as major contributors to our domestic energy supply and/or those having particularly serious solid waste management problems. These include oil shale, coal solid wastes generated in urban areas, disposal capacity for coal-related wastes, health risks resulting from radioactivity in coal and nuclear waste disposal.

Solid and Hazardous Waste Disposal at Commercial Oil Shale Facilities

Volume of Waste Generated

The solid waste disposal needs anticipated for a commercial oil shale operation are unprecedented. It has been estimated that a 1 million bbl/d industry using above ground retorts would process approximately 600 million tons of raw oil shale per year and would require the disposal of approximately 10 billion cubic feet of compacted spent shale.¹¹

In-situ retorting would disturb less of the surface although the amount of subsurface disturbance for a given level of oil production would be increased due to lower recovery rates and use of some leaner deposits of shale. Because oil shale expands in volume during mining and retorting, not more than 80 percent of the excavated material can be returned to the mine, even under the most favorable circumstances.

For each barrel of oil produced, surface retorting generally produces about 1.4 tons of processed shale, true in-situ leaves 2.8 tons of spent shale underground, and a modified in-situ process leaves 1.9 tons underground, with 0.4 tons of processed shale requiring surface disposal.¹⁸

Over 90 percent of the wastes generated by synthetic fuels will result from activity in oil shale production. The problem of spent shale disposal is localized in Federal Region 8, the Mountain Region, where the combined total of solid wastes in the region is expected to rise from under 4 million tons in 1975 to between 385 to 576 million tons under the National Energy Plan scenario for the year 2000.¹⁸

Volume and Nature of Hazardous Waste Generated

Retorted shale contains varying amounts of organic and inorganic residuals depending on the retorting process. It presents a major solid waste management and disposal problem for the surface and modified in-situ operations from both the amount and its content. A 50,000 barrel per day oil shale facility will produce enough spent shale to occupy a volume of almost 2 million cubic feet, or about a 2-foot depth over a square mile every month of operation.¹⁰ Assuming a 1 percent generation rate of hazardous material, this facility would produce 110 tons per day of hazardous waste requiring disposal.

Contamination of surface and groundwaters by salts, organic substances and trace constituents can occur as a result of erosion of, runoff from, and percolation through retorted shale.

Like natural terrain, a disposal pile will be subject to surface erosion and runoff during storms and snowmelt. Soluble substances, particularly inorganic salts, can be mobilized from retorted shale along with suspended material during the erosion process. About 20 lbs/ton of salt (primarily sodium sulfate) is water soluble in fresh, carbonaceous retorted shales (e.g., TOSCO II). Burned shales (e.g., Paraho) may contain larger quantities of soluble salts. Further, additional soluble substances are added to retorted shale in the form of process water (about 2.2 lbs soluble salt/ton of processed shale).¹⁰

In addition to the potential for mobilizing common inorganic ions from retorted shales, water running off of or migrating through a disposal pile may dissolve organic and trace inorganic constituents. Other solid and liquid wastes likely to be contained in a disposal pile include process wastewaters, oily sludges, spent catalysts, and shale coke. Water contacting such materials may dissolve toxic or carcinogenic organic substances (phenolics, organic acids, POM) and hazardous trace elements (arsenic, nickel, molybdenum, chromium). Since small scale experiments conducted to date have generally not included materials other than retorted shale, the potential for waterborne transport of suspended or dissolved substances derived from the above mentioned waste would be largely speculative.

The composition of leachate from simulated in-situ spent shales has been

studied by a number of investigators.¹⁰ These leachates are rich in total dissolved solids (TDS), they contain significant quantities of sulfate, carbonate, bicarbonate, chloride, fluoride, potassium, calcium, silicon, and sodium and lesser amounts of phenols, organic nitrogen, zinc, lead and other trace constituents, and they are alkaline, the pH ranging from 8 to 13. The composition of spent shale from field experiments, although somewhat different in mineralogy because of the high temperatures produced, results in leachate with lesser amounts of total dissolved solids and a lower pH. However, this leachate may be enriched in certain trace elements with respect to the concentrations in leachate from simulated in-situ spent shale.¹⁰

Disposal Options and Siting Constraints

The technical methods for controlling oil shale solid waste impacts are uncertain. Because an oil shale industry has not yet developed, its wastes are chemically and physically different from those of other industries, and the volume of wastes would exceed those of any comparable operation. Although the enormous volumes of processed shale could be handled by a number of existing techniques, a major uncertainty involves the long-term integrity of disposal and reclamation methods.

Disposal techniques vary according to the retorting process employed, but major concerns associated with oil shale solid wastes from both processes involves the adequacy of strategies to control leachates from underground retorts and solid waste disposal piles. Solid wastes such as catalysts, water treatment sludges, and refinery coke will contain toxic components that could degrade water quality unless properly controlled. Retort water, which is produced in large volumes from modified in-situ processing, is characteristically strongly contaminated with inorganic and organic constituents. Disposal of this wastewater is not adequately addressed in present industrial planning.¹⁰

Thus, the problems of disposing of enormous quantities of oil shale waste are compounded by its potentially hazardous characteristics. The organic contaminants of concern include benzo(a)pyrene, which is used as an indicator compound for potential carcinogenicity of materials in which it is found. Process waters, which are used to moisturize the spent shale before disposal,

contain benzo(a)pyrene that may be subject to later removal by runoff or percolation through disposal piles.

There is some evidence from preliminary tests that wastewater produced from oil shale retorting contains chemicals that are potential genetic hazards. Further testing must be conducted to determine the actual degree of hazard associated with this waste stream and possible cleanup processes. In addition, polycyclic organic material extracted from retorted shale by water may be an animal skin carcinogen.¹¹ (See Section 4, Effects).

Disposal of oil shale wastes, at present, is subject to RCRA criteria which discourages siting of disposal facilities in environmentally sensitive areas. If these wastes are designated hazardous, there would be significant economic constraints to disposing of the oil shale industry's wastes based on EPA's hazardous waste regulations. In addition, public opposition to the concentration of hazardous wastes in a limited geographical area would limit the availability of disposal sites.

More land may become available through pending legislation (H.R. 7857) which seeks to amend the Mineral Leasing Act of 1920 to permit off-site disposal of oil shale wastes on federal lands.²³

Processed shale and other solid wastes from surface retorting will be disposed of in nearby gulches and canyons. Impoundments will be provided to collect runoff, which will be recycled to the pile or used in the plant. Nonetheless, despite the best efforts to collect runoff, surface disposal of solid wastes represents a long-term hazard to water quality.¹⁰ After a site is abandoned, the impoundment would eventually be filled with sediment, water would be no longer withdrawn for in-plant use, and runoff from the disposal pile would be discharged. If contaminants cannot be kept below an acceptable level, complete abandonment of disposal piles is not possible, and custodial care would be needed.¹⁰

Subsurface disposal of processed shale is an alternative to surface disposal and would reduce the land impacts, but this method could contaminate the groundwater. In this technique, the mine is backfilled with a slurry of processed shale or, simply, with pulverized dry material.

Leachates produced from in-situ retorts are an especially difficult environmental problem because groundwater is found in practically all oil shale deposits of commercial interest, and control of such leachates is

uncertain.¹⁰ The permeability that would result from mining, fracturing, and retorting would facilitate the leaching process if the retorts are backflooded when the natural hydraulic gradient is restored. Organic and inorganic residuals in the spent shale of the retort would then be added to the groundwater, although they would tend to be dispersed at increasing distances and would be diluted with the progress of leaching.

The crucial question facing land reclamation for an oil shale industry, therefore, is the long-term effectiveness of the selected control strategies. Because of the large areas required for storage of raw shale and disposal of retorted shale, the land can never be restored to its original form or use. The majority of this land is, however, low quality grazing land. The resulting potential loss of habitat for plant and animal communities and natural erosion of the disposal piles by wind and water may not be fully mitigated by vegetating or physically stabilizing the disposal sites. Problems and uncertainties related to the vegetation of retorted shale include water requirements, accumulation of toxic trace substances in the vegetation, and long-term stability.

Environmental control systems to mitigate these impacts should, in most cases, be available; however, potential problems with stability of waste piles will require several years to emerge and uncertainties will remain for 10 to 20 years.¹¹ Thus, long-term management of disposal piles appears to be necessary. Periodic maintenance also would be needed to remove accumulated sediment and salts from impoundments. In summary, it is uncertain that disposal piles of processed shale could ever be truly abandoned without risking some hazard from undesirable runoff.¹⁰

Coal Combustion in Highly Urbanized Areas

Expected Increases in Coal Combustion and Solid Waste Generation

The increased use of coal is one of the cornerstones of the National Energy Act (NEA) of 1978.¹⁷ One of the statutes contained in NEA is the Powerplant and Industrial Fuel Use Act (PIFUA). With certain exceptions, PIFUA prohibits the use of oil or gas as a primary fuel source for new electric powerplants and certain new major fuel burning installations. It further grants DOE the authority to require existing coal-

capable powerplants and installations to convert to coal or alternate fuels.¹⁷

Estimates indicate that coal combustion will increase by 200 million tons per year by 1985 as a direct result of the implementation of NEA. This increase is in addition to a 400 million tons per year increase resulting from natural growth in supply and demand.¹⁷

The solid waste impacts from such a program will be substantial, and largely borne by the industrial sector. Because of soaring prices and uncertain supplies of fuels, the electric utilities had planned, prior to PIFUA, to add little gas or oil capacity between now and 1985 and none after 1985. Therefore, PIFUA's impacts will occur largely in the industrial sector, where more than 60 percent of the projected increase in oil and gas use in the U.S. between 1975 and 1985 is forecast to occur.

Typical waste generation quantities are 578 tons of ash and scrubber sludge/year/MW for facilities with Flue Gas Desulfurization (FGD) and 312 tons coal ash/year/MW for facilities without FGD facilities.¹⁹ For a typical industrial boiler of 50 MW capacity with FGD, the annual quantity of waste generated is almost 30,000 tons.¹⁸

Land Availability and Siting Constraints

Meier, et al (1978)²⁴ have looked at land availability for solid waste disposal for future utilities, and found that land requirements for sludge disposal are not so excessive as to be considered a crucial constraint. The sharp growth in the number of throwaway, lime/limestone systems now planned suggests that most utilities have coped with the sludge disposal problem quite well, and certainly there is little evidence that land availability will be a problem in most areas of the country.²⁴ Even in the Northeast, where there have been few commitments to FGD systems and where one might expect greatest difficulties in site selection in view of high population densities, review of recent utility and power pool planning reports suggests that the utilities have still been able to assemble sites of 1000 to 3000 acres to accommodate future coal-fired plants in the 1980's and early 1990's. This makes them of sufficient size to accommodate sludge disposal on-site for units planned at these sites.²⁴

In order to confirm these findings at a national scale, a national survey was under-

taken of utilities that presently have plans for coal-fired units in the early 1980's all of the planned facilities surveyed have adequate acreage to accommodate on-site FGD waste disposal. Many of the utility engineers indicated that contingency plans existed if FGD systems were to be required. These results indicate that on-site FGD system waste disposal is technically feasible even at plants which do not presently plan to use such systems and would only in rare cases pose a serious problem. Meier, et al.²⁴, conclude, therefore, that availability of sludge disposal sites will unlikely constrain increased coal utilization in the electric utility sector. Land availability could, however, be a problem for some urban plants if they are required to convert from oil to coal.

A solid waste analysis of electric utilities prepared for the RIIA program concludes that the matter of FGD system retrofit (where an oil plant is converted to coal) is one of concern. The authors state that "if there is a situation in which one can really talk of solid waste problems being a real constraint (rather than just a matter of economies), it is where an existing facility must be retrofitted. It is in these situations where one can with some credibility claim lack of land for solid waste disposal; or, in many cramped urban sites, lack of space even to accommodate very limited ash (and coal) handling facilities."¹⁵

For industries, the problems of solid waste management may be more complex. According to the Second Regional Issue Identification and Assessment Program (RIIA-II) Solid Waste Analysis, ash from industrial coal combustion will increase from 9.0 metric tons (mt) in 1975 to 41 mt by 2000, an eightfold increase. Ash from electric utilities will increase in the same timeframe from 53 mt to 97.5 mt.²⁷ Of particular concern is the large fraction of coal solid wastes, particularly in the industrial sector, that will occur in urban areas. (See Tables 2.5 and 2.6). By 2000, 53% of industrial ash will be generated in urban areas, rising from 3.9 mt in 1975 to 22 mt in 2000.²⁷

One example of the disposal problems associated with increased coal combustion in urban areas is related in the Environmental Impact Statement for PIFUA.²⁵ The land areas needed for disposal of fly ash and scrubber sludge produced as a result of the PIFUA are given in Table 2.7. In 1990, it is estimated that a maximum of 1722 hectares (4255 acres) of land will be needed for

waste disposal. Over the period 1978 to 1990, the cumulative land requirement would be approximately 10,300 hectares (25,500 acres). Assuming a 40-year life span for each MFBF that converts to coal, a maximum of 69,000 hectares (170,000 acres) of land will be required for waste disposal between 1978 and 2030.

Approximately 65 to 67 percent of the coal waste produced under the PIFUA legislation will be generated in Region 6, largely along the Texas Gulf Coast, which is

the most heavily industrialized area in the region. Disposal of coal wastes will be difficult and costly due to competing demands for land. For example, much of the industrialized portion of the region is surrounded by agricultural land that is intensively managed for rice production. Rice lands in Texas are considered to be prime or unique farmlands as defined by the Soil Conservation Service (U.S. Department of Agriculture, 1978). Using a large area of such lands for waste disposal would create a

Table 2.5
Distribution of Ash Residuals by Degree of Utilization
(10⁶ tons¹)

	1975	2000	
		High Scenario	Low Scenario
Electric Utilities			
Urban	13.1 (24%)	25.0 (26%)	20.7 (23%)
Intermediate	32.5 (62%)	58.0 (59%)	54.4 (61%)
Rural	7.1	14.5 (15%)	13.9 (16%)
TOTAL	52.7	97.5	88.0
Industrial Combustion			
Urban	3.9 (43%)	22.1 (53%)	21.7 (52%)
Intermediate	4.4 (48%)	17.3 (42%)	17.8 (43%)
Rural	0.7 (9%)	1.9 (5%)	1.9 (5%)
TOTAL	9.0	41.3	41.4

¹Excluding flyash captured in wet FGD systems.

Source: Brookhaven National Laboratory, *RIIA - II Solid Waste Analysis, National Summary*, Draft DOE/RID (1980).

Table 2.6
Distribution of Sludge Residuals by Degree of Utilization (10⁶ tons¹)

	1975	2000	
		High Scenario	Low Scenario
	Electric Utilities		
Urban	3.2 (60%)	49.9 (24%)	69.5 (23%)
Intermediate	1.9 (36%)	108.6 (52%)	95.0 (61%)
Rural	0.2 (4%)	48.7 (24%)	36.5 (16%)
TOTAL	5.3	207.2	201.0

¹Includes flyash captured by wet FGD systems. Tonnages are on a wet basis: tons of dry sludge solids are about half the wet basis tons [i.e., reflect unthickened sludge waste streams rather than treated (or chemically fixed) wastes].

Source: Brookhaven National Laboratory, *RIIA - II Solid Waste Analysis, National Summary*, Draft DOE/RID (1980).

Table 2.7

Solid Waste Produced and Land Required for Disposal¹

Region	Tons of Waste Produced ($\times 10^3$)		Land Required ² or Disposal, ^{2,3} hectares (acres)			
	1985	1990	1985		1990	
I	0.70	1.12	15-23	(38-57)	25-37	(61-91)
II	0.71	1.26	16-23	(39-58)	28-41	(68-102)
III	0.90	1.67	20-30	(49-73)	36-55	(90-136)
IV	3.47	6.51	76-114	(187-281)	142-214	(352-528)
V	2.34	2.92	51-77	(127-190)	64-96	(158-237)
VI	19.28	35.17	422-633	(1042-1563)	769-1154	(1901-2851)
VII	0.50	0.80	11-17	(27-41)	17-26	(43-65)
VIII	0.17	0.32	4-6	(9-14)	7-11	(17-26)
IX	1.53	2.52	34-50	(83-124)	55-83	(136-204)
X	0.11	0.21	2-4	(6-9)	4-7	(11-17)
Total	29.72	52.49	650-975	(1606-2410)	1148-1722	(2837-4255)

¹See Appendix M for assumptions made in calculating solid waste.

²Assumes depth of waste disposal area is 10 ft.

³Low limit of range assumes waste density of 2000 lb/m³, upper limit of range assumes waste density of 3000 lb/m³.

Source: U.S. Department of Energy, *Final Environmental Impact Statement - Fuel Use Act*, DOE/EIS-0038, (April, 1979).

serious impact on the region's agriculture.²⁵ Reclamation of landfills in these areas to return them to rice production would be highly unlikely.

Alternatives to disposing of coal wastes in close proximity to the industries creating them would be to transport them further to the west or north, where land use is predominantly rangeland or forest. Although transportation costs would be higher, the potential impacts on agriculture would be somewhat less. However, in the trier areas adjacent to the Texas Gulf Coast, competition for water supplies is extremely intense. Special care would have to be used in containing landfills in this region to avoid contaminating underground aquifers and damaging regional water supplies. Reclamation of areas used for disposal of coal wastes may be successful if sufficient soil cover is placed over the waste to isolate toxic materials from the cover vegetation. Such areas when reclaimed might be used for a wide variety of purposes including rangelands, forestlands, recreation developments, housing, industrial purposes, etc. Such areas probably could not be returned to agricultural cropland use because the potential for contamination of crops by coal waste products is high.²⁵

Disposal of coal wastes in urban areas is likely to become an increasingly difficult problem. Competing demands for land, and the application of more stringent environmental standards will increase the costs to existing facilities of hauling their wastes off-site and will cause additional criteria to be considered when siting new facilities.

Nuclear Waste Management

Disposal Problems

Fissioning of nuclear fuel at nuclear power plants produces heat which is used to produce steam for generating electricity. In addition to heat, the nuclear fissioning generates fission products and neutron activation products which include plutonium, other transuranic radionuclides, and activated elements in some parts of the reactor itself. The quantity of radionuclides released by the nuclear fuel cycle in 1975 and 2000 for two world oil price scenarios are given in Table 2.8. Low level, transuranic and high level wastes are discussed in Section 3.

Many techniques for the disposal of radioactive wastes are under investigation. They include deep geological burial; sea-

bed, ice sheet, and extraterrestrial disposal; transmutation; and disposal by rock melting in deep mined cavities and in deep drilled holes. Only burial in deep geological formulations will be discussed in this section. Burial of radioactive wastes in deep geological repositories is the most advocated technique, with rock salt being the most studied and foremost candidate rock formation.

Before proceeding with large-scale disposal of radioactive wastes in geologic repositories, several issues still need to be resolved. First, the scientific community is not totally convinced that geologic burial is completely safe, because accurately predicting the fate of buried radionuclides over several hundred to millions of years is unprecedented.²⁸ Because of the corrosive nature of groundwater, any container the wastes are placed in will lose its integrity after about 100 years, leaving the wastes themselves subject to the leaching action of groundwater. Consequently, the wastes must be cast into forms of extremely low solubility and resistant to the effects of radiation.

Because the earth science disciplines are relatively new, there is little experience with the long-term effects of heat on rock mechanics, groundwater on the leaching and transport of wastes, and tectonic history on the host medium. Second, test facilities are needed in order to fill the aforementioned knowledge gaps. Third, criteria for repository site locations must be established so that major population centers and minable resources can be sufficiently isolated from waste repositories.

Approaching permanent disposal of nuclear waste on a stepwise basis in a technically conservative manner means that each step in the process, including site or concept examination, safety review, handling of the wastes and post-placement monitoring, should be conducted with care. All data must be carefully examined and conclusions reached with adequate scientific review. The environmental consequences of *not* proceeding with such care could, of course, be significant due to the hazardous nature of the wastes being handled.

Not until last fall when two of the country's three authorized dump sites for the disposal of low-level radioactive wastes were closed, which threatened to halve nuclear medical treatment and research, did the public finally focus on a problem which has been developing for years and which could confront generations to come. For 35

years, the United States has developed nuclear energy for military and commercial uses. Over 75 million gallons of highly radioactive waste produced by the Federal Government during this period is stored in temporary tanks. The 70 licensed commer-

cial nuclear reactors have generated 600,000 gallons of highly radioactive waste and 7700 metric tons of spent fuel which is stored in temporary "pools" at reactor sites.²⁹ The amount of commercial spent fuel is predicted to double during the next three

Table 2.8

Quantity of Radionuclides Released by the Nuclear Fuel Cycle in 1975 and 2000 for Two World Oil Price Scenarios (Curies)

	1975	2000-Low World Oil Price	2000-High World Oil Price
RADIONUCLIDES TO AIR			
Thorium-230	0.57	4.8	5.4
Uranium & Daughters	2.6	21.	24.
Tritium	740.	6000.	6900.
Iodine-129	0	0	0
Iodine-131	2.8	24.	26.
Krypton-85	7.1×10^6	6.1×10^7	6.8×10^7
Radium-226	0.57	4.8	5.4
Radon-222	2600.	2.0×10^4	2.3×10^4
Carbon-14	470.	4000.	4500.
Other Fission & Activation Products	3.5×10^5	3.0×10^6	3.3×10^6
Transuranics	0.03	0.30	0.33
Other	1.2×10^6	1.0×10^7	1.2×10^7
TOTAL*	8.7×10^6	7.4×10^7	8.3×10^7
RADIONUCLIDES TO WATER			
Thorium-230	0.04	0.36	0.40
Uranium & Daughters	60.	500.	500.
Cesium-134	0.75	6.3	7.0
Cesium-137	0.54	4.6	5.1
Cesium-144	0.01	0.08	0.08
Cobalt-60	0.01	0.07	0.08
Tritium	5900.	5.0×10^4	5.5×10^4
Iodine-131	0.19	1.6	1.8
Radium-226	0.10	0.81	0.90
Ruthenium	0.01	0.12	0.12
Strontium-90	0.01	0.10	0.11
Other Fission & Activation Products	49.	410.	460.
Other	0.29	2.4	2.7
TOTAL*	6.0×10^3	5.1×10^4	5.6×10^4
RADIONUCLIDES - SHALLOW BURIAL			
Uranium & Daughters	1.7×10^4	1.5×10^5	1.6×10^6
Other	1.1×10^7	8.9×10^7	9.9×10^7
TOTAL*	1.1×10^7	8.9×10^7	9.9×10^7
RADIONUCLIDES - DEEP BURIAL			
TOTAL*	2.6×10^8	2.2×10^8	2.5×10^8
GRAND TOTAL*	2.8×10^8	2.4×10^8	2.7×10^8

*Totals may not equal the sum of individual values; this results from the use of two-figure accuracy.

Source: U.S. Department of Energy, *Environmental Impacts of the National Energy Plan II, Appendices*, (1979).

years and could increase even more markedly since there are an additional 90 nuclear powerplants scheduled to come on-line in the next ten years.¹⁸ (See Table 2.2). Many wastes contain highly radioactive isotopes, which retain their high toxicity for as long as 100,000 years.

The temporary storage sites have proved less than successful. Over 500,000 gallons of liquid wastes have leaked from steel storage tanks at the federal site in Hanford, Washington, and similar leaks have occurred at other temporary facilities. Already, several commercial utilities have exhausted the capacity of their temporary storage pools, and within five years the pools of at least fifteen others will be filled.

The problem with "low-level" waste—30-40 percent of which stems from medical use of isotopes to treat or diagnose illness—is also severe. Approximately 3 million cubic feet of low-level waste is generated annually, and unless new dumping sites are found, there very soon will simply be no place to put it.²⁹

On February 12, 1980, President Carter announced a comprehensive plan for the management of radioactive waste. His Executive Order established a State Planning Control to advise the executive branch and to work with Congress, but he avoided the controversial question of a state veto. He set a goal of 1985 for the selection of the site for the first full scale repository and called for it to be operational by the "mid-1990's."

Temporary AFR facilities would handle the wastes on an interim basis.²⁹

Radioactivity in Coal

The problem of assessing the extent of the impact of radioactivity in coal is, in part, due to the variability in levels of radioactivity, dependent upon the coal's origin. However, the primary impacts relate to the threat to human health of the storage of coal wastes and the radioactive limitations on the utilization of these wastes due to radioactivity.

Levels of Radioactivity in Coal, Fly Ash and Bottom Ash

By far, the largest percentage of the radioisotopes in coal stay with fly ash, i.e., over 80% for uranium-234, uranium-238, and lead-210. Approximately 8 to 9% of the radioisotopes in the feed coal stay with bottom ash. The radionuclides observed in coal, bottom ash, and fly ash are given in Table 2.9. Specific concentrations of the various radionuclides in ash are given in Table 2.10. All of the radionuclides studied tend to become enriched with ash relative to the input coal, and in general tend to concentrate on the finer particulates.

Eisenbud and Petrow measured the amounts of Ra²²⁶ and Ra²²⁸ in fly ash from the combustion of six samples of Appalachian coal and estimated the average uranium and thorium contents of the coal

Table 2.9

Natural Radionuclides Observed in Coal, Bottom Ash and Fly Ash

Natural Decay Chain Origin	Source After Fractionation	Gamma-Producing Nuclide	Gamma Energy (keV)
²³² Th	²²⁸ Ra	²²⁸ Ac	338
²³² Th	²²⁸ Ra	²²⁸ Ac	911
²³² Th	²²⁸ Th	²¹² Pb	238
²³² Th	²²⁸ Th	²⁰⁸ Tl	583
²³⁸ U	²³⁴ Th	²³⁴ Th	63
²³⁸ U	²²⁶ Ra	²²⁶ Ra	185
²³⁸ U	²²⁶ Ra	²¹⁴ Pb	295
²³⁸ U	²²⁶ Ra	²¹⁴ Pb	352
²³⁸ U	²¹⁴ Bi	²¹⁴ Bi	609
²³⁸ U	²¹⁴ Bi	²¹⁴ Bi	1120
²³⁸ U	²¹⁴ Bi	²¹⁴ Bi	1764
²³⁸ U	²¹⁰ Pb	²¹⁰ Pb	46
²³⁵ U	²³⁵ U	²³⁵ U	185

Source: Coles, D.G., et al., *The Behavior of the Natural Radionuclides in Western Coal-Fired Power Plants*, Lawrence Livermore Laboratory, (December, 1976).

Table 2.10

Contents of the Various Radionuclides in Coal, Bottom Ash and Fly Ash¹

	ppm			pCi/g						
	U	Th	K	⁴⁰ K	²²⁸ Th	²²⁸ Ra	²¹⁰ Pb	²²⁶ Ra	²³⁸ U	²³⁵ U
Plant A ²										
Coal	0.71	1.6	860	0.73	0.17	0.17	0.26	0.21	0.24	0.012
ESP fly ash	5.6	15	5400	8.1	1.7	1.7	1.4	2.3	1.9	0.093
Bottom ash	4.6	14	7900	6.8	1.5	1.5	0.58	1.9	1.5	0.072
Plant B ³										
Coal	2.6	5.0	1660	1.4	0.56	0.55	0.68	0.64	0.85	0.037
ESP fly ash	11	22	7400	6.3	2.4	2.4	2.2	2.9	3.5	0.14
Bottom ash	8.4	19	7200	6.2	2.2	2.1	0.84	2.5	2.8	0.11
Scrubber ash	11	22	7200	6.2	2.5	2.5	2.8	3.0	3.6	0.14
Plant B ⁴										
Post-ESP (stack)										
Fly ash (mmd) ⁵										
17 m	16	25	£200	7.0	2.8	2.7	4.3	3.3	5.4	0.17
6 m	20	31	£600	7.3	3.3	3.5	10	4.6	6.8	0.28
3.8 m	30	36	£600	7.4	3.3	4.0	14	5.3	10	0.39
2.5 m	36	38	£100	7.0	3.3	4.2	17	5.9	12	0.50

Source: Coles, D.G., et al., *The Behaviour of the National Radionuclides in Western Coal-Fired Power Plants*, Lawrence Livermore Laboratory (December, 1979).

Notes: ¹10-20% propagated 1 error from the mean.

²Samples from Plant A; input coal contains 11.3% H₂O, 9.2% ash, and 0.52% sulfur.

³Samples from Plant B; input coal contains 6.8% H₂O, 23.2% ash, and 0.46% sulfur.

⁴mmd = mass median diameter determined by centrifugal sedimentation.

Table 2.11

Radiochemical Analysis of Coal and Coal By-Products, pCi/g

Date	Identification	^{226}Ra	^{234}U	^{235}U	^{238}U	^{228}Th	^{230}Th	^{232}Th
6/76	E. Ky. Coal	0.28 ± 0.01	0.54 ± 0.07	0.03 ± 0.01	0.51 ± 0.07	0.40 ± 0.04	0.46 ± 0.03	0.30 ± 0.03
	W. Ky. Coal	1.98 ± 0.01	0.80 ± 0.10	0.04 ± 0.01	0.78 ± 0.03	0.21 ± 0.03	0.71 ± 0.05	0.19 ± 0.02
	W. Ky. Fly Ash	7.0 ± 0.1	6.3 ± 1.1	0.33 ± 0.09	8.6 ± 1.1	1.9 ± 0.1	6.5 ± 0.3	1.8 ± 0.1
	W. Ky. Bottom Ash	5.0 ± 0.1	5.6 ± 0.8	0.22 ± 0.07	5.5 ± 0.8	1.9 ± 0.4	6.0 ± 0.7	1.6 ± 0.3
6/77	E. Ky. Coal	0.46 ± 0.01	0.56 ± 0.16	0.07 ± 0.02	0.58 ± 0.12	0.58 ± 0.12	0.61 ± 0.13	0.39 ± 0.09
	W. Ky. Coal	0.72 ± 0.01	0.92 ± 0.10	0.05 ± 0.02	0.92 ± 0.10	0.34 ± 0.04	0.85 ± 0.05	0.27 ± 0.03
	W. Ky. Fly Ash	3.8 ± 0.1	4.2 ± 0.5	0.20 ± 0.07	4.4 ± 0.5	1.8 ± 0.2	4.5 ± 0.3	1.57 ± 0.18
	W. Ky. Bottom Ash	3.1 ± 0.1	2.7 ± 0.4	0.09 ± 0.04	2.7 ± 0.3	1.7 ± 0.2	2.7 ± 0.3	1.3 ± 0.2

Source: Krieger, H. and B. Jacobs, "Analysis of Radioactive Contaminants in By-Products From Coal-Fired Power Plant Operations", U.S. Environmental Protection Agency, EPA-600/4-78-039 (July, 1978).

(assuming secular equilibrium) to be 1.1 and 2 ppm, respectively.³⁰ A survey of the uranium and thorium concentrations in 799 coal samples from all regions of the United States is presented in the residuals category of Section 4 (Table 4.17). The radioisotopes in utility coal combustion wastes will rise from 130 curies/year of Ra²²⁶ activity in 1975 to 473 curies/year in 2000. As shown in Figure 1.2, the bulk of this will occur in Region 6 (Texas, New Mexico, Oklahoma, Arkansas and Louisiana), the areas most heavily dependent on Gulf Province Lignite, which has the highest radioisotope content. The corresponding increase in Ra²²⁶ activity from industrial sources is 23 curies/year in 1975 to 178 curies/year in 2000.³¹ Table 4.17 indicates that concentrations of 1 ppm for uranium and 2 ppm for thorium in coal are reasonable estimates of the average values for all coal in the United States. However, the data also show that some coals contain concentrations of several orders of magnitude higher than these values.

The results from a radiochemical analysis of samples from the Louisville, Kentucky power plant one year apart are listed in Table 2.11. These data illustrate the variation in radioactive composition as coal sources vary. This will result when the natural activity is in a different state of equilibrium at the time of mine operations.³²

Accumulation of Radionuclides in Ash Ponds

The accumulation of radionuclides in ash ponds is related to radionuclide concentration in feed coal; quantity of coal burned; partitioning of radionuclides to bottom ash, fly ash, and stack gasses; and efficiency of emission controls. The radionuclide balance in the pulverized coal/electrostatic precipitator system of the Neal Station (located on the east bank of the Missouri River) indicates that over 90% of the uranium-234, uranium-238, and lead-210 remain with ash (bottom ash and fly ash). The rates at which these radionuclides accumulate in the ash pond under normal operating conditions at the Neal Station are given in Tables 2.12 and 2.13. The accumulation of radionuclides in the ash pond is directly proportional to the radionuclide concentration in the feed coal.³³

One potential problem associated with the accumulation of radionuclides in ash ponds is the emanation of radon-222 from

the radium-226 accumulated in the ash. The emanation of radon-222 is related to several factors including the concentration of radium-226 in the ash, the "emanation power" or the fraction of the radon-222 which is free to diffuse out of the ash pond, quantity and configuration of ash in the pond, and several parameters such as moisture content and compaction of the ash which affect the ability of the radon-222 to diffuse out of the ash pond. If it is assumed that radium-226 is in secular equilibrium with uranium-238 in feed coal and that radium-226 follows uranium-238 during combustion, then the concentrations of radium-226 in fly ash and bottom ash at the Neal Station would be approximately 2.5 pCi/g and 4.2 pCi/g, respectively. These concentrations are above average "background" concentrations for soil in the United States. The concentration of radionuclides in bottom ash and fly ash is related to ash content of the feed coal. The coal burned at the Neal Station contained 11.9% ash, but some coals have ash contents on the order of 3%. This could result in an increase in the radium-226 concentration in the ash by a factor of approximately four.³³ Still assuming that radium-226 is in equilibrium with and follows uranium-238 during combustion, radium-226 could accumulate in the ash ponds at the Neal Station at a rate of 0.53 Ci/yr. At this rate, approximately 15.8 Ci of radium-226 would accumulate in the ash pond over a period of 30 years. This quantity of radium-226 would result in the production of radon-222 at a rate of about 2.7 Ci/day. Only a fraction of the radon-222 produced would be released to the atmosphere. The literature contains several widely varying estimates of this fraction. At the present time, it is not clear what the magnitude of radon-222 release would be.¹⁰ The potential environment impact of radon-222 emanation from ash ponds warrants further attention.

Lee et al. have suggested that emanation of radon-222 from ash disposal ponds will be the most serious radionuclide problem associated with increased use of coal.³⁴

Utilization of Coal Wastes

Gurmond and Fitzgerald have suggested a potential hazard associated with the use of fly ash in cement and concrete blocks and in roadway construction.³⁵ The radium-226 in these concrete blocks used for home construction may constitute an important source of radon-222 dose to the public. If the coal ash is incorporated in concrete and

Table 2.12

Radionuclide Balance for Unit #2 of The Neal Station

Component	Radionuclide Throughput (pCi/sec)				
	U-234	U-238	Po-210	Pb-210	Po-210 ^b
Input Coal	17843	16793	38484	23090	29388
Bottom Ash	1446	1350	2685	1946	2685
Fly Ash	15849	15376	19302	18866	19302
Stack	2644	2665	3241	5160	3241
Total Output	19939	19391	25228	25972	25228
% Relative Imbalance	-12	-15	+34	-12	+14

-Out of the arithmetic context of the above table, these values should not be used with more than three significant figures.

^bOctober 23 coal measurement only.

Source: Styron, C.E. et al., "Assessment of the Radiological Impact of Coal Utilization," Monsanto Research Corporation, Miamisburg, Ohio (February, 1979).

concrete products as a replacement for cement, radon may become a problem and may result in possible radioactive emanations from walls and floors of buildings constructed from this material. Other uses of the fly ash have been in reclaiming surface mine spoil and as a soil nutrient.

Research Needs

The efficiency of bag houses, scrubbers, etc. in removing radionuclides from stack effluents has not been evaluated. It is anticipated, however, that numerous small manufacturers will be turning to Western coal, since its low sulfur concentration may eliminate the need for expensive emission control equipment to control SO_x emissions. Table 2.14 presents results of calculations of doses assuming 10% and 100% reductions in emissions controls. These doses are most likely unrealistically high because they are based on conservative assumptions.³³ Nonetheless the magnitude of these doses indicates that a realistic, site-specific assessment of the radiological environmental impact of burning coal with a very large radionuclide content should be performed when and if such coal is used in the future.

If scrubbers are not employed, or if these collectors operate at less than maximum efficiency, the radiation hazard may become significant. If present coal supplies are replaced with fuel of a higher radioactive and ash content, an increase in the radiation hazard results from mining and pre-

combustion operations, and it is these activities that must be carefully monitored.

Table 2.13

Rate of Accumulation of Radionuclides in Ash Ponds at the Neal Station

Nuclide	Rate of Accumulation	
	(pCi/sec)	(Ci/yr)
U-234	17300	0.55
U-238	16700	0.53
Po-210	22000	0.69
Pb-210	20800	0.66

Source: Styron, C.E., et al., "Assessment of the Radiological Impact of Coal Utilization," Monsanto Research Corporation, Miamisburg, Ohio (February, 1979).

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Table 2.14

Estimation of Maximum Annual Doses in Vicinity of the Neal Station Under Conditions of Reduced Emission Control

Nuclide	Organ	Dose Under Normal Operating Conditions (mrem)	Dose with 10% Emission Control Reduction (mrem)	Dose with No Emission Control (mrem)
Inhalation				
U-234	Lung	0.0272	0.0435	0.190
	Bone	0.05541	0.00866	0.0379
	Kidney	0.00129	0.00206	0.00903
U-238	Lung	0.0238	0.0375	0.161
	Bone	0.00498	0.00785	0.0531
	Kidney	0.00113	0.00178	0.0121
Po-210	Lung	0.0198	0.0316	0.138
	Bone	0.000251	0.000401	0.000175
	Kidney	0.00186	0.00297	0.0128
Pb-210	Lung	0.0267	0.0365	0.124
	Bone	0.0268	0.0366	0.125
	Kidney	0.0216	0.0295	0.101
Total	Lung	0.098	0.15	0.61
	Bone	0.037	0.054	0.22
	Kidney	0.026	0.036	0.14
Ingestion				
Pb-210	Bone	3.53	4.82	16.4
	Kidney	3.42	4.67	15.9
	Liver	1.10	1.61	5.50

Source: Krieger, H. and B. Jacobs, "Analysis of Radioactive Contaminants In By-Products From Coal-Fired Power Plant Operations", U.S. Environmental Protection Agency, EPA-600/4-78-039 (July, 1978).

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3. DATA CHARACTERIZATION

INTRODUCTION TO THE POLLUTANT MEDIUM

The General Nature of Solid and Hazardous Wastes

The Resource Conservation and Recovery Act (RCRA) defines solid wastes as:

"any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid, or contained gaseous material, resulting from industrial, commercial, mining, and agricultural operations and from community activities, but does not include solid or dissolved material in a domestic sewage, or solid or dissolved materials in irrigation return flows or industrial discharges which are joint sources subject to permits under section 402 of the Federal Water Pollution Control Act, as amended (86 Stat. 880), or source, special nuclear, or byproduct material as defined by the Atomic Energy Act of 1954, as amended (68 Stat. 923)."

A hazardous waste is defined under the Act as one that, because of its quantity, concentration, or physical, chemical, or infectious characteristics, may (a) cause or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness; or (b) pose substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed (sec. 1005(5)).

Over 6 billion tons of solid wastes are generated annually in this country. The largest part, by volume, are the "animal" wastes, from agriculture, food and timber processing, and the "mineral" wastes, from extraction and processing of ores. While these wastes present severe environmental

problems, it is municipal and industrial wastes that affect the most people and receive the most attention. At least 40 million tons of solid wastes, primarily in the industrial category, contain toxic chemicals which possess mutagenic, carcinogenic, teratogenic or acutely toxic properties.²

Technological breakthroughs in the last few decades have resulted in a large increase in the number of toxic chemicals released to the environment. For many years waste streams containing these chemicals were disposed of with little regard to their impact on the hydrogeologic cycle or on the environment. Recently publicized episodes of long term careless dumping of wastes in this country have caused the public and all levels of government to register sharp, insistent protest over the apparent continuation of inadequate hazardous waste management practices. RCRA and other Federal and state laws were passed to eliminate or greatly reduce public and environmental exposure to the wastes. The designation of energy waste streams as hazardous or non-hazardous will depend on the results of studies conducted by government and industry in the next few years pursuant to RCRA implementation.

The degree to which a regulatory requirement constrains the realization of a particular energy use scenario cannot be unambiguously determined in the case of solid/hazardous wastes, even if a set of known regulations were in place.

In almost all instances, engineering solutions are available to mitigate any undesired effect, thereby making the key issue one which is associated with the cost of solid waste disposal. Even if the disposal of wastes were restricted from particular ecologically sensitive areas, truck haulage of the wastes to sites outside the restricted zones is almost always feasible from a purely technical standpoint. Complete containment, say by the use of an artificial liner, is also primarily a matter of cost, while

calculation of the probability of failure of such a liner, from which one might derive a measure of the likelihood of substantive detrimental environmental impact, is simply not possible at the present time in view of the absence of data.³

Solid waste from energy technologies has become a subject of increasing concern, due to the quantities that must be handled and the existence of hazardous substances in some energy wastes. Increasingly stringent air and water pollution regulations result in a larger fraction of residuals in the form of solid wastes. Some pollution control technologies, such as flue gas desulfurization (FGD), not only shift the residuals from other media into solid wastes but multiply the absolute quantity of wastes several fold. Collection of residuals as solid wastes can concentrate toxic contaminants which otherwise would be more widely dispersed. This concentration may be desirable since it allows better containment and control. On the other hand, it can increase occupational exposure and, if controls are inadequate, can lead to population exposures to higher concentrations of toxic materials than would otherwise have been the case.

Energy solid wastes are distinguished for their variability. Each waste and each disposal site is unique. Waste characteristics depend on the composition of the coal (or other fuel), specific processes used and plant design and operation. Coal itself is an extremely heterogeneous substance and its composition varies widely from seam to seam, from mine to mine within a seam, and even within a single mine. In general, the residuals or contaminants in the coal are collected and concentrated in the solid wastes. No two plants have exactly the same residuals treatment systems and as a result, solid/hazardous wastes produced by different plants vary.

Fossil fuel solid wastes of concern include coal cleaning residuals, fly ash, bottom ash, scrubber sludge, spent fluidized bed material from coal combustion; chars, acid gas clean-up wastes, air and water pollution control wastes, tar and oil sludges, biosludges, and spent catalysts from coal synfuels; raw shale dust, spent shale, sludges, coke and a variety of non-shale wastes from shale oil production.

Fossil fuel generated wastes currently regarded as hazardous include separator sludge, oily float, slop oil emulsion solids, heat exchanger sludge, and leaded tank sludge from oil refineries. Oil and gas ex-

traction and geothermal development do not produce solid/hazardous wastes; these processes use liquid injection fluids or brines which are currently not treated to remove solids. Hazardous wastes from the nuclear industry are graded by degree of hazard and include spent fuels; reprocessing, refabrication, and radioisotope wastes; mill tailings; and radioactive structures and land from decommissioning facilities.

In addition to the regulation of solid/hazardous waste management, one of the basic goals of RCRA is to promote conservation of valuable materials and energy resources. EPA has developed guidelines for financial and technical assistance for resource recovery from a variety of solid wastes. Wastes as fuel programs, development of product categories such as cement and concrete, and public education programs are major activities under RCRA at the regional and federal level.

Recovery of resources from energy-related wastes is already a substantial business, but further R&D work is needed to expand their use and reuse. Current research includes development of the following range of recovery alternatives:

- Use of fly ash and bottom ash in concrete and cement;
- Recovery of energy from waste oils and sludges by recycling into boilers and reaction chambers; and
- Recovery of solvents used in the Stretford process for sulfur recovery from acid gases.⁴

This introduction to the pollutant medium has developed certain perspectives on examining energy-related solid/hazardous waste and defined six categories of data on these perspectives. Management data describe the regulatory framework within which EPA and the states can direct the energy industry's waste management practices. Residuals refer to the conformation or content of a waste type. Levels of waste generation, often referred to in the field as loadings, quantify this description. The environmental impact of solid/hazardous waste disposal and the disposal option chosen are functions of the relative hazard characteristics of the medium; methods of long term disposal can be evaluated according to potential environmental problems resulting from degradation or breachment of the site. A brief description of the amounts and locations of disposal sites follow, and this media book closes with an examination of the potential for recycling

or reusing energy wastes as either a product component or fuel source.

The fuel cycles reported on in each of these data categories are inclusive but focus on problematrical areas of energy related waste disposal as defined in the issues section: increased coal utilization, both for industrial and utility power generation, and the emerging technologies for which there are current data gaps—oil shale and syn-fuels production. Biomass, the technology for converting agricultural products or residuals into alcohol as a petroleum replacement, is not included even though it does produce a solid waste. The wet pulp residual may be malodorous but has no demonstrable hazardous characteristics and can easily be converted to animal food or organic fertilizer.

MANAGEMENT DATA

The Resource Conservation & Recovery Act (PL 94-580)

Implementation of the Resource Conservation and Recovery Act of 1976 (RCRA) by EPA and by the state will result in "cradle to grave" regulation of all solid wastes generated in the country. The impact of RCRA on the disposal of solid waste depends largely on whether the wastes are designated hazardous or non-hazardous. In many cases, classification will depend on analysis of the individual waste. The costs associated with the environmental safeguards required for hazardous waste management could be up to fivefold greater than those for non-hazardous waste management.⁵ Long-term commitment of land resources is also greater for hazardous waste management.⁶ The chief objectives of the Act are:

- Regulation of the management of hazardous wastes from point of generation through disposal, by EPA or by state programs authorized by EPA.
- Regulation of the disposal on land of all other solid wastes by the states in accordance with minimum federal criteria.
- Establishment of resource recovery and conservation as the preferred solid waste management approach.¹

RCRA includes solids, liquids, semi-solids, sludges and contained gaseous materials as solid wastes. Wastes are included irrespective of whether they are discarded, used, reused, recycled, reclaimed, stored or transported.

At least seven other federal laws could impact disposal of hazardous wastes. Where possible, RCRA will be integrated with other acts. No underground injection of hazardous waste will be allowed unless a permit is received under the Underground Injection Control Act (PL 95-190) as promulgated under the Safe Drinking Water Act (PL 93-523). Ocean dumping will be regulated under the Marine Protection, Research, and Sanctuaries Act (PL 92-532). Clean Water Act (PL 95-217) regulations will take precedence where the jurisdiction of that program allows. Thus, any hazardous waste water discharge may be regulated under BAT Toxics program (Sec. 301, 307 and 311), the pretreatment standards (Section 307) or the National Pollutant Discharge Elimination System (NPDES) permits (Sec. 402) of the Clean Water Act. There will be some areas in which RCRA takes precedence. One such example is where municipal sewage sludge would be considered hazardous. This waste would then be controlled under Subtitle C of RCRA.

Integration will occur with the Clean Air Act (PL 95-95) primarily where volatile wastes may exist. No program for these wastes has been developed. Integration with TSCA has already been considered in Section 1. Presently the Office of Surface Mining (OSM) of the Department of the Interior controls disposal of mining wastes under the Surface Mining Control and Reclamation Act (PL 95-87). EPA is negotiating an agreement with OSM whereby RCRA coverage of mining wastes will be covered under SMCRA, assuming that the stringency of the controls will be equivalent to those RCRA would impose.⁶

Wastes classified as hazardous would be subject to a number of provisions of RCRA. Section 3001 directs EPA to promulgate criteria and test procedures to be used in determining whether or not a waste is hazardous and maintain a list of specific waste and waste sources. Section 3002 requires EPA to issue hazardous waste handling procedures to be implemented by generators of hazardous waste, including record keeping and labelling practices, and use of a manifest system to assure that the waste is designated for proper treatment, storage and disposal. Section 3003 governs the establishment of standards which are applicable to hazardous waste transporters. Section 3004 establishes standards which are applicable to owners and operators of hazardous waste treatment, storage and

disposal facilities; and Section 3005 establishes permits for the treatment, storage and disposal of hazardous wastes. The implementation of the regulations promulgated under RCRA is the responsibility of the individual states. Section 3006 directs EPA to provide guidelines to assist states in the development of state hazardous waste programs.

The following section details various guidelines and requirements which have been promulgated under RCRA, including: criteria for defining hazardous wastes, testing and analysis procedures, solid and hazardous waste disposal requirements, and guidelines for state solid/hazardous waste management programs.

Criteria for Defining Hazardous Wastes

Recently, EPA issued interim final rules for Subtitle C hazardous waste control which address Section 3001 through 3006.⁷ A major action in the interim rulemaking is the removal of a "special waste" category from consideration.

Originally, EPA designated a number of "special wastes" under the proposed hazardous waste regulations. The majority of these were energy-related wastes, including utility waste (fly ash, bottom ash, and FGD sludge), uranium mining waste, oil and gas drilling muds and brines, and "other mining wastes." The Agency's rationale for the special waste distinction was:

- Large volumes of these wastes are generated; and
- Portions of these wastes will probably be identified as hazardous, although limited available information indicates that they pose a relatively low hazard to the environment; and these wastes generally are not amenable to the control techniques required for disposal of a hazardous waste.

The special waste designation meant that the hazardous portions of the wastes would be subject to a very limited subset of the hazardous waste management regulations called for by RCRA. EPA proposed to conduct two year studies on appropriate methods for handling these wastes, with substantive technology-specific disposal regulations to be developed based on these studies.

EPA's proposed approach to special wastes generated considerable protest. Commenters generally objected either to the concept of the special waste category, or

to the need for, or the sufficiency of, the limited standards proposed for that category. Therefore, EPA abolished the special waste category, upon the decision that a waste meeting the criteria for hazardous waste should be treated as such, regardless of volume. At the same time, EPA tightened the corrosivity and toxicity requirements in order to narrow the category of waste classified as hazardous under the Subtitle C standards.

Upon removal of the special waste category, those portions of the six proposed special wastes which are determined to be hazardous will be subject to applicable RCRA regulations. However, EPA has temporarily deferred imposition of the regulations for two of the originally proposed special solid wastes, i.e., oil and gas drilling muds and oil production brines, and utility wastes. This deferral is in response to Congressional action to exempt these wastes from Subtitle C regulation for a limited time pending completion of the EPA studies.⁸

In redefining the characteristics of hazardous waste in a more rigorous manner, EPA revised the corrosivity and some toxicity requirements. For corrosivity, the upper pH limit was moved from 12.0 to 12.5 (requiring a more basic or caustic waste for inclusion as hazardous) while the lower pH limit was moved from a pH value of 3.0 to a value of 2.0 (requiring a more acidic waste for inclusion as hazardous than as previously defined).⁹ One set of the toxicity requirements was modified to allow for a less stringent control of wastes. EPA addressed the problem by developing a test procedure called the Extraction Procedure (EP) designed to identify wastes likely to leach hazardous concentrations of particular toxic constituents into groundwater under conditions of improper management. Under this procedure, species were extracted in a manner designed to stimulate leaching in landfills. The extract was then analyzed for parameters identified in the National Interim Primary Drinking Water Standards (NIPDWS).¹⁰ The proposed regulation defined a waste as hazardous if the concentration of any parameter was in excess of ten times the NIPDWS for that parameter.¹¹ Since there were few empirical data on which to base this dilution factor, EPA decided to revise this dilution factor to one deemed more appropriate in defining the relative cost/benefit for a hazardous waste listing. Thus, EPA is adopting a 100-fold dilution factor from NIPDWS on

the basis that any waste failing this test (i.e. concentrations are greater than 100-fold) has the potential to present a substantial hazard regardless of any attenuation mechanisms at play.¹² EPA indicated that most of the special wastes that would have met hazardous waste criteria would have done so due to toxic extracts between 10 and 100 times the PDWS.

EPA chose two criteria for identifying hazardous waste characteristics: 1) a characteristic could be described within the statutory definition in terms of some physical, chemical, or other properties, and 2) the properties used to fulfill the first criterion could be measured by standardized and available testing protocols. Due to these criteria, EPA has removed organic toxicity, carcinogenicity, mutagenicity, teratogenicity, bioaccumulation potential and phytotoxicity from the list of proposed characteristics in the December 18, 1978, Federal Register.¹³ Other categories were retained, however. These are:

- Ignitability
- Corrosivity (as discussed previously)
- Reactivity
- EP toxicity (as redefined and discussed previously).

Two new categories have been developed consistent with EPA RCRA goals:

- Acute Hazardous Waste, which is deemed in this manner if:
 - It has been found to be fatal to humans in low doses
 - Oral LD₅₀ (rat) less than 50 mg/kg
 - Inhalation LC₅₀ (rat) less than 2 mg/l
 - Dermal LD₅₀ (rabbit) less than 200 mg/kg
 - It is capable of causing or significantly contributing to an increase in serious irreversible or incapacitating reversible illness.¹⁴
- Toxic Waste, defined as waste containing a species listed in Table 4.1¹⁵, unless deemed non-hazardous by the Administrator following consideration of:
 - The nature of toxicity
 - The concentration of toxic constituents
 - Environmental transport potential
 - Environmental persistence
 - Rate of degradation to non-harmful species
 - Plausible types of improper management
 - Quantities of waste on a local, regional or national basis

- Nature and severity of health and environmental impacts
- Other Governmental action
- Other factors as appropriate.¹⁶

The characteristics of ignitability, corrosivity and reactivity are summarized in Subpart C, Sections 261.21, 261.22, and 261.23, respectively. The characteristics which determine EP toxicity, that is concentrations of leachate species above which the waste is considered hazardous, are summarized in Table 4.2.¹⁷ It should be noted that the maximum concentration of contaminants for extracting toxicity characteristics now is set at 100 times the Drinking Water Standard for each hazardous constituent, rather than the originally proposed 10 times the Drinking Water Standard.

Tables 4.3 and 4.4 contain lists of waste streams which the EPA Administrator has defined as hazardous. The hazard code in the right hand side of each table defines the reason for categorizing these waste streams as hazardous according to the six characteristics discussed previously:

Ignitable	(I)
Corrosive	(C)
Reactive	(R)
EP Toxic	(E)
Acute Hazardous	(H)
Toxic	(T) ¹⁸

Table 4.5 lists the chemical species for which each waste stream was deemed hazardous.¹⁹ Other sections discussed chemical products, off-specification products, and spill residues and are discussed in Section 261.33.²⁰ These parameters are not as important in terms of energy use and comparative studies as are the characteristics, waste streams and chemicals discussed previously and listed in Tables 4.1 through 4.5. Although no coal use streams are listed, five petroleum refining streams are listed as containing toxic hazardous wastes.

Testing and Analysis Procedures

An imperative part of RCRA definition and enforcement comes from the proper use of sampling, testing and analyses procedures and protocols. Many tests are standard and had been previously developed by EPA and/or the American Society for Testing and Materials (ASTM). However, given the nature of the unique sampling and analytical problems associated with standardized solid wastes measurements, EPA developed protocols and publications to

document these new methods. These procedures are summarized in Table 4.6. The chemical analysis methods are more straightforward and although they are reprinted in "Test Methods for Evaluating Solid Waste,"²¹ they have appeared elsewhere when the administrator has published methods for chemical environmental analyses as required by law.²² The methods are summarized for most of the toxic chemical species in Table 4.7 and 4.8.²³

The biggest difficulty from an analytical standpoint will be to ensure that extraction protocols are rigorously followed. Although the methodology produced reasonable reproducibility, some problems were found.^{24,26} This is a potential issue that must be monitored closely. A possible solution would be to certify testing laboratories using similar procedures to those followed for certifying drinking water analytical laboratories. The laboratories to be certified would differ in many areas, but mechanisms for certification, testing and recordkeeping could be standardized.

Solid Waste Disposal Requirements

Section 4004 criteria for Solid Waste Disposal were issued in final form on September 13, 1979. The eight criteria address a broad range of health and environmental effects including flood plains, endangered species, surface water, groundwater, disease, air, application to land used in the production of food chain crops, and safety. They are for use in determining which solid waste disposal facilities and practices pose a reasonable probability of adverse effects on health or the environment.²⁷

The criteria apply to the full range of practices for the disposal of solid waste with the following exceptions:

- Agricultural wastes, including manures and residues, returned to the soil as fertilizers or soil conditioners;
- Overburden from mining operations intended for return to the mine site;
- Domestic sewage or treated domestic sewage (criteria do apply to disposal of sludge resulting from the treatment of domestic sewage);
- Solid or dissolved materials in irrigation return flows;
- Source, special nuclear or by-product materials;

- Industrial discharges subject to permits under Section 402 of the Clean Water Act as amended;
- Hazardous waste disposal facilities subject to regulation under Subtitle C of RCRA; and
- Underground well injection facilities subject to regulations for the Underground Injection Control Program.²⁸

The criteria are flexible and provide the opportunity for state and local solid waste management agencies to take into account site-by-site variations and make assessments on local conditions. The criteria are the same for existing and new facilities, although it was suggested that there be less stringent criteria for existing facilities. However, in regard to the implementation of the criteria, the Act does recognize the need to continue controlled use of existing facilities while alternatives that comply with the criteria are being developed.

In addition, the criteria apply to both small and large facilities, both urban and rural. EPA felt that the exclusion of small facilities would foster the development of additional small facilities in order to escape the cost of compliance.³¹ The standards established in the criteria constitute minimum requirements. The criteria do not pre-empt other state and federal requirements.³²

The states have the responsibility of evaluating existing disposal facilities to determine whether they comply with the Section 4004 criteria. Those facilities which do not satisfy the criteria are "open dumps," and EPA will publish a list of open dumps in the Federal Register. The inventory of "open dumps" will serve two major functions. First, it will inform Congress and the public about the extent of the problem. Second, it will provide an agenda for action by identifying problem facilities routinely used for disposal which should be addressed in state solid waste management plans in accordance with Section 4003 of the Act.³³ Specific criteria developed in Section 4004 for disposal of solid wastes are discussed below.

Floodplains

The three components of this criterion are that facilities in floodplains shall not: 1) restrict the flow of the base flood (a flood with a one percent or greater chance of occurring in any one year); 2) reduce the tem-

porary water storage of the floodplain and 3) result in a washout of solid waste that would pose a hazard to human life, wildlife, or land or water resources.³⁴ It is generally desirable to locate disposal facilities outside of floodplains because wastes may be carried from the site, affecting downstream water quality. Structures located on the floodplain may restrict the flow of water, causing greater flooding upstream, and filling the floodplain may reduce the water-retaining capacity of the soils, causing more rapid flooding downstream. The floodplain criterion prevents these adverse impacts, but does not prohibit location of a facility in a floodplain (see Figure 4.1).

Endangered Species

The endangered species criterion states that facilities or practices shall not cause or contribute to the taking of any endangered or threatened species of plants, fish, or wildlife or destroy or modify the critical habitat of these species.³⁵ The "taking" definition is very broadly stated and encompasses a variety of adverse effects. Taking is defined as harassing, harming, pursuing, hunting, wounding, billing, trapping, capturing or collecting, or attempting to engage in such conduct.

Surface Water

The surface water criterion requires compliance with the Clean Water Act (CWA) as amended. It requires that a facility or practice shall not: 1) cause a discharge of pollutants in violation of the National Pollutant Discharge Elimination System (NPDES) under Section 402 of the CWA, 2) cause a discharge of dredged or filled materials that is in violation of Section 404 of the CWA, and 3) cause non-point pollution of waters that violates the legal requirements of implementing water quality management plans developed under Section 308 of the CWA.³⁷ In the final regulation, EPA has sought to coordinate the surface water standards with programs developed under the CWA. However, concerns have been raised over the ability of NPDES permitting agencies to process applications and issue permits for point source discharges of pollutants from solid waste disposal facilities because few permits have been issued for such discharges.³⁸ In addition, very few approved state 208 plans exist at this time.

Groundwater

The groundwater criterion states that a facility or practice shall not contaminate

underground drinking water beyond the solid waste boundary or any boundary established by an approved state solid waste management agency.³⁹ Contamination occurs when leachate from the disposal activity causes the concentrations of certain pollutants in ground water to either: 1) exceed the maximum contaminant level (based on the primary drinking water standards specified for that pollutant), or 2) increase at all where the background concentration of the pollutant already exceeds the applicable contaminant level. An underground drinking water source is an aquifer currently supplying drinking water for human consumption or an aquifer in which the concentration of total dissolved solids is less than 10,000 mg/l.⁴⁰ In establishing the criterion, EPA recognized that groundwater quality is important for other uses and that differing standards may be appropriate for these other purposes, however, at this time, human health effects from direct consumption has highest priority. In addition, EPA has developed standards for drinking water but has not established standards for other uses.⁴¹

Federal regulations prohibit commitment of any federal funds to a project which might contaminate the stream flow or recharge zone of an aquifer which has been designated as a sole or principle source of drinking water. Table 4.9 lists aquifers designated or proposed for this status.⁴²

Disease

The criterion states that the facility must control the vectors of disease through the periodic application of cover material or other techniques that are appropriate for protecting public health. The criterion also closely defines the conditions under which sewage sludge or septic tank pumpings may be applied to the land surface.⁴³

Air

The air criterion has two components. First, there shall be no open burning of residential, commercial, institutional or industrial solid waste. This provision does not apply to infrequent burning of agricultural wastes, silvicultural waste, land clearing debris, and debris from emergency clean-up operations. Second, air emissions caused by a solid waste disposal facility shall not violate requirements developed for SIP's under the Clean Air Act.⁴⁴

Safety

The regulation requires that the concentration of explosive gases not exceed 25 per-

cent of the lower explosive limit for the gases in the facility structure and the lower explosive limit for gases at the property boundary. The criterion also contains provisions dealing with fires, bird hazards to aircraft, and access.⁴⁵ Although this standard could potentially be applicable to several explosive gases, it is only applied to methane at this time.⁴⁶

Criteria Flexibility

The criteria were designed to be flexible so that state and local solid waste management agencies can take into account site specific conditions; however, this flexibility may present a problem. Concern has been expressed that there is too much room for individual interpretation and that inspection and evaluation of disposal facilities and subsequent listing on EPA's open dump list may be a very subjective undertaking despite the efforts to make the criteria as objective as possible.⁴⁷ Flexibility is a key issue, especially when one takes in to account that most states have little experience in solid waste management and few if any precedents have been set. Under such conditions, it is difficult for industry to determine how the state plans to act. EPA has developed a manual to instruct states on how to conduct the inventory and they will hold training sessions for state personnel; however, it will be up to the individual states to interpret the criteria, conduct the open dump inventory, and determine the process for compliance.⁴⁸

Hazardous Waste Disposal Requirements

The regulations for hazardous waste disposal under Section 3004 of the Act set interim operating and technical standards for the treatment, storage and disposal of hazardous wastes. However, EPA is aware that it may take several years to resolve the more complex technical issues raised by the regulations in such a way that will allow promulgation of nationally acceptable, detailed standards.⁴⁹

The interim regulations will go into effect in November, 1980. By this time all existing facilities must have applied to the EPA for a permit and have upgraded their facilities to meet the interim standards. As soon as a facility applies for a permit it obtains interim status. EPA recognizes, however, that processing permits could take years for some facilities.

Theoretically, a facility could obtain a permit from a state solid waste management agency; however, it is not anticipated that any states will have approved hazardous waste management programs in the near future. The interim status standards are minimum requirements that EPA feels are broadly applicable to large numbers of facilities and vast amounts of hazardous wastes. The standards address manifests, recordkeeping, reporting, waste analysis, training, contingency plans, groundwater monitoring and closure (see Table 4.10 for a complete listing of all items subject to regulation under Interim Status Standards for Owners and Operators of Hazardous Waste Treatment Storage, and Disposal Facilities). These standards have a significant degree of flexibility.⁵⁰

The closure and groundwater monitoring standards are considerably more specific and strict than the other interim standards. This is because EPA felt that the benefits obtained from early implementation substantially outweighed the disadvantages. The closure standard requires that facilities closed during interim status will be required to meet full closure and post-closure care requirements, including the requirement to have the plans for those activities approved by EPA. Although facilities have an additional twelve months to comply, all hazardous waste landfills, surface impoundments, and land treatment facilities must have groundwater monitoring systems unless a hydrogeological study demonstrates that such a system is unnecessary. The delayed schedule for compliance was allowed so that there would be sufficient time to install the systems.⁵¹

These interim status standards, Phase I of the regulatory process, are only the bare outline of what will occur in Phases II and III. EPA expects to publish the Phase I regulations in the fall of 1980. They will be a set of technical regulations based on the agency's best engineering judgement of technical requirements that a facility must meet. The regulations will allow permits to be processed in a manner which takes into account both site specific factors and the nature of the waste being handled. The Phase III regulations will be a more definitive counterpart of the Phase II regulations and are expected to make the permitting process even more straightforward. The Phase III standards may also include standards for specific industries and wastes which require special management standards. No date has been set for the issuance of these regulations.⁵¹

State Programs for Solid/ Hazardous Waste Management

During passage of RCRA, Congress stated that "the key to coping with the ever-increasing volume of discarded materials appears to be a regional approach to its disposal, (however) few areas have achieved the necessary planning or coordination to develop such an approach."⁵⁴

Subtitle D of the RCRA establishes the state's role in solid waste management. Section 4002(b) directs EPA to promulgate guidelines for the development and implementation of state solid waste management plans. Though the plan the state identifies a general strategy for protecting public health and the environment from adverse effects associated with solid waste disposal, for encouraging resource recovery and conservation, for providing adequate disposal capacity in the state, and for dealing with older solid waste management issues. The plan must also set forth the institutional arrangements for implementing the strategy, including the identification of regions, agencies, and responsibilities for solid waste management.

Section 4003 identifies the minimum requirements that state plans must address. Under Section 4007, EPA reviews and approves state plans which satisfy the minimum requirements. States are eligible to receive financial assistance if the state plan has been approved by EPA.

Under section 4004(a) of RCRA, EPA is to promulgate "regulations containing criteria for determining which facilities shall be classified as sanitary landfills and which shall be classified as open dumps. . ."⁵⁵ The criteria establish the level of protection necessary to assure that adverse effects to health or the environment will not result from operation of the site. The States are given prime authority to investigate all sites, determining those which violate the criteria, and are therefore considered open dumps. EPA will publish an inventory of open dumps based upon results of the States' survey.

Every state now has some form of solid waste management program in effect. Most are being modified to meet EPA's guidelines for State Solid Waste Management Programs, promulgated in January 1979.

Due to recent action by Congress, most energy-related solid wastes will be regulated under Subtitle D, rather than as "special" wastes under Subtitle C. This means that disposal criteria will vary from state to

state, although EPA's guidelines should minimize the differences somewhat. States are entitled to develop disposal standards that are more stringent than those in the federal guidelines.

RCRA assigns responsibility for hazardous waste management directly to EPA. The task is so complex, however, that the agency would have difficulty in handling the program without state help. The law authorizes EPA to encourage each state, by means of financial incentives, to develop a comprehensive hazardous waste management program. Thus far, 47 States have indicated the intention of seeking primacy for hazardous waste management.

Guidelines for state hazardous waste programs were first proposed in February, 1978.⁵⁶ Major portions were finalized in May, 1980. The delay caused some difficulty for states which were trying to design or upgrade their programs to meet EPA's requirements for interim or full authorization. Table 4.11 lists requirements for interim and full authorization of state hazardous waste programs, and Table 4.12 gives a profile of the status of state programs in meeting these requirements.

RCRA requires that state programs be "equivalent to and consistent with" the federal program. Some states have hazardous waste definition criteria or disposal standards which are more stringent than the federal program. While RCRA allows this for solid wastes, it is not yet clear whether or not states can regulate hazardous wastes more stringently than the federal program.

Final designation of most energy-related wastes as hazardous or non-hazardous will be based on research conducted over the next two years. The recently promulgated standards for identification and listing of hazardous wastes and recent action by Congress in removing energy wastes from the "special waste" category indicate that very few energy-related wastes will receive the hazardous designation in addition to petroleum refinery wastes.

RESIDUALS

Acquiring knowledge of the composition of wastes produced by energy activities is the first step in a waste management program. Chemical constituents of solid/hazardous wastes are completely different across fuel types, vary considerably across fuel cycles, and are also a changing function of the effluent removal method used. This section describes the components present in

ash, char, inorganic solids, and sludges from coal utilization, both combustion and conversion cycles. Other waste types analyzed are tars, oil sludges, biosludges, catalysts, and coal cleaning wastes. Residuals from shale oil production are examined in detail. Solid/hazardous wastes from other energy technologies are also described with attention given to uranium wastes.

Solid Wastes Associated with Coal Utilization

Utilization of coal as an energy source gives rise to a myriad of solid wastes requiring disposal. There are six major categories of solid wastes: (1) chars and ashes from combustion and conversion (gasification and liquefaction); (2) inorganic solids and sludges from FBC, air and water pollution control, and acid gas removal; (3) tars and oil sludges; (4) biosludges; (5) spent catalysts; and (6) coal cleaning wastes. Some, if not all, of these wastes may pose environmental hazards if not managed carefully. This section reviews the source and characteristics of these wastes. Their hazard potentials are discussed later in this report.

The residual wastes listed above are produced regularly from energy generation activities. There are other wastes that are typically part of a processing step and not commonly handled, but may require handling as a result of process malfunctions or mishaps, e.g., valve, pumping, or line failure. These process streams may be under high pressure or high temperature and pose a serious danger to occupational safety. If these wastes must be removed from the system for safety or for any other reasons, their handling and deposition in an environmentally sound manner may become a significant problem.

Coal Ash and Char

Ashes and chars are the primary solid residue produced in the coal use fuel cycles. The characteristics of solid residues produced by the combustion cycle could differ from those of the conversion cycle (gasification and liquefaction). They are discussed separately below.

Ash from Coal Combustion

The combustion of coal produces an ash residue consisting of the inorganic material constituents present in coal, as well as the organic matter that is not fully burned.

Several types of coal ash can be produced in coal combustion processes ranging in size from less than one micron to 4 centimeters in diameter.

Fly ash is that fraction of noncombustible coal residue which is too small to settle out in the combustion chamber and becomes suspended in the high velocity flue gas. The fly ash fraction generally consists of fine spherical particulates ranging in diameter from 0.5 micron to 100 microns. As much as 5 percent by weight or 20 percent by volume of fly ash consists of cenospheres, which are silicate glass spheres filled with nitrogen and carbon dioxide. These very lightweight particles tend to float on ash pond surfaces.

The bottom ash fraction of the coal combustion residue is composed primarily of coarser, heavier particles with porous surfaces. If the bottom ash melts to slag at burner operating temperatures, the residue resolidifies as angular, black particles with a glassy appearance.

The type of particulate collector employed determines the particle size distribution and total surface area of the collected fly ash. An electrostatic precipitator collects a much higher percentage of the very small particles (less than 1.5 microns) than does a mechanical collector. The collected fly ash, however, is much less sensitive to changes in efficiency of collection than is the fly ash released to the atmosphere. The difference is most dramatic in the total mass. A change from 98 percent removal of total to 99 percent removal results in slightly more than a 1 percent increase in mass of fly ash collected but a 50 percent decrease in the mass emitted to the atmosphere.

Mather⁵⁷ analyzed size-differentiated fractions of fly ash and concluded that lithophile materials (aluminosilicates) and alkalis (Na and K) were generally more concentrated in the finer fractions and thus in ash collected by an electrostatic precipitator. Magnetite-hematite materials (iron-bearing) were more concentrated in the coarser fractions of ash collected from the mechanical collector than they were in ash collected from the electrostatic precipitator. Carbon particles also increased in abundance as the particle size increased. Natusch⁵⁸ demonstrated that the toxic trace elements, arsenic, antimony, cadmium, lead, selenium, and thallium, were most concentrated in the smallest respirable particles emitted from coal burning plants. These elements are probably

volatilized during combustion and preferentially absorb or condense on small particles which have the greatest surface area. As collection efficiency is increased, larger fractions of these particles with high concentrations of toxic elements will be collected as solid waste. Since the total additional mass is small, however, this will not lead to great changes in the overall concentration of these toxic elements in the solid waste.

The major constituents of coal ash, including silicon, aluminum, iron, and calcium, make up 95 to 99 percent of the total composition. Minor constituents, such as magnesium, titanium, sodium, potassium, sulfur, and phosphorus, generally comprise 0.5 to 3.5 percent.⁵⁸ Coal ash is composed almost entirely of oxides. The composition varies over a wide range and there is no typical ash analysis. Table 4.13 gives the range of variation of the principal constituents of coal ash.⁵⁹

Trace Elements

Coal ash can also contain trace concentrations of from 20 to 50 elements, including: antimony, arsenic, barium, beryllium, boron, copper, flourine, lead, manganese, mercury, molybdenum, nickel, selenium, tellurium, thallium, tin, uranium, vanadium, and zinc.⁵⁸

Available data indicate that partitioning and concentration of trace metals occur during combustion, and that certain elements can concentrate in selected size ranges of particulates.^{60,61} Enrichment-volatilization behavior of trace elements in coal combustion is determined by the geochemical properties of the elements, the nature of the combustion process, and the reactions occurring in the emission control devices.

Many studies have been conducted in recent years in an attempt to quantify the chemical constituents of coal ash. Table 4.14 is a composite of these studies, showing the maximum and minimum value found for 64 elements present in bottom ash and fly ash. The studies were made on different sizes and types of systems with respect to megawatt output, furnace type, collector configuration, and, of course, type of coal burned.⁵⁹ Data illustrate a tremendous variability in the concentrations of many elements present in coal ashes.

Trace Organics

Trace quantities of hydrocarbon compounds exist in coal ash, according to an

Oak Ridge National Laboratory report.⁶³ Individual hydrocarbon compounds exhibited concentration ranges from 66-816 ppb, with a total detected concentration of about 9 ppm. The C28-C30 hydrocarbons were in greatest concentration with C29 the highest. Table 4.15 summarizes the estimated hydrocarbon concentration in the ash sampled. The same ash was analyzed by ORNL for the presence of polycyclic aromatic hydrocarbons (PAH). Concentrations were low, ranging from about 10 to 20 ppb, with a maximum of about 0.2 ppm. Table 4.16 gives the PAH concentrations found in the ash sampled.⁶³

In a recent study by Lee, et al., concentrations of monomethyl and dimethyl sulfate in fly ash collected in the flue-line of a power plant burning low sulfur coal were found to be as high as 830 ppm. Dimethyl sulfate has been shown to have mutagenic and carcinogenic properties.⁶⁴

Radionuclides

The presence of radionuclides in coal and coal waste streams has been the subject of several studies.^{65,66} USGS data, summarized in Table 4.17, indicate that concentrations of 1 and 2 ppm for uranium and thorium, respectively, are reasonable estimates of the average values for all U.S. coals. Some coals contain concentrations 10 to 40 times higher than these values.⁶⁵

The presence of radionuclides in coal ash was studied by Coles, et al.⁶⁷ Natural radionuclides identified in coal, bottom ash, and fly ash are listed in Table 4.18. The results of analyses of specific concentrations of the various radionuclides in ash are given in Table 4.19. All of the radionuclides studied do become enriched in ash relative to the input coal, and in general, tend to concentrate on the finer particulates.

A recent study from Monsanto⁶⁶ also followed the fate of coal radionuclides during combustion, with a particular focus on the efficiency of electrostatic precipitators in collecting these elements. The results of the study agreed with Coles, et al., in that bottom ash and fly ash were found to contain relatively higher concentrations of radionuclides than did the feed coal. The ESPs were found to be quite efficient, allowing a small fraction (a total of 0.1 to 1.0 percent of measured background concentrations over a 20-year period) to escape.⁶⁶

Potential problems relative to the concentration of radionuclides in waste bottom ash and fly ash and their accumulation in

ash ponds, and the commercial utilization of these wastes are examined in the topics section of this report.

Ash and Char From Coal Conversion

Three types of coal ash can be produced in gasification and liquefaction operations: (1) dry (including fly ash); (2) melted (slag); or (3) softened (self-agglomerating). Some conversion processes, such as Synthane gasification, and H-Coal liquefaction, also produce char.

Nearly all of the inorganic constituents present in the feed coal are contained in the ashes and chars. Reported values for the residual carbon in ash and char range from a few percent to over 50 percent. The carbonaceous material in chars and ashes is primarily elemental carbon with small amounts of highly polymeric aromatic and heterocyclic organics.

Char Characteristics^{68,69}

Char is the solid residue remaining after the removal of moisture and volatile matter from coal. If carbon removal during the conversion process is incomplete, char will be produced. Depending on the nature of the process, coal conversion can produce net char amounts ranging from between 10 and 55 percent of coal feed weight.⁵⁹ A single gasification plant can produce as much as 4 million to 5 million tons per year of char. In general, there is a considerable reduction in total sulfur and volatile matter, hydrogen and oxygen in char compared to the original coal. Table 4.20 shows the analyses of the coal feeds and resulting chars for the synthane gasification process.⁵⁹ Table 4.21 shows the analysis of the inorganic content of the char from the H-Coal liquefaction process using Illinois #6 coal.⁷⁰

Char in general can be used for many purposes. Providing that there is sufficiently high carbon content, char can be reused for conversion chamber feedstock, utility combustion fuel as a hydrocarbon source, or as an absorbent in pollution control devices. Ash produced from utilization or char may have similar characteristics to that from combustion or conversion of coal.

Ash Characteristics^{68,69}

The composition of ashes from conversion processes is a function of the coal characteristics, severity of treatment, and location within a reactor bed. Similar to

coal combustion ash, major components of conversion ashes include such substances as SO_2 , Fe_2O_3 , and Al_2O_3 ; lesser components will include CaO , MgO , and SiO_2 . In addition, many trace elements will be included, and enriched in comparison to their abundance in coal. However, the composition of conversion ash may vary substantially from that of ash generated in conventional power plants because portions of the ash may be produced by different pathways. (e.g., at lower temperatures in some conversion processes).

A few studies have generated data on the composition of coal and ash from coal conversion. Trace element concentrations of the coal and ash generated by various conversion processes are given in Table 4.22, 4.23, and 4.24.^{59,71,72}

Inorganic Solids and Sludges

The major sources of inorganic solids and sludges from coal utilization facilities include: (1) sludges and solids from SO_2 emission control processes; (2) spent residues from FBC boilers; (3) bottom sludges from acid gas treatment processes; and (4) sludges from chemical treatment of wastewater and water supplies. Generation and characterization of these wastes are presented below.

SO_2 Emission Control Wastes

Much of the sulfur in coal is converted to sulfur dioxide in combustion and to hydrogen sulfide in conversion. In combustion processes, removal of SO_2 from flue gas is necessary to meet Clean Air Act requirements. Removal of sulfur compounds from coal conversion raw gas prior to gas processing is necessary to prevent fouling of catalysts.

In coal conversion processes, sulfur recovery units are used to convert stripped sulfur compounds to either dilute sulfuric acid or elemental sulfur. The vast majority of sulfur recovery units are designed to utilize Claus technology and to recover sulfur in its elemental form. Tail gas treatment units are usually included as part of the Claus technology units to reduce sulfur emissions. Unrecovered sulfur in Claus plant tail gas includes mainly hydrogen sulfide, elemental sulfur, sulfur dioxide, and lesser amounts of other sulfur compounds. Sulfur dioxide removal technologies, such as the Stretford process and others developed for industries such as power plants and sulfuric acid plants, may

be directly applicable to Claus emissions from coal facilities.

The removal of sulfur dioxide by means of scrubbers is accomplished by two general types of processes—throwaway and regenerable. The first scrubber process type refers to those FGD scrubbers which produce a solid waste stream that is not presently marketable and requires disposal. Regenerable scrubber systems are those which, because of their specific chemical reactions, produce a marketable product of sulfur and, in some cases, regenerate the solvent which can be reused. Some common examples of regenerable processes are the Wellman-Lord Sulfite, Westvaco Activated Carbons, AI Aqueous Carbonate, and IFP Catalytic and the Limestone Injection Multi-Stage Burner (LIMB), all of which produce a usable sulfur by-product, such as elemental sulfur, sulfuric acid, and/or gypsum.

Some sulfur by-products, such as elemental sulfur and gypsum, are likely to contain impurities originating from coal. The nature and extent of contamination are, however, largely unknown, and tests to determine the quality of sulfur by-products from the standpoint of their environmental effects are required.

The wet throwaway processes are at present the major systems used by the utilities for several reasons, including lower capital costs in comparison to regenerable processes, availability and ease of use of sorbent and relative simplicity. But they have the major disadvantage of producing large amounts of waste. No dry systems are at present operating commercially. However, four companies have sold spray dryer-based systems, and these are expected to be operating by 1980 and 1981.⁷³ The dry systems do not at present achieve such a high degree of SO₂ removal as do the wet systems. However, the NSPS for utility boilers will require some degree of scrubbing, and dry systems could be used in conjunction with low-sulfur coal. They may also be used by industry if SO₂ scrubbing is required under the NSPS being developed by EPA.

The major wet scrubbing systems employ a slurry of either lime or limestone to remove the SO₂ and produce a waste consisting of calcium sulfate, calcium sulfite and unreacted limestone. Factors influencing the composition of sludge from a specific application include composition of the coal, the alkali added, the scrubber process operation, oxidation, and alkali utiliza-

tion efficiency. Chemical analyses of lime process sludges from various power plant sources are shown in Tables 4.25, 4.26 and 4.27. They reveal that many elements can be included in FGD sludge and that the sludge composition concentrations can be highly variable. Concentrations of trace elements in leachate from ponded scrubber sludges are the focus for the greatest concern about impacts from FGD processes. As can be seen in Table 4.28, which contains results of leachate monitoring, the concentration of arsenic, barium, boron, cadmium, chromium, lead, mercury, and selenium in leachate can be quite high.

In addition to trace elements, the chemical oxygen demand (COD) total dissolved solids (TDS), and the higher levels of sulfate, chloride, calcium, and magnesium are additional sources of potential pollutions.

The quality of wet scrubber wastes can be improved by oxidation later to gypsum or by chemical stabilization. These treatments are discussed in this section.

The major dry systems are either a spray drier or dry injection. In the spray drier, the flue gas is contacted with a calcium based slurry or sodium solution such that the gas is evaporated to apparent dryness. The dry injection system involves the introduction of a dry sorbent, the most promising being nahcolite (sodium bicarbonate) into the flue gas. The resulting waste, consisting of a dry mixture of sodium or calcium sulfite and sulfate, is collected by a baghouse. A major difference between the dry and wet systems is that in the majority of wet systems, the ash is collected by a precipitator prior to the scrubber, whereas in the dry systems the ash and scrubbing waste are collected together.

Very little data are available on the characteristics of dry scrubbing wastes. The lime spray dryer systems are expected to have similar impacts to wet lime/limestone systems. However, dry waste should be easier to handle and dispose of. Nevertheless, there is concern about the sodium based systems because sodium compounds are 100 times more soluble than calcium compounds.⁷⁴

FBC Spent Residues

FBC (Fluidized-Bed Combustion) technology involves the combustion of crushed coal in a bed of inert ash and limestone or dolomite which has been fluidized by the injection of combustion air

through the bottom of the bed. The limestone or dolomite in the bed reacts with the sulfur dioxide released by the combustion of the coal, and forms a solid sulfate material which can be disposed of as a stable dry solid along with the ash. Instead of disposal, sulfated lime residues can be regenerated for reuse in the combustor by contacting them with an appropriate reducing agent under appropriate conditions (e.g., hydrogen and carbon monoxide gases at about 2000 °F in a fluidized bed).

There are two major waste streams from a FBC plant, the spent bed material and the elutriated fines captured by particulate collection equipment. Both of these are dry wastes.

Potentially, very large amounts of solid waste will be produced if regeneration is not used. At a Ca/S mole ratio of 2:1, the FBC process generates about 0.35 to 0.40 pound of waste per pound of coal burned. This is more than a conventional system and should amount to about 700,000 tons per year at a typical 500 MW plant.⁷⁵

Using limestone as the sorbent, the spent bed material is expected to be composed primarily of calcium sulfate and calcium oxide in the approximate ratio of 2:3 with small amounts of calcium carbonate and magnesium oxide.⁷⁶ If dolomite is used, the major components are calcium sulfate and magnesium oxide in the approximate proportion 3:1.⁷⁷ It is expected that virtually all the coal ash will be elutriated along with approximately 40 percent of the spent bed material. About 12 percent of the carbon is unburnt in the main bed as is elutriated. There will be a carbon burn up cell which will combust about a further 90 percent. This leaves about one percent of the original carbon in the solid waste. The elutriated material will be collected by a cyclone followed by a baghouse. It is expected that the collected particulate matter will be added to the bed material for disposal.⁷⁸

FBC spent sorbent does not contain CaSO_3 , which, in the form of its hemihydrate, tends to occlude water and impact thioxotrophic properties of the slurry (sludge) discharged by the FGD systems. Thus, even if exposed to rain water or runoff water, FBC spent sorbent is not expected to form a sludge. However, the greater solubility of CaSO_4 as compared to CaSO_3 (2000-3000 vs. 4 ppm) poses a somewhat greater threat of groundwater pollution by leaching. Also, if calcium oxide is "active," a water runoff of very high

pH would result. This possibility has been verified by leaching tests.^{79,80} However, it is also possible that calcium oxide could be rendered "inactive" if it is surrounded by an insoluble calcium sulfate shell. There is some evidence that a shell may form, at least under certain operating conditions.⁷⁶

The retention of trace elements by the ash will be higher than their retention in the ash of a conventional boiler. Therefore, a larger total quantity of trace elements will be present in the waste material. The total concentration, however, might not differ greatly due to the larger amounts of material.⁷⁶ Table 4.24 includes trace element concentration ranges for FBC solid wastes.⁷²

Preliminary tests on the spent bed material and collected elutriated matter from the DOE's Morgantown Energy Research Center⁸¹ suggest that the following leachate characteristics do not appear to present problems. Total organic carbon and sulfide leachate concentrations are below detection limits and the trace metals for which some type of drinking water or potable water standard, regulation or criterion exists, through EPA, the Public Health Service or the World Health Organization (Ag, As, Ba, Be, Cd, Cr, Co, Fe, Hg, Mn, Ni, Pb, Se, Sn, and Zn) show leachate concentrations below the drinking water standards. However, these conclusions are tentative.

Acid Gas Treatment Sludges

In coal gasification and liquefaction technologies, removal of H_2S and trace sulfur species from raw product gas from the conversion reactor is necessary to prevent catalyst poisoning in the subsequent methanation step. Removal of CO_2 is also necessary to obtain a product gas with heating value equivalent to that of natural gas. H_2S and CO_2 may be removed either simultaneously or separately, depending on the specific acid gas removal process chosen and its design.

Acid gas removal processes utilize at least one of three possible techniques: (1) absorption into a solvent, (2) chemical conversion into another compound, and (3) adsorption on solids. Depending on the characteristics of the acid gas and the acid gas treatment processor employed, a sorbent blowdown containing a high concentration of solids (including possibly some organics) may be produced. The treatment of this stream may generate a sludge requiring disposal. Such a sludge would most likely contain coal-derived particulate matter,

sorbent, and sorbent degradation products.⁸² Little data on the characteristics of acid gas treatment sludges are available. The blowdown itself is estimated to have the composition shown in Table 4.29.⁸³

Sludges from Chemical Treatment of Water and Wastewater

In coal-fired combustion or conversion facilities, large quantities of water are used in treatment of coal, as feed for boilers or conversion reactors, and for cooling or quenching. Water treatment chemicals are used to demineralize and clarify most water supplies.

On the other hand, there are wastewater streams from coal combustion or conversion facilities, such as: (1) coal washing effluents, (2) slags and ashed sluice water, (3) gas liquor (coal conversion), and (4) condensates from stream units. These wastewater streams require treatment before being discharged or reused.

Some wastewater streams are highly contaminated. For example, the gas liquor of coal conversion contains various components of the product gas (carbon monoxide, carbon dioxide, hydrogen, hydrogen cyanide, and methane) in addition to pollutants such as sulfur and nitrogen compounds, ash, phenols, emulsified tar and oils, and soluble salts. Concentrations of soluble salts are high, as 300 ppm may accumulate in aqueous streams.¹⁹

Water supply and wastewater treatment may involve the use of chemicals such as lime, iron, and aluminum salts for chemical precipitation (e.g., of heavy metals) or for coagulation of particulates from process wastewaters. The sludge produced from such chemical treatments may contain precipitated inorganics (e.g., ferric and aluminum hydrolysis products, and other metal hydroxides, calcium, etc.) and inorganic particulate matter removed from the wastewater.

Tars and Oil Sludges

Tars and oils are produced in several coal conversion processes. Some conversion processes, such as BIGAS, CO₂-Acceptor, and Synthane ("deep-bed") coal injection modes of operation produce little or no tars and oil. Other processes including (gasification) Hygas, Lurgi, Slugging Gasifier, and COGAS, and (liquefaction) H-Coal, SRC, and Donor Solvent produce varied quantities of tar and oil.

Initially, tars and oils may be combined in process water. The treatment of oily processes by gravity separation (and/or flotation) and by emulsion breaking results in the production of tar and oily sludges. Tar and oily sludges can contain considerable amounts of water depending on the nature of the raw wastewater and emulsions and the system design. Oil content ranging from 7 percent to as much as 98 percent oil has been reported in the sludges from the API separators in petroleum refineries. The organic fraction of the sludge is expected to have characteristics similar to the bulk tars and oils in the process. Furthermore, tar and oily sludge is likely to contain high levels of coal-derived organic and inorganic particulate matter.¹⁹ Table 4.30 lists the major components of German high temperature conversion process coal tar. Table 4.31 lists concentrations for 3 other coal conversion tars. The highest reported concentrations are for naphthalene, phenanthrene, and fluoranthene.⁸² Table 4.32 lists trace elements in coal conversion tars and slurries.

Biosludges

In gasification and liquefaction processes, the raw gas scrubber water for gas quenching can be highly contaminated. For example, the gas quench water from gasification processes such as Lurgi, Synthane and Hygas contains high levels of organics (e.g., up to 6600 mg/l of phenols and up to 10,000 mg/l of total organic carbon). These quench waters also contain varying concentrations of trace organics such as carbazoles, benzofurans and benzo(a)-pyrenes which can be hazardous. Tables 4.33 and 4.34 present the identification and levels of organics in product waters from coal conversion processes. In addition to trace organics, the quench water can also contain significant levels of certain trace elements originally present in the coal. Table 4.35 presents the trace element concentrations in Synthane and HYGAS quench waters and the percentages of the trace elements originally present in the coal found in the aqueous condensate from the Lurgi process at the SASOL facility, South Africa.⁸²

When biological processes are employed for the treatment of quench water and other aqueous wastes, the degradation of organics and the physical entrapment and settling of suspended particles produces a biosludge. Sludges produced in the ac-

tivated sludge and trickling filtration processes are settled in the clarifiers which follow the aeration tank or the trickling filter. In these processes, a portion of the settled sludge is recycled to the aeration tank or the trickling filter, while the excess sludge is waste and requires disposal. Sludges removed from final clarifiers typically contain 2 to 5 percent solids, which generally contain 50 to 70 percent volatile matter. When lagoons and stabilization basins are used for biological treatment, the biological sludge which is produced and the settleable matter in the raw wastewater settle to the bottom, while the degradable material in the settled sludge undergoes aerobic and/or anaerobic decomposition. Depending on the nature and quantity of the solids in the raw wastewater and the lagoon design, periodic cleansing of the lagoons to remove the settled sludge may be necessary. Certain elements (e.g., heavy metals) and refractory organics which may be present in the raw wastewater at relatively low concentration levels may concentrate in the biosludges. Trace organics and metals may present an environmental problem for disposal of biosludge from coal conversion.

Spent Catalysts

Many types of catalysts are used in coal gasification and liquefaction technologies (see Table 4.36). These catalysts are used to enhance chemical reactions (coal conversion, shift, methanation) and process stream purification. While some organics are used as catalysts, the majority of catalysts used are metal-containing solid particles. For example, the shift catalysts are generally cobalt molybdate-based and the methanation catalysts are nickel-based materials supported on an inert substance such as alumina or silica.

Due to contamination, catalyst activity decreases with increased operating time. Catalysts are frequently poisoned (deactivated) by free carbon, sulfur and chlorine. The characteristics of the feedstock and catalyst as well as the operating severity are factors which determine the rate of catalyst deactivation. The conceptual design for commercial SNG facilities in the U.S. assumes a catalyst life of 6 months to 2 years.⁵⁹

Spent catalysts can either be regenerated by returning them to the manufacturer, or disposed of along with other solid wastes such as coal ash. Because of the proprietary

nature of the catalysts, very little data relative to their environmental effects are available. However, it is possible that disposal of spent catalysts may cause environmental problems. For example, it has been indicated that the spent catalysts from both shift conversion and methanation operations contain coal-derived trace elements (e.g., arsenic, cadmium), elemental carbon, and highly polymeric organic materials, in addition to cobalt and/or nickels originally existing in the catalysts.⁶²

Coal Cleaning Wastes

About half of the total coal mined in the United States is prepared or cleaned prior to utilization to remove some of the non-combustible materials. Coal cleaning is usually done at the minehead, although some may be done at utilization sites. Coal cleaning wastes consist of rocks and mineral matter such as clays, quartz, pyrites, marcasite, as well as small amounts of residual coal and unidentified matter. The rejected material represents, on the average, about 20 percent by weight of the raw coal.

Presently most of the coal cleaned in the U.S. is by physical methods.⁶⁴ The mineral wastes produced by such methods amount to 100 million tons per year. Coal cleaning is receiving increased attention as a means of reducing the coal sulfur content, and the annual production rate of coal cleaning waste is expected to double within a decade.⁶⁴

It has been known for several years that the acidic drainage from coal refuse disposal sites is often highly contaminated with various species such as iron, manganese and sulfate ions. More recently, the Los Alamos Scientific Laboratory has investigated the structure, weathering and leaching behavior of trace elements in selected samples of coal cleaning wastes.^{65,66} The study revealed the great potential of these wastes in releasing harmful quantities of trace elements.

Oxidative degradation of the pyrite and marcasite present in the coal cleaning wastes produces leachates with pH values below 2, which would put many untreated coal cleaning wastes on the corrosive waste list, even under the recently relaxed RCRA criteria. The highly acidic leachates can easily dissolve a variety of trace elements present in the wastes. Included among these are fluorine, aluminum, manganese, iron, cobalt, nickel, copper, zinc, arsenic, and lead. Some of them (e.g., copper, zinc, and cadmium) have significantly exceeded

public water supply criteria (see Table 4.37). Based on prioritization using the MEG system, six elements including iron, aluminum, manganese, calcium, nickel, and zinc were identified as presenting possible environmental concerns, particularly for the wastes resulting from high sulfur coal. The severity of contamination caused by the low-sulfur waste would be less pronounced than that caused by the high-sulfur wastes.

Solid Wastes Associated with Oil Shale Processing

The solid wastes resulting from oil shale processing include fines from crushing and conveying of the raw shale and the processed (or retorted) shale remaining after retorting. Together these constitute most of the process solids requiring disposal. Other solids to be discarded depend primarily upon the extent of upgrading of the crude shale oil which is carried out in conjunction with the retorting operations, and may include shale oil coke if experience shows that such material is not usable or marketable. Certain nonshale wastes such as spent catalysts may also be generated during the processing of shale oil. The nature and sources of solid wastes from oil shale processing are given below. The toxicity potential of these wastes is also described.

Raw Shale Fines

The primary sources of raw shale fines are the crushing operations conducted on the as-mined shale, and dust from raw shale transport within the mine-plant complex. The composition of the fines, or coarse, is essentially that of the mined, raw shale and its contained organic matter. A typical chemical analysis of the organic matter and associated mineral matter in the raw shale is given in Table 4.38.

Retorted Shale

Pyrolysis of oil shale results in the conversion of most of the original organic material in raw shale to gaseous and liquid hydrocarbons. Retorted shales containing solid organic residues can be disposed of directly as a solid waste, or can be further processed for recovery of the heat value of the residue.⁸⁷

The major physical and chemical properties of processed shale differ according to whether direct or indirect heating is used (Table 4.39). Processed shale from indirect methods is finely divided. Shale produced

by the Paraho direct-mode is coarser. Chemically, processed shale is composed primarily of sodium, aluminum, calcium, magnesium, iron, and silicon, with lesser amounts of titanium, chlorine, phosphorus, arsenic, selenium, molybdenum, and other trace elements (Table 4.40). The mineral phases that are formed during processing depend largely on the temperature reached in the retort and range from metallic oxides in low temperature processes to silicates in higher temperature processes. These mineral phases will control the leachability of the processed shale, its permeability and strength on compaction, and hence, its rehabilitation potential.⁸⁸

Burned Shale (e.g., Paraho Direct Mode [Gas Combustion Retort])

After retorting at approximately 900°F, the remaining processed shale is soft and friable. It usually has an organic "carbon" content of 2 to 3 percent, depending upon the retorting process. Direct Mode Paraho retorting produces a retorted shale which has been partially "burned" after pyrolysis of oil shale kerogen. Residual organic carbon amounts to about 2 percent by weight, and typically 30 percent of the contained carbonate minerals have been calcined.⁸⁹ Particle size is greater than 1.2 cm (0.5 inch). It is possible, in principle, to oxidize this carbonaceous material, as a source of process energy, and to discard a completely carbon-free shale residue, or ash. Typical shale ash has a composition similar to Portland cement and has certain cement-like physical properties. A typical composition is shown in Table 4.41 for several retorted shale residues.

Carbonaceous Retorted Shale (e.g., TOSCO II, Union B, Paraho Indirect Mode)

Several retorting processes do not utilize completely the carbonaceous residue remaining on the shale after pyrolysis, as a source of energy. Therefore, the retorted shale still contains about 5 percent organic matter. In addition, the maximum temperature during retorting is commonly less than that at which the dolomite and calcite in the shale rock decomposes, or at which calcium silicates form. Typical chemical composition of the ashes from TOSCO II and Union B processes is given in Table 4.23.⁹⁰⁻⁹²

Retorted shale from the Superior process will have different properties than retorted shales from other processes. The raw oil

shale found in deep deposits of the Northern Piceance Basin contains sodium and aluminum minerals, and these are slated for recovery along with pyrolysis products by the Superior Oil Company. Superior retorted and processed shale may be partially "burned," depending on the mode of operation, and will have been stripped of most of the soluble sodium and aluminum salts. Little is known at present about the detailed physical and chemical properties of such processed shale.

Organic Substances in Retorted Shales

The carbonaceous component of processed shales contains organic substances which can be extracted by organic solvents (e.g., benzene), and by water. From .01 to .1 percent by weight of processed shales are benzene soluble, and substances such as phenols, aromatic acids, and amines are present in the soluble fraction. Compounds belonging to the polycyclic organic matter (POM) class are also present in benzene extracts, including the suspected carcinogen benzo(a)pyrene (BaP).⁹³

Trace Metals In Retorted Shale

Distribution and migration of trace metals during retorting of oil shale was analyzed by Shendrika and Faudel.⁹⁴ Results (see Table 4.42) indicate that the majority (greater than 99 percent in all cases except arsenic) of the trace elements are retained by the retorted shale.

Processed shales contain mineral components which may be partially dissolved by water. Laboratory and field experiments have shown that sodium, calcium, magnesium, potassium, barcarbonate, sulfate, and chloride are present in water which has contacted freshly processed shale.⁹⁵ Table 4.53 presents the results of laboratory leaching experiments of raw and retorted shales. TOSCO II and USBM retorted shale each contain about 10 kg/tonnes (20 lbs/ton) of readily leachable salts, roughly ten times that leachable from raw oil shale. Data for the burned shale from the Union A process (Column 4 in Table 4.43) indicate that total soluble salts depend heavily upon the extent of carbon burnoff and mineral decomposition which occurs in the combustion zone of a gas combustion retort.

The rate and extent of leaching of soluble inorganic salt from retorted shale which will occur under field conditions depends on a number of factors in addition to the type of retorting process employed. Such factors

include the amount of water added, the degree of compaction accomplished, the manner in which a pile is laid down (e.g., slope, depth of pile), the extent of preleaching which is accomplished in connection with revegetation, and the age or weathered state of the shale pile. Also, burned shales can form partially cemented barriers to water within a disposal pile, which can serve to inhibit further leaching.

Other Shale-Derived Solid Wastes

Retorting and on-site shale oil upgrading can result in the production of shale-derived wastes such as coke and oily sludges.

Shale Oil Coke

If the crude shale oil produced by retorting is upgraded on site prior to shipment to market, a possible product is coke. This coke must be stored prior to sale or will require disposal as a waste. Shale oil coke is expected to have the typical composition shown in Table 4.54. Storage or disposal piles are potentially the sources of salts and organic substances to the environment.^{96,97}

API Separator Sludges

Oily and tarry material separated from wastewater may constitute a semi-solid waste requiring disposal. Such material may contain suspended solids, hazardous organics, and trace elements; and may have characteristics similar to separator sludges produced in coal conversion processes and petroleum refineries. Handling options include (1) burial with other solid wastes in the processed shale pile, (2) incineration with air pollution control, and (3) reinjection into the retort or upgrading units.

Non-Shale Solid Wastes

If substantial upgrading operations are conducted at or near the retorting site, non-shale solid wastes will be generated which require disposal. Such wastes include spent catalysts from hydrotreating, sulfur recovery, and arsenic removal operations; lime sludges and other solids from water and waste water treatment systems, and spent carbon and diatomaceous earth from gas and oil treating units.⁹⁸ Catalysts used in upgrading could contain from 72 to 136 tons of arsenic per year, as well as trace amounts of nickel, vanadium, and other metals. The quantities of upgrading solid wastes are shown in Table 4.45.

Emission of hazardous materials may result during the handling, disposal or reprocessing of these wastes. Hydrodenitrication catalysts for example, may contain 10 to 13 percent carbon, 8 to 10 percent sulfur, and up to 7 percent arsenic after their useful activity has been exhausted and regeneration or disposal is required.⁹⁸

Solid Wastes Associated with Other Energy Technologies

Geothermal Technologies

Geothermal resources of near-term interest are of three types: hydrothermal, geopressured, and hot dry rock.⁹⁹

Hydrothermal Systems

Hydrothermal systems are convective systems of water and steam that are trapped in fractured rocks or permeable sediments by impermeable surface layers. Geothermal fluids may be released when such systems are tapped by drilling.

Geopressured Systems

Geopressured zones consist of highly porous sands saturated with saline water at very high pressure and temperature. The high temperature is thought to be the result of normal heat flow being trapped by un-compacted clays which serve as insulating layers.

The magnitude of the resource is substantial, and its economic value is enhanced by the presence of natural gas dissolved in the geopressured fluid; however, difficult technical and economic problems must be solved before geopressured resources can be utilized commercially.

Hot Dry Rock Systems

Hot dry rock resources are those geothermal reservoirs where the heat is contained in rock of low permeability.

Development of these resources requires drilling into the rock, inducing fractures, injecting fluids, and removing the resultant heated fluid through separate wells. Technical problems associated with fracturing and maintaining the fractures must be solved before these resources can be developed commercially.

One of the major environmental concerns in geothermal energy utilization has to do with the disposal of spent geothermal fluids. These materials represent a significant potential for contamination of ground and surface water.

Many geothermal fluids contain sodium chloride, sulfates, and bicarbonates, constituents normally found in groundwater in much lower concentrations. The specific composition of geothermal fluid naturally varies from place to place. In Boise, Idaho, for example, where a major effort to develop geothermal systems for commercial and residential heating is under way, the geothermal fluids contain fluoride at concentrations of up to 22 ppm, 12 times the drinking water standard. Arsenic, lead, potassium, and total dissolved solids also reach high levels in some areas.¹⁰⁰ Table 4.46 compares geothermal fluids with water.

The hydrothermal resources in the Salton Sea geothermal resource area in Imperial Valley, California, produce highly saline fluids containing primarily NaCl with varying amounts of Ca. Potassium concentration is high relative to surface water. Sulfate content is low and small amounts of carbonate bicarbonate are usually present. B, Li, Mn, Sr, and Zn are among the more abundant trace elements in geothermal brines throughout the valley.¹⁰¹

Spent fluids may be reinjected into the geothermal systems, but have greater significance in geopressured systems due to the difficulty in injecting the spent fluids back into the reservoir because of great depths and very high pressures. The problem is minimized somewhat in the hydrothermal case due to the relatively lower salinity of spent fluids.

If the spent fluids are dumped on the ground instead of being reinjected there is a risk of seepage into shallow groundwater systems. Though surface water contamination is usually avoided by reinjection, some contamination can still occur.

Long term subsurface injection in many cases may not be possible without the treatment of the spent fluids to remove solids that would plug the well bore or reservoir. Should treatment be required, additional, possibly significant, quantities of solid wastes will be generated and require disposal.

Oil and Gas Extraction

Oil and gas extraction wastes include oil and gas drilling fluids and oil production brines. Oil production brines are coproduced in association with crude oil from an underground reservoir and consist primarily of brackish waters. Drilling fluids are used in the drilling of oil and gas wells to cool

and lubricate the drilling bit, transport drill cuttings to the surface, balance formation pressure, seal the walls of the bore hole, and perform various other related functions.

This section provides a characterization of the oil and gas drilling fluids in terms of their composition, volume, and current disposal techniques. Information presented is primarily summarized from a recent report by Fred C. Hart Associates, Inc.¹⁰²

Composition of Oil and Gas Extraction Wastes

The basic drilling fluid predominantly used by the industry is a water-based bentonitic or attapulgite clay suspension with ferrochrome or chrome lignosulfate added to control fluid viscosity, barium sulfate added to increase fluid density, and a caustic added to maintain an alkaline pH of about 9-11. Oil-based fluids are used for some special applications, but their use is much less common than water-based fluids. Also, oil-based fluids are generally saved for re-use rather than being disposed of after completing a well.

Additives to the basic drilling fluid provide specifically desired properties. Hundreds of compounds are available for use as drilling fluid additives, and about 12 may be used for drilling a given well. Some of the more commonly added materials include detergents, organic polymers, tannin, phosphates, corrosion inhibitors, and bactericides. In addition, fluids may contain asbestos fibers, dissolved metals (e.g., barium, cadmium, chromium, copper, iron, lead, nickel and zinc), salts, and humic acids.

Although water-based drilling fluids consist of over 99 percent water and other relatively non-toxic components, many of the additives to drilling fluids contain materials which are considered toxic. Of particular concern are the bactericides (e.g., aldehydes, quaternary amines, diamine salts, sodium pentachlorophenate and other chlorinated phenols), corrosion inhibitors (e.g., arsenites), metals, coal tar derivatives, emulsion breakers, and low molecular weight organic additives (e.g., benzoic acids, dihydroxybenzenes, substituted naphthalenes, amines, and imidazolines). Many drilling fluid additives are water soluble; therefore leachate from drilling fluid disposal could contain dissolved toxic materials, a high salt concentration, and caustic materials.

Oil Refining Wastes

Wastes from the petroleum refining industry include: American Petroleum Institute (API) separator sludge, dissolved air flotation (DAF) float, slop oil emulsion solids, heat exchanger bundle cleaning sludge and tank bottoms (lead). Biosludges from refineries have been reported to contain Cr and Zn values of 540 and 200 mg/kg of dry sludge, respectively.¹²⁹

Tar Sands

Tar sands are mixtures of mineral grain (normally sand grains) and organic (bitumen), which are potential sources of liquid fuels (e.g., gasoline, jet fuel, heating oils). To make liquid fuels from tar sands the bitumen and the mineral grains must be separated, and the bitumen must then be converted to a material which is suitable for a liquid fuel. The conversion process usually involves coking to raise the hydrogen-to-carbon ratio and hydrotreating to remove sulfur.

The solid wastes to be dealt with in a major tar sand operation are: top soil, overburden, and tailings. Top soil and overburden are produced when the material is extracted by open pit or surface mining, and they may be handled in the same manner as at surface coal mining operations. Tailings are the processed tar sands which are generally pumped in slurry form to the tailing pond and stored for dewatering and revegetation. In addition to these wastes, bitumen conversion processes would produce solid wastes, such as coke and oily sludges.

The general lack of hard data on energy waste streams, discussed earlier in this document, extends to tar sands processing as well.

EPA reported sulfur contents of Utah tar sands ranging from 0.14 percent to 6.2 percent. An average of 0.4 percent of sulfur is quoted for the tar sands in the Uinta Basin (80 samples). Average metal concentration of Utah tar sands are listed as:¹⁰⁴

Chromium	103 parts per million
Cobalt	102 parts per million
Copper	110 parts per million
Manganese	547 parts per million
Nickel	203 parts per million
Zinc	212 parts per million

Leachates from tailings piles need to be analyzed for organics, salinity, nitrogen, heavy metal and trace organics. Bioassay studies are also needed, particularly in light

of the reported aquatic toxicity of seepage from the wastepond of the Great Canadian Oil Sands.¹⁰⁴

Nuclear Power Generation

Radioactive wastes, the inevitable by-products of the generation of electricity by nuclear reactors, are encountered at all stages of the nuclear fuel cycle—in mining and milling, in fuel fabrication, in reactor operation, in spent fuel assemblies, and in the reprocessing of spent fuel. Nuclear wastes can be divided into 5 classes: high-level waste (HLW), made up of spent fuel and reprocessing wastes; transuranic (TRU) waste; low-level waste (LLW); uranium tailings; and decommissioning/decontamination (D/D) waste.

This section presents the kind and quantities of radioactive wastes that are generated in the nuclear fuel cycle, and identifies several areas of potential risks associated with the disposal of these wastes.

High-Level Wastes

High-level wastes can be either intact spent fuel assemblies removed from a reactor after serving their useful life or the wastes generated as a result of spent fuel reprocessing. A 1000-MWe light-water reactor discharges annually about 30 metric tons of spent fuel using the once-through fuel cycle.¹⁰⁵ Commercial spent fuel contains about 96 weight percent of the uranium originally charged to the reactor as fresh fuel in addition to 3 weight percent fission products and 1 weight percent TRU elements and daughters.¹⁰⁶ Most fission products decay to stable elements after several hundred years, whereas TRU elements remain radioactive for thousands of years. Consequently, spent fuel initially generates a great deal of heat and is very radioactive. After a decade, the heat generated decays by a factor in excess of 300, while the radioactivity decays by a factor of 1000.¹⁰⁵ Currently, commercial spent fuel assemblies are stored at the reactor site awaiting a decision on the question of spent fuel reprocessing. If reprocessing is not used in the nuclear fuel cycle, spent fuel will remain the bulk of the waste generated. Twenty-three hundred metric tons of heavy metal already exist from past reactor operations.¹⁰⁷

If the nuclear fuel cycle is closed and spent reactor fuel is reprocessed to recover uranium and/or plutonium, a different type of HLW will become the bulk of the

wastes generated. Reprocessing wastes contain 84 weight percent fission products and 16 weight percent actinide wastes,¹⁻⁸ i.e., elements with atomic numbers greater than the element actinium. In addition to lessening the volume of wastes that must be disposed of, spent fuel reprocessing reduces the amounts of transuranic elements in the waste. However, the consequent reduction in waste disposal risk achieved by reprocessing and recycling must be balanced against the new risks entailed in using plutonium in the active fuel cycle and in processing large quantities of radioactive materials.

Transuranic Wastes

Transuranic wastes, i.e., wastes containing elements with atomic numbers greater than uranium, result primarily from spent fuel reprocessing and fuel assembly refabrication; very little is generated by the once-through fuel cycle. Transuranic wastes are currently defined as material containing more than 10 nanocuries of TRU activity per gram of material.¹⁰⁹ Because of their long half-lives, TRU wastes must be isolated from biosphere for time periods similar to those for HLWs, i.e., 10^3 to 10^6 years.¹¹⁰ However, problems associated with heat generation and temperature increases are absent, and since TRU wastes are easier to handle than the HLWs, the operational demands on disposal system designed for TRU waste alone would be more modest than those associated with an HLW repository. This means a special TRU repository could precede the development of an HLW repository due to the elimination of concerns about heating effects.

Low-Level Wastes

In contrast to TRU wastes, low-level wastes are defined as containing less than 10 nanocuries of TRU per gram of material or may be altogether free of TRU activity, but LLWs might have potentially hazardous amounts of fission products. LLWs are generated in all phases of the nuclear fuel cycle and other operations that utilize radioisotopes. Disposal of LLWs consists of burial in shallow pits; 14×10^6 of commercial and 46×10^6 metric tons of defense LLWs have already been buried.¹⁰⁷

Uranium Tailings

The residues from the mining and milling of uranium also contain low concentrations of naturally occurring radioactive elements.

Uranium mill tailings are generated in large volumes and 130 million metric tons are now stored uncovered at various sites of mining and milling operations.¹⁰⁷ Because tailings emit the carcinogenic gas radon-222, the stabilization of these piles from water and erosion is of great concern. According to Victor Gilinsky, nuclear physicist and NCR member, uranium tailings could become the dominant source of radiation exposure to the public from the nuclear fuel cycle, unless the tailings are isolated from the atmosphere.¹¹¹

Decommissioning/Decontamination Wastes

The final category of nuclear wastes involves those generated upon the retirement of a nuclear facility due to obsolescence or adverse economics of radioactive wastes. D/D is potentially a source of large quantities of radioactive wastes. The volume of LLW (no TRU) that might result after the shutdown of an 1160 MWe reactor could vary from 60 m³ under a mothballing procedure, to 23,000 m³ for complete removal/dismantling.¹⁰⁶ Until retired nuclear facilities and land are decontaminated, such facilities and land must be considered and treated as waste storage sites.

CURRENT LEVELS OF SOLID WASTE GENERATION

One of the most basic problems in solid waste management is the quantity of materials that require collection, transportation and disposal. Currently, solid wastes are produced in this country at a rate of 487 million tons per year. This includes 344 million tons of industrial solid waste, 130 million tons of municipal refuse, 5 million tons (dry weight) of municipal waste water treatment sludges, and 8 million tons (dry weight) of scrubber sludges from air pollution control devices.¹¹²

With the future increased reliance upon coal utilization and synthetic fuel technologies, and the concurrent application of pollution control devices, projections are for a substantial increase in solid wastes, largely attributable to the energy industry. Figure 4.2 shows the projected changes in the generation of noncombustible solid waste (including bottom and fly ash, boiler slag, spent shale and particulates) and sludges (including FGD

scrubber sludge, sludges from municipal wastewater treatment and industrial air and pollution control treatment) from 1975 to 2000, depending on the world oil price. These figures were derived from projections based upon the President's Second National Energy Plan.¹¹² The following discussion is also taken from an analysis of the solid waste trends and impacts which might result from meeting the Second National Energy Plan.

In 1975, the energy industry contributed only 1.6 percent of the total sludge (Table 4.57). The relative contribution would increase to 75 percent in 2000 under the low world oil price scenario and 85 percent under the high world oil price scenario. These increases in sludge generation would be caused almost exclusively by the installation of wet scrubber systems for removal of sulfur compounds from stack gases of both utility and industrial coal-fired boilers and from the synthetic fuels industry. Whereas electric utilities produced about 70 thousand tons of sludge in 1975, by 2000 production would be more than 35 million tons under the low world oil price and 40 million tons under the high oil price. These scrubber sludges in 2000 are 56 and 48 percent from utilities under the low and high world oil price, respectively.¹¹²

While the amount of industrial sludge generated is a function of pollution control efficiency, noncombustible solid waste production is related to the types and quantities of energy resources being converted. Table 4.58 indicates that the generation of noncombustible solid waste would increase from about 76 million tons in 1975 to 568 million tons in 2000 under the low world oil price and to over 775 million tons in 2000 under the high world oil price scenario. Of these amounts, 372 and 537 million tons, respectively, are from oil shale retorting.¹

Noncombustible waste would be generated primarily by the energy industry in both the high and low oil price scenarios, because of the increased level of activity in the coal electric utility industry and in the production of synthetic fuels, especially shale oil. The amount of solid waste generated by the energy industries combined would increase by a factor of 10 in the low world oil price scenario and by a factor of 14 under the high price scenario. The energy industries would contribute 89 and 92 percent of the noncombustible solid waste and sludge in 2000 under the high and low oil prices, respectively.¹¹²

Coal-fired electric utilities would produce more than double the amount of noncombustible solid waste in 2000 as in 1975 under both world oil price scenarios. The percentage contribution of the coal-fired utilities, however, would drop under both scenarios due to the growth of the synthetic fuels industry.

In 2000, the synthetic fuels and oil shale industry would contribute 384 million tons of solid waste under the low world oil price scenario and 576 million tons of waste under the high world oil price scenario, accounting for 68 and 74 percent of the total solid waste generated in the high and low scenarios, respectively. Over 90 percent of the wastes generated by synthetic fuels would result from activity in oil shale production. Synthetic fuels from coal would result in 12 to 39 million tons of noncombustible solid waste in 2000, approximately 13 percent of those electric utility ashes in the low world oil price scenario and 36 percent of those electric utility ashes in the high price scenario.¹¹²

At this time, uncertainties as to the eventual choice of synfuel processes, pollution control technologies, and the mix of energy sources make accurate estimations of solid waste quantities difficult. The following sections are a compilation of available data on energy related solid waste generation from the primary sources.

Coal Combustion

There are six major categories of solid wastes associated with coal utilization: (1) chars and ashes from combustion and conversion (gasification and liquefaction), (2) inorganic solids and sludges from FBC, air and water pollution control, and acid gas removal, (3) tars and oil sludges, (4) oil sludges, (5) spent catalysts, and (6) coal cleaning wastes.

Based on the quantitative estimates of solid wastes conducted by Argonne National Laboratory, a significant increase in energy-related solid wastes was projected (see Table 4.49). Ash from electric utility sources was estimated to increase from 58 million tons (MT) in 1976 to 134 MT in 1995; ash from industrial coal combustion increases from 7 MT in 1976 to 46 MT by 2000, a sixfold increase. FGD sludge increased from 0.8 MT in 1976, to 51 MT, an increase by almost 40 times. These estimates were based on an energy scenario used in a DOE annual report to Congress (1978).¹¹³

Of particular concern is the large fraction of coal solid wastes, particularly in the industrial sector, that will occur in urban areas. By 2000, 53 percent of industrial ash will be generated in urban areas, rising from 3.9 MT in 1975 to 22 MT in 2000, and eightfold increase (see Table 4.50).¹¹⁴

As expected, the fraction of wastes occurring in urban areas in the Northeast is substantially higher than in the nation as a whole, as indicated below:

% Residuals in Urban Areas, 2000 High Scenario

	Utility Ash	Utility FGD	Industrial Ash
New England	68	61	50
New York/NJ	51	47	82
National Average	26	24	53

This points to the special problems likely to be encountered in this region.¹²⁰

While waste quantities vary greatly depending upon fuel characteristics and pollution control measures, typical waste generation quantities are 578 tons of ash and scrubber sludge/year/MW for facilities with Flue Gas Desulfurization (FGD) and 312 tons coal ash/year/MW for facilities without FGD facilities.¹¹⁵ For a typical industrial boiler of 50 MW capacity with FGD, the annual quantity of waste generated is almost 30,000 tons.¹¹⁵

Attainment of current state implementation plans (SIPs) by 1985 will require that some 69 coal fired units be either retrofitted with FGD systems or require coal cleaning. 30 GW of the nationwide 39 GW of such capacity is concentrated in the states of Ohio, Michigan, and Illinois (Federal Region 5). Because 28 of these units are in urban areas, areas where sludge disposal would be likely to encounter the greatest difficulty, the necessity to rapidly expand mine-mouth coal cleaning capabilities in this region becomes clear if SIPs are to be met by 1985.

The largest increase in utility ash production is projected to occur in Region 6 (Texas, Oklahoma, New Mexico, Louisiana, and Arkansas), from 1.7 MT in 1975 to 32.4 MT in 2000, accounting for 35 percent of the national increase in ash generation.¹¹⁴

The largest increases in utility scrubber sludge occur in Region 5 (Illinois, Indiana, Michigan, Ohio, Wisconsin, and Minnesota); because this region burns higher sulfur coals than Region 6, the quantity of FGD wastes per unit of electricity generated is much greater.¹¹⁴

Synthetic Fuels from Coal

Solid wastes generated during the gasification or liquefaction of coal include tars, elemental sulfur, char and ash. Tars are generated during the gasification processes at the rate of 12 to 25 gallons per ton of coal feedstock. Char and ash are generated at the rate of approximately 200 pounds per ton of coal gasified.¹¹²

The basic types of solid waste streams produced by coal gasification and liquefaction processes come from: coal pretreatment, the reaction modules, product purification and upgrading, and auxiliary processes such as pollution control and power generation. Estimates of how much of each solid waste will be produced by a full-scale facility vary, as shown in Tables 4.51 and 4.52. Comparison of estimates from different studies is not easy because sizes of full-scale facilities used for the estimates vary, system configurations and modules employed vary, assumptions about coal types used vary, and units in which plant sizes and emissions are expressed also vary. The estimates shown, however, are within one order of magnitude, and indicate that for a 4.8×10^{11} Btu/day Lurgi gasification facility, annual solid waste production could be as much as 1×10^6 tons of coal preparation refuse, $5-8 \times 10^5$ tons per year of gasifier and boiler ash, 1 to 9×10^5 tons per year of FGD sludge, and 14-20,000 tons per year of biosludges from wastewater treatment. Total annual solid waste production is estimated at 1.35×10^6 tons per year. This could require 50 acres of land per year for disposal by ponding or landfill (assuming 10 foot depth in landfill) or up to 1000 acres in 20 years, the expected life of the plant.¹¹⁶

An H-Coal plant of the same size could produce annually 3.6×10^5 tons of char, ash or mineral residue, 7×10^5 tons of sludges, 3×10^5 tons of spent catalysts, and 94×10^5 tons of particulates. Total solid wastes produced annually could equal 1.7×10^6 tons, 25 percent more than the Lurgi plant, and require 63 acres of land for disposal each year by landfill.¹¹⁶

Oil Shale Wastes

Over 90 percent of the wastes generated by synthetic fuels would result from activity in oil shale production. The problem of spent shale disposal is localized in Federal Region 8, where the combined total of solid wastes in the region is expected to be from

under 4 million tons in 1975 to between 385 to 576 million tons in the year 2000.¹¹²

Oil shale conversion produces large volumes of solid wastes in the form of processed shale, mine overburden, construction debris, catalysts, and sludges. The quantities and nature of these materials depend on the type of kerogen extraction process that is used. For the 47,000 barrel per day Colony Development Operation at Grand Valley, Colorado, in which the TOSCO II process will be used, the amounts of solid wastes are summarized in Table 4.53.⁸⁸ Processed shale, which is a residue remaining after the kerogen has been extracted, is the principal solid waste. Because oil shale expands in volume during mining and retorting, not more than 80 percent of the excavated material can be returned to the mine, even under the most favorable circumstances, and much of the processed shale inevitably must be disposed of somewhere on the surface.

On-site surface disturbances for oil shale development would depend on the location, size, and nature of the operation. For the richer grades of oil shale, surface retorting generally produces about 1.4 tons of processed shale for each barrel of oil. In situ processes, in the other hand, leave large quantities of spent shale underground and produce lesser amounts of solid wastes for surface disposal. A true in situ process may leave about 2.8 tons of spent shale underground for each barrel of oil produced. If a modified in situ process is used, 20-30 percent of the in-place shale is mined and is either stockpiled on the surface or retorted. If the mined material is retorted, then, for each barrel of oil produced, 0.4 ton of processed shale must be disposed of at the surface, while 1.9 tons of spent shale is left underground.⁸⁸ The issue of handling these large amounts of waste was examined in detail in the first section of this report.

Current plans for spent shale disposal are summarized in Table 4.54. In addition to the processed shale, the retorting process generates an effluent referred to as "retort water," which is produced with the oil. Retort water originates from combustion, mineral dehydration, steam used in the retorting process, and—for underground retorts—from inflow of groundwater. Retort water may pose a major environmental problem because of its volume and composition. The quantities of retort water produced for some pilot and field experiments are given in Table 4.55. In situ

processes may generate more water than they consume, producing from 0.4 to 22 barrels of retort water for each barrel of oil, depending on the process and the feasibility of controlling inflow of groundwater. Thus, for a 100,000 barrel per day in situ industry, which may be reached in the next decade (Table 4.56), from 2 million to 92 million gallons of retort water may be produced each day. On the other hand, surface processes may produce less than 0.15 barrels of water per barrel of oil, and all this water can be used in the process.⁸⁸

Nuclear Wastes

The future contribution of nuclear power to the nation's energy supply is difficult to predict. As of March 31, 1979, 70 nuclear power plants with a combined generating capacity of 51,000 MW were licensed to operate in the United States on 48 sites in 37 of the 48 contiguous states. Together, they supply about 13 percent of the nation's electrical power and about 4 percent of total U.S. energy use. An additional 96 units representing 101,000 MW were under construction or authorized. Since October 1978, utilities have announced slowdowns in construction or have cancelled plans for 25 nuclear plants: 7 because demands for electricity continue to be lower than expected a few years ago, 9 for financial reasons, and 9 because of construction difficulties.¹¹⁷

Estimates of nuclear waste generation in Table 4.49 assume a sixfold increase in nuclear generation from 1976 to 1995. The RIIA II Solid Waste Analysis predicts that nuclear generation in the 2000 scenario will be 4.1 times the base year generation, with exhaustion of storage pool capacity in existing plants by the mid-1980's.¹¹⁴ Table 4.57 lists quantities of existing waste; Table 4.59 provides quantities of solid waste generated annually.¹²⁰ Also, see Section 5, Nuclear Waste Disposal Sites, for a further breakdown of the existing quantities of nuclear waste.

Oil and Gas Extraction Drilling Fluids

The quantities of drilling fluids and various fluid components used during a drilling operation vary depending on the requirements of the drilling station, formation characteristics, and specific drilling practices. The amount of drilling fluid used for a typical 15,000 to 18,000 foot offshore well has been estimated at 690 to 820 tons, with a variability of as much as 50 percent

from well to well. For onshore wells of comparable depth, similar quantities of drilling fluids would be used, and for shallower onshore wells, the quantity of fluid required would be somewhat less. For example, the quantity of fluid used for drilling wells at the Naval Petroleum Reserves ETK Hills field is estimated at 50 to 100 barrels per thousand feet of well depth, for a total of approximately 50,000 barrels per year for approximately 150 wells of 5,000 to 10,000 foot depths.

During some offshore drilling operations, used fluids may be combined with solid cuttings and rig deck wash water, and stored for later disposal. Mixing with wash water greatly increases the total volume of material requiring disposal; typically, 5,000 to 50,000 barrels may be collected by the end of such a drilling operation.

Regarding annual disposal requirements for drilling fluids used in U.S. drilling operations, the quantity of gas and oil drilling muds and oil production brines are estimated by EPA to be 5 million metric tons per year.

Oil Refining Wastes

The EPA has proposed regulations (400 CFR 419) which would require the petroleum refining industry to pretreat process wastewater before discharging it into publicly owned treatment works and into U.S. waters, as specified by the requirements of the Clean Water Act. According to EPA, achievement of BAT effluent limitations will remove from process wastewater approximately 123,000 pounds per year of chromium, 86,180 pounds of phenols annually, as well as substantial quantities of other toxic pollutants. Some 48.7 million pounds per year of conventional pollutants are expected to be removed by achievement of BAT effluent limitations. These solid/hazardous wastes, largely in the form of sludges, will require proper disposal.

Other Solid/Hazardous Wastes

The vast quantities of industrial, municipal, and agricultural non-energy related wastes form the bulk of our national waste disposal problem. They are a larger burden to state and federal regulatory programs, and compete with energy waste sources for available disposal sites. Several comparisons are applicable to the examination of energy production and solid/hazardous waste media. For industrial hazardous

wastes, EPA estimated in mid-1979 that, under RCRA classifications of hazardous wastes, 10 to 15 percent of the 344 million metric tons of industrial waste produced each year is hazardous. Of this 51 million tons, 1.5 tons is generated by oil refining.¹¹⁸ Such hazardous waste is estimated to be growing at three percent per year.¹¹⁷ Municipal solid waste and sewage sludge will also increasingly burden disposal sites as RCRA implementation empowers EPA to close open dumps and require upgrading of treatment plants. Municipal solid waste is estimated to have been 154 million tons in 1978, the equivalent of 1,400 pounds per person.¹¹⁷ Sewage sludge was 4 million dry metric tons in 1977 and projected to be 5 million tons in 1987.¹¹⁹ Agricultural wastes, including animal manure, crop residues, and timber production, was calculated at 642 million dry tons in 1979.¹¹⁹

EFFECTS AND METHODS OF SOLID/HAZARDOUS WASTE DISPOSAL

The degree of relative hazard to public health and the environment inherent in solid waste handling is a major factor in the engineering of disposal methods. Wastes that exhibit relatively few hazardous characteristics can much more easily be recycled, e.g., as a product component. If these low level wastes are not utilized, the disposal sites, such as ponds or fills, may be reclaimable. More dangerous wastes must be segregated from contact with the environment, especially groundwater. This section on solid hazardous waste disposal will relate hazard characteristics to disposal options. It will also examine the potential for environmental threat if containment structures degrade over time or are accidentally breached. Nuclear waste disposal is unique among energy related waste handling problems. This very controversial issue centers around the length of time for which disposal is required, up to one million years. The issue of viable disposal methods for handling radioactive wastes was discussed previously in the issues section and, therefore, has not been repeated here.

Hazard Characteristics

The environmental impact of solid wastes from energy-related activities cannot be assessed without a thorough understanding

of their hazard characteristics. This section attempts to explore the hazard potentials of selected waste streams by considering such factors as leachate composition, toxic substances, and biological effects.

Numerous wastes from the industrial sector have been determined by EPA to be potentially hazardous to human health and the environment. For example, the ammonia still lime sludges from the coking industry, and slop oil, API separator bottom, and DAF float produced in petroleum refineries have been determined to be potentially hazardous and would be subject to appropriate management requirements under Subtitle C of RCRA. In this section, wastes streams generated in energy-related activities which may be closely related to industrial hazardous wastes are identified. Table 4.59 gives a summary of the relative hazard potential for energy wastes presently not included under Subtitle C.

Coal Utilization Wastes

Ash from Coal Combustion

Trace Elements: Generally, the soluble matter in coal ash includes several mg/l of iron, nickel, and zinc sulfates, as well as trace quantities of chromium, copper, lead, arsenic, and cadmium.¹¹⁸ The largest quantity of soluble matter, however, consists of calcium, magnesium, potassium, and sodium sulfates, and anhydrous oxides, which raise TDS levels but are not considered toxic pollutants. Fly ash typically contains higher concentrations of soluble material than does bottom ash, usually in the range of several percent. Table 4.60 presents recent available data on concentrations of various pollutants including some priority pollutants found in ash pond liquors and sluicing waters. In Table 4.61, trace element concentrations in leachate from conventional combustion ash (FGD) are compared with those from FBC, H-Coal and Lurgi gasification.⁷²

Table 4.62 compares the equilibrium concentrations of various trace elements in ash leachates from five different power plants with the various water quality standards.¹²⁰ Concentrations that exceed one or more of the standards are encircled in the table. Note that the concentrations of arsenic, barium, boron, chromium, mercury, molybdenum, and selenium exceeded one or more of the water quality criteria at one or more of the power plants. The pH of the leachates studied ranged from 8.2 to 12.5.

The American Society for Testing Materials (ASTM) has recently conducted a study to evaluate the toxicity potential of leaching trace elements from various fossil energy materials, including, among other things, coal fly ash, bottom ash, boiler slag, and fluidized bed combustion residues.¹²¹ Each of the waste materials was tested using three different extraction procedures: ASTM Methods A and B, and EPA's proposed Extraction Procedure (EP). The leachates extracted under each method were analyzed for pH, calcium, and metals including arsenic, barium, cadmium, chromium, mercury, lead, selenium and silver. Eighteen laboratories participated in the program. The study concluded that:

"Analytical test methods and extraction procedures have not been developed to the point where testing can lead to reliable statements regarding classification of materials tested under the program with respect to their toxicity."¹²¹

Nevertheless, the report reveals that, for many of the waste residues tested, selenium levels were, on the average, in excess of then proposed EPA limits (i.e., ten times the EPA Interim Proposed Primary Drinking Water Standards). Other average trace metal concentrations which occasionally exceed the proposed limits were arsenic, cadmium, chromium, and lead. None of the residues yielded a leachate containing excessive concentrations of barium, mercury, or silver.

Trace element levels in coal ashes and leachates are compared in the following paragraphs against that of some industrial wastes which have been classified as hazardous.

EPA has determined that, in the petroleum refining industry, the wastes including API separator sludge, dissolved air flotation (DAF) float, slop oil emulsion solids, heat exchanger bundle cleaning sludge and tank bottoms (lead) may pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, disposed of, or otherwise managed.¹²² The waste water treatment sludges from the electroplating operations and the primary zinc smelting and refining operations have also been determined to be potentially toxic. These wastes contain significant levels of toxic heavy metals such as lead and chromium. In addition to being toxic, lead has been shown to be potentially carcinogenic and bioaccumulative.

Table 4.60 shows the data on the composition of some of these wastes as well as that of bottom ash and fly ash generated from conventional coal combustion. Some of these data are quite comparable.

Trace Organics

A number of reports have been published on the mutagenicity of coal fly ash.^{60,123,124} Reports from two different group samplings at seven power plants have concluded that although fly ash leaving the stack to the atmosphere is mutagenic in the Ames Salmonella reversion assay, the ash that is collected as solid waste in the electrostatic precipitator is not mutagenic in this assay.

Bonnell and Schilling¹²⁵ also reported no mutagenic activity in fly ash collected in the electrostatic precipitator hoppers from a large British coal fired power plant. Fisher, et al.⁶⁰ concluded that if there is any mutagenic activity in collected ash, it must be less than 0.2% of that in the material emitted to the air. Apparently the mutagenic activity is due to compounds volatilized or formed during combustion and absorbed on the surface of fine particles—which present the most surface area—as the effluent stream cools. This presumably takes place after the exhaust gases pass through the precipitator. They also conclude that use of low temperature precipitators could lead to contamination of the bulk of the collected fly ash with mutagens. They recommended high temperature, high efficiency collection of particles followed by cooling of the effluent stream and separate collection of the organic matter. The latter would yield a hazardous solid waste that is much smaller in volume.

In addition to the mutagen assay studies, there have been reports of specific mutagenic agents in fly ash. Dow Chemical Corporation reported 38 g/g tetrachlorodibenzo-p-dioxin (TCDD) in the stack effluent of an industrial power plant burning coal and fuel oil.¹²⁶ These findings are disputed in a report finding no evidence of TCDD in the fly ash emitted from coal-fired power plant stack.¹²⁷ No measurements have apparently been made for TCDD or other dioxins in fly ash collected as solid waste.

Lee et al.⁶⁴ reported finding dimethyl and monomethyl sulfate in the particles emitted from a soaker type coal-fired heating plant and a large coal-fired power plant. Similar to TCDD, one would expect lesser quantities in the collected ash. Moreover, there is

some question as to the general applicability of the results.

These studies would indicate that there is no risk of mutagenic activity in fly ash collected in current ESP hoppers of large coal-fired utilities. The limited number of plants studied, however, cannot allow this conclusion to be drawn generally with much confidence. Much more testing is needed. Further, it is particularly important that testing be done in situations where flue gases are apt to be cooled before particle collection. This would include some industrial boilers and facilities with bag houses. The effect of wet scrubbing on mutagenic activity in collected ash must also be evaluated. Finally, findings of mutagenic activity in ash released to the air may lead to the need for new air pollution control measures. It is thus necessary to anticipate the potential of collecting mutagenic ash.

Limited tests have been conducted to determine the biological effects of coal ashes. Results indicate that coal ashes can be toxic to certain test animals. Alairc, et al.¹²⁸ reported that long-term exposure of monkeys and guinea pigs to rearsolized stack-collected fly ash did not result in pathological changes in the lungs although light microscopy revealed fly ash in the alveolar macrophage (AM). They did not test the functional integrity of these cells. Aranyi, et al.¹²⁹ demonstrated *in vitro* that fly ash from conventional coal combustion was cytotoxic to rabbit AMs and that the effect was dependent on particle size.

Ash and Char from Coal Conversion

Trace Elements: Griffin, et al., has conducted a study on the solubility and toxicity of trace elements in coal-related solid wastes.¹³⁰ As part of that study, the chemical composition of coal ash and slurry supernatant solutions of the ash from the Lurgi gasification process were investigated. The results are presented in Table 4.64. Of approximately 60 chemical constituents measured in the raw Lurgi ash, 16 were found to be in forms soluble enough to exceed recommended water quality levels in some samples at pH values between three and eight. Table 4.65 lists these 16 constituents. Nine constituents (B, Ca, Cd, K, Mn, NH₄, Pb, SO₄ and Sb) exceeded recommended levels in all Lurgi ash solutions over the pH range three to nine. The authors concluded that these nine constituents pose the highest potential pollution hazard.

Tamura and Boegly⁷¹ recently presented the research results related to the impacts of land disposal of coal conversion ash. Included are the results of the batch leaching tests using the EPA-EP procedures. Ash samples from several gasification/liquefaction processes were tested. Table 4.66 presents leaching results along with proposed RCRA criteria (100 times the drinking water standards). None of the wastes listed exceeded the criteria.

As was mentioned previously, certain solid waste effluents from the petroleum refining, electroplating, and primary zinc smelting and refining industries have been determined by EPA to be potentially hazardous. Analytical data for these wastes could provide certain inference as to the toxic potential of coal conversion wastes. Table 4.63 compares the composition of some industrial hazardous wastes with coal ashes generated from specific coal conversion processes.

Biological Effects: A considerable amount of information has been accumulated in recent years showing that many organic compounds and trace elements contained in coal ashes from conversion processes can produce a wide range of toxic effects. Potential effects of different organic contaminants represent a major concern.

Chemical and bioassay tests were conducted on gasifier ash and cyclone dust from a Wellman-Galusha low-Btu coal gasification plant.¹³¹ Tables 4.66 and 4.67 present trace elements and organics that were found in potentially hazardous constituents in ash and ash leachate. The major contributors to the ash discharge severity are trace elements, including barium, chromium, iron, lithium and nickel. The major contributors to the ash leachate are the unidentified organics. The health base bioassay tests (Ames, RAM and Roder. Acute Toxicity) indicate a low hazard potential. The only ecological bioassay test conducted on the gasifier was the soil microcosm test. While the results from this test cannot be interpreted in terms of low, medium or high hazard potential, the test did indicate that the gasifier ash was clearly more toxic than the cyclone dust. Tables 4.68 and 4.69 show compounds found in potentially hazardous concentrations in the cyclone dust and cyclone dust leachates, respectively. The major contributors according to the report are the organics, arsenic, barium, chromium, iron, lead, lithium, manganese, nickel and selenium.

Many of the inorganic components of coal ash are known to be toxic to aquatic biota, and the presence of these compounds in water leaching from coal ash may be a potential hazard to aquatic biota.¹³² Table 4.70 presents acute toxicities in terms of 48-h LC_{50} (the percent dilution of the leachate in spring water which caused a 50 percent mortality in 48 hours) for three coal ash leachates to *Daphnia Magna*.¹³³ *Daphnia Magna* is very sensitive to pH, with a 48-h LC_{50} for acidity at pH 6.4 and for an alkalinity of pH 10.3. This sensitivity is reflected in the toxicities of the more acidic Illinois #5 and #6 leachate fractions. Probable interactants are also the high trace metal concentrations associated with the more acidic fractions. Many of these trace metals are present in the leachates at concentrations that have been found to be toxic to *Daphnia Magna* and other freshwater biota.

The Rosebud leachate had the highest pH and the lowest toxicity of the three leachates. The first three column volumes leached from the Rosebud ash had pHs ranging from 6.8 to 9.5 and were nontoxic. The fourth column volume had a pH of 10 and had a 48-h LC_{50} at a dilution of 49 percent. Since the 48-h LC_{50} for alkaline pH is 10.3 and the Rosebud leachates had the lowest concentration of heavy metals of the three leachates, the toxicity of the leachates was probably caused by their high pH.¹³³

The Illinois #5 leachates had pHs ranging from 4.5 to 5.6 and had heavy metals concentrations between those of the Rosebud and the Illinois #6 leachates. These conditions were reflected in their intermediate toxicities, as compared with the other leachates.

Plant materials would most likely be exposed to leachates in groundwater, either during revegetation of the landfill site or even perhaps through the use of groundwater for the irrigation of crops. Soil and groundwater variables at specific sites will play important roles in the actual hazard potential of these wastes. Table 4.71 compares the phytotoxic effects of various leachate column volumes.¹³³ No effects of pH on radish hypocotyl elongation were observed between pH 3.6 and pH 9.3. However, at a pH of 3.2, growth was slightly inhibited, and a pH of 10 greatly reduced hypocotyl growth. The first column volume of Illinois #6 was the most toxic of all the leachates, causing 62 percent growth reduction at 10 percent concentration. At least two of the fractions of all leachates tested

cause significant growth reduction of radish hypocotyls. However, only one of the fractions of Illinois #6 produced a growth reduction at the 10 percent concentration.

FBC Spent Solids

Characteristics and environmental implications of FBC residues were recently reviewed by Henschel.¹³⁴ His findings based on results from EPA's FBC solid residue programs are summarized as follows:

1. The residue, in general, does not appear to be "hazardous" according to the procedures currently proposed under Sec. 3001 of RCRA. None of the trace metals treated exceeded the threshold of 10 times the NIPDWR (National Interim Primary Drinking Water Regulations) for any of the FBC residues. The residues are expected to be not "corrosive," "ignitable," or "reactive" according to the criteria proposed for hazardous wastes under RCRA. It is possible, however, that in some specific cases, residues from an individual FBC plant may be found to be "hazardous." For example, the specific coal burned, or the specific sorbent used for an individual plant, could result in a residue which might yield a leachate having a high trace metal content, and which might thus be found to be "hazardous" using the Extraction Procedure.
2. The primary environmental problem with FBC residue is that the leachate has a high pH and a high total dissolved solids (TDS) content. In addition, sulfate ion concentrations are high. The levels of pH, TDS, and sulfate are significantly above EPA's proposed NSDWR (National Secondary Drinking Water Regulations), the World Health Organization potable water standards and/or the Public Health Service regulations on drinking water. (These species are not covered by the NIPDWR.) When the leaching medium is distilled, de-ionized water, the pH of the leachate can be 12 or higher (in the range of 10 to 13) if the spent bed material is leached by itself; this pH is well above the NSDWR range of 6.5 to

8.5. TDS levels in FBC residue leachates are typically in the range 1000 to 3000 mg/l or higher, above the NSDWR of 500 mg/l. Sulfate concentrations are generally in the range 1000 to 2000 mg/l, above the NSDWR of 250 mg/l.

3. Trace metal leaching would appear to be much less of a concern in comparison with pH, TDS and sulfate. When a variety of FBC residues were leached using distilled, deionized water, none of the 15 trace metals, including silver, arsenic, barium, beryllium, cadmium, chromium, copper, iron, mercury, manganese, nickel, lead, selenium, tin and zinc exceeded available standards/regulations/criteria.^{135,136}
4. Substantial heat is released from the residue upon initial exposure to water, due to hydration of the CaO content forming calcium hydroxide.^{135,136} This heat release could necessitate some care in handling the residue, and could represent an occupational safety concern, but is not expected to be a major environmental concern. Heat release may be less of a concern for pressurized FBC systems, since the non-sulfated calcium may, to a greater extent, be in the form of CaCO_3 ; however, even in residues from pressurized systems, some CaO may be present, and potential heat release problems may exist.
5. The leachate from one sample of spent bed material from one pressurized FBC unit had a low level of toxicity according to one set of fresh-water aquatic bioassays (using algae, fathead minnow and daphnia as the test organism).¹³⁷
6. Total organic carbon and sulfide are below detection limits in the FBC samples that have been tested, and are not expected to be problems.^{135,136}

Sludges from Chemical Treatment of Process Wastewater

Chemical sludges produced from the treatment of gas liquor produced in coal

conversion may be closely related to the waste stream produced from ammonia stripping during the by-product coke making.¹³⁸ EPA had determined that the ammonia still lime sludges from the coking industry may pose a potential hazard to human health or the environment and should be subject to appropriate management requirements under Subtitle C of RCRA. These ammonia sludges contain hazardous constituents such as cyanide, naphthalene, phenols, and arsenic in significant concentrations. Furthermore cyanide and phenols leached in significant concentrations were detected from an ammonia still lime sludge water sample. Although no leachate data is currently available for naphthalene and arsenic, EPA believes that, based on constituent solubilities, these two constituents are likely to leach from the wastes in harmful concentrations when the wastes are improperly managed.¹²²

Table 4.72 compares the composition of gas liquor from Synthane, Lurgi, Koppers-Totzek and SCR-1 with that of coke plant ammonia liquor. Conversion processes appear to produce process wastewater with a composition similar to coke plant ammonia liquor.¹³⁸

Tars and Oil Sludges

Oil sludges and tars generated in coal conversion processes are potentially toxic. The counterpart of oil sludge and tars from coal conversion processes would be the slop oil, API separator bottoms, and DAF float produced in petroleum refineries. These refinery wastes, which have been classified to be hazardous under RCRA, contain significant concentrations of toxic heavy metals and organics.

Instead of disposal, coal tars and oil sludges produced in coal conversion processes may be used as a fuel for combustion or feedstock for chemical processes. Under these conditions, the health and environmental effects of tars and oil sludges will, of course, be much different from those previously discussed.

Biosludges

Table 4.73 lists known or suspected carcinogens that may be present in waste streams from coal liquefaction.¹³⁹ Table 4.74 shows specific organic compounds in aqueous energy-related effluents from in situ gasification, low Btu gasification, and in situ oil shale processing.¹⁴⁰

Data from chemical and bioassay tests of coal conversion biosludges are yet to be produced. The characteristics of the biosludges from coal conversion facilities are expected generally to be similar to those detected in conversion process wastewater or to those of petroleum refinery biosludges and perhaps wood preserving wastewater treatment sludges. Biosludges from refineries have been reported to contain Cr and Zn values of 540 and 200 mg/kg of dry sludge, respectively.¹⁰³ The sludges generated from the treatment of wastewater from certain wood preserving processes have been determined to contain significant concentrations of toxic phenolic compounds, polynuclear aromatics, and volatile organic solvents such as benzene and toluene. These wastes have been classified to be hazardous under RCRA.¹²² Polynuclear aromatics are known to be toxic, mutagenic, teratogenic, and carcinogenic. Phenolics are toxic, and in toluene are relatively toxic, and benzene is a carcinogen.

Oil Shale Processing Wastes

A major environmental concern with the development of the oil shale technology is the potential for long term health hazards such as carcinogenesis, mutagenesis, and teratogenesis. The exposures of workers to crude shale oils, particulate matter, contaminated aqueous materials, and air pollutants represent health hazards. There are additional health and environmental concerns associated with oil shale extraction and processing. Blasting and mining will produce dust, particulate organic matter, CO, NO, SO₂, hydrocarbons, silica, and metal salts. Crushing and screening the ore produces more dust, silica, and particulate organic matter. In addition, retort operations can produce polycyclic organic compounds, H₂, NH₃, and volatiles. Some of these compounds, as well as arsenic and other metals, are produced in the upgrading process. Disposal of the solid waste products is a major environmental concern. Many of these compounds may contaminate not only the atmosphere but water as well. Since water is a necessary commodity in the oil shale industry, many of these compounds may be found in the waste and runoff waters.

Polycyclic aromatic hydrocarbons (PAHs), as a group, are known to be toxic, mutagenic, teratogenic and carcinogenic. Long-term dermal exposure (1-43 years) to coal tar has been reported to cause malig-

nant tumors on hands, face, and neck of briquette factory workers. When small amounts of coal tar were fed to ducks, the toxicologic effect was anemia and extensive liver damage.¹²⁰

Bioassay studies have indicated potential mutagenicity of tar samples. Research Triangle Institute has conducted Ames tests for mutagenicity on crude tar samples and their fractions.¹⁴¹ The test organism for these bioassay studies was TA-98 *Salmonella* bacteria strain, which tests for frame shift mutagens. Fractions were obtained from gasification test runs of Western Kentucky #9, Illinois #6, North Dakota lignite, and Wyoming sub-bituminous. Bioassay tests results are presented in Table 4.75. One significant finding is that tar base fractions from coal gasification tests with three coals Western Kentucky #9, Wyoming sub-bituminous and North Dakota lignite—showed more severe mutagenic effects on strain TA-98 than the crude tar samples from which they were obtained.

The levels of PAH in coal tar are closely comparable with those in creosote (see Table 4.76). The wastewater treatment sludge generated in the production of creosote has been determined by EPA to pose a substantial present or potential hazard to human health or the environment. The hazardous substances likely to be present in these wastes include creosote and its constituents, benz(a)anthracene, benzo(b)fluoranthene, and benzo(a)pyrene, all of which are carcinogens. For example, benzo(a)pyrene can induce cancerous skin tumor in mice when only 0.25 mg is injected subcutaneously.¹²⁰ Benzo(a)pyrene is the most widely accepted indicator of PAH content and biological activity.

Another PAH-containing industrial waste effluent that has been determined by EPA to be hazardous is bottom sediment sludge from wood preserving plants. In addition to PAH, it contains chlorinated phenols and volatile organic solvents such as toluene and benzene. PAH levels measured in coal tars⁹⁹ and bottom sediment sludge from a wood preserving plant¹²⁰ are fairly close, as can be seen in Table 4.77.

Leaching of solid wastes from oil shale development is an important environmental problem because of the amount of processed shale that is produced by retorting and because of its physical and chemical properties. The leachates derived from oil shale processing are potentially hazardous

and could enter surface streams and groundwater unless adequate controls are installed.

Leachates produced from in-situ retorts are an especially difficult environmental problem because groundwater is found in practically all of the oil shale deposits of commercial interest, and control of such leachates is uncertain.⁸⁸ The permeability that would result from mining, fracturing, and retorting would facilitate the leaching process if the retorts are backflooded when the natural hydraulic gradient is restored. Organic and inorganic residuals in the spent shale of the retort would then be added to the groundwater, although they would tend to be dispersed at increasing distances and would be diluted with the progress of leaching.

The composition of leachate from simulated in situ spent shales has been studied by a number of investigators, and some of their results are summarized in Table 4.78.⁸⁸ These leachates are rich in total dissolved solids (TDS), they contain significant quantities of sulfate, carbonate, bicarbonate, chloride, fluoride, potassium, calcium, silicon, and sodium and lesser amounts of phenols, organic nitrogen, zinc, lead, and other trace constituents, and they are alkaline, the pH ranging from 8 to 13. The composition of spent shale from field experiments, although somewhat different in mineralogy because of the high temperatures produced, results in leachate with lesser amounts of total dissolved solids and a lower pH. However, this leachate may be enriched in certain trace elements with respect to the concentrations in leachate from simulated in situ spent shale.⁸⁸

The potential effect of groundwater contamination by leachates from in situ processing can be appreciated in the light of present uses of groundwater in the Piceance Creek Basin. This water is currently withdrawn primarily from alluvial aquifers and is used mostly for single-family domestic supplies, stock watering, and irrigation. The alluvial aquifers slowly receive water discharged from deeper groundwater, and the effects of in situ processing on their water quality may not be seen for many years. However, if the alluvial aquifers are reduced by substantial oil shale development, it is likely that the deeper groundwater would become a principal supply. This water would likely be relatively more contaminated.

Table 4.79 compares the water quality criteria recommended by EPA to existing water quality in the Piceance Creek Basin and to leachate from in situ retorts.⁸⁸ Table 4.80 summarizes the potential effect of the discharge of leachates to streams of the Upper Colorado River Basin. While significant degradation of surface water is indicated, preliminary estimates indicate that it may take from 130 to 1,450 years for leachates released from retorts on tracts C-a and C-b to reach the nearest surface stream.⁸⁸

Acute and Chronic Toxicity

Weaver and Gibson¹⁴² reported on the acute and chronic studies on four crude shale oils, three raw shales and four spent shales (Table 4.81). The results do not show that the materials are acutely toxic.

Weaver and Gibson¹⁴² also reported on chronic inhalation studies of two raw shales and two spent shales. In the study, rats and monkeys were subjected to the inhalation of the respirable dusts at concentrations of 10 and 30 mg/m³. After one year of exposure, no adverse effects were seen in the animals.

Teratogenicity

The possibility of carcinogens leaching into the general environment represents a concern. Since spent shale may be used in revegetation of the disturbed land, it is possible that products leached from spent shale may, upon ingestion of plants (or water) containing the contaminants, create a teratogenic hazard.

A study was undertaken to evaluate the potential embryotoxic and/or teratogenic effects of spent shale in New Zealand white rabbits.¹⁴³ The results are summarized in Table 4.82. Control rabbits given water showed no anomalies except for rudimentary ribs, and four of the 41 implants were dead or resorbed. The animals given carbon or spent shale did not differ from the control group in the number of implants dead or resorbed. There was a slight increase in the number of abnormalities. The data showed that spent shale does not cause significantly more abnormalities than does inert carbon.

Mutagenicity

Materials leached from both raw shale and spent shale can be routed for human exposure. Adverse human health effects might result particularly from long term exposure to polycyclic aromatic hydrocarbons

and trace elements emitted in various forms from the shale oil. Epler¹⁴⁴ has selected a group (Table 4.83) of organic compounds pertinent to shale oil and then evaluated their mutagenic effects on the Salmonella histidine-reversion system. Although a number of the compounds may be promoters or modifiers of carcinogenesis (that is, active in co-carcinogenesis, perhaps in some cases as inhibitors), they do not appear to be mutagenic.

Carcinogenicity

Benzo(a)pyrene (BaP) is a readily measurable member of the POM class of compounds. Commonly, BaP is used as an indicator compound for potential carcinogenicity of materials in which it is found. BaP levels in oil shale and some natural and industrial materials are given in Table 4.84. Carbonaceous retorted shales contain BaP in concentrations similar to those found in many natural organic materials.¹⁴⁵ Shale oils, in contrast, contain relatively high levels of BaP.

The search for the carcinogen in Scottish shale eluded many investigators until 1943, when Berenblum and Schoental¹⁴⁶ identified BaP in shale oil, but they also observed a fraction of shale oil to be carcinogenic that did not contain detectable quantities of BaP. Later, Hueper and Cahamann¹⁴⁷ and Bogovsky¹⁴⁸, respectively, reported BaP-free American and Estonian oil shale to be carcinogenic in mouse skin painting studies.

Table 4.85 shows the carcinogenic potency of two crude shale oils from two different processes. The two oils produced very little difference in tumor incidences and average latent period.¹⁴⁹

Another study determined the BaP content found in raw shale oil, upgraded shale oil, processed shale, processed water, native grass, leached water, raw shale and native soil.¹⁴³ The results of these determinations are given in Table 4.86. BaP concentrations found in all samples were considered low.

The results of topical application of raw oil shale and upgraded oil to mouse skin are also presented in Table 4.85.¹⁵³ It may be seen that shale oil induced tumors in 86 percent of the effective number with an average time for appearance of about 30 weeks, whereas the upgraded oil induced tumors in 13 percent of the effective number with an average latent period of 49 weeks. A solution of 0.05% BaP in toluene resulted in 91% of the effective number of mice developing tumors with an average latent period of 46 weeks. No tumors were

observed in the mice treated with toluene alone after eighty weeks of topical application.

Barkley¹⁴³ tested carcinogenic potential of four shale oils and raw spent shales that Weaver and Gibson studied for their acute and chronic toxicity.¹⁴² After 60 weeks of topical applications of the materials to the backs of mice, all the animals treated with the shale oils developed tumors or died. The incomplete results of this study are presented in Table 4.87. No tumors have been observed in the mice receiving raw and spent shale suspended in white mineral oil.

Methods and Problems Associated; with Long Term Storage and Disposal

Although a small proportion of the solid waste produced may be used, for the most part, environmentally acceptable methods of disposal must be found. This section discusses the available options for solid waste disposal and some of the mechanisms by which containment areas may be breached, thus, causing adverse health and environmental impacts. The current waste disposal practices in the industry are also reviewed.

Disposal Options

Available options for solid waste disposal and management include:

- a) Ponding
- b) Landfill
- c) Mine Disposal
- d) Ocean Disposal
- e) Deep Well Disposal
- f) Soil Application
- g) Incineration
- h) Chemical Treatment

The principal options are described below in light of their applicability of energy-related wastes.

Ponding

This disposal method involves sluicing or trucking of solid waste/sludges to on-site disposal ponds, where the sludge solids settle and the overflow liquor is pumped back to the plant (e.g., FGD system) for reuse (closed loop operation) or discharged to water bodies (open loop operation).

Dumping ashes into on-site shallow ponds or lagoons has been the principal means of ash disposal in the electric utility industry. At present, the most common disposal for FGD is also by ponding. The sludge, normally untreated, is usually mixed with the ash and transported to on-site disposal ponds.

Most sludge and ash ponds used to date are unlined. To reduce the possibility of liquids leaching into groundwater, the disposal ponds can be lined with some impermeable material such as clay. Another alternative is to include pond under-drainage.¹⁴⁹ This method retains the advantage of transferring the sludge to the disposal site by liquid transfer. The leachate from the base of the sludge is returned to the scrubber. The advantages of this method may be economic and environmental. By eliminating a supernate head above the sludge most of the time, and minimizing it for short periods after rainfalls, percolation of sludge leachate into the subsoil can be avoided during the active fill period. Tests have shown drained sludge to have structural qualities adequate to support lightweight construction equipment.

Landfill

Landfill has usually been used by utilities for ash disposal when land was not available on site for ponding. The ash may be ponded and then after drying out, be transported to a landfill site.

Landfill operations range from open dumping of debris to controlled disposal in "secure" landfills. Open dumps, in which wastes are piled on the surface of the terrain, are prohibited in most states and are to be totally phased out under the provisions of RCRA even for non-hazardous waste. In sanitary landfills, the wastes are usually compacted to confine them to the smallest practical area, and then are covered with a layer of soil at regular intervals (usually at the end of a day's operations). Provided that adequate measures are taken to reduce the potential for contamination of ground and surface waters and to minimize the nuisance associated with landfill operation, sanitary landfilling can be an environmentally acceptable and cost-effective method of solid waste disposal.

To minimize ground and surface water contamination, landfills must be located in areas where the subsurface formation is relatively impervious to infiltration (e.g., dense clays) and where the distance to the groundwater table is significantly large. The landfill surface area should also be properly contoured to divert surface runoff from the site. When subsurface formations do not provide adequate barriers against leachate infiltration, the use of artificial barriers such as plastic, asphalt, concrete or clay materials for lining the landfill may be

necessary. The intercepted leachate would be pumped to a surface facility for treatment. Observation wells should also be installed downstream of the land fill site (in the direction of groundwater flow) to detect leachate migration.

Controlled landfilling is the most likely method for the majority of energy related wastes generated from fossil fuel energy industries. Virtually all the present proposals for commercial oil shale mining and rectoring include plans for disposal of solid waste in controlled landfills. The objective is to create a stable disposal pile suitably contoured and revegetated, with protection against runoff and leaching of substances into ground and surface waters.

Mining Disposal

This disposal option entails the return of wastes to surface and underground mines. Disposal in surface mines is essentially one form of landfilling where the overburden material is used as the cover material. The operation is subject to the same restrictions as sanitary landfills. When coal is mined by deep mining, there would be a greater time delay before the waste can be deposited in the mine. The physical operation of returning the waste to the mine is also more difficult, requiring certain changes in mine design and operation to accommodate the space and equipment for returning the waste.

Both strip mine reclamation and deep mine filling have been used for ash disposal from power plants for a number of years. Evaluations of this form of disposal are being undertaken for FGD wastes. Initial assessments have been undertaken by Aerospace¹⁴⁹ and Le et. al.⁵ and are summarized below.

In general, interior region surface-area coal mines appear to be more promising than western (Rocky Mountain and Pacific Coast) surface coal mines. However, surface-area mines both in the Interior and the West were considered much more promising than eastern surface contour mines, because of the latter's relatively low capacity for FGD wastes, and in many cases, the difficulty of waste placement in contour mines.

Placement and handling techniques for FGD sludge disposal in both surface and underground mines are available and have been demonstrated for disposal of other materials in mines (e.g., coal refuse), although the techniques may require modifications for application of FGD

sludge disposal. The FGD wastes will have to be dewatered to the extent necessary for landfill operations.

When transportation costs are not excessive, return of coal gasification and liquefaction solid wastes and sludges to the coal mines would be an attractive means for the disposal of such wastes, especially when area surface mining is practiced. The designs for proposed commercial Lurgi SNG plants have called for the return to surface mines of all plant solid wastes.

At present, only one of the proposals for ill shale development includes mine disposal of the retorted shale. The Superior process plans to return all processed shale underground, as a wet coke, for compaction into the void spaces remaining after room-and-pillar mining. It is expected that the 24,000 tons per day commercial operation will dispose of some 4.6 million tons of leached spent shale annually. The leached shale wet cake will be returned to the mine and converted into a slurry, which will be pumped into the empty underground rooms and allowed to drain to approximately 25 percent moisture content. Because of the dipping beds on the Superior property in the northern Piceance Basin in Colorado, it is claimed that the slurry can be emplaced up to the ceiling, by proper withdrawal of the slurry discharge pipe as each room fills.⁸⁷

Ocean Disposal

The Marine Protection, Research and Sanctuaries Act of 1972 directs the EPA and the U.S. Army Corps of Engineers to administer permit systems to control ocean dumping. Vast amounts of materials, including sewage sludge, industrial wastes, radioactive wastes and dredged material, are disposed of under the permit system, mostly off the East Coast (Table 4.88).¹¹⁷ Ocean disposal of fly ash has been practiced, and studies have been undertaken to look at the economic and environmental feasibility of the ocean disposal of FGD sludges.¹⁴⁹

Deep Well Disposal

Deep well disposal is a method of pumping or injecting liquid waste into subsurface formations. Many industries which generate large quantities of concentrated waste have used injection well disposal systems due to lower capital and operating costs. Concentrated toxic liquid waste and odorous fluids are disposed of in deep wells

without treatment, and very little surface area is required except for the well pumping equipment. In the U.S., more than 100 liquid waste disposal wells have been drilled, handling liquid waste capacities up to 1100 gpm. Deep well disposal of wastes is being discouraged because of the uncontrolled nature of pollutant release and the irreversibility of environmental impacts.

Soil Application

When large land areas are available and the climate (rainfall, evaporation) and hydrogeological conditions (distance to groundwater, groundwater flow, type of soil and geological formation) are favorable, some organic and inorganic wastes may be disposed of by application to soil. This method has been used for the disposal of waste sludges from municipal sewage treatment plants. Solid waste/sludge is applied to the soil by "spreading" or "flooding," disked under and worked into the top soil. The organic components of the waste undergo biodegradation in the soil and eventually become part of the soil humus. Inorganic sludges and ashes can also be disposed of on land and incorporated into the top soil. Depending on the soil type, such sludges and ashes can improve soil structure, reduce acidity, provide plant nutrients, and decrease the availability and hence, toxicity of certain cations. Although tar and oil sludges from petroleum refineries have been shown to be degradable when applied to soils, sludges from coal gasification plants may be more resistant to degradation in the soil environment due to the highly aromatic nature of the organics in these sludges. Land disposal of sludges can present an odor problem and result in the contamination of surface waters and groundwaters, unless sites are properly located, designed and operated.

Incineration

Carbonaceous wastes such as tars, oil, chars and dewatered biosludges can be incinerated before disposal. Depending on the water content of the feed, the combustion may be self-sustaining and also allow for heat recovery. The operation can be combined with on-site power generation or be carried out in a separate waste disposal incinerator. Incineration has proven to be very reliable and efficient and has been widely used for the disposal of a variety of industrial sludges and solids, municipal

refuse, and biosludges from the treatment of sanitary sewage. Nearly complete destruction of organics can be achieved in properly designed and operated incinerators. Compared to land disposal methods, incineration requires very little space. Except for potential air pollution problems, which can be controlled by the use of the good design, afterburners, and particulate control devices, incineration can be the most desirable disposal option (when resource recovery is inapplicable), especially for the destruction of hazardous organics.

Incineration at sea holds the promise of becoming a major alternative to land-based incineration or dumping into ocean waters. Vessels specially designed and equipped with on-board incinerators load hazardous or toxic liquid combustible wastes at port and steam offshore to a permitted point for the burn. Tests to date have been so successful that a U.S. incinerator ship will be built and the feasibility of ocean platform incineration is being studied.¹¹⁷

Chemical Treatment

The physical and chemical properties of some solid wastes can be altered by chemical treatment to produce useful by-products, and/or to make them easier for handling, and more suited to landfill disposal. For example, the quality of lime/limestone scrubber wastes can be improved by oxidation or by chemical fixation. By oxidation, the precipitated calcium sulfite/sulfate mixtures are oxidized to produce by-product gypsum. Oxidation of FGD sludges has been practiced in Japan where FGD-derived gypsum is marketable. By fixation, materials, such as fly ash, lime, silicates, and/or polyvalent metal ions are mixed with wet sludges for form low grade concretes. The objective of fixation is to solidify the sludges by promoting pozzolanic and other cementitious reactions between lime compounds in additives, alumina/silica in the fly ash, and calcium-sulfur compounds in the sludge. Chemical fixation makes the sludges more suited to landfill disposal, and subsequent reclamation and vegetation reduces the volume of sludge and minimizes the danger of leachates infiltrating into the groundwater. A number of vendors are currently marketing fixation treatment systems. Most of them produce a stable inert material that has high resistance to the release of toxic metals and soluble species, and of sufficient compressive strength to support building construction.

Engineering Concerns

Chemical composition data indicates a pollution problem from leaching of many energy-related solid wastes and a need for careful site selection and monitoring. In some cases, installation of special control measures, such as liners, sealants, under-drainage collections systems, and devices for routing ground and surface flow may also be needed. Although these control measures are potentially applicable to landfill as well as pond disposal sites, long-term effectiveness is still a matter of concern.

The following subsections discuss soil mechanisms by which containment areas may be breached, thus causing surface and groundwater pollution.

Deterioration of Landfill Cover

Cover material of landfills serves many purposes. It helps in disease vector and rodent control; helps contain odor, litter, erosion, and air emissions; enhances aesthetics; reduces infiltration of rainwater and thereby decreases potential leachate generation and surface and groundwater contamination; and enhances the site appearance and utilization after completion.

According to the EPA,¹⁵⁰ hazardous waste landfill operations should specify what soils are to be used as cover material, where they are to be obtained, and how they are to be placed over the waste in order to meet the aforementioned objectives. If the cover is to be exposed longer than one year, a three foot soil cover is recommended by the EPA for isolation of wastes from the environment.¹⁵¹ Even so, the effectiveness of landfill cover could decrease over the long-term as a result of numerous natural phenomena, including erosion, cracking, landslide and subsidence.

Erosion results from detachment and movement of soil by water, wind, ice, and gravity. Cracking is caused by volume changes in cover soils; shrinkage upon loss of water and expansion at additions of water. Erosion and cracking can deteriorate the structure of a landfill and increase the likelihood of water entering the site. Subsequent infiltration and development of hydraulic head can hasten the vertical migration of pollutants from the site.

Landslides, along with floods and erosion, are common occurrences due to weather, the nature of solids, and gravity. Each, however, can produce a change in a site, thereby directly affecting the rate at which contaminants reach the environment. Subsidence of a landfill could breach the

landfill containment system by causing depression of landfill surfaces in which surface water can accumulate, thereby enhancing infiltration and hastening vertical movement of pollutants.

Limited Soil Attenuation Capacity

Landfills in most cases are underlined with natural soils. Contaminants in leachate can be attenuated when passing through soils by physical, chemical, mechanical, and/or biological processes. The mechanisms by which these processes are formed include: filtration, ion exchange, absorption, chemical precipitation, biodegradation and complexing. For acidic or neutral leachates, soil attenuation of trace contaminants usually occurs through absorption/ion exchange mechanisms. In this case, soil properties, such as soil texture (e.g., clay content or particle size distribution), surface area, percentage of free ion oxides, and pH, are the most important controlling factors.^{143,144} Other factors such as percentage of hydrated oxides of manganese, aluminum oxides, and silicates as well as organic contents in the soils and competing ions in the soil solution are also important factors.

Attenuation of the leachate contents by percolation through soil has been detected in many cases to provide substantial protection against trace elements reaching an aquifer. Laboratory attenuation (percolation) data obtained on soils at utility stations indicate that after ten years of continuous flow, the level of chromium and selenium (at soil depth of 30-50 feet) would still be 95 percent less than it is in the original ash leachate. Boron and arsenic were also significantly absorbed by the same soil.¹⁵⁴

Absorption/ion exchange capacities of soils are limited; beyond the limits which migration of pollutants to the environment will occur. Quantitative estimation of the capacity of absorption/ion exchange can be determined by using the Cation Exchange Capacity (CEC). In general, high CEC values usually indicate high clay content, high surface area, and thus higher attenuation capacity. For a specific site condition, (i.e., soil permeability, cation exchange capacity, and depth), soil attenuation capacity can be quantitatively expressed as "breakthrough time," which refers to the years the specific site is capable of attenuating metal species in the leachate. Since most metals may be leached from coal residues over a long (hundreds to millions of years) period of time, and soil attenua-

tion capacities are limited, long-term protection of groundwater supplies may require the utilization of control methods in addition to soil attenuation.¹⁵⁴

Long-Term Reliability of Impervious Liners

The use of liners to isolate hazardous waste from the environment is becoming more widespread when impervious basins are desired at a landfill site and the existing soil is not suitable. Liners may be natural or man-made, or a combination of both. Natural impermeable barriers consist of clay and fine-grained soils; man-made liners range from asphaltic compositions to concrete compositions to various synthetic polymeric membranes.

Numerous artificial pond liners have been proposed, including both flexible films of rubber or various plastics and non-flexible liners such as asphalt, cement or even stabilized FGD wastes. The useful lifetimes of potential liners, which are determined by the aging characteristics of the material and by chemical interactions with the sludge and soil, are a matter of concern. Flexible liners are generally guaranteed for 20-25 years, and nonflexible liners are expected to have a somewhat longer life, but long-term service data for sludge containment are not yet available for either type of liner.¹⁵⁴

The possible chemical reactions between the soil liner and waste can result in decomposition of liner material. For example, some natural impermeable soils may fail when exposed to strong acids. Also, artificial liners and synthetic membranes may fail if not properly installed or constructed, or when exposed to some hydrocarbon solvent. The organic compounds have been shown in experiments to affect some types of disposal site liners, resulting in failure, loss of strength or increase in permeability.^{155,156}

The following are some of the observations regarding potential deterioration of liner materials:

- Clay soils, including bentonites, can lose their impermeability when impounding strong acids, strong bases, or brine.
- Exposure of the liner to sunlight can cause some polymers, such as polyvinyl chloride, to become brittle and crack. Butyl rubber is susceptible cracking from ozone attack.
- Soil liners may be damaged by drying or by freezing/thawing of exposed areas.

Potential Environmental Problems from Disposal Methods

Land disposal of energy-related solid wastes could lead to a number of environmental problems. The primary areas of concern are contamination of groundwater by leachate from disposal ponds and landfills, release of toxic organics to air, and land use impacts determined by long-term physical and engineering properties. Disposal of energy-related solid wastes can result in varying degrees of groundwater pollution depending on chemical composition, solubilities and permeabilities, and the location, hydrogeological characteristics, and design and operation of the disposal site.

In terms of land use impacts, ponding and landfill may be aesthetically objectionable, and food crops may be contaminated by such potentially toxic substances as lead, nickel, cadmium, chromium, arsenic, mercury and selenium existing in energy-related solid wastes if the reclaimed disposal sites are used for agricultural production. In addition, surface water contamination by overflow or runoff could occur, and air quality deterioration could result from wind erosion and chemical volatilization at the waste disposal sites.

Little documentation is available to determine whether or not leachate from operating energy-related solid wastes disposal (e.g., ash ponds) is a potential source of groundwater pollution. However, this is not to be interpreted that a pollution problem does not exist. The composition of specific solid wastes, the concentration of soluble constituents, the pH of the leaching medium, and/or the lateral water movement in underlying aquifers are site-specific variables, and may be such that the problem areas have not been identified.

The following section discusses the environmental concerns associated with the disposal options for specific energy technologies.

Coal Combustion Ash and FGD Sludge Disposal

Water Pollution: At most of the FGD installations, clarified liquor from the thickener and/or the settling pond is returned to the scrubber. Overflow from the pond is not uncommon, however, because most of the systems operate with an open water loop. The amount of fresh water used to irrigate the mist eliminator sufficiently to

keep it from plugging usually far exceeds the quantity of water lost from the system by evaporation and by occlusion within the FGD solids. The copious use of fresh water also facilitates scrubber operation by limiting the build-up of dissolved solids, such as chloride ions, which have an adverse effect on process chemistry and construction materials. In the obvious trade-off between the technical and the environmental performance of FGD system, operational considerations have prevailed thus far. If closed loop operation is unattainable, a water treatment system will be required for the discharge.

Contamination of groundwater supplies by leaching is a definite threat because of the permeability of the wastes. Untreated wastes, with permeabilities in the range 10^{-4} - 10^{-5} cm/sec (10-100 ft/yr), offer little resistance to the flow of scrubber liquor to the pond floor.¹⁵⁴

The leachability of a given species in the ash will be determined largely by its solubility. Generally about 2 - 5 percent of fly ash is water-soluble. The resulting solution is usually alkaline due to the effect of free lime, although some ashes, especially from eastern coals, produce acidic leachates. The acidic liquors often exceed stream criteria with respect to sulfate, total iron, zinc, lead, cadmium, and manganese but they are usually acceptable with respect to copper.¹⁵⁴

Aside from solubility, another factor influencing the leachability of ash is the possibility that some of the solubles may become fixed by participation in a pozzolanic reaction.

Leaching studies have indicated that fixation can reduce the concentration of dissolved solids in the first pure volume of leachate by about 50 percent. After passage of 3 - 5 pure volumes, concentrations of dissolved solids in leachates of treated sludges were about 25 - 50 percent of those observed for untreated sludges and remained constant.¹⁵⁴

During the active life of the pond, while sludge is continually being deposited and there is supernatant scrubber liquor, the concentrations of leachate components will approach their concentrations in steady state scrubber liquor. If the wastes are still physically unstable and cannot be protected from exposure to rainfall when operations cease, leaching will continue. Although the concentration of trace sludge components in the leachates will gradually decrease, those of major components will remain

constant. The possibility therefore exists for infiltration of substantial quantities of bulk and trace components of scrubber liquors into the underlying soil.

The rate of migration from the pond of trace components in the leachates can be slowed by the retentive characteristics of some soils, but it is known that some substances, such as boron and selenium, are not attenuated effectively by soil. Adverse effects on the quality of surface and groundwater have not been detected thus far, but the limited time and extent of investigation provide little assurance. Because effects might take long to appear and be long lasting, disposal of potentially hazardous wastes in a pond without an impervious liner cannot be regarded as an environmentally acceptable practice. It should also be emphasized that fixation of the sludge does not eliminate the need for a pond liner unless the treatment is one that reduces the permeability of the solids to 10^{-6} cm/sec or less.¹⁵⁴

In the past, ash and untreated FGD sludges have been dumped in unlined ponds with very little control. However, this situation will change. Even though coal combustion wastes are currently exempted from the hazardous waste category - and most would undoubtedly not fall into that category anyway - some upgrading in waste management will be necessary for many plants.

Air Pollution: Ash deposited in lagoons may pose a dust hazard as the material dries out. The small, hollow cenospheres have a low density and are susceptible to wind erosion. Proper compaction of the ash helps to prevent this. Also, in some instances, the ash tends to form a skin that, if undisturbed, protects it against blowing. Spraying the surface with polymer emulsions is also effective in preventing wind erosion. Long-term control is best achieved by establishing a suitable vegetative cover.

Initial measurements on FGD sludge ponds have shown emissions of volatile gases. These were largely reduced sulfur gases: hydrogen sulfide, carbonyl sulfide, dimethyl sulfide, and carbon disulfide. Emission rates were reported to be approximately 2 kg/day (as sulfur) from a 100 acre pond. In addition, traces of benzene, toluene and picene were also identified in the emissions.¹⁵⁷

Interest has recently centered on radioactive releases from ash piles. This problem was addressed in the issues section.

Land Degradation: Serious degradation of the land can result if the filled lagoons

are not subsequently reclaimed. Reclamation has not been practiced much in the past, but with increasing concern for the environment and regulations governing disposal practices, functional and aesthetic restoration of ponds is likely to be undertaken.

Reclamation of Ash Ponds: Ash does not readily support plant growth. This is due partly to lack of the necessary nutrients (a need that can be supplied by application of fertilizers) and partly to the presence of inhibiting elements such as boron. Yet natural colonization of an ash surface by vegetation often takes place. The first plant to appear is usually a moss, which can cover a moist ash surface within six months and which effectively binds together the ash particles to inhibit erosion. A common weed is usually the next colonizer to appear, and this can be followed by a range of other plants.¹⁵⁸

Tests on ash piles have shown that boron may be 20 times as available in fresh ash as it is in normal soil. Chemical treatments for removing the excess boron proved to be too expensive. Fortunately, various useful plant species tolerate ash conditions. The clover family, in general, and some grasses, particularly rye grasses, are tolerant. Of the arable crops, those of the beet and cabbage families do well. Considerable success has been obtained with rye and wheat on a field scale and (at a later stage) even with the relatively intolerant barley.¹⁵⁸

A variety of trees (alder, honey locust, spruce, poplar, and willow) are tolerant to ash conditions, but their growth is not sufficiently vigorous to sustain commercial timber production. A number of shrubs can also be grown on ashes. Thus, it should be possible to landscape an ash disposal site with these tolerant species.

FGD Sludge Pond Reclamation: The disposal ponds used for untreated FGD sludge disposal may be reclaimed by allowing the sludge to dry and covering it with a soil overburden. However, certain characteristics may limit the reuse of the land. Proper contouring to control rainfall runoff and minimize percolation of water through the overburden will be necessary to avoid resaturating the sludge.

If the sludge has been stabilized prior to disposal, the land reclaimed will have greater stability and should be suitable for wildlife, recreation, agriculture, or light construction. The stabilized sludge would not provide sufficient strength for heavy construction, and the groundwater directly under or near the site would have to be used with care.¹⁵⁹

FGD Sludge Landfill: Chemically treated sludges can be used as landfill in above-grade conditions. The material can be placed and compacted such that rainwater does not penetrate the surface and leachate is not produced. The potential environmental impact of treated sludge is less than that of untreated sludge under most disposal methods, although the added assurance afforded by the chemical process increases the cost of disposal.

The Aerospace Corporation has studied the effects of chemical fixation on the disposal of wet FGD sludge and their conclusions are given below.¹⁴⁹

The soluble salt content in the leachate from treated sludges is typically about one-half that of the untreated sludge. Additionally, the permeability of the treated sludge appears to be at least one order of magnitude less than that of the untreated sludge. Therefore, the dissolved salts that may be leached from chemically treated sludge and available to the environment are considerably less in concentration and mass than from untreated sludge.

The structural stability of treated sludge exceeds that of the untreated sludge. The treated sludge texture ranges from soil-like to concrete-like and develops strength equal to or in excess of natural soils. Restrictions on subsequent land use will depend upon local conditions and the long-term stability of the treated sludge. Laboratory data have not been developed by any source from which it would be possible to predict the time-dependent stability of treated sludge.

Landfill is a disposal option for the waste from dry spray-dryer FGD systems. There are a number of potential problems however, in its use for wastes from the injection process using nahcolite. All contact with water must be avoided during and after burial in a landfill due to the high solubility of the waste. Landfill leachate or groundwater in contact with the waste could easily have a dissolved solids content of 50,000 mg/l as compared with standards of 50-250 mg/l.¹⁶⁰ Also any contact with water would seriously decrease the stability of the waste. Because of the problem of leachate the landfill site would need to be lined. It would therefore appear that although landfill can be used it is best suited to arid and semi-arid areas.

FGD Sludge Mine Disposal: The most important potential adverse chemical impact if FGD sludge disposal in mines is increased constituent loadings (especially sodium and calcium chlorides and sulfates)

to the mine drainage discharge. In areas removed from the influence of mine drainage pump-out, the principal potential adverse chemical impact of FGD sludge is leachate contamination of groundwaters. The generation of sludge leachate will be site-specific, with the greatest amount produced when sludge is within a groundwater regime of high transmissibility (having a steep hydraulic gradient and high soil permeability). Attenuation of FGD sludge leachate is also site-specific, with the least attenuation in acidic groundwater environments having soil and rock of limited ion exchange capacity. Discharge of sludge leachate to surface waters can adversely affect aquatic life by the addition of biocumulative trace metals. In the case of sludges containing sulfite, there is the potential toxicity of dissolved sulfite itself as well as the potential depletion of dissolved oxygen in the water due to the sulfite.

The overall conclusion from the assessment of FGD sludge disposal in mines is that while promising from both a technological and an environmental standpoint, uncertainties still exist regarding control of potentially significant environmental impacts, and each proposal for FGD sludge disposal must be assessed on a case-by-case basis to determine the magnitude and acceptability of these impacts.

FGD Sludge Ocean Disposal: Until more definitive data are available, disposal of sulfite-rich FGD wastes on the Continental Shelf or in the deep ocean was not considered to be advisable by Aerospace.¹⁴⁹ Sulfite rich sludges can have an adverse effect on oxygen demand. In addition, inadequate initial dilution of sulfite-rich sludge would result in sulfite concentrations in excess of lethal doses for fish under laboratory conditions.⁵ FGD wastes, whether sulfite or sulfate and treated or untreated, should not be disposed of by quick-dumping surface craft or pipeline (outfall) on the Continental Shelf. Several options using surface craft appear promising:

1. Dispersed disposal of sulfate-rich FGD wastes on the Continental Shelf;
2. Concentrated disposal of chemically treated brick-like FGD wastes on the Continental Shelf;
3. Dispersed disposal of sulfate-rich FGD wastes in the deep ocean; and
4. Concentrated disposal of both sulfate-rich and chemically treated FGD wastes in the deep ocean.

The environmental effects of layering the ocean bottom with wastes described in 1, 3 and 4 above have yet to be defined. In addition, their environmental effect while traveling down the water column is also unknown.

A more promising method is considered to be item 2 above. This is based on the favorable characteristics of treated materials in laboratory leaching and permeability tests. Long-term effects on the volumetric and structural integrity of the material as affected by submergence in sea water are unknown. Further the solubility of trace metals within the sludge matrix is not known, but during the dumping process the concentration of several trace metals suspended in seawater would exceed recommended levels.⁵

An artificial reef consisting of 500 tons of wastes from coal-fired power plants has been placed in the Atlantic Ocean near Fire Island, NY, as part of a program sponsored by DOE, the Electric Power Research Institute and New York State. The full-scale demonstration began after smaller scale tests of blocks cast from fly ash and sludge from stack gas scrubbers established that the blocks did not discharge toxic substances into the environment. The blocks were fabricated in a conventional concrete block plant and the ten cubic foot reef is expected to provide new habitats for marine life. If successful, the test could demonstrate the feasibility of an important alternative for disposing of power plant wastes. Regular surveys of the reef will be conducted to monitor its stability and effects on the local marine biology.

Atmospheric Fluidized Bed Combustion Landfill: Since the spent sorbent is discharged as a dry particulate solid, it should be easy to dispose of in a landfill. Tests have shown that the potential problems with AFBC leachate include high pH, total dissolved solids, sulfate, and calcium.^{72, 78, 161}

Trace element leaching is a function of the ash rather than the spent bed material. It is probably advantageous to mix ash and spent bed material since, in general, trace elements display greatly decreasing solubilities with increasing pH as provided by the bed material. The trace elements of major concern appear to be arsenic, cadmium, chromium, lead and mercury. Calcium sulfate (CaSO_4) and calcium carbonate (CaCO_3) are chemically stable and are suitable for direct disposal. However, unreacted lime (CaO) will readily hydrate to

form calcium hydroxide (Ca(OH)_2) on contact with water and will recombine with CO_2 in the presence of moist air. Both these reactions, although exothermic and resulting in a significant heat release, appear to pose no environmentally adverse effects.⁸⁴ In fact, this reaction has been shown to produce a cementation of the outer surface thus creating a structural barrier that minimizes water contact with leachable components.¹⁶¹

On the basis of these relatively meager data, it can tentatively be concluded that leaching of FBC spent sorbent will most likely not pose a major threat of ground-water pollution provided that proper landfill techniques are used.¹⁵⁴

Coal Gasification and Liquefaction Waste Disposal

The wastes from the two processes are similar in nature for disposal purposes and will therefore be considered together. Virtually all the waste streams can be disposed of by landfill but some may require treatment first. The largest quantities of waste come from coal pretreatment (particularly in the liquefaction process) and the ash/char from the gasification/liquefaction process.

The potential of liquefaction or gasification ash for leaching trace elements may vary substantially from that of ash generated in conventional power plants because portions of the ash may be produced by different pathways (e.g., reducing rather than oxidizing conditions). Significant differences in mineralogy and chemical form of produced species may affect the solubility of elements in the ash and thus affect their potential as pollutants (MITRE, 1978).¹⁶⁶

Clearly, existing information concerning the environmental destiny of ash leaches is insufficient to make a definite assessment on their role as potential environmental contaminants. However, if leachate is found to be a problem and depending on how the wastes are designated under RCRA, the residues can be landfilled.

The catalyst wastes from the conversion processes contain high metal contents, carbonaceous material (e.g., polycyclic organic material) and sulfur compounds and may be designated as hazardous material under RCRA. They may, however, still be disposed of in landfills provided certain precautions are taken. Chemical fixation processes are available to reduce solubility and chemical reactivity of the waste and hence reduce the

potential for leachate. The waste may also be encapsulated in plastic, metal or concrete containers or coated with self-setting resins prior to disposal.¹⁶⁰ These methods are expensive but the catalysts represent a small intermittent quantity of waste.

The other waste streams consist of tar and oil sludge, inorganic solids and sludges and biosludges. It is thought that all these streams may be disposed of by landfill.¹⁶⁰ In some cases, for example biosludges, dewatering and possibly chemical fixation will be required. Again, it is possible that some of the streams may be found hazardous, and in this case, although they could be treated prior to landfilling, this may be an uneconomical disposal option.

Oil Shale Wastes

Like natural terrain, a disposal pile will be subject to surface erosion and runoff during storms and snowmelt. Soluble substances, particularly inorganic salts, can be mobilized from retorted shale along with suspended material during the erosion process. About 20 lb/ton of salt (primarily sodium sulfate) is water soluble in fresh, carbonaceous retorted shales (e.g., TOSCO II). Burned shales (e.g., Paraho) may contain larger quantities of soluble salts. Further, additional soluble substances are added to retorted shale in the form of process water (about 1 kg soluble salts/tonne of processed shale).⁸⁸

Although retorted shales have low permeability, water has been shown to penetrate into retorted shale piles. Winter freeze-thaw cycles can significantly reduce compaction densities, creating greater permeability in the upper portion (1 meter) of a pile than was originally the case.

In addition to the potential for mobilizing common inorganic ions from retorted shales, water running off of or migrating through a disposal pile may dissolve organic and trace inorganic constituents. Other solid and liquid wastes likely to be contained in a disposal pile include process wastewaters, oily sludges, spent catalysts, and shale coke. Water contacting such materials may dissolve toxic or carcinogenic organic substances (phenolics, organic acids, POM) and hazardous trace elements (arsenic, nickel, molybdenum, chromium). Since small scale experiments conducted to date have generally not included materials other than retorted shale, the potential for waterborne transport of suspended or dissolved substances derived from the

above mentioned wastes is largely speculative.

Disposal Techniques: Present industrial plans call for disposal of processed shale and other solid wastes in nearby gulches and canyons. Impoundments will be provided to collect runoff from these wastes over the life of the project, and this runoff will be recycled to the pile or used in the plant.

Nonetheless, despite the best efforts to collect runoff, surface disposal of solid wastes represents a long term hazard to water quality. After a site is abandoned, the impoundment would eventually be filled with sediment, water would be no longer withdrawn for in-plant use, and runoff from the disposal pile would be discharged. The composition of this runoff is not accurately known, but the U.S. Bureau of Land Management considered that failure of Colony's catchment dams would temporarily release substantial amounts of sediment to Parachute Creek and the Colorado River, although the salts and trace metals would be diluted to insignificant concentrations by the voluminous discharge. In short, if contaminants cannot be kept below an acceptable level, complete abandonment of disposal piles is not possible, and custodial care would be needed.⁹⁸

Subsurface disposal of processed shale is an alternative to surface disposal and would reduce the land impacts, but this method could contaminate the groundwater. In this technique, the mine is backfilled with a slurry of processed shale or, simply, with pulverized dry material. However, because of swelling of oil shale during mining, crushing, and retorting, this method can never eliminate the need for surface disposal of some solid wastes. Subsurface disposal would be suitable only in areas without groundwater and in nonsubsiding (or at most, slowly subsiding) underground mines—that is, those mined by room-and-pillar, chamber-and-pillar, and sublevel sloping methods. This disposal method, besides reducing some of the land requirements, could control subsidence and, hence, could stabilize an active mine. Still, if leaching of processed shale is a problem, as it would be in much of the Piceance Creek Basin, additional costs could be incurred to control this impact, assuming that a suitable control procedure can be found.

Retort Water Disposal: Most effluents produced by an oil shale plant can be treated and reused. However, economically feasible procedures have not been

demonstrated for removing all contaminants from water produced during retorting, and much of the effort to purify this water has been discouraging.⁸⁸

Retort water from surface retorting processes is not anticipated to be a major problem because it would be produced in comparatively small volumes (perhaps as little as 0.10-0.15 gallon per gallon of oil if indirect heating is used). This water can be beneficially used to moisturize processed shale.

Pollution from retort water produced by *n* situ processes, on the other hand, could be a potentially difficult problem to control because the quantities may be large—from 0.40 to 22 gallons per gallon of oil. Present industrial plans do not adequately address treatment and disposal of this water (Rio Blanco Oil Shale Project, 1977b; C-b Shale Oil Venture, 1977a).⁸⁸ The plans indicate only that the retort water will be either discarded with processed shale or evaporated, after removal of ammonia and hydrogen sulfide. For the quantities of retort water involved, neither disposal with processed shale nor evaporation is technically or economically feasible because of design considerations for disposal piles and the large land area needed for evaporation ponds. Thus, a commercial oil-shale industry will require a technology to contain, treat, and dispose of these effluents. Conceivably, such a technology could produce clean water for further use.

Land Reclamation: The surface of a disposal pile is subject to natural erosion by wind and water. In principle, non-vegetative protection or stabilization of pile surfaces is possible, but the large areas involved in commercial oil shale operations make vegetative stabilization the preferred or economic alternative.

Several greenhouses and field experiments or tests have been conducted to investigate the potential of retorted shale to support plant growth.¹⁷² The results of these experiments indicate that the successful establishment of vegetation directly on the surface of retorted shale piles is partially limited by inherent properties of retorted shale itself. These include the high soluble salt content of the shale, the alkalinity of burned shale, the dark heat absorbing color of carbonaceous retorted shale, and the lack of nutrients needed for plant growth. Many of these problems, it is thought, can be overcome and certain studies suggest that revegetation may be possible.¹⁶³

The crucial issue facing land reclamation for an oil shale industry is the long-term effectiveness of the selected control strategies. Whatever practices are selected, they must be able to withstand natural processes that accelerate erosion. A high rate of erosion would destroy the vegetative cover, and expose the processed shale. Plants grown on the processed shale may accumulate toxic trace metals, which may be damaging to wildlife and livestock. Thus, long-term management of disposal piles appears to be necessary. Periodic maintenance also would be needed to remove accumulated sediment and salts from impoundments. In summary, it is uncertain that disposal piles of processed shale could ever be truly abandoned without risking some hazard from undesirable runoff.¹⁶³

Oil and Gas Extraction Fluid Disposal

Current Disposal Practices: Only a portion of the drilling fluids is lost to the bore hole during oil or gas drilling; the remaining fluid must be disposed of or, in the case of oil-based fluids, processed for re-use after completion of a well. In offshore drilling operations, the drilling wastes are typically disposed in the ocean, following EPA guidelines as specified in NPDES permits. In onshore drilling operations, used drilling fluids have historically been disposed on land. Land disposal practices have included spreading over land surfaces or evaporation in a diked area, holding pond, or pit. The area used is generally covered over after the mud has dried. State governments are becoming increasingly concerned about the land disposal of waste drilling fluids and some, such as California, have opposed surface spreading so that disposal in holding ponds or pits must be used.

Oil brines are commonly either reinjected into the reservoir or evaporated in a manner similar to the drilling fluids.¹⁰²

SOLID/HAZARDOUS WASTE DISPOSAL SITES

Comprehensive data as to the number and location of energy-related disposal sites is limited to nuclear waste disposal. The following is a summary of the quantities of waste produced and number of disposal sites according to the type of nuclear waste.

High Level Waste (HLW)

High level waste resulting from DOE defence and R&D related programs exists in a variety of forms at a number of sites. Total volumes of high level waste stored at the Savannah River, Idaho, and Hanford sites currently equal 9.4 million cubic feet and is projected to decline to 9.1 million cubic feet in 1985 as a result of evaporation and processing (cesium and strontium recovery and encapsulation; calcining of HLW). Liquids constitute about 40 percent of the current volume, with salt cake and sludge representing nearly all the remainder. High level wastes have also accumulated through the operation of the only commercial reprocessing plant in the United States, the NFS facility at West Valley, New York (which is shut down). These wastes currently total 82,000 cubic feet. Table 4.89 shows existing HLW disposal sites and total waste enclosed.⁵⁹

Transuranic Waste (TRU)

Existing inventories of commercial transuranic waste are buried at 5 of the 6 commercial low level burial sites (i.e., The Barnwell, South Carolina, site has always prohibited burial of transuranic wastes.) The transuranic content of low level waste buried totals 123 kilograms and ranges from 69 kilograms at Maxey Flats, Kentucky, to 4 kilograms at West Valley, New York, as shown in Table 4.90. The only commercial waste burial site currently receiving TRU waste is Hanford. Approximately 15 million cubic feet of TRU waste exists at six DOE sites as shown in Table 4.91. Of that volume, nearly 2 million cubic feet is retrievably stored while the balance is buried. Burial of DOE TRU waste was ceased at most sites in 1970 and at all sites by 1974.¹⁶⁴

Low Level Waste (LLW)

Most LLW, which is found in a wide variety of forms, remains radioactive for up to several hundred years. The current means of disposing of this waste is through shallow-land burial. At present, DOE has 14 active and 2 closed nuclear waste burial grounds, and commercial operators maintain 3 open and 3 closed sites. The commercial facilities serve the nation's nuclear power industry and other industry processors of nuclear waste such as hospitals and research organizations.¹⁶⁴

Intermediate Level Waste (Oak Ridge)

Some radio active wastes generated by the Oak Ridge National Laboratory are disposed of onsite by mixing the wastes with cement and injecting the resultant grout into the shale medium (after hydrofracturing) which exists below the site. This technique has resulted in the disposal of 1.6 million gallons as of 1 January 1977. Of that total, approximately 25 percent consisted of sludge, and the remainder of waste solution. Annual additions of approximately 90,000 gallons are expected to continue in the foreseeable future. This disposal technique has no effect on burial grounds or repository requirements.¹⁶⁴

SOLID WASTE UTILIZATION

Recovery of energy and materials from solid wastes, particularly municipal solid wastes, began in Europe after World War II. In the United States, this technology has grown largely as a result of the environmental movement of the 1970s, as a result of increased costs of materials, such as aluminum, which were being discarded, as a result of the increased costs and land requirements for safe solid waste disposal.

Presently, utilization of coal combustion wastes is only around 29 percent, and there is a need for increased research and development into resource recovery from a variety of energy-related solid wastes. Under RCRA, EPA has developed guidelines for financial and technical assistance for resource recovery. Wastes as fuels programs, development of product categories for reusing wastes such as cement and concrete, and public education programs are major activities under RCRA that should stimulate further waste utilization.

Recovery of energy-related solid wastes is not only environmentally sound because it reduces the quantity of wastes requiring disposal, but can also be economically attractive. Given adequate commercial incentives and technological research and development, industry can decrease disposal costs, lengthen the lifetime of operating disposal facilities, and gain a marketable product. In addition, separating out the useful portions of energy-related solid wastes will help direct attention to those hazardous portions that

cannot be used and must be carefully handled and disposed of. This section summarizes current activities in municipal solid waste recovery and then focuses on specific uses for solid wastes from coal utilization.

Municipal Solid Wastes

The economics of solid waste disposal and public opposition to new disposal sites have prompted many urban areas to initiate programs for recovery of energy (refuse-derived fuel) and commercially valuable material. Table 4.92 shows the composition of municipal solid wastes and Table 4.93 gives a summary of municipal energy and resource recovery programs in 1977. Table 4.94 shows estimates and projected trends in urban resource recovery over a 25-year period. While activity is definitely increasing as the resource recovery industry and technology are developing (see Table 4.95), the percent of total gross discards recovered is only projected to be 13 percent by 1985.¹¹⁷

Principal municipal waste-fed energy recovery technologies are: the waterwall incinerator, the modular incinerator, and conversion of trash into "refuse-derived fuel". Other technologies, such as gasification and pyrolysis, are also being applied to these solid wastes with varying degrees of success. Table 4.96 compares energy recovery efficiencies for several of these processes.¹¹⁷

Solid Waste from Coal Utilization

Coal combustion wastes (ash, slag, FGD sludge, and fluidized bed material) comprise one of the largest waste streams in the United States. European countries utilized a major fraction of their national production of fly ash in 1971 (79 percent in the Federal Republic of Germany, 65 percent in France, 54 percent in the United Kingdom, 4 percent in Belgium, and 44 percent in Poland). At least in the case of the UK, this is largely due to a strong marketing effort by the Central Electricity Generating Board.

In contrast, U.S. utilization is only around 20 percent. However, it is encouraging to note the growth in actual tonnage of ash consumed in beneficial end-use (Table 4.97). The tonnage used in 1977 was over four times that used in 1966 (14.0 compared to 3.1 million tons), even though the percent utilization less than doubled (from 12.1 to 20.7 percent). As production of ash expands over the next few years, a greater

tonnage may be utilized—but not necessarily a higher percentage.¹¹⁹

Enough technically sound applications have been developed to potentially absorb more than the annual quantity generated (Table 4.98 - 4.100); this is not likely to occur in the near future, partly because of customer uncertainties about reliability, technical complexity of application, uniformity and quality of product.¹⁶⁵ Major deterrents to utilization of lime/limestone scrubber wastes are their variable physical and chemical properties, high transportation costs, dewatering requirements for many applications, and their inability to compete economically with other materials. Although some applications appear to be technically and economically feasible, the potential usage is so limited that only a small fraction of the expected sludge production could be marketed. At least for the near term, disposal of wastes by ponding or landfill will continue to be the major alternatives.

Major routes for reuse of these wastes are in building material, road construction and agriculture.

Building Materials

Ash from Conventional Combustion

There are several products which can utilize ash as a component; these include cement, concrete, structural fills, and bricks. Blended cements are usually made by integrating cement clinker with industrial by-products such as fly ash or granulated blast furnace slag. Fly ash is attractive because it is widely produced in large amounts and in a form that is usually immediately suitable for the purpose. Research by the Bureau of Reclamation showed the replacement of 15 to 100 percent prevents or greatly retards corrosion of the reinforcing steel.

There are several economic and ecological advantages in utilizing fly ash as a substitute for part of the cement used in concrete construction. Among these advantages are:

- **Cost:** Where delivered price of cement is about \$30/ton fly ash will cost \$6-\$7/ton.
- **Convenience:** It takes less pouring time and less finishing time than does standard concrete.
- **Conservation:** There is a considerable savings in energy (1,300 kWh/ton for cement vs. nominal kWh/ton for waste fly ash).

- **Expansive Production:** Plant capacity is expanded with practically no investment in new facilities.¹⁶⁶

A considerable quantity of fly ash was utilized in 1975 for producing lightweight concrete, and this use is expected to expand rapidly. Its resistance to freezing and thawing makes lightweight aggregate prepared from sintered fly ash more valuable to road-builders and to the concrete construction industry.

Because of its high load-bearing capacity, fly ash is often used as load-bearing structural fill for industrial buildings, schools, etc. Its light weight and self-hardening properties make fly ash an ideal construction raft for building development over poor ground. Settlement is reduced to a minimum; the hardened fly-ash raft forms a monolithic structure that can then bridge weak spots in the subgrade and thus reduce differential settlement.

Extensive R&D has been conducted on fly-ash brick by the Coal Research Bureau of West Virginia University (CRB/WVU). A fly-ash brick plant designed to produce 35 million bricks yearly, using a process developed at the CRB/WVU, is operating at Edmonton, Alberta. The demand for fired products from fly ash has led to the construction of a second plant for the manufacture of paving tile. Further expansion is reportedly being considered for this plant. However, efforts to expand the use of fly ash in the manufacture of ceramic brick in the U.S. have not resulted in consumption of substantial quantities.

Using FGD sludges in the production of aerated and poured concrete appears at present to be an attractive possibility.¹⁶⁸ Experiments on the potential use in wallboard are being conducted and Southern Services Wallboard has been manufactured using a 50/50 blend of natural and FGD sludge-derived gypsum. Evaluations of FGD gypsum related to manufacturing wallboard are not, however, available.¹⁴⁹

Fluidized Bed Material

One of the uses considered for spent sorbent is in the manufacturing of gypsum board (wallboard). TVA conducted a study for EPA to provide a detailed assessment of abatement gypsum in terms of its production and market potential, including its use for wallboard manufacture. It does not seem likely that spent limestone sorbent, which usually contains only about 25 to 35 percent CaSO_4 , or dolomite spent sorbent,

with its high content (20 percent) of magnesia, could meet the industry's chemical specifications or displace the much-favored natural gypsum.⁷⁷

The Coal Research Bureau of West Virginia University has investigated the use of spent lime sorbent plus fly ash for the manufacture of cement or cinder blocks, facing-quality brick mineral wool, cracking beds, ceramic castings, and glaze-coated materials. Of these, mineral wool production seems to have some promise.⁷⁷

Other Solid Wastes

Early investigations have suggested that spent oil shale could be used in concrete blocks, building brick and Portland cement.¹⁵⁹ Ash from gasification and liquefaction plants could also be used for the production of brick.¹⁶⁷

Road Construction Material

Ash

The use of lime/fly ash aggregate (LFA) and lime/cement/fly ash aggregate (LCFA) mixtures in pavement construction has increased substantially during recent years. In general, power plant aggregates (ash and slag) can be successfully used in asphalt pavement compositions. The advantages of fly ash as mineral filler in asphalt paving are lower cost, acceptable size, gradation without processing, and superior resistance to water.

Agricultural Use

FGD Wastes

The use of lime/limestone wastes as a filler material and source of sulfur in granular fertilizers is being investigated at the pilot-plant scale by TVA in the Interagency Energy-Environment Program. In addition to process development, the program includes field tests, economic/marketing studies, and comparison of trace element contents with those of conventional fertilizers.

The use of natural gypsum as a calcium source for peanuts is fairly well established in the U.S., and the growth of peanuts and soybeans in mixtures of soils and Chiyoda-produced gypsum is being evaluated at the University of Florida Agricultural Center, Quincy, Florida. Early results indicate the feasibility of applying up to 20 tons of the gypsum per acre.⁷⁷

Fluidized Bed Material

Rather favorable results have been obtained with limestone spent sorbent as a nutrient for peanut growing. When applied to plots planted with peanuts, spent limestone sorbent from the Pope, Evans, and Robbins small (about 0.7 MW) pilot plant improved yields by about 10 percent over those obtained with no fertilizer. These results were equal to, or slightly better than, the improvements afforded by land plaster (natural gypsum).⁷⁷

Initial studies by Ralph Stone and Co.¹⁶⁵ have shown that fluidized-bed residues can be used beneficially as a soil conditioner when soils are acidic, high in heavy metals or deficient in trace metals. The height of tomato plants increased from 15 to 70 percent with the application of the residue. They also conclude that substitution of FBC residues for calcium carbonate as a source of calcium can be economically feasible for selected crops grown in alkaline soils containing a very high sodium ratio.

One concern with the agricultural use of the fluidized bed waste is the possibility of contamination of the food by such potentially toxic substances as lead, nickel, cadmium, chromium, arsenic, mercury, and selenium. Preliminary analysis indicates that lead, nickel, cadmium, and chromium may be present in sufficiently high concentrations to warrant concern for production of certain crops.⁸⁰

Sulfur from Coal Utilization

The solid waste problem presented by the current use of coal and by anticipated increases in combustion of coal by conventional and fluidized bed technologies could be alleviated somewhat by the use of regenerable SO_2 sorbents. The primary drawback to this solution is the limited market for the sulfuric acid and elemental sulfur produced from these technologies. Table 4.101 compares the potential sulfur production from various types of coal-based technologies with the total U.S. sulfur sales.

Most sulfur consumed in the United States is used to produce sulfuric acid, 58 percent of which is consumed in the fertilizer industry. Consumption for non-acid purposes uses another 12 percent of the market.¹⁶⁶ Several sulfur concrete technologies, such as the Sudicrete process recently licensed by the Sulfur Development Institute of Canada, could also provide a market for the sulfur byproduct.¹⁶⁸

Other routes for elemental sulfur resale include production of sulfur-containing fertilizers to slow the release of urea, sulfur-based paving material as a bulk aggregate limestone substitute, sulfur foams for pavement subsurfaces, and thermal and acoustical insulation. New uses for sulfur include plastics, surface bonding structural materials, mortar and brick panels, asphalt paving mixes and binders, soil stabilizers, and electrodes for lithium batteries. Potential agricultural uses of sulfuric acid include reclamation of sodic soils to increase plant nutrient availability; treatment of alkaline or ammoniated irrigation water; control of certain weeds and pathogens; and improvement of range grass establishment.

Other Uses for Wastes

One of the most significant potential areas currently in the R&D phase is metal recovery from coal ash. As an example, approximately 65 percent of the nation's need for aluminum could be satisfied by chemical extraction from coal ash, and significant quantities of other metals could also be separated in the process.¹¹⁵

The Tennessee Valley Authority recently approved a project to extract minerals from coal ash. The pilot plant will process 24 tons of coal ash daily to extract aluminum, iron, silicon and other metals. TVA coal-burning plants produce about six million tons of ash annually, enough to yield over one million tons of recoverable aluminum.¹⁶⁹

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4. SOLID/HAZARDOUS WASTE DATA

The data described in Section 3 are presented here in six parts:

- Solid/Hazardous Waste Management
- Residuals and Loadings
- Current Levels of Solid Waste Generation
- Effects and Methods of Solid/Hazardous Waste Disposal
- Solid/Hazardous Waste Disposal Sites
- Solid Waste Utilization

Each of these data sets is preceded by a listing of tables and figures.

SOLID/HAZARDOUS WASTE MANAGEMENT

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Table 4.1

Hazardous Constituents Identified in RCRA

Acetaldehyde	Cadmium and compounds, N.O.S.
(Acetato) phenylmercury	Calcium chromate
Acetonitrile	Calcium cyanide
3-(alpha-Acetonylbenzyl)-4-hydroxycoumarin and salts	Carbon disulfide
2-Acetylaminofluorene	Chlorambucil
Acetyl chloride	Chlordane (alpha and gamma isomers)
1-Acetyl-2-thiourea	Chlorinated benzenes, N.O.S.
Acrolein	Chlorinated ethane, N.O.S.
Acrylamide	Chlorinated naphthalene, N.O.S.
Acrylonitrile	Chlorinated phenol, N.O.S.
Aflatoxins	Chloroacetaldehyde
Aldrin	Chloroalkyl ethers
Allyl alcohol	p-Chloroaniline
Aluminum phosphide	Chlorobenzene
4-Aminobiphenyl	Chlorobenzilate
6-Amino-1, 1a, 2, 8, 8a, 8b-hexahydro-8-(hydroxymethyl)-8a-methoxy-5-methylcarbamate azirino (2', 3':3,4) pyrrolo (1, 2-a) indole-4, 7-dione (ester) (Mitomycin C)	1-(p-Chlorobenzoyl)-5-methoxy-2-methylindole-3-acetic acid
5-(Aminomethyl)-3-isoxazolol	p-Chloro-m-cresol
4-Aminopyridine	1-Chloro-2, 3-epoxybutane
Amitrole	2-Chloroethyl vinyl ether
Antimony and compounds, N.O.S. ¹	Chloroform
Aramite	Chloromethane
Arsenic and compounds, N.O.S.	Chloromethyl methyl ether
Arsenic Acid	2-Chloronaphthalene
Arsenic pentoxide	2-Chlorophenol
Arsenic trioxide	1-(o-Chlorophenyl) thiourea
Auramine	3-Chloropropionitrile
Azaserine	alpha-Chlorotoluene
Barium and compounds, N.O.S.	Chlorotoluene, N.O.S.
Barium cyanide	Chromium and compounds, N.O.S.
Benz c acridine	Chrysene
Benz a anthracene	Citrus red No.2
Benzene	Copper cyanide
Benzeneearsonic acid	Creosot
Benzenethiol	Crotonaldehyde
Benzidine	Cyanides (soluble salts and complexes), N.O.S.
Benzo a anthracene	Cyanogen
Benzo b fluoranthene	Cyanogen bromide
Benzo j fluoranthene	Cyanogen chloride
Benzo a pyrene	Cycasin
Benzo b fluoranthene	2-Cyclohexyl-4,6-dinitrophenol
Benzo k fluoranthene	Cyclophosphamide
Benzo a pyrene	Daunomycin
Benzo b fluoranthene	DDD
Benzo k fluoranthene	DDE
Benzyl chloride	DDT
Beryllium and compounds, N.O.S.	Diallate
Bis(2-chloroethoxy)methane	Dibenz a,h acridine
Bis(2-chloroethyl) ether	Dibenz a,j acridine
N, N-Bis(2-chloroethyl)-2-naphthylamine	Dibenz a,h anthracene (Dibenzo a,h anthracene)
Bis(2-chloroisopropyl) ether	7H-Dibenzo c,g carbazol
Bis(chloromethyl) ether	Dibenz a,e pyrene
Bis(2-ethylhexyl) phthalate	Dibenzo a,h pyrene
Bromoacetone	Dibenzo a,i pyrene
Bromomethane	1,2 Dibromo-3-chloropropane
4-Bromophenyl phenyl ether	1,2-Dibromoethane
Brucine	Dibromomethane
2-Butanone peroxide	Di-n-butyl phthalate
Butyl benzyl phthalate	Dichlorobenzene, N.O.S.
2-sec-Butyl-4, 6-dinitrophenol (DNBP)	3,3'-Dichlorobenzidine

Table 4.1 (cont.)

1,1-Dichloroethane	Ethyleneimine
1,2-Dichloroethane	Ethylene oxide
trans-1,2-Dichloroethane	Ethylenethiourea
Dichloroethylene, N.O.S.	Ethyl menthanesulfonate
1,1-Dichloroethylene	Fluoranthene
Dichloromethane	Fluorine
2,4-Dichlorophenol	2 Fluoroacetamide
2,6-Dichlorophenol	Fluoroacetic acid, sodium salt
2,4-Dichlorophenoxyacetic acid (2,4-D)	Formaldehyde
Dichloropropane	Glycidylaldehyde
Dichlorophenylarsine	Halomethane, N.O.S.
1,2-Dichloropropane	Heptachlor
Dichloropropanol, N.O.S.	Heptachlor epoxide (alpha, beta, and gamma isomers)
Dichloropropene, N.O.S.	Hexachlorobenzene
1,3-Dichloropropene	Hexachlorobutadiene
Dieldrin	Hexachlorocyclohexane (all isomers)
Diepoxybutane	Hexachlorocyclopentadiene
Diethylarsine	Hexachloroethane
0,0-Diethyl-S-(2-ethylthio) ethyl ester of phosphorothioic acid	1,2,3,4,10,10-Hexachloro-1,4,4a,5,8,8a, hexahydro-1,4:5,8-endo, endo- dimethanonaphthalene
1,2-Diethylhydrazine	Hexachlorophene
0,0-Diethyl-S-methylester phosphorodithioic acid	Hexachloropropene
0,0-Diethylphosphoric acid, O-p-nitrophenyl ester	Hexaethyl tetraphosphate
Diethyl phthalate	Hydrazine
0,0-Diethyl-O-(2-pyrazinyl) phosphorothioate	Hydrocyanic acid
Diethylstilbestrol	Hydrogen sulfide
Dihydrosafrole	Indeno (1,2,3-c,d)pyrene
3,4-Dihydroxy-alpha-(methylamino)- methyl benzyl alcohol	Iodomethane
Di-isopropylfluorophosphate (DFP)	Isocyanic acid, methyl ester
Dimethoate	Isosafrole
3,3'-Dimethoxybenzidine	Kepone
p-Dimethylaminoazobenzene	Lasiocarpine
7,12-Dimethylbenz a anthracene	Lead and compounds, N.O.S.
3,3'-Dimethylbenzidine	Lead acetate
Dimethylcarbamoyl chloride	Lead phosphate
1,1-Dimethylhydrazine	Lead subacetate
1,2 Dimethylhydrazine	Maleic anhydride
3,3-Dimethyl-1-(methylthio)-2-butanone-O- (methylamino) carbonyl oxime	Malononitrile
Dimethylnitrosoamine	Melphalan
alpha, alpha-Dimethylphenethylamine	Mercury and compounds, N.O.S.
2,4-Dimethylphenol	Methapyriline
Dimethyl phthalate	Methomyl
Dimethyl sulfate	2-Methylaziridine
Dinitrobenzene, N.O.S.	3-Methylcholanthrene
4,6-Dinitro-o-cresol and salts	4,4'-Methylene-bis-(2-chloraniline)
2,4-Dinitrophenol	Methyl ethyl ketone (MEK)
2,4-Dinitrotoluene	Methyl hydrazine
2,6-Dinitrotoluene Di-n-octyl phthalate	2-Methylactonitrile
1,4-Dioxane	Methyl methacrylate
1,2-Diphenylhydrazine	Methyl methanesulfonate
Din-n-propylnitrosamine	2-Methyl-2(methylthio)propionaldehyde-o- (methylcarbonyl) oxime
Disulfoton	N-Methyl-N'-nitro-N-nitrosoguanidino
2,4-Dithiobiuret	Methyl parathion
Endosulfan	Methylthiouracil
Endrin and metabolites	
Epichlorohydrin	
Ethyl cyanide	
Ethylene diamine	
Ethylenebisdithiocarbamate (EBDC)	

Table 4.1 (cont.)

Mustard gas	Phosphorothioic acid, 0,0-dimethyl ester, 0-ester with N,N-dimethyl benzene sulfonamide
Naphthalene	Phthalic acid esters, N.O.S.
1,4-Naphthoquinone	Phthalic anhydride
1-Naphthylamine	Polychlorinated biphenyl, N.O.S.
2-Naphthylamine	Potassium cyanide
1-Naphthyl-2-thiourea	Potassium silver cyanide
Nickel and compounds, N.O.S.	Pronomide
Nickel carbonyl	1,2-Propanediol
Nickel cyanide	1,3-Propane sultone
Nicotinic acid and salts	Propionitrile
Nitric oxide	Propylthiouracil
p-Nitroaniline	2-Propyn-1-ol
Nitrobenzene	Pryidine
Nitrogen dioxide	Reserpine
Nitrogen mustard and hydrochloride salt	Saccharin
Nitrogen mustard N-oxide and hydrochloride salt	Safrole
Nitrogen peroxide	Selenious acid
Nitrogen tetroxide	Selenium and compounds, N.O.S.
Nitroglycerine	Selenium sulfide
4-Nitrophenol	Selenourea
4-Nitroquinoline-1-oxide	Silver and compounds, N.O.S.
Nitrosamine, N.O.S.	Silver cyanide
N-Nitrosodi-N-butylamine	Sodium cyanide
N-Nitrosodiethanolamine	Streptozotocin
N-Nitrosodiethylamine	Strontium sulfide
N-Nitrosodimethylamine	Strychnine and salts
N-Nitrosodiphenylamine	1,2,4,5-Tetrachlorobenzene
N-Nitrosodi-N-propylamine	2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)
N-Nitroso-N-ethylurea	Tetrachloroethane, N.O.S.
N-Nitrosomethylethylamine	1,1,1,2-Tetrachloroethane
N-Nitroso-N-methylurea	1,1,2,2-Tetrachloroethane
N-Nitroso-N-methylurethane	Tetrachloroethene (Tetrachloroethylene)
N-Nitrosomethylvinylamine	Tetrachloromethane
N-Nitrosomorpholine	2,3,4,6-Tetrachlorophenol
N-Nitrosornicotine	Tetraethyldithiopyrophosphate
N-Nitrosopiperidine	Tetraethyl lead
N-Nitrosopyrrolidine	Tetraethylpyrophosphate
N-Nitrososarcosine	Thallium and compounds, N.O.S.
Nitro-o-toluidine	Thallic oxide
Nitramethylpyrophosphoramidate	Thallium (I) acetate
Nitro alcohol condensed with 2 moles ethylene oxide	Thallium (I) carbonate
Osmium tetroxide	Thallium (I) chloride
7-Oxabicyclo 2.2.1 heptane-2,3-dicarboxylic acid	Thallium (I) nitrate
Parathion	Thallium selenite
Pentachlorobenzene	Thallium (I) sulfate
Pentachloroethane	Thioacetamide
Pentachloronitrobenzene (PCNB)	Thiosemicarbazide
Pentachlorophenol	Thiourea
Phenacetin	Thiuram
Phenol	Toluene
Phenyl dichloroarsine	Toluene diamine
Phenylmercury acetate	o-Toluidine hydrochloride
N-Phenylthiourea	Tolylene diisocyanate
Phosgene	Toxaphene
Phosphine	Tribromomethane
	1,2,4-Trichlorobenzene
	1,1,1-Trichloroethane
	1,1,2-Trichloroethane
	Trichloroethene (Trichloroethylene)

Table 4.1 (cont.)

Trichloromethanethiol	Tris(2,3-dibromopropyl) phosphate
2,4,5-Trichlorophenol	Trypan blue
2,4,6-Trichlorophenol	Uracil mustard
2,4,5-Trichlorophenoxyacetic acid (2,4,5-T)	Urethane
2,4,5-Trichlorophenoxypropionic acid (2,4,5-TP) (Silvex)	Vanadic acid, ammonium salt
Trichloropropane, N.O.S.	Vanadium pentoxide (dust)
1,2,3-Trichloropropane	Vinyl chloride
0,0,0-Triethyl phosphorothioate	Vinylidene chloride
Trinitrobenzene	Zinc cyanide
Tris(1-aziridinyl) phosphine sulfide	Zinc phosphide

The abbreviation N.O.S. signifies those members of the general class "not otherwise specified" by name in this listing.

Source: 45 FR 33121 (May 19, 1980) Subpart B, Sec. 251.11(a)(3).

Table 4.2

Maximum Concentration of Contaminants For Characteristics of EP Toxicity

EPA Hazardous Waste Number	Contaminant	Maximum Concentration (Milligrams Per Liter)
D004	Arsenic	5.0
D005	Barium	100.0
D006	Cadmium	1.0
D007	Chromium	5.0
D008	Lead	5.0
D009	Mercury	0.2
D010	Selenium	1.0
D011	Silver	5.0
D012	Endrin (1,2,3,4,10,10-hexachloro-1,7 epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo, endo-5,8-dimethano naphthalene)	0.02
D013	Lindane (1,2,3,4,5,6-hexachlorocyclohexane, gamma isomer)	0.4
D014	Methoxychlor (1,1,1-Trichloro-2,2-bis(p-methoxyphenyl) ethane)	
D015	Toxaphene (C ₁₀ H ₁₀ Cl ₈ , Technical chlorinated camphene, 67-69 percent chlorine)	0.5
D016	2,4-D, (2,4-Dichlorophenoxyacetic acid)	10.0
D017	2,4,5-TP Silvex (2,4,5-Trichlorophenoxypropionic acid)	1.0

Source: 45 FR 33122 (May 19, 1980).

Table 4.3

Hazardous Waste From Nonspecific Sources

Industry and EPA Hazardous Waste No.	Hazardous Waste	Hazard Code
Generic:		
F001	The spent halogenated solvents used in degreasing, tetrachloroethylene, trichloroethylene, methylene chloride, 1,1,1-trichloroethane, carbon tetrachloride, and the chlorinated fluorocarbons; and sludges from the recovery of these solvents in degreasing operations	T
F002	The spent halogenated solvents, tetrachloroethylene, methylene chloride, trichloroethylene, 1,1,1-trichloroethane, chlorobenzene, 1,1,2-trichloro- 1,2,2-trifluoroethane, o-dichlorobenzene, trichlorofluoromethane and the still bottoms from the recovery of these solvents	T
F003	The spent non-halogenated solvents, oxylane, acetone, ethyl acetate, ethyl benzene, ethyl ether, n-butyl alcohol, cyclohexanone, and the still bottoms from the recovery of these solvents	I
F004	The spent non-halogenated solvents, cresols and cresylic acid, nitrobenzene, and the still bottoms from the recovery of these solvents	T
	The spent non-halogenated solvents, methanol, toluene, methyl ethyl ketone, methyl isobutyl ketone, carbon disulfide, isobutanol, pyridine and the still bottoms from the recovery of these solvents	I,T
F006	Wastewater treatment sludges from electroplating operations	T
F007	Spent plating bath solutions from electroplating operations	R,T
F008	Plating bath sludges from the bottom of plating baths from electroplating operations	R,T
F009	Spent stripping and cleaning bath solutions from electroplating operations	R,T
F010	Quenching bath sludge from oil baths from metal heat treating operations	R,T
F011	Spent solutions from salt bath pot cleaning from metal heat treating operations	R,T
F012	Quenching wastewater treatment sludges from metal heat treating operations	T
F013	Flotation tailings from selective flotation from mineral metals recovery operations	T
F014	Cyanidation wastewater treatment tailing pond sediment from mineral metals recovery operations	T
F015	Spent cyanide bath solutions from mineral metals recovery operations	R,T
F016	Dewatered air pollution control scrubber sludges from coke ovens and blast furnaces	T

Source: 45 FR 33123 (May 19, 1980).

Table 4.4

Hazardous Waste From Specific Sources

Industry and EPA Hazardous Waste No.	Hazardous Waste
Wood Preservation:	
K001.....	Bottom sediment sludge from the treatment of wastewaters from wood preserving processes that use creosote and/or pentachlorophenol
Inorganic Pigments:	
K002.....	Wastewater treatment sludge from the production of chrome yellow and orange pigments
K003.....	Wastewater treatment sludge from the production of molybdate orange pigments
K004.....	Wastewater treatment sludge from the production of zinc yellow pigments
K005.....	Wastewater treatment sludge from the production of chrome green pigments
K006.....	Wastewater treatment sludge from the production of chrome oxide green pigments (anhydrous and hydrated)
K007.....	Wastewater treatment sludge from the production of iron blue pigments
K008.....	Oven residue from the production of chrome oxide green pigments
Organic Chemicals:	
K009.....	Distillation bottoms from the production of acetaldehyde from ethylene
K010.....	Distillation side cuts from the production of acetaldehyde from ethylene
K011.....	Bottom stream from the wastewater stripper in the production of acrylonitrile
K012.....	Still bottoms from the distillation of benzyl chloride
K013.....	Bottom stream from the acetonitrile column in the production of acrylonitrile
K014.....	Bottoms from the acetonitrile purification column in the production of acrylonitrile
K015.....	Still bottoms from the distillation of benzyl chloride
K016.....	Heavy ends of distillation residues from the production of carbon tetrachloride
K017.....	Heavy ends (still bottoms) from the purification column in the production of epichlorohydrin
K018.....	Heavy ends from fractionation in ethyl chloride production
K019.....	Heavy ends from the distillation of ethylene dichloride in ethylene dichloride production
K020.....	Heavy ends from the distillation of vinyl chloride in vinyl chloride monomer production
K021.....	quecus spent antimony catalyst waste from fluoromethanes production

Table 4.4 (cont'd.)

Industry and EPA Hazardous Waste No.	Hazardous Waste	
K022	Distillation bottom tars from the production of phenol/acetone from cumene	
K023	Distillation light ends from the production of phthalic anhydride from naphthalene	
K024	Distillation bottoms from the production of phthalic anhydride from naphthalene	
K025	Distillation bottoms from the production of nitrobenzene by the nitration of benzene	
K026	Stripping still tails from the production of methyl ethyl pyridines	
K027	Centrifuge residue from toluene diisocyanate production	
K028	Spent catalyst from the hydrochlorinator reactor in the production of 1,1,1-trichloroethane	
K029	Waste from the product stream stripper in the production of 1,1,1-trichloroethane	
K030	Column bottoms or heavy ends from the combined production of trichloroethylene and perchloroethylene	
K054	Chrome (blue) shavings generated by the following subcategories of the leather tanning and finishing industry; hair pulp/chrome tan/retan/wet finish; hair save/chrome tan/retan/wet finish; no beamhouse through the blue; and shearing	T
K055	Buffing dust generated by the following subcategories of the leather tanning and finishing industry; hair pulp/chrome tan/retan/wet finish; hair save/chrome tan/retan/wet finish; retan/wet finish; no beamhouse; and through-the-blue	T
K056	Sewer screening generated by the following subcategories of the leather tanning and finishing industry; hair pulp/chrome tan/retan/wet finish; hair save/chrome tan/retan/wet finish; retan/wet finish; no beamhouse; through-the-blue; and shearing	T
K057	Wastewater treatment sludges generated by the following subcategories of the leather tanning and finishing industry; hair pulp/chrome tan/retan/wet finish; no beamhouse; through-the-blue and shearing	T
K058	Wastewater treatment sludges generated by the following subcategories of the leather tanning and finishing industry; hair pulp/chrome tan/retan/wet finish; hair save/chrome tan/retan/wet finish; and through-the-blue	R,T
K059	Wastewater treatment sludges generated by the following subcategory of the leather tanning and finishing industry; hair save/non-chrome tan/retan/wet finish	R

Table 4.4 (cont'd)

Industry and EPA Hazardous Waste No.	Hazardous Waste	
Iron and Steel:		
K060.....	Ammonia still lime sludge from coking operations	T
K061.....	Emission control dust sludge from the electric furnace production of steel	T
K062.....	Spent pickle liquor from steel finishing operations	C,T
K063.....	Sludge from lime treatment of spent pickle liquor from steel finishing operations	T
Primary Copper: K064.....	Acid plant blowdown slurry/sludge resulting from the thickening of blowdown slurry from primary copper production	T
Primary Lead: K065.....	Surface impoundment solids contained in and dredged from surface impoundments at primary lead smelting facilities	T
Primary Zinc:		
K066.....	Sludge from treatment of process wastewater and/or acid plant blowdown from primary zinc production	T
K067.....	Electrolytic anode slimes/sludges from primary zinc production	T
K068.....	Cadmium plant leach residue (iron oxide) from primary zinc production	T
Secondary Lead: K069.....	Emission control dust sludge from secondary lead smelting	T

Source: 45 FR 33123 (May 19, 1980).

Table 4.5

Basis for Listing Hazardous Waste

EPA Hazardous Waste No.	Hazardous Constituents for Which Listed
F001	tetrachloroethylene, methylene chloride trichloroethylene, 1,1,1-trichloroethane chlorinated fluorochemicals, carbon tetrachloride
F002	tetrachloroethylene, methylene chloride, trichloroethylene, 1,1,1-trichloroethane, chlorobenzene, 1,1,2-trichloro- 1,2,2 trifluoroethane, o-dichlorobenzene, trichlorofluoromethane
F003	N.A.
J4	cresols and cresylic acid, nitrobenzene
J5	methanol, toluene, methyl ethyl ketone, methyl isobutyl ketone, carbon disulfide, isobutanol, pyridine
F006	cadmium, chromium, nickel, cyanide (complexed)
F007	cyanide (salts)
F008	cyanide (salts)
F009	cyanide (salts)
F010	cyanide (salts)
F011	cyanide (salts)
F012	cyanide (complexed)
F013	cyanide (complexed)
F014	cyanide (complexed)
F015	cyanide (salts)
F016	cyanide (complexed)
K001	benzene, benz(a) anthracene, benzo(a) pyrene, chrysene, 4-nitrophenol, toluene, naphthalene phenol, 2-chlorophenol, 2,4-dimethyl phenol, 2,4,6-trichlorophenol, pentachlorophenol, 4,6-dinitro-o-cresol, tetrachlorophenol
K002	chromium, lead
K003	chromium, lead
K004	chromium
K005	chromium, lead
K006	chromium
K007	cyanide (complexed), chromium
K008	chromium
K009	chloroform, formaldehyde, methylene chloride, methyl chloride, paraldehyde, formic acid
K010	chloroform, formaldehyde, methylene chloride, methyl chloride, paraldehyde, formic acid, chloroacetaldehyde
K011	acrylonitrile, acetonitrile, hydrocyanic acid
K012	acrylonitrile, acetonitrile, acrolein, acrylamide
K013	hydrocyanic acid, acrylonitrile, acetonitrile
K014	acetonitrile, acrylamide
K015	benzyl chloride, chlorobenzene, toluene, benzotrithiol
J6	hexachlorobenzene, hexachlorobutadiene, carbon tetrachloride, hexachloroethane, perchloroethylene
K017	epichlorohydrin, chloroether (bis(chloromethyl) ether and bis (2-chloroethyl) ethers), trichloropropane, dichloropropanols
K018	1,2-dichloroethane, trichloroethylene, hexachlorobutadiene, hexachlorobenzene
K019	ethylene dichloride, 1,1,1-trichloroethane, 1,1,2-trichloroethane, tetrachloroethanes (1,1,2,2-tetrachloroethane and 1,1,1,2-tetrachloroethanes), trichloroethylene, tetrachloroethylene, carbon tetrachloride, chloroform, vinyl chloride, vinylidene chloride
K020	ethylene dichloride, 1,1,1-trichloroethane, 1,1,2-trichloroethane, tetrachloroethanes, (1,1,2,2-tetrachloroethane and 1,1,1,2-tetrachloroethane), trichloroethylene, tetrachloroethylene, carbon tetrachloride, chloroform, vinyl chloride, vinylidene chloride.
K021	antimony, carbon tetrachloride, chloroform
K022	phenol, tars (polycyclic aromatic hydrocarbons)
K023	phthalic anhydride, maleic anhydride
K024	phthalic anhydride, polynuclear tar-like materials, naphthoquinone

Table 4.5 (cont.)

EPA Hazardous Waste No.	Hazardous Constituents for Which Listed
K025	meta-dinitrobenzene, 2,4-dinitrotoluene
K026	paraldehyde, pyridines, 2-picoline
K027	toluene diisocyanate, toluene-2,4-diamine, tars (benzimidazapone)
K028	1,1,1-trichloroethane, vinyl chloride
K029	1,2-dichloroethane, 1,1,1-trichloroethane, vinyl chloride, vinylidene chloride, chloroform
K030	hexachlorobenzene, hexachlorobutadiene, hexachlorethane, 1,1,2,2-tetrachloroethane, ethylene dichloride
K031	arsenic
K032	hexachlorocyclopentadiene
K033	hexachlorocyclopentadiene
K034	hexachlorocyclopentadiene
K035	creosote, benzo(a) anthracene, benzo(b)fluoroanthene, benzo(a)pyrene
K036	toulene, phosphorodithioic and phosphorothioic acid esters
K037	toluene, phosphorodithioic and phosphorothioic acid esters
K038	phorate, formaldehyde, phosphorodithioic and phosphorothioic acid esters
K039	phosphorodithioic and phosphorothioic acid esters
K040	phorate, formaldehyde, phosphorodithioic and phosphorothioic acid
K041	toxaphene
K042	hexachlorobenzene; ortho-dichlorobenzene
K043	2,4-dichlorophenol, 2,6-dichlorophenol, 2,4,6-trichlorophenol
K044	N.A.
K045	N.A.
K046	lead
K047	N.A.
K048	chromium, lead
K049	chromium, lead
K050	chromium
K051	chromium, lead
K052	lead
K053	chromium
K054	chromium
K055	chromium, lead
K056	chromium, lead
K057	chromium, lead
K058	chromium, lead
K059	N.A.
K060	cyanide, naphthalene, phenolic compounds, arsenic
K061	chromium, lead, cadmium
K062	chromium, lead
K063	chromium, lead
K064	lead, cadmium
K065	lead, cadmium
K066	lead, cadmium
K067	lead, cadmium
K068	lead, cadmium
K069	chromium, lead, cadmium

Source: 45 FR 33131 (May 19, 1980), Appendix VII.

Table 4.6

Test Methods for Evaluating Solid Wastes

Method	Reference
Sampling	
Extremely viscous liquid	ASTM D140-70 D346-75 D420-69 D1452-65
Fly Ash	ASTM D2234-76
Containerized Liquid Wastes	EPA (new methods)
Liquid Waste From Ponds, Lagoons, etc.	EPA (new methods)
Analysis	
Ignitability	ASTM D-93-79 or ASTM D-3278-78
Corrosivity	EPA (new methods)
Reactivity	45 FR 33122 Section 261.23
EP Toxicity	EPA (new methods) or 45 FR 33127 (Appendix II)
Acute Hazard	See Sec. 2.2.1
Toxic	See Sec. 2.2.1

Source: RCRA, P.L. 94-580.

Table 4.7

Analytical Methods for Organic Chemicals

Compound	Sample Handling Class/Fraction	Non-GC Methods	Measurement Techniques		
			GC/MS	Conventional GS	Detector
Acetonitrile	Volatile		8.24	8.03	NSD
Acrolein	Volatile		8.24	8.03	NSD
Acrylamide	Volatile		8.24	8.01	FID
Acrylonitrile	Volatile		8.24	8.03	NSD
Benzene	Volatile		8.24	8.02	PID
Benz(a)anthracene	Extractable/BN	8.10(HPLC)	8.25	8.10	FID
Benzo(a)pyrene	Extractable/BN	8.10(HPLC)	8.25	8.10	FID
Benzotrichloride	Extractable/BN		8.25	8.12	ECD
Benzyl chloride	Volatile or Extractable/BN		8.24	8.01	HSD
			8.25	8.12	ECD
Benz(b)fluoranthene	Extractable/BN	8.10(HPLC)	8.25	8.10	FID
Bis(2-chloroethoxy)methane	Volatile		8.24	8.01	HSD
Bis(2-chloroethyl)ether	Volatile		8.24	8.01	HSD
Bis(2-chloroisopropyl)ether	Volatile		8.24	8.01	HSD
Carbon disulfide	Volatile		8.24	8.01	HSD
Carbon tetrachloride	Volatile		8.24	8.01	HSD
Chlordane	Extractable/BN		8.25	8.08	HSD
Chlorinated dibenzodioxins	Extractable/BN		8.25	8.08	ECD
Chlorinated biphenyls	Extractable/BN		8.25	8.08	HSD
Chloroacetaldehyde	Volatile		8.24	8.01	HSD
Chlorobenzene	Volatile		8.24	8.01	HSD
				8.02	PID
Chloroform	Volatile		8.24	8.01	HSD
Chloromethane	Volatile		8.24	8.01	HSD
2-chlorophenol	Extractable/BN		8.25	8.04	FID,ECD
Chrysene	Extractable/BN	8.10(HP_C)	8.25	8.10	FID
Creosote	Extractable/BN		8.25	8.10	ECD
Cresol(s)	Extractable/A		8.25	8.04	FID,ECD
Cresylic acid(s)	Extractable/A		8.25	8.04	FID,ECD
Dichlorobenzene(s)	Extractable/BN		8.25	8.01	HSD
				8.02	PID
				8.12	ECD

Table 4.7 (cont.)

Compound	Sample Handling Class/Fraction	Non-GC Methods	Measurement Techniques		
			GC/MS	Conventional GS	Detector
Dichloroethane(s)	Volatile		8.24	8.01	HSD
Dichloromethane	Volatile		8.24	8.01	HSD
Dichlorophenoxyacetic acid	Extractable/A		8.25	8.40	HSD
Dichloropropanol	Extractable/BN		8.25	8.12	ECD
2,4-Dimethylophenol	Extractable/A		8.25	8.04	FID,ECD
Dinitrobenzene	Extractable/BN		8.25	8.09	FID,ECD
4,6 Dinitro-o-cresol	Extractable/A		8.25	8.04	FID,ECD
2,4 Dinitrotoluene	Extractable/BN		8.25	8.09	FID,ECD
Endrin	Extractable/P		8.25	8.08	HSD
Ethyl ether	Volatile		8.24	8.01	FID
Formaldehyde	Volatile		8.24	8.02	FID
Formic acid	Extractable/BN		8.25	8.01	FID
Heptachlor	Extractable/P		8.25	8.06	FID
Hexachlorobenzene	Extractable/BN		8.25	8.06	HSD
Hexachlorobutadiene	Extractable/BN		8.25	8.12	ECD
Hexachloroethane	Extractable/BN		8.25	8.12	ECD
Hexachlorocyclopentadiene	Extractable/BN		3.25	8.12	ECD
Lindane	Extractable/P		8.25	8.08	HSD
Maleic anhydride	Extractable/BN		8.25	8.06	ECD,FID
Methanol	Volatile		8.24	8.01	FID
Methomyl	Extractable/BN	8.32(HPLC)			
Methyl ethyl ketone	Volatile		8.25	8.01	FID
Methyl isobutyl ketone	Volatile			8.02	FID
			8.25	8.01	FID
				8.02	FID
Naphthalene	Extractable/BN		8.25	8.10	FID
Naphthoquinone	Extractable/BN		8.25	8.06	ECD,FID
				8.09	FID
Nitrobenzene	Extractable/BN		8.25	8.09	ECD,FID
4-Nitrophenol	Extractable/A		8.24	8.04	ECD,FID
Paraldehyde (trimer of acetaldehyde)	Volatile		8.24	8.01	FID

Table 4.7 (cont.)

Compound	Sample Handling Class/Fracion	Non-GC Methods	Measurement Techniques		
			GC/MS	Conventional GS	Detector
Pentachlorophenol	Extractable/A		8.25	8.04	ECD
Phenol	Extractable/A		8.25	8.04	ECD, FID
Phorate	Extractable/BN			8.22	FPD
Phosphorodithioic acid ethers	Extractable/BN			8.06	ECD, FID
				8.09	ECD, FID
				8.22	FPD
Phthalic anhydride	Extractable/BN		8.25	8.06	ECD, FID
				8.09	ECD, FID
2-Picoline	Extractable/BN		8.25	8.06	ECD, FID
				8.09	ECD, FID
Pyridine	Extractable/BN		8.25	8.06	ECD, FID
				8.09	ECD, FID
Tetrachlorobenzene(s)	Extractable/BN		8.25	8.12	ECD
Tetrachloroethane(s)	Volatile		8.24	8.01	HSD
Tetrachloroethene	Volatile		8.24	8.01	HSD
Tetrachlorophenol	Extractable/A		8.24	8.04	ECD
Toluene	Volatile		8.24	8.02	PID
Toluenediamine	Extractable/BN		8.25		
Toluene diisocyanate(s)	Extractable/nonaqueous		8.25	8.06	FID
Toxaphene	Extractable/P		8.25	8.08	HSD
Trichloroethane	Volatile		8.24	8.01	HSD
Trichloroethene(s)	Volatile		8.24	8.01	HSD
Trichlorofluoromethane	Volatile		8.24	8.01	HSD
Trichlorophenol(s)	Extractable/A		8.25	8.04	HSD
2,4,5-TP (Silvex)	Extractable/A		8.25	3.40	HSD
Vinyl chloride	Volatile		8.24	8.01	HSD
Vinylidene chloride	Volatile		8.24	8.01	HSD
Xylene	Volatile		8.24	8.02	PID

¹Analyze for phenanthrene and carbazole; if these are present in the ratio between 1.4:1 and 4:1, creosote should be considered present.

Notes: ECD = Electron capture detector, FID = Flame photometric detector; HSD = Halide specific detector; HP LC = High pressure liquid chromatography; NSD = Nitrogen specific detector, PID = Photoionization detector.

Source: 45 FR 33130 (May 13, 1

Table 4.8

Analytical Methods for Inorganic Species

Species	Sample Handling Class	Measurement Technique	Method Number
Antimony	Digestion	Atomic Absorption-Furnace/Flame	8.50
Arsenic	Hydride	Atomic Absorption-Flame	8.51
Barium	Digestion	Atomic Absorption-Furnace/Flame	8.52
Cadmium	Digestion	Atomic Absorption-Furnace/Flame	8.53
Chromium	Digestion	Atomic Absorption-Furnace/Flame	8.54
Cyanides	Hydrolysis	Atomic Absorption-Spectroscopy	8.55
Lead	Digestion	Atomic Absorption-Furnace/Flame	8.56
Mercury	Cold Vapor	Atomic Absorption	8.57
Nickel	Digestion	Atomic Absorption-Furnace/Flame	8.58
Selenium	Hydride Digestion	Atomic Absorption-Furnace/Flame	8.59
Silver	Digestion	Atomic Absorption-Furnace/Flame	8.60

Source: 45 FR 33130 (May 19, 1980).

Table 4.9

Sole Source Aquifers, August 1980

DESIGNATED:

Edwards Underground Reservoir, San Antonio,
TX
Fresno County, CA
Buried Valley, NJ (East Orange)
Nassau-Suffolk Counties, Long Island, NY
Biscayne, FL
Spokane-Rathrun Valley, WA
On Guam

PROPOSED:

Ten Mile Creek, MD
Cape Cod, MA
Santa Cruz, Scotts Valley, CA

Source: USEPA Drinking Water Program, 1980

Table 4.10

Interim Status Standards for Hazardous Waste Disposal

Subpart	Section
B - General Facility Standards	265.10 Applicability.
	265.11 Identification number.
	265.12 Required notices.
	265.13 General waste analysis.
	265.14 Security.
	265.15 General inspection requirements.
	265.16 Personnel training.
	265.17 General requirements for ignitable, reactive, or incompatible wastes.
C - Preparedness and Prevention	265.30 Applicability.
	265.31 Maintenance and operation of facility.
	265.32 Required equipment.
	265.33 Testing and maintenance of equipment.
	265.34 Access to communications or alarm system.
	265.35 Required aisle space.
	265.36 [Reserved].
	265.37 Arrangements with local authorities.
D - Contingency Plan and Emergency Procedures	265.50 Applicability.
	265.51 Purpose and implementation of contingency plan.
	265.52 Content of contingency plan.
	265.53 Copies of contingency plan.
	265.54 Amendment of contingency plan.
	265.55 Emergency coordinator.
	265.56 Emergency procedures.
E - Manifest System, Recordkeeping, and Reporting	265.70 Applicability.
	265.71 Use of manifest system.
	265.72 Manifest discrepancies.
	265.73 Operating record.
	265.74 Availability, retention, and disposition of records.
	265.75 Annual report.
	265.76 Unmanifested waste report.
	265.77 Additional reports.
	265.78-265.89 [Reserved].
F - Groundwater Monitoring	265.90 Applicability.
	265.91 Groundwater monitoring system.
	265.92 Sampling and analysis.
	265.93 Preparation, evaluation, and response.
	265.94 Recordkeeping and reporting.
	265.95-265.109 [Reserved].
G - Closure and Post-Closure	265.110 Applicability.
	265.111 Closure performance standard.
	265.112 Closure plan; amendment of plan.
	265.113 Time allowed for closure.
	265.114 Disposal or decontamination of equipment.

Table 4.10 (cont.)

Subpart	Section
	265.115 Certification of closure.
	265.116 [Reserved].
	265.117 Post-closure care and use of property; period of care.
	265.118 Post-closure plan; amendment of plan.
	265.119 Notice to local land authority.
	265.120 Notice in deed to property.
	265.121-265.139 [Reserved].
H - Financial Requirements	265.140 Applicability.
	265.141 [Reserved].
	265.142 Cost estimate for facility closure.
	265.143 [Reserved].
	265.144 Cost estimate for post-closure monitoring and maintenance.
	265.145-265.169 [Reserved].
I - Use and Management of Containers	265.170 Applicability.
	265.171 Condition of containers.
	265.172 Compatibility of waste with container.
	265.173 Management of containers.
	265.174 Inspections.
	265.175 [Reserved].
	265.176 Special requirements for ignitable or reactive waste.
	265.177 Special requirements for incompatible wastes.
	265.178-265.189 [Reserved].
J - Tanks	265.190 Applicability.
	265.191 [Reserved].
	265.192 General operating requirements.
	265.193 Waste analysis and trial tests.
	265.194 Inspections.
	265.195-265.196 [Reserved].
	265.197 Closure.
	265.198 Special requirements for ignitable or reactive waste.
	265.199 Special requirements for incompatible wastes.
	265.200-265.219 [Reserved].
K - Surface Impoundments	265.220 Applicability.
	265.221 [Reserved].
	265.222 General operating requirements.
	265.223 Containment system.
	265.224 [Reserved].
	265.225 Waste analysis and trial tests.
	265.226 Inspections.
	265.227 [Reserved].
	265.228 Closure and post-closure.
	265.229 Special requirements for ignitable or reactive wastes.
	265.230 Special requirements for incompatible wastes.
	265.231-265.249 [Reserved].

Table 4.10 (cont.)

Subpart	Section
L - Waste Piles	265.250 Applicability
	265.251 Protection from wind.
	265.252 Waste analysis.
	265.253 Containment.
	265.254-265.255 [Reserved].
	265.256 Special requirements for ignitable or reactive wastes.
	265.257 Special requirements for incompatible wastes.
	265.258-265.269 [Reserved.]
M - Land Treatment	265.270 Applicability.
	265.271 [Reserved].
	265.272 General operating requirements.
	265.273 Waste analysis.
	265.274-265.275 [Reserved].
	265.276 Food chain crops.
	265.277 [Reserved].
	265.278 Unsaturated zone (zone of aeration) monitoring.

Table 4.11

Proposed Requirements for Authorization of State Hazardous Waste Management Programs

General Program Requirements under the Consolidated Permit System:

1. State permit program
2. Compliance evaluation program.
3. Enforcement authority.
4. Procedures for collection and reporting of data.
5. Specific elements of a program submission:
 - A letter from the Governor requesting authorization
 - A complete program description
 - A statement from the State Attorney General on the adequacy of enabling legislation and existing program
 - Copies of forms to be used and applicable State laws, Court decisions, and regulation
 - A Memorandum of Agreement between EPA Regional Administrator and State Director (of Hazardous Waste Management Program).

Specific Requirements for Interim Authorization under Subtitle C, in addition to those listed above:

1. Substantial equivalency to Federal program including the ability to:
 - Control by permit or equivalent document all on-site or off-site hazardous waste disposal facilities. Control of treatment or storage facilities, while desirable, is not required.
 - Commit adequate resources and provide the administrative capability to process permits and conduct an effective enforcement program, including compliance evaluation.

The States also must show substantial compliance with other provisions of the regulations, including those covering certain operational requirements and enforcement authority.

2. Program description as in General Requirements and the following additional information:
 - A general description and estimates of:
 - The number, types, and relative sizes of activities to be regulated during the interim authorization period
 - If available, the total quantity of hazardous waste expected to be disposed of annually from both in-State and out-of-State sources.
 - An "authorization plan" describing the additions or modifications necessary to the State program to qualify for full authorization at the end of the interim period. It must include the schedule under which the State proposes to achieve those additions and modifications, plus a description of any changes in the State's legal authority, resources, permit system, and surveillance and enforcement program that will be necessary.
3. Progress reports to Regional Administrators.
4. Attorney General's statement.
5. Legal authority to operate a manifest system.

Specific Requirements for Full Authorization under Subtitle C, in addition to those listed above:

1. Full equivalency with Federal program, including authority to regulate special wastes with a permit by rule.
 2. Consistency with the Federal program.
 3. Program description which also includes:
 - A description of the State manifest system
 - A description of the types and relative sizes of regulated activities, including an estimate of number of generators, transporters, and on- and off-site storage, treatment, and disposal facilities that must file for or have been issued a State permit
 - An estimate, if available, of the annual quantities of wastes generated within the State, transported into or out of the State, and stored, treated, or disposed of on-site and off-site.
-

Source: McDonald, C. and N. Johnson, *Regulation of Solid Waste from Coal Gasification and Liquefaction Facilities*, Revised Final Report, Systems Consultants, Inc. (January, 1980).

Table 4.12

Status of Solid and Hazardous Waste Management Laws and Regulations in 18 Selected States

State	Lead Agency	Solid Waste Legislation	Enactment of Latest Amendment	Hazardous Waste Enabling Legislation	Enactment of Latest Amendment	Hazardous Waste (HW) Management	Hazardous Waste Definition Tied to or Consistent with RCRA	Energy (E)/Industrial (I)/Special (S) Addressed Waste	Notes
Alabama	State Board of Health	X	1971	X	1978	HW regs being drafted; 1972 SW regs in effect, HW handling requirements determined on a waste-specific basis.	Yes	I	Applying for interim and full authorization.
Arizona	Dept. of Health Ser./ Bureau of Sanitation, HW Section	X	1971	X ^a	—	HW authority contained in other existing legislation; 1979 SW regs will be updated early 1980 to address HW for first time.	No	S	Applying for interim authorization.
California	Dept. of Health Services	X	1978	X	1978	1974 HW regs in effect. State program is the result of pilot effort by EPA to develop state HW regs.	Yes	E	Applying for interim and possible full authorization.
Colorado	Dept. of Health	X	1979	D	—	HW not specifically addressed in existing 1972 SW regs; HW law being drafted for 1980 session. Regs will come later.	No	—	Will apply for authorization eventually.
Illinois	Illinois Environ. Protection Agency	X	1979	X ^a	1979	1979 HW regs passed; SW and HW reg. authority granted by Ill. Environ. Protection Act.	No	S	SW and Special Waste Hauling Regs contained in Ill. Pollution Control Board Rules and Regs

Table 4.12 (cont.)

State	Lead Agency	Solid Waste Legislation	Enactment of Latest Amendment	Hazardous Waste Enabling Legislation	Enactment of Latest Amendment	Hazardous Waste (HW) Management	Hazardous Waste Definition Tied to or Consistent with RCRA	Energy (E) ¹ /Industrial (I)/Special (S) Addressed Waste	Notes
Indiana	Environ. Management Board/Solid Waste Mgmt. Section	X	1978	P	—	1974 SW regs contain minimal references to HW. HW reg. authority contained in new chapter of Environmental Management Act.	No	—	Will apply for interim but may not be able to exhibit adequate resources. Regs at least one year off.
Kentucky	Dept. of Natural Resources and Environ. Protection/Div. of Hazardous Material and Waste Mgmt.	X	1978	X ³	1978	1979 emergency HW regs in effect. HW reg. authority granted by Ky Environ. Protection Law. Permanent HW regs being written.	No ²	—	Applying for authorization.
Montana	Dept. of Health/ Environ. Improvement Division	X	1977	X ³	1977	1977 SW regs based upon degree of hazard; new SW regs addressing HW are being drafted, issuance in 1981 anticipated.	Yes	I, E	Will apply for authorization after regs are adopted.
New Mexico	Health and Environ. Dept., Environ. Improvement Div.	X	1974	X	1977	1978 HW regs in effect. Will adopt EPA regs when complete package is final.	No ²	I, E	Will apply for authorization after regs are adopted.
North Dakota	Dept. of Health/Div. of Water Supply and Pollution Control	X	1976	X ³	1976	SW defined as including HW; 1976 SW regs in effect.	No	E	Applying for interim authorization.

Table 4.12 (cont.)

State	Lead Agency	Solid Waste Legislation	Enactment of Latest Amendment	Hazardous Waste Enabling Legislation	Enactment of Latest Amendment	Hazardous Waste (HW) Management	Hazardous Waste Definition Tied to or Consistent with RCRA	Energy (E)/Industrial (I)/Special (S) Addressed Waste	Notes
Ohio	Ohio Environ. Protection Agency	X	1978	X	1978	HW not specifically addressed in 1976 SW regs; SW Disposal Law specifies that regs be adopted modified or repealed to be consistent with RCRA.	No ²	—	Will apply for interim authorization if enabling legislation is passed.
Pennsylvania	Dept. of Environ. Resources/Div. of Solid	X	1972	P ³	—	Amendment of 1977 SW regs addressing HW proposed. New SW law addressing HW proposed. Regs will be drafted after law is passed.	Yes	E	Applying for full authorization.
Texas	Dept. of Health (Municipal) Dept. of Water Resources (Industrial)	X	1977	X ³	1977	1977 SW regs in effect for municipal SW. Industrial SW management regs effective 1979, address HW.	Yes	I	Applying for authorization.
Utah	State Board of Health	X	1976	X	1978	1974 SW regs in effect contain minimal reference to HW; HW regs under new HW law are being written to be compatible with RCRA.	No ²	—	Applying for authorization.
Virginia	Dept. of Health	X	1979	X ³	1979	1971 SW regs in effect, HW handling requirements determined case-by-case; new SW regs addressing HW being drafted, issuance later 1980 anticipated.	Yes	—	Will apply for authorization when regs are adopted.

Table 4.12 (cont.)

State	Lead Agency	Solid Waste Legislation	Enactment of Latest Amendment	Hazardous Waste Enabling Legislation	Enactment of Latest Amendment	Hazardous Waste (HW) Management	Hazardous Waste Definition Tied to or Consistent with RCRA	Energy (E) ¹ /Industrial (I)/Special (S) Addressed Waste	Notes
Washington	Dept. of Ecology	X	1977	X	1976	1977 HW regs in effect. Regs should be adequate for authorization but additional enabling legislation may be needed. Regs address degree of hazard.	No	—	Applying for authorization.
West Virginia	Dept. of Natural Res. Water Resources Div/ HW Section	X	1979	X ³	1979	1974 SW regs in effect, HW handling requirements determined case-by-case; HW reg authority granted by Water Pollution Control Act; HW regs being drafted.	No ²	—	Applying for full authorization.
Wyoming	Dept. of Environ. Quality/Land Quality Division	X	1973	P ³ X ³	1980	1975 SW regs in effect; HW regs proposed. SW and HW are regulated by the Land Quality and Water Quality Divisions.	No	E	Applying for interim authorization. SW reg. authority augmented by Wyo. Environmental Quality Act 1973, amended 1978

¹Include utility waste.²Draft of proposed laws or regulations expected to be consistent with RCRA.³Hazardous waste enabling legislation contained in solid waste, environmental quality, water quality or other act.

P = Proposed, D = Draft

Source: McDonald, C. and Johnson, W., *Regulation of Solid Wastes from Coal Gasification and Liquefaction Facilities: An Analysis of Federal and Selected State Hazardous Waste Management Programs under RCRA*, Systems Consultants, Inc., (January, 1980).

Figure 4.1

Flood-Plain Status of Coal-Fired Plants

Source: Grimsrud et al, "Evaluation of Flood Levels for Solid Waste Disposal Areas", EPR# FF-1205 (October, 1979).

RESIDUALS

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Table 4.13

**Major Chemical Constituents
of Coal Ash**

Constituents	Range %
Silica (SiO_2)	6.0 - 68
Alumina (Al_2O_3)	4.0 - 44
Ferric Oxide (Fe_2O_3)	1.0 - 44
Calcium Oxide (CaO)	0.2 - 52
Mangesium Oxide (MgO)	0.1 - 14
Titanium Dioxide (TiO_2)	0.4 - 4.17
Potassium Oxide (K_2O)	0.1 - 4.0
Sodium Oxide (Na_2O)	0.09 - 28
Sulfur Trioxide (SO_3)	0.1 - 32
Carbon (C) and Volatiles	0.1 - 20

Source: Fred C. Hart Associates, Inc., *The Impact of RCRA (PL 94-580) on Utility Solid Wastes*, Electric Power Research Institute, Palo Alto, CA, EPRI FP-878 TPS 78-779, August, 1978.

Table 4.14

Chemical Constituents of Bottom Ash and Fly Ash

	Fly Ash (ppm)		Bottom Ash/Slag (ppm)	
	Min.	Max.	Min.	Max.
Aluminum (Al)	11,500.0	144,000.0	88,000.00	135,000.0
Antimony (Sb)*	0.8	1,000.0	0.14	12.0
Arsenic (As)*	2.3	1,700.0	0.98	40.0
Barium (Ba)	96.0	13,900.0	500.00	4,000.0
Beryllium (Be)*	1.0	1,000.0	3.00	10.6
Bismuth (Bi)	< 0.0	30.0	—	—
Boron (B)	10.0	3,000.0	70.00	300.0
Bromine (Br)	0.3	670.0	2.00	11.0
Cadmium (Cd)*	0.1	250.0	< 0.50	< 250.0
Calcium (Ca)	5,400.0	177,100.0	8,400.00	50,600.0
Cerium (Ce)	28.0	320.0	84.00	310.0
Cesium (Cs)	1.4	17.0	7.70	—
Chlorine (Cl)	13.0	25,000.0	< 1,100.00	1,800.0
Chromium (Cr)*	11.0	7,400.0	15.00	270.0
Cobalt (Co)	6.0	1,500.0	3.60	380.0
Copper (Cu)*	30.0	3,020.0	2.80	720.0
Dysprosium (Dy)	4.2	31.0	37.00	—
Europium (Eu)	1.0	16.7	1.11	15.0
Fluorine (F)	0.4	624.0	10.60	100.0
Gallium (Ga)	10.0	10,000.0	5.00	64.0
Germanium (Ge)	< 10.0	11,000.0	—	—
Gold (Au)	0.004	0.5	0.10	—
Hafnium (Hf)	1.4	11.0	4.60	8.5
Indium (In)	0.1	2.4	1.00	—
Iodine (I)	0.1	200.0	9.50	—
Iron (Fe)	7,300.0	289,000.0	27,000.00	203,000.0
Lanthanum (La)	17.0	270.0	155.00	75.0
Lead (Pb)*	3.1	1,600.0	< 5.00	35.0

Table 4.14 (cont.)

	Fly Ash (ppm)		Bottom Ash/Slag (ppm)	
	Min.	Max.	Min.	Max.
Lithium (Li)	77.0	120.0	60.00	78.0
Lutetium (Lu)	0.41	4.3	2.50	—
Magnesium (Mg)	4,900.0	60,800.0	4,500.00	32,500.0
Manganese (Mn)	31.0	4,400.0	100.00	720.0
Mercury (Hg)*	0.01	22.0	0.01	< 4.0
Molybdenum (Mo)	6.5	500.0	3.00	45.0
Nickel (Ni)*	1.8	8,000.0	10.00	700.0
Niobium (Nb)	16.0	< 20.0	12.00	20.0
Palladium (Pd)	0.2	—	—	—
Phosphorus (P)	600.0	2,500.0	300.00	1,600.00
Platinum (Pt)	0.7	—	—	—
Potassium (K)	1,534.0	34,700.0	7,300.00	15,800.0
Rhodium (Rh)	0.02	—	—	—
Rubidium (Rb)	25.0	300.0	48.00	300.0
Samarium (Sm)	3.7	43.0	8.20	46.0
Scandium (Sc)	2.0	400.0	10.00	85.0
Selenium (Se)*	1.2	< 500.0	0.08	7.7
Silicon (Si)	196,000.0	271,000.0	180,000.00	273,000.0
Silver (Ag)*	1.0	50.0	25.00	—
Sodium (Na)	1,180.0	20,300.0	1,800.00	13,100.0
Sulfur (S)	0.11	0.25	0.06	0.09
Strontium (Sr)	40.0	9,600.0	170.00	1,800.0
Tantalum (Ta)	0.5	2.6	0.95	1.03
Tellurium (Te)	0.11	10.0	< 0.02	—
Thallium (Tl)	1.1	100.0	0.25	0.30
Thorium (Th)	1.8	68.0	12.00	15.0
Tin (Sn)	< 3.0	4,250.0	—	—
Titanium (Ti)	400.0	15,900.0	3,300.00	7,210.0
Tungsten (W)	2.9	42.0	38.00	—
Uranium (U)	0.8	30.1	6.78	14.9

Table 4.14 (cont.)

	Fly Ash (ppm)		Bottom Ash/Slag (ppm)	
	M n.	Max.	Min.	Max.
Vanadium (V)	20.0	1,180.0	44.00	670.0
Ytterbium (Yb)	1.7	23.0	18.00	0.0
Yttrium (Y)	21.0	800.0	30.00	44.0
Zinc (Zn)*	14.0	13,000.0	24.00	950.0
Zirconium (Zr)	100.0	5,000.0	220.00	—

*On the EPA list of 65 priority pollutants.

Source: Fred C. Har. Associates, Inc., *The Impact of RCRA (PL 94-580) on Utility Solid Wastes*, for Electric Power Research Institute, Palo Alto, CA, EPRI FP-878. TPS 78-779, (August, 1978).

Table 4.15

Estimated Saturated n-Hydrocarbon Concentrations in Coal Ash

Component	Concentration, ppb
C ₁₅	T*
C ₁₆	192
C ₁₇	608
C ₁₈	740
C ₁₉	383
C ₂₀	308
C ₂₁	528
C ₂₂	548
C ₂₃	480
C ₂₄	308
C ₂₅	319
C ₂₆	366
C ₂₇	516
C ₂₈	664
C ₂₉	816
C ₃₀	660
C ₃₁	596
C ₃₂	344
C ₃₃	199
C ₃₄	66
Total	8.6 ppm

*T = Trace.

Source: Van Hook, R.L., Intra-Laboratory Correspondence, Oak Ridge National Laboratory, (October 11, 1976).

Table 4.16

**Estimated Polycyclic Aromatic Hydrocarbon (PAH)
Concentration in Coal Ash**

PAH	Concentration ppb
Naphthalene	8.3
2-Methylnaphthalene	5.0
1-Methylnaphthalene	T*
2,6-Dimethylnaphthalene	T
1,5- and/or 2,3-Dimethylnaphthalene	T
0,10-Dihydroanthracene	12.6
Phenanthrene	17.6
2-Methylanthracene	9.1
1-Methylphenanthrene	24.8
Fluoranthene	13.4
Pyrene	19.0
1,2-Benzofluorene	36.8
2,3-Benzofluorene	11.8
1-Methylpyrene	T
Picene	T
Total	< 0.2 ppm

*T = Trace

< = Interference allows estimate only of maximum possible concentration.

Source: Van Hook, R. L., Intra-Laboratory Correspondence, Oak Ridge National Laboratory (October 11, 1976).

Table 4.17

Range of Uranium and Thorium Concentrations and Geometric Means for Coal Samples From Various Regions of the United States (N is the number of samples)

Region	Coal Rank	N	Uranium (ppm)		Thorium (ppm)	
			Range	Geometric Mean	Range	Geometric Mean
Pennsylvania	Anthracite	45	0.3 - 25.2	1.2	1.8 - 14.4	4.7
Appalachia ¹	Bituminous	331	<0.2 - 10.5	1.0	2.2 - 47.8	2.8
Interior ²	Bituminous	143	0.2 - 43	1.4	<3 - 79	1.6
Northern Great Plains ³	Subbituminous, lignite	93	<0.2 - 2.9	0.7	<2.0 - 8.0	2.4
Gulf ⁴	Lignite	34	0.5 - 16.7	2.4	<3.0 - 28.4	3.0
Rocky Mountain ⁵	Bituminous, subbituminous	134	<0.2 - 23.8	0.8	<3.0 - 34.8	2.0
Alaska	Subbituminous	18	0.4 - 5.2	1.0	<2.0 - 18	3.1

¹Pennsylvania, Ohio, Maryland, West Virginia, Virginia, Kentucky, Tennessee and Alabama.

²Michigan, Indiana, Iowa, Nebraska, Missouri, Kansas, Oklahoma and Arkansas.

³North Dakota, Montana, and Wyoming.

⁴Alabama, Mississippi, and Arkansas.

⁵Wyoming, Colorado, Utah, Arizona, and New Mexico.

Note: Note that the analyses for U and Th were performed on whole coal. The arithmetic average concentrations of Th and U for all coal samples and various ranks of coal for the whole United States are: all coal, N = 799, 4.7 ppm Th, 1.8 ppm U; anthracite, N = 53, 5.4 ppm Th, 1.5 ppm U; bituminous, N = 509; 5.0 ppm Th, 1.9 ppm U; subbituminous, N = 183, 3.3 ppm Th, 1.3 ppm U; and lignite, N = 54, 63 ppm Th, 3.5 ppm U.

Source: McBride, J. P. et al. "Radiological Impact of Airborne Effluents of Coal and Nuclear Plants," *Science* 202, p. 1045 (December 8, 1978).

Table 4.18

Natural Radionuclides Observed in Coal, Bottom Ash and Fly Ash

Natural Decay Chain Origin	Source After Fractionation	Gamma-Producing Nuclide	Gamma Energy (keV)
^{232}Th	^{228}Ra	^{228}Ac	338
^{232}Th	^{228}Ra	^{228}Ac	911
^{232}Th	^{228}Th	^{212}Pb	238
^{232}Th	^{228}Th	^{208}Tl	583
^{238}U	^{234}Th	^{234}Th	63
^{238}U	^{226}Ra	^{226}Ra	185
^{238}U	^{226}Ra	^{214}Pb	295
^{238}U	^{226}Ra	^{214}Pb	352
^{238}U	^{214}Bi	^{214}Bi	609
^{238}U	^{214}Bi	^{214}Bi	1120
^{238}U	^{214}Bi	^{214}Bi	1764
^{238}U	^{210}Pb	^{210}Pb	46
^{235}U	^{235}U	^{235}U	185

Source: Coles, D. G., et. al., *The Behavior of the Natural Radionuclides in Western Coal-Fired Power Plants*, Lawrence Livermore Laboratory, (December, 1976).

Table 4.19

Contents of the Various Radionuclides in Coal, Bottom Ash and Fly Ash¹

	ppm			pCi/g						
	U	Th	K	⁴⁰ K	²²⁸ Th	²²⁸ Ra	²¹⁰ Pb	²²⁶ Ra	²³⁸ U	²³⁵ U
Plant A ²										
Coal	0.71	1.6	860	0.73	0.17	0.17	0.26	0.21	0.24	0.012
ESP fly ash	5.6	15	9400	8.1	1.7	1.7	1.4	2.3	1.9	0.093
Bottom ash	4.6	14	7900	6.8	1.5	1.5	0.58	1.9	1.5	0.072
Plant B ³										
Coal	2.6	5.0	1660	1.4	0.56	0.55	0.68	0.64	0.85	0.037
ESP fly ash	11	22	7400	6.3	2.4	2.4	2.2	2.9	3.5	0.14
Bottom ash	8.4	19	7200	6.2	2.2	2.1	0.84	2.5	2.8	0.11
Scrubber ash	11	22	7200	6.2	2.5	2.5	2.8	3.0	3.6	0.14
Plant B ⁴										
Post-ESP (stack)										
Fly ash (mmd) ⁵										
17 m	16	25	8200	7.0	2.8	2.7	4.3	3.3	5.4	0.17
6 m	20	31	8600	7.3	3.3	3.5	10	4.6	6.8	0.28
3.8 m	30	36	8600	7.4	3.3	4.0	14	5.3	10	0.39
2.5 m	36	38	8100	7.0	3.3	4.2	17	5.9	12	0.50

¹10-20% propagated 1 error from the mean.²Samples from Plant A; input coal contains 11.3% H₂O, 9.2% ash, and 0.52% sulfur.³Samples from Plant B; input coal contains 6.8% of H₂O, 23.2% ash, and 0.46% sulfur.⁵mmd = mass median diameter determined by centrifugal sedimentation.Source: Coles, D. G. et. al., *The Behavior of the Natural Radionuclides in Western Coal-Fired Power Plants*, Lawrence Livermore Laboratory, (December, 1979).

Table 4.20

Representative Analyses of Coals and Chars (Wt. %)

Component	Illinois Number 6	Western Kentucky	Wyoming Subbituminous	North Dakota Lignite	Pittsburgh Steam
Coals					
Moisture	8.3	4.3	18.1	20.6	2.5
Volatile matter	37.5	34.6	31.9	32.9	30.9
Fixed carbon	43.0	44.5	32.0	38.2	51.5
Ash	11.2	16.6	18.0	8.3	15.1
Hydrogen	5.3	4.7	5.4	5.7	4.7
Oxide	15.9	10.9	30.3	32.6	9.3
Carbon	63.0	32.7	45.2	51.5	68.4
Nitrogen	1.1	1.2	0.6	0.7	1.2
Sulfur	3.5	3.9	0.5	1.2	1.3
Chars					
Moisture	0.8	1.2	0.5	1.2	1.4
Volatile matter	4.0	4.8	5.1	10.0	1.6
Fixed carbon	69.9	63.3	38.1	50.2	69.3
Ash	25.3	30.7	56.3	38.6	27.7
Hydrogen	1.0	1.0	1.0	0.9	1.0
Oxygen	1.3	1.1	1.2	0.0	1.7
Carbon	70.4	64.5	40.6	58.9	68.9
Nitrogen	0.6	0.7	0.4	0.2	0.5
Sulfur	1.4	2.0	0.5	2.0	0.2

Source: Braunstein, H. M., et. al., *Environmental, Health, and Control Aspects of Coal Conversion: An Information Overview*, Oak Ridge National Laboratory, prepared for the U.S. Energy Research and Development Administration, ORNL/EIS-94, UC-11, -41, 18c, -90i, (April, 1977).

Table 4.21

Inorganic Elements in the Mineral Residue from the H-Coal Process Utilizing Illinois Number 6 Coal

Element		Concentration in Coal Residue (ppm)
Name	Symbol	
Aluminum	Al	17,253
Antimony	Sb	1.2
Arsenic	As	1.5
Barium	Ba	40
Beryllium	Be	1.8
Boron	B	300
Bromine	Br	6.7
Cadmium	Cd	0.4
Calcium	Ca	7,862
Cerium	Ce	16
Cesium	Cs	1.7
Chlorine	Cl	1,000
Chromium	Cr	27.5
Cobalt	Co	4.45
Copper	Cu	14
Europium	Eu	0.69
Fluorine	F	100
Gallium	Ga	4.6
Germanium	Ge	4.9
Gold	Au	—
Hafnium	Hf	0.86
Iron	Fe	23,662
Lanthanum	La	9.8
Lead	Pb	32
Lithium	Li	—
Lutetium	Lu	0.024
Magnesium	Mg	884
Manganese	Mn	77
Mercury	Hg	—
Molybdenum	Mo	6.4
Nickel	Ni	21
Phosphorus	P	44
Potassium	K	2,490
Rubidium	Rb	16
Samarium	Sm	2.3
Scandium	Sc	4.1
Selenium	Se	—
Silicon	Si	39,641
Silver	Ag	0.16

Table 4.21 (cont.)

Element		Concentration in Coal Residue (ppm)
Name	Symbol	
Sodium	Na	619
Strontium	Sr	30
Sulfur	S	18,000
Tantalum	Ta	0.17
Tellurium	Te	0.1
Thallium	Tl	1.7
Thorium	Th	3.5
Tin	Sn	0.6
Titanium	Ti	1,019
Tungsten	W	4.4
Uranium	U	5.7
Vanadium	V	33
Ytterbium	Yb	1.0
Yttrium	Y	—
Zinc	Zn	71
Zirconium	Zr	41

Source: Parker, C. L. and D. I. Dykstra, *Environmental Assessment* Data-Base for Coal Liquefaction Technology, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, EPA-600/7-18-184b, (September, 1978).

Table 4.22

**Trace Element Concentrations (ppm) in Illinois Coal and in the
Unquenched Gasifier Ash Obtained from Lurgi Gasification**

Reference	Illinois Number 5 Coal		Ash	
	Peabody ¹	Argonne ²	Peabody ¹	Argonne ²
Element				
Ag	0.3		3.0	
S	1.6	1.9 ± 1.003 (B)	0.3	
Ba	307		673	
Be	2.2	2.0 ± 0.1	22	490 ± 250 (B) 19.8 ± 1.0
Br		6.6 ± 1.0 (A)		
Cd	< 0.3		< 0.3	
Ce				41 ± 4 (AA)
Co	3.7	3.8 ± 0.6 (A)		38 ± 4 (AA)
Cr	15	15 ± 2 (A)	551	592 ± 59 (AA)
Cs				11 ± 2 (A)
Cu	10		273	
Dy				
Eu				
F	59	55 ± 11		4.6 ± 0.9
Fe (x10 ⁴)		1.3 ± 0.1 (AA)		15 ± 2 (AA)
Hg	0.20	0.17 ± 0.02	0.01	0.016 ± 0.002
K (x10 ³)		1.3 ± 0.1 (AA)		14 ± 1 (AA)
La		6 ± 0.5 (A)		42 ± 4 (AA)
Li	5.5		54	
Mn	21	23 ± 2 (AA)	338	305 ± 30 (AA)
Mo	7		8	
Na (x10 ²)		2.8 ± 0.3 (AA)		29 ± 3 (AA)
Ni	32		462	
Pb	30	28.1 ± 2.8	219	200 ± 10
Sb	0.3	0.1 ± 0.02 (A)	0.3	19 ± 2 (AA)
Sc		1.6 ± 0.2 (AA)		
Se		9 ± 5 (B)		
Sm				
Ta				1.3 ± 0.7 (B)
Tb				
V	21		181	
Yb			181	
Zn (x10 ²)	1.82	2.4 ± 1.2 (B)	15.8	11 ± 2 (B) 16 ± 2 (A)

Table 4.22 (cont.)

Reference	Illinois Number 6 Coal		Ash	
	Peabody ¹	Argonne ²	Peabody ¹	Argonne ²
Element				
Ag	0.3		3.8	
As	1.0	2.1 ± 1.0 (B)	0.1	
B	132		622	
Ba				
Be	1.8	1.55 ± 0.08	14	13.4 ± 0.7
Br		4.1 ± 0.7 (A)		
Cd	< 0.3		< 0.3	
Ce				38 ± 4 (AA)
Co	4.3	3.2 ± 0.5 (A)	40	34 ± 3 (AA)
Cr	22	18.3 ± 2.7 (A)	705	806 ± 81 (AA)
Cs				
Cu	12		239	
Dy				8.5 ± 1.3 (A)
Eu		0.2 ± 0.1 (B)		
F	79	79 ± 16		5.2 ± 1.0
Fe (× 10 ⁴)		1.2 ± 0.1 (AA)		13 ± 1 (AA)
Hg	1.0 ³	1.18 ± 0.12	0.04	0.007 ± 0.001
K (× 10 ³)		1.5 ± 0.1 (AA)		16 ± 2 (AA)
La		3.9 ± 0.4 (AA)		40 ± 20 (B)
Li	9.2		74	
Mn	20	18.6 ± 1.9 (AA)	243	156 ± 16 (AA)
Mo	7		6	
Na (× 10 ²)		3.0 ± 0.3 (AA)		27 ± 3 (AA)
Ni	14		456	
Pb	12	8.0 ± 0.8	96	46.0 ± 2.3
Sb	0.1	(C)	0.2	
Sc		2.1 ± 0.2 (AA)		24 ± 2 (AA)
Se		(C)		
Sm		0.005 ± 0.003 (B)		
Ta				
Tb				3.1 ± 1.6 (B)
V	29		301	
Yb		1.4 ± 0.7 (B)		11 ± 2 (A)
Zn (× 10 ²)	0.43	(C)	4.69	(C)

¹The precision of the Peabody results is estimated to be ±10% in all cases.

²The accuracy of the Argonne results for mercury is estimated to be 10%; the precision of the Argonne results for beryllium is ±5%; for lead ±5%; for lanthanum ±5% to 10%; for fluorine ±20%. The confidence ratings shown for the Argonne results obtained by neutron activations analysis correspond to the following accuracy levels: AA—±10%; A—±15%; B—±50%; and C—identification only.

³Not representative of seam: contamination suspected.

Source: Braunstein, H. M. et al., *Environmental, Health, and Control Aspects of Coal Conversion: An Information Overview*, Oak Ridge National Laboratory, prepared for U.S. ERDA, ORNL/EIS-94, UC-11, -41, -48, -90; (April, 1977).

Table 4.23

Chemical Composition of Coal Ashes from Gasification/Liquefaction Plants

Element	Waste 1	Waste 2	Waste 3	Waste 4
	wt. %			
Al	8.8	10.1	8.8	6.7
Ca	18.5	2.9	2.2	2.4
Fe	3.8	13.4	17.2	13.3
K	0.6	1.5	1.4	1.4
Mg	4.9	0.8	0.5	0.5
Na	0.3	1.8	0.2	0.3
Ti	0.5	0.6	0.0	0.4
Si	17.9	22.5	20.1	16.4
S	0.4	0.3	3.8	4.0
C	1.0	1.8	1.7	20.2
	g/g			
Ag	1.0	0.3	0.3	0.5
B	287.3	1302.2	590.7	386.4
Ba	654.5	454.0	531.0	1013.0
Be	10.3	18.1	12.6	6.3
Cd	1.0	0.8	1.6	5.0
Ce	146.5	85.2	25.9	49.6
Co	7.2	137.3	33.7	16.3
Cr	78.1	386.1	642.0	145.4
Cu	29.8	61.9	93.5	58.7
Ga	65.9	103.6	106.0	98.6
La	152.1	92.5	89.2	61.4
Li	86.3	80.7	63.7	41.4
Mn	3987.2	425.4	293.2	249.4
Mo	4.0	18.8	72.6	43.5
Nb	17.2	11.9	1.7	1.3
Ni	73.0	254.0	150.0	148.0
P	466.7	275.5	436.3	544.8
Sc	30.2	24.4	19.3	12.4
Sr	519.8	503.3	182.1	139.1
Th	28.8	16.2	15.8	12.2
V	154.3	237.2	449.5	416.8
Y	54.8	53.6	41.1	23.8
Zn	8.3	65.7	96.1	413.2
Zr	191.7	196.6	170.2	97.4

Source: Tamura, T., and W.J. Boegly, Jr., *Leaching Studies of Coal Gasification Solid Waste to Meet RCRA Requirements for Land Disposal*, paper presented at the Second Environmental Control Symposium, U.S. Department of Energy, Virginia, April, 1980.

Table 4.24

Composition of Solid Residues (mg/kg)

	Synthane PDU Gasifier ¹	Low Btu Lurgi Gasifier ²	High Btu ^{3,4,5} Lurgi Gasifier			Lurgi H-Coal ⁵	FBC ^{6,7,8}		Conventional Combustion (with FGD) ⁹⁻¹⁴	
	Bottom Ash	Filter Fines	Bottom Ash	Cyclone Ash	Bottom Ash	Vacuum Still Bottoms	Spent Bed	Fly Ash	Bottom Ash (mg/k)	Fly Ash (mg/kg)
As	2.9-6.5	3.7-6.5	4	27	0.3-74	1.5	35-70	35.140	2.3-40 (8.)	3.2-160 (74)
Ba	98-140	80-130	496	460	490-10,000	40	100-3500	100-3100	300-5600 (750)	470-15,000 (2200)
Be	2.1-5.7	1.6-7.2	22	6	0.3-22	1.8	1-250	1-510	0.4-7.9	4.7-13.0 (5.2)
B	160-380	32-64	130	70	360-1700	300	120-380	20-800	42-120 (80)	180-1040 (270)
Cd	0.8-1.6	0.7-1.6	3	2	0.3-1.6	0.4	0.4-1.0	0.5-2	0.19-250 (1.1)	0.29-100 (4.2)
Co	9.5-95	4.1-17	61	16	6-38	4.5	0.1-90	1.5-70	21-380	39-520
Cr	120-240	29-120	510	90	17-590	27.5	50-450	80-520	3.4-270	3.6-300 (34)
Cu	22-40	18-70	540	130	18-270	14	20-80	25-410	20-720 (110)	43-2300 (130)
F	150-320	610-740	56	720	4.6-250	100	40-100	20-550	45-96 (61)	84-2900 (120)
Fe	10,000	5,000-10,000	79,000	65,000	65,000-150,000	24,000	4300-20,000	33,000-110,000	66,000-110,000	51,000-121,000
Hg	0.04	0.06-0.02	0.01	0.01	0.01-0.55	0.01	0.01	0.6	0.01-0.22 (0.028)	0.01-0.32 (0.08)
Li	38-67	21-38	190	27	8-54	8	15-150	20-150	—	—
Mn	160-500	40-140	680	120	340-1900	77	50-150	30-150	57-720 (300)	160-700 (290)
Ni	25	11-18	120	30	15-460	21	35-200	50-50	15-700 (85)	34-900 (100)
P	460-2100	460-10,300	1200	3500	87-3500	44	150	3500	—	—
Pb	5.7-21	2.2-8.9	7	60	32-219	32	3-180	13-300	1-21 (5.5)	4-130 (28)
Sb	0.10-1.9	0.04-0.95	1	8	0.3-19	1.2	1.5-14	6.5-20	0.48-12 (1.0)	1-94 (4.4)
Se	3.8-4.7	4.7-15	20	24	0.2-1.0	—	16-45	22-35	0.08-4.7 (0.36)	1.7-7.3 (16)
Sn	0.88-1.9	0.93-1.4	4	2	2.7	0.6	1.0	1.4	2-200 (16)	2-8 (3)
V	47-190	41-50	150	100	20-180	33	0.1-124	40-90	24-670 (100)	25-700 (100)
Zn	66-100	11-48	26	85	10-1600	71	35-470	60-1600	8-950 (100)	92-3100 (380)

Table 4.24 (cont.)

Note: Values in parentheses are median values.

Source: ¹Forney, A. J., *Trace Elements and Major Component Balance Around the Synthene PDU Gasifier*, EPA-600/2-76-149, June (1976).

²Page, D. C., *Fate of Pollutants in Industrial Gasifier*, EPA Symposium Proceedings: Environmental Aspects of Fuel Conversion Technology II, Hollywood, Fla., Dec. (1975), EPA-600/2-76-149, June (1976).

³Somerville, M. H., *A Comparison of Trace Elements Analysis of North Dakota Lignite Laboratory Ash with Lurgi Gasifier Ash and Their Use in Environmental Analysis*, EPA-600/2-76-149, June (1976).

⁴Sather, N. F. and W. M. Swift, *Potential Trace Elements Emissions from the Gasification of Illinois Coals*, EPA-600/2-76-149, June (1976).

⁵Griffin, R. A., et al., *Solubility and Toxicity of Potential Pollutants in Solid Coal Wastes*, EPA-600/2-76-149, June (1976).

⁶Progress Report, December 1975 to September 1976, *Environmental Assessment of Residues from the Fluidized Combustion of Coal*, Ralph Stone and Co., Inc., September (1976).

⁷The U.S. Environmental Protection Agency's Fluidized-Bed Combustion Program, FY 1976, Battelle-Columbus Laboratories, EPA-600/7-77-012, February (1977).

⁸Vogel, G. J., et al., *Reduction of Atmospheric Pollution by the Application of Fluidized Bed Combustion and Regeneration of Sulfur-containing Additives*, Argonne National Laboratory (EPA-ORC), Argonne, Illinois, September (1974) (MTIS PB 237-754).

⁹Kaakinen, J. W. et al., *Trace Element Behavior in Coal-Fired Coal Plant*, Environmental Science and Technology, 973, October (1975).

¹⁰Klein, D. H. et al., *Pathways of Thirty-Seven Trace Elements Through Coal-Fired Power Plant*, Environmental Science and Technology, 973, October (1975).

¹¹Dreesen, D. R., *Comparison of Levels of Trace Elements Extracted from Fly Ash and Levels Found in Effluent Waters from a Coal-Fired Coal Plant*, Environmental Science and Technology, 1017, October (1977).

¹²Block, C. and R. Dams, *Study of Fly Ash Emission During Combustion of Coal*, Environmental Science and Technology, 1011, October (1976).

¹³Davison, R. L., et al., *Determination of the Surface Predominance of Toxic Elements in Airborne Particles*, Analytical Chemistry, 1514, September (1977).

¹³Linton, R. W. et al., *Determination of the Surface Predominance of Toxic Elements in Airborne Particles*, Analytical Chemistry, 1514, September (1977).

Table 4.25

Chemical Analysis of Lime Process Sludges on a Dry Solid Basis (%)

Component	Sample ¹					
	A	B	C	D	E	F
CaO	18.1	43.2	40.7	43.4	25.6	43.8
MgO	2.4	0.2	NDM	0.0001	1.2	NDM
Total sulfur	7.2	18.9	18.1	20.0	10.9	22.9
SO ₂	12.1	33.0	32.9	29.2	10.8	45.8
SO ₃	2.9	5.9	4.8	13.6	13.6	NDC
CO ₂	3.2	6.7	2.3	7.1	2.2	1.0
Free carbon	NDM	NDM	NDM	2.8	0.14	NDC
SiO ₂	31.6	4.9	3.76	0.58	21.3	0.18
Al ₂ O ₃	18.3	3.4	1.71	12.1	11.3	0.39
Fe ₂ O ₃	4.3	0.6	0.86	0.39	5.6	0.29
Na ₂ O ₃	NDM	NDM	NDM	0.35	0.76	0.09
K ₂ O	NDM	NDM	NDM	0.03	0.98	0.01
Free base as CaO	0.3	1.3	7.9	0.06	0.06	NDC

NDM = Not Determined

NDC = Not Detected

¹A power station prior to fly ash collections; B-power station after ash collection; C-Chemico using carbide lime; D-power plant using proprietary scrubbing; E-wet limestone pilot plant scrubber; F-molybdenum sulfide pilot plant scrubbing effluent.

Source: Braunstein, H. M. et al., *Environmental Health, and Control Aspects of Coal Conversion: An Information Overview*, Oak Ridge Laboratory, prepared for the U.S. ERDA, ORNL/EIS-94, UC-11, -41, -48, -90i, (April, 1977).

Table 4.26

Chemical Analysis of Flue Gas Desulfurization Sludges

	Sludge	Elutriate/Leachate
Total organic carbon (elutriate only)		X
Total solids	X	
Dissolved solids		X
Suspended solids (leachate only)		X
pH		X
Hardness (elutriate only)		X
Conductivity		X
Antimony	X	X
Barium	X	X
Bismuth	X	X
Calcium	X	X
Chromium	X	X
Copper	X	X
Lead	X	X
Magnesium	X	X
Manganese	X	X
Mercury	X	X
Nickel	X	X
Selenium	X	X
Zinc	X	X
Chloride		X
Cyanide	X	X
Fluoride (calcium fluoride sludge only)		
Nitrate	X	X
Nitrite	X	X
Sulfate	X	X
Sulfite	X	X

Source: Braunstein, H.M., et al., *Environmental, Health, and Control Aspects of Coal Conversion: An Information Overview*, Oak Ridge National Laboratory, prepared for the U.S. ERDA, ORNL/EIS-94, UC-11, 141, 148, 90i, (April, 1977).

Table 4.27
Trace Element Concentration Ranges in FGD Sludges

	FGD Sludges ¹		Wet Limestone Sludge ² (mg/kg)
	Liquors (mg/l)	Solids (mg/kg)	
Aluminum	0.03 - 2.0	NA	NA
Arsenic	0.0004 - 1.8	0.6 - 52	4.0 - 33.0
Barium	NA	NA	20.0 - 500.0
Boron	NA	NA	41.8 - 211.0
Beryllium	0.001 - 0.18	0.05 - 6	NA
Cadmium	0.004 - 0.11	0.08 - 4	0.4 - 25.0
Calcium	10 - 200	(10.5) - (26.8)	NA
Chromium	0.011 - 0.5	10 - 250	1.6 - 17.0
Copper	0.002 - 0.56	8 - 76	10.0 - 104.0
Lead	0.005 - 0.52	0.23 - 21	1.0 - 290.0
Magnesium	0.1 - 2750	NA	NA
Manganese	NA	NA	30.0 - 340.0
Mercury	0.00005 - 0.07	0.001 - 5	0.1 - 6.0
Nickel	NA	NA	13.0 - 75.2
Potassium	5.9 - 760	NA	NA
Selenium	0.0006 - 2.7	2 - 17	2.1 - 60.0
Sodium	10.0 - 29,000	(3.7)	NA
Vanadium	NA	NA	50.0 - 100.0
Zinc	0.001 - 0.59	45 - 430	13.9 - 2,050

Notes: Parentheses indicate weight percent
NA = Not Analyzed

Sources: ¹Leo, P. P. and J Rossoff: *Control of Wastes and Water Pollution from Coal-Fired Power Plants Second R&D Report*, EPA-600/7-78-224, (November 1978).

²Fred C. Hart Associates, Inc., *The Impact of RCRA (PL 94-580) on Utility Solid Wastes*, EPRI FP-878, TPS 78-779 (August 1978).

Table 4.28
Elemental Composition of Scrubber Sludge Leachate

Element	Public Water Supply Standard	Leachate Composition		Drinking Water Standard Exceeded
		Max. (mg/l)	Min.	
As	0.05	0.130 0.300	0.0010 0.0080	yes
Ba	1.00	2.000	0.0020	yes
B	1.00	40.000	0.2200	yes
Cd	0.01	0.047	0.0005	yes
Cr	0.05	0.011 0.250	0.0010	yes
Cu	1.00	0.560	0.0020	no
Pb	0.010	0.040	0.0030	yes
Hg	0.002	0.070 0.003	0.0004	yes
Ni	—	0.050	0.0150	no
Se	0.01	0.540	0.0005	yes
V	—	0.200	0.1000	—
Zn	5.00	4.200	0.0100	no

Source: Fred C. Hart Associates, Inc., *The Impact of RCRA (PL 94-580) on Utility Solid Wastes*, for Electric Power Research Institute, Palo Alto, CA, EPRI FP-878, TPS 78-779 (August, 1978).

Table 4.29

**Estimated Characteristics of Rectisol
Acid Gas Recovery Still Bottoms/
Spent Sorbent Blowdown**

Phenols	20 mg/l
CN ⁻ + SCN ⁻	100 mg/l
NH ₃	40 mg/l
COD	1600 mg/l
Methanol	1000 mg/l

Source: U.S. Environmental Protection Agency
Draft Pollution Control Guidance Document for Indirect Liquefaction of Coal
(1980).

Table 4.30

Major Components of German High-Temperature Conversion Process Coal Tar

Component	Boiling point (°C)	Melting Point (°C)	Average Weight (percent)
Naphthalene	217.9	80.3	10.0
Phenanthrene	338.4	100.0	5.0
Fluoranthene	383.5	111.0	3.3
Pyrene	393.5	150.0	2.1
Acenaphthylene	270.0	93.0	2.0
Fluorene	297.9	115.0	2.0
Chrysene	441.0	256.0	2.0
Anthracene	340.0	218.0	1.8
Carbazole	354.8	244.4	1.5
2-Methylnaphthalene	241.1	34.6	1.5
Diphenylenoxide	285.1	85.0	1.0
Indene	182.4	-1.6	1.0
Acridine	342.9	111.0	0.6
1-Methylnaphthalene	244.7	-30.5	0.5
Phenol	181.8	40.9	0.4
Cresol	202.2	12.2	0.4
Benzene	80.1	5.5	0.4
Diphenyl	255.0	69.2	0.4
Acenaphthene	227.5	95.0	0.3
2-Phenylnaphthalene	359.8	101.0	0.3
Toluene	110.6	-95.0	0.3
Chinoline	237.1	-14.2	0.3
Diphenylsulfide	331.4	97	0.3
Thionaphthene	219.9	31.3	0.3
m-Xylene	139.1	-47.9	0.2
o-Cresol	191.1	31.0	0.2
p-Cresol	201.9	34.7	0.2
Isochinoline	243.3	26.5	0.2
Chinaldine	247.6	-1.0	0.2
Phenanthridine	349.5	107.0	0.2
7,8-Benzochinoline	340.2	52.0	0.2
2,3-Benzodiphenylenoxide	394.5	208.0	0.2
Indole	254.7	-52.5	0.2
3,5-Dimethylphenol	221.7	63.3	0.1
2,4-Dimethylphenol	210.9	24.5	0.1
Pyridine	115.3	-41.8	0.02
a-Picoline	129.4	-66.7	0.02
b-Picoline	144.1	-18.3	0.01
γ-Picoline	145.4	3.7	0.01
2,6-Intidine	144.0	-6.1	0.01
3,4-Intidine	158.4	-64.0	0.01

Source: Ghassemi, M., et al., *Environmental Assessment Data Base for High - But Gasification Technology: Volumes 1, 2, and 3*, TRW Environmental Engineering Division, prepared for U.S. Environmental Protection Agency, EPA-600/7-79-18a, b, and c, September, 1978.

Table 4.31

Organic Compounds in Synfuels Tars

	MERC Tars			Synthane** Tars	GFERC Tars
*Benzene	27 ± 7.6	21 ± 3	72.8	15,500 – 33,500	27000
*Toluene	T	45 ± 207	1334		
Biphenyl	T	T	8210		16000
*Phenol	T	400		22,880 – 111,930	82000
*Cresol	T	17,600			
Xylenol					
*Naphthylene	7250 ± 1810	2890 ± 500	21,350	94,770 – 155,230	59000
Methylnaphthylenes	114 ± 46	714 ± 40	33,610		
Dimethylnaphthylenes					
*Acenaphthene				90,690 – 129,100	
*Acenaphthylene		450			
*Anthracene/Phenanthrene				73,530 – 120,916	28000
*Chrysene				28,600 – 62,090	10000
*Fluorene	T		470	58,820 – 87,420	25000
*Fluoranthene					23000
*Pyrene				11,440 – 33,500	25000
*Benzpyrenes					11000
Pyridine					13000
Dibenzofuran	T		4030	39,400 – 51,470	12000

Notes: All concentrations in ppm.

*Priority Pollutant.

**Estimated from volume % and a specific gravity = 0.817

Source: McDonald, C. and N. Johnson, *Summary of Available Information on Quantity, Chemical Composition, and Hazardous Nature of Solid Wastes from Coal Gasification and Liquefaction Facilities*, Systems Consultants, Inc., Washington, D.C., (September 1980).

Table 4.32

Trace Element Concentrations in Tar and Slurries From Syntuels Plants

		Gasification			Liquefaction			
		Tar (15)	Quench Liquor (15)	Est. Max. Conc. in Slurry (26)	Lurgi Ash Slurries (0)		H-Coal Ash Slurries (9)	
					pH 7.6	pH 2.7	pH 8.8	pH 3.1
*Antimony	Sb	0.8	0.1	—	0.2	0.6	<0.4	<0.4
*Arsenic	As	4.0	0.2	0.3	ND	ND	<1	<1
Barium	Ba	27	0.1	0.8	ND	ND	<0.1	<0.1
*Beryllium	Be	0.1	—	—	ND	0.03	<0.1	<0.1
Bismuth	Bi	—	—	—	—	—	—	—
Boron	B	19	2	41	4.0	5.5	11.0	13.6
*Cadmium	Cd	—	≤0.02	—	0.02	0.03	<0.03	<0.03
Cesium	Cs	0.1	1.0	0.4	—	—	—	—
*Chromium	Cr	3	0.03	11	ND	0.12	<0.02	<0.02
Cobalt	Co	5	≤0.08	0.3	ND	0.19	<0.1	<0.1
*Copper	Cu	3	0.1	6	0.01	0.73	<0.05	<0.05
Fluorine	F	22	2	2.6	0.31	0.64	1.0	0.86
Gallium	Ga	8	0.006	1	—	—	—	—
Germanium	Ge	1	≤0.02	0.03	—	—	—	—
*Lead	Pb	10	0.04	0.06	0.10	0.20	<0.1	0.25
Lithium	Li	4	0.2	0.6	1.8	2.0	<0.1	0.02
*Mercury	Hg	0.12	0.007	<0.0001	ND	ND	<0.002	<0.002
*Nickel	Ni	5	0.1	6	0.03	0.50	<0.07	<0.07
Phosphorus	P	17	MC	<3	—	—	—	—
*Selenium	Se	?	4	<0.17	—	—	<0.05	<0.05
*Silver	Ag	—	—	—	—	—	—	—

Table 4.32 (cont.)

		Gasification				Liquefaction		
		Tar (15)	Quench Liquor (15)	Est. Max. Conc. in Slurry (26)	Lurgi Ash Slurries (0)		H-Coal Ash Slurries (9)	
					pH 7.6	pH 2.7	pH 8.8	pH 3.1
Strontium	Sr	10	0.2	30	1.8	2.9	3.2	0.50
Tellurium	Te	—	—	—	ND	ND	< 0.5	< 0.5
*Thallium	Tl	—	—	—	—	—	< 0.4	< 0.4
Titanium	Ti	29	0.05	< 25	ND	ND	< 0.6	< 0.6
Uranium	U	—	—	—	—	—	—	—
Vanadium	V	0.8	0.004	4.7	—	—	< 0.5	< 0.5
*Zinc	Zn	7	0.07	1.2	0.12	17	0.01	0.27

*On the EPA list of 65 priority pollutants.

Source: McDonald, C. and N. Johnson, *Summary of Available Information on Quantity, Chemical Composition, and Hazardous Nature of Solid Wastes from Coal Gasification and Liquefaction Facilities*, Systems Consultants, Inc., Washington, D.C., (September, 1980).

Table 4.33

**Organics in Product Water from Gasification
of Illinois No. 6 Coal**

Compound	Quantity (ppm)
Phenol	3400
Cresols	2840
C ₂ -Phenols	1090
C ₃ -Phenols	110
Dihydrics	250
Benzofuranols	70
Indanols; acetophenones	150
Hydroxybenzaldehyde; benzoic acids	60
Naphthols	160
Indenols	90
Benzofurans	N.A.
Dibenzofurans	N.A.
Biphenols	40
Benzothiophenols	110
Pyridines	N.A.
Quinolines	N.A.
Indoles	N.A.

N A = Not available.

Notes: Low-voltage mass spectrometry data.

Source: Braunstein, H. M., et. al., *Environmental, Health, and Control Aspects of Coal Conversion: An Information Overview*, Oak Ridge National Laboratory, prepared for the U.S. ERDA, OHL/EIS-94, UC-11, -41, -48, -90I, (April, 1977).

Table 4.34

Organic Compounds in Coal Conversion Wastewaters

	GFERC Gas Quench Condensate	Coal Conversion Waste Waters	Gasification Waste Waters	Treatment of Gasification Waste Waters		Biounit Effluent
				Before	After	
*Benzene						
*Toluene						
Biphenyl	19			0.2	0.01	0.03 - 0.11
*Phenol	5647	0.6	1000 - 4480			0.39
*Cresol	1965	2.5	530 - 3580			0.04
Xylenol	453	1.5				0.38
*Naphthylene		0.05		5.0	2.5	0.81
Methylnaphthylenes	34	0.03		2.0	1.0	
Dimethylnaphthylenes	26	0.15		2.0	1.0	0.05 - 1.12
*Acenaphthene		0.2				
*Acenaphthylene				< 0.1	< 0.05	0.01 - 0.06
*Anthracene/Phenanthrene	318	1.4		1.1	0.55	0.26
*Chrysene	12					
*Fluorene	17	0.17		0.3	0.15	0.08
*Fluoranthene	100	0.6		0.4	0.2	0.06 - 0.63
*Pyrene				0.6	0.3	0.24
*Benzopyrenes	71					
Pyridine			30 - 580			
Dibenzofuran	74		10	0.6	0.3	0.09 - 0.32

All concentrations in ppm or $\mu\text{g/l}$.

*Priority pollutants

Source: McDonald, C. and N. Johnson, *Summary of Available Information on Quantity, Chemical Composition, and Hazardous Nature of Solid Wastes from Coal Gasification and Liquefaction Facilities*, Systems Consultants, Inc., Washington, D.C., (September, 1980).

Table 4.35

Trace Elements Reported in Product Gas Quench Waters

Element	Trace Element Concentration (mg/l)		% of Element Originally Present in Coal
	Synthane PDU (mg/l)	Hygas Pilot Plant (mg/l)	
Hg	0.027	—	32
As	0.001	—	90
Zn	0.13	37 - 63	—
Mn	0.2	40 - 206	36
Cr	0.043	< 24	—
F	39	—	42
B	43	251 - 12000	3.5
Be	—	< 2	1.6
Cd	—	< 20	35
Pb	—	< 60	3.2
V	—	< 200	0.06
Sb	—	—	36

Source: Ghassemi, M., et. al., *Environmental Assessment Data Base for High-Btu Gasification Technology*: Volumes 1, 2, and 3, TRW Environmental Engineering Division, prepared for U.S. EPA 600/7-79-186a, b, and c, (September, 1978).

Table 4.36

Catalysts Used in Coal Conversion Processes

Catalysts	Use
Activated carbon	Purification
Iron oxide	Purification
Methanol	Purification
Propylene carbonate	Purification
Sodium carbonate	Purification
Potassium carbonate	Purification
Amines	
Monethanolamine	Purification
Diethanolamine	Purification
Diglycolamine	Purification
Zinc oxide	Purification
Cobalt-molybdenum	Shift conversion, liquefaction (hydrotreating), purification
Limestone dolomite	Sulfur recovery
Molten salt	
Nickel	Methanation or liquefaction
Vanadium	
Dolomite	Purification
Bauxite	Sulfur recovery
Iron	Shift conversion or liquefaction
Isopropyl ether	Phenol recovery
n-Methyl-2-pyrrolidine	Purification
Dimethyl ether polyethylene glycol	Purification
K ₃ AsO ₃	Liquefaction
Tungsten	Liquefaction
Zinc chloride	Liquefaction
Sodium sulfite	Purification
Co-Mo/SiO ₂ -Al ₂ O ₃	Liquefaction
Sulfoxide	Sulfur recovery
Chelated iron salt	Sulfur recovery
Nickel-tungsten	Liquefaction (hydrotreating)
Ruthenium	Methanation

Source: Braunstein, H. M., et. al., *Environmental, Health, and Control Aspects of Coal Conversion: An Information Overview*, Oak Ridge National Laboratory, prepared for the U.S. Energy Research and Development Administration, ORNL/EIS-94, UC-11, -41, -48, -90i, (April, 1977).

Table 4.37

**Trace Element Concentration for Drainage Produced
by Illinois Basin Coal Refuse**

Element	Leachates Concentration (mg/l)	EPA Public Water Supply Criteria (mg/l)
Na	21 - 700	—
Mg	61 - 369	—
Al	8.1 - 910	—
K	21 - 28	—
Ca	130 - 532	—
Mn	5.6 - 44	—
Fe	610 - 12000	—
Co	3.7 - 28	—
Ni	5.6 - 43	—
Cu	0.3 - 8	—
Zn	2.2 - 55	5.0
Cd	0.02 - 0.24	0.01
pH (S.U.)	1.7 - 2.9	5.9

Source: Wewerka, E. M., et. al., *Trace Element Characterization of Coal Wastes — Second Annual Progress Report*, Los Alamos Scientific Laboratory, for the U.S. Department of Energy (DOE-600/7-78-028a), July, 1978.

Table 4.38

Typical Analysis of Organic and Mineral Matter in the Raw Shale

Organic Matter	wt. %	Mineral Matter	wt. %
Carbon	80.5	Dolomite	32
Hydrogen	10.3	Calcite	16
Nitrogen	2.4	Quartz	15
Sulfur	1.0	Illite	19
Oxygen	5.8	Albite	10
		Microcline	6
		Pyrite	1
		Anacite	1

Source: Crawford, K. W., et. al., *A Preliminary Assessment of the Environmental Impacts from Oil Shale Development*, TRW Environmental Engineering Division, for the U.S. Environmental Protection Agency, Cincinnati, Ohio, (EPA-600/7-77-069), July, 1977.

Table 4.39

Chemical and Physical Properties of Processed Shale Produced by Surface Retorting

Property	Direct internal Combustion ¹	Indirect Heating ²
Principal constituents (weight percent):		
Total carbon	2.95	10.2
Organic carbon	0.80	4.49
Hydrogen	0.10	0.44
Nitrogen	0.13	0.35
Sulfur	0.08	0.76
Ash	92.88	84.2
Trace metals (parts per million):		
Lead	24	10
Mercury	0.06	0.1
Molybdenum	18	4.9
Selenium	0.4	0.08
Arsenic	18	7.2
Boron	82	140
Other properties:		
pH	11	8
Geometric mean size (centimeters)	0.205	0.007
Permeability (cm ²)	3.46×10^{-9}	2.5×10^{-10}
Bulk density (grams per cubic centimeter)	1.44	1.30

¹Analyses on oil shale from Anvil Points Mine, Paraho test program (White River Shale Project, 1976; Harbert and Berg, 1978).

²Analyses based on TOSCO II retorting of oil shale from pilot mine of Colony Development Operation (U.S. Bureau of Land Management, 1977).

Source: National Academy of Sciences, *Surface Mining of Non-Coal Minerals, Appendix II: Mining and Processing of Oil Shale and Tar Sands*, ISBN 0-309-03037-4 (1980).

Table 4.40

**Chemical Composition of Spent Oil Shale
(parts per million)**

	LLL 125-Kg retort LETC 10-ton retort		Fischer Assay ²	Fischer Assay ²	TOSCO ³	TOSCO: Fischer Assay ²		Paraho Direct Mode Pilot- plant and Semi-works Plant ¹		Paraho Direct and Indirect Mode Plant ¹	
Ag	—	—	—	—	—	—	—	—	—	—	—
Al	—	—	—	5.2 - 7.3	4.8	—	—	—	—	—	—
As	83	91	60 - 65	—	—	80	79	35	19	21	18
B	—	—	54 - 110	—	—	145	146	48	82	52	18
Ba	790	650	—	—	—	—	—	180	310	—	—
Be	—	—	0.95 - 1.2	—	—	—	—	2	1	0.7	2
Bi	—	—	—	—	—	—	—	—	—	—	—
Br	0.9	—	—	—	—	—	—	0.2	0.2	—	—
Ca	—	—	—	10.6 - 24.2	12.6	—	—	—	—	—	—
Cd	—	—	1.5 - 1.8	—	—	—	—	—	—	—	—
Ce	—	62	—	—	—	—	—	59	100	—	—
Cl	—	—	—	—	—	—	—	43	42	—	—
Co	12	21.1	7.0 - 8.0	—	—	—	—	19	15	13	16
Cr	50	52	48.9 - 55.0	—	—	—	—	230	110	137	66
Cs	8.3	8	—	—	—	—	—	6	10	—	—
Cu	—	133	46.0 - 55.0	—	—	52	47	57	53	44	26
Dy	—	—	—	—	—	—	—	—	—	—	—
Er	—	2.0	—	—	—	—	—	—	—	—	—
Eu	0.99	0.82	—	—	—	—	—	—	—	—	—
F	—	—	1239 - 1352	—	—	1120	1080	1000	320	1000	450
Fe	3.24%	4.21%	—	2.6 - 4.1	2.3	—	—	—	—	—	—
Ga	—	11	—	—	—	—	—	17	13	—	—

Table 4.40 (cont.)

	LLL 125-Kg retort LETC 10-ton retort		Fischer Assay ²	Fischer Assay ²	TOSCO ³	TOSCO: Fischer Assay ²		Paraho Direct Mode Pilot- plant and Semi-works Plant ¹		Paraho Direct and Indirect Mode Plant ¹	
Gd	—	3.3	—	—	—	—	—	1	0.9	—	—
Ge	—	—	—	—	—	—	—	0.9	0.2	—	—
Hf	2.8	1.3	—	—	—	—	—	—	—	—	—
Hg	0.008	0.003	—	—	—	—	—	0.06	0.06	0.07	0.03
Ho	—	0.73	—	—	—	—	—	—	—	—	—
I	—	—	—	—	—	—	—	0.2	0.2	—	—
K	—	—	—	1.3 - 3.7	1.2	—	—	—	—	—	—
La	29.4	34	—	—	—	—	—	21	33	—	—
Li	—	—	—	—	—	—	—	85	370	—	—
Lu	0.48	0.34	—	—	—	—	—	—	—	—	—
Mg	—	—	—	4.2 - 8.1	4.7	—	—	—	—	—	—
Mn	—	—	257 - 275	—	—	240	224	300	700	600	272
Mo	—	—	37.7 - 44.5	—	—	38	36	14	18	33.7	41.5
Na	2.35%	2.34%	—	1.2 - 3.3	0.6	—	—	—	—	—	—
Nb	—	—	—	—	—	—	—	7	8	—	—
Nd	—	30	—	—	—	—	—	6	9	—	—
Ni	—	70	27.5 - 28.5	—	—	31	29	75	20	38	14
P	—	—	—	—	—	—	—	—	—	—	—
Pb	0	0	34.5 - 3.70	—	—	39	37	23	24	18	11
Pr	—	7.5	—	—	—	—	—	2	5	—	—
Rb	107	130	—	—	—	81	86	110	85	—	—
S	—	—	—	0.04 - 2.0	10.5	—	—	—	—	—	—
Sb	2.9	3.4	—	—	—	—	—	0.7	1	0.7	0.8
Sc	9.8	9.4	—	—	—	—	—	26	20	—	—
Se	0.6	3.6	11.4 - 16.7	—	—	3.2	2.9	0.5	0.4	0.3	0.2
Si	—	—	—	13.4 - 24.9	15.5	—	—	—	—	—	—

Table 4.40 (cont.)

	LLL 125-Kg retort LETC 10-ton retort		Fischer Assay ²	Fischer Assay ²	TOSCO ³	TOSCO: Fischer Assay ²	TOSCO: Fischer Assay ²	Paraho Direct Mode Pilot- plant and Semi-works Plant ¹		Paraho Direct and Indirect Mode Plant ¹	
Sm	5.0	4.9	—	—	—	—	—	2	1	—	—
Sn	—	—	—	—	—	—	—	0.2	2	—	—
Sr	—	1120	—	—	—	770	770	970	760	—	—
Ta	—	0.8	—	—	—	—	—	—	—	—	—
Tb	—	0.51	—	—	—	—	—	0.7	0.6	—	—
Te	—	—	—	—	—	—	—	—	—	—	—
Th	9.6	8.2	—	—	—	—	—	7	4	—	—
Ti	—	—	—	—	—	—	—	—	—	—	—
Tl	—	—	—	—	—	—	—	—	—	—	—
Tm	—	0.35	—	—	—	—	—	—	—	—	—
U	4.4	12.6	—	—	—	6.6	6.4	5	7	—	—
V	—	—	51.8 - 70.6	—	—	—	—	180	110	116	88
W	—	—	—	—	—	—	—	—	—	—	—
Y	—	—	—	—	—	10.6	10.2	40	17	—	—
Yb	—	1.8	—	—	—	—	—	—	—	—	—
Zn	42	125	76.0 - 80.0	—	—	82	72	22	17	16	21
Zr	—	—	—	—	—	—	—	65	41	43	62

¹Mahogany zone, Anvil Points, Colorado²Mahogany zone, Colony mine, Colorado³Mahogany ledge, Anvil Points, ColoradoSource: National Academy of Sciences, *Surface Mining of Non-Coal Minerals, Appendix II: Mining and Processing of Oil Shale and Tar Sands*, ISBN 0-309-03037-4 (1980).

Table 4.41

Ash Composition of Typical Retorted Oil Shale

Component	TOSCO II (wt%)	Union B (wt%)	GCR (wt%)
SiO ₂	33.0	31.5	43.8
Fe ₂ O ₃	2.5	2.8	4.6
Al ₂ O ₃	6.8	6.9	12.2
CaO	15.8	19.6	22.1
MgO	5.3	5.7	9.3
SO ₃	—	1.9	2.2
Na ₂ O	8.7	2.2	3.4
K ₂ O	3.3	1.6	2.4

Notes: Ref. 1, data represent Mahogany zone shale (35 gal/ton) from Parachute Creek area.
 Ref. 2, data represent Mahogany zone shale (35 gal/ton) from Parachute Creek area.
 Ref. 3, data represent Mahogany zone shale (30 gal/ton) from Anvil Points.

Sources: 1. Colony Development Operation, *Draft Environmental Impact Statement Proposed Development of Oil Shale Resources in Colorado*, U.S. Department of the Interior, Bureau of Land Management, December, 1975.
 2. Lipman, S. C., *Union Oil Company Revegetation Studies*, Environmental Oil Shale Symposium, Colorado School of Mines, Golden, Colorado, October 18-20, 1975.
 3. Stanfield, K. E., et. al., *Properties of Colorado Oil Shale*, U.S. Bureau of Mines, Report of Investigations No. 4825, 1975.

Table 4.42

Distribution of Trace Metals During Oil Shale Retorting

Element	Weight (ppm)				% Recovery	% Distribution		
	Raw shale	Spent shale	Oil	Water		Spent shale	Oil	Water
Arsenic	60.0	60.0	21.0	0.0	87.4	95.0	5.0	0.0
Beryllium	1.0	1.2	0.0	0.0	99.6	100.0	0.0	0.0
Boron	63.3	54.0	0.48	0.55	70.9	99.8	0.1	0.0
Cadmium	1.25	1.50	0.00	0.00	99.6	100.0	0.0	0.0
Chromium	41.7	53.8	0.8	0.004	107.3	99.8	0.2	0.0
Cobalt	6.5	8.0	0.26	0.005	102.7	99.5	0.5	0.0
Copper	47.5	55.0	0.25	0.16	96.2	99.9	0.1	0.0
Fluoride	1162.	1352.	< 1.0	2.6	96.6	99.9	0.0	0.0
Lead	282.3	34.5	0.14	0.0	97.8	99.9	0.1	0.0
Manganese	230.	275.	0.05	0.02	99.2	99.9	0.0	0.0
Molybdenum	30.0	37.7	0.50	0.006	104.5	99.8	0.2	0.0
Nickel	23.9	27.5	1.4	0.034	96.2	99.2	0.8	0.0
Selenium	14.6	16.7	0.0	0.1	94.9	99.9	0.0	0.0
Vanadium	57.1	70.6	0.48	0.0	102.7	99.9	0.1	0.0
Zinc	65.0	76.0	1.4	0.045	97.3	99.7	0.3	0.0

Source: Shendrikar, A. D. and G. E. Faudel, *Distribution of Trace Metals During Oil Shale Retorting*, Environmental Science and Technology, 12 (3), pp. 332-334, (March, 1978).

Table 4.43

**Inorganic Ions Leachable from Freshly Retorted Shales (kgs/tonne) —
Based on Laboratory Tests**

Ion	Raw Shale	TOSCO II	GCR (USBM)	GCR (Union A)
K ⁺	0.24	0.32	0.72	6.25
Na ⁺	0.48	1.65	2.25	21.0
Ca ⁺⁺	0.1	1.15	0.42	3.27
Mg ⁺⁺	0.01	0.27	0.04	0.91
HCO ₃ ⁻	0.75	0.20	0.38	0.28
Cl ⁻	0.22	0.00	0.13	0.33
SO ₄ ⁼	0.79	7.3	6.0	02.3
Total (kg/tonne)	1.95	10.96	9.94	94.34
(lbs/ton)	(3.9)	(22)	(20)	(188)

Source: Ward, J. E., et. al., *Water Pollution Potential of Rainfall on Spent Shale Residues*, Colorado State University, prepared for the EPA under grant #14030EDB, December, 1971.

Table 4.44

Typical Composition of Shale Oil Coke

	(1)	(2)
Ash, wt %	10-15	12.6
Moisture, wt %	7.0	N/A
Carbon, wt %	91	
Hydrogen, wt %	3.6	82.5
Oxygen, wt %	1.3	
Total Nitrogen, wt %	3.9	4.1
Sulfur, wt %	0.5	0.8
Arsenic, ppm	5-10	N/A
(0.3 water soluble)		

Notes: Ref. 1, data are for shale oil produced by TOSCO II retorting:

Ref. 2, data are for combination Paraho and TOSCO II produced shale oil.

Source: 1. U.S. Energy Outlook, Appraisal by Oil Shale Task Group, National Petroleum Council, 1972.
2. Detailed Development Plan Federal Oil Shale Lease Tract C-b (Roxama Oil Shale Project), submitted to Area Oil Shale Supervisor, 1975.

Table 4.45

Solid Wastes from Upgrading 50,000 Barrels Per Day of Crude Shale Oil

Facility	Waste product	Quantity (tons per year)
Coker	Coke	290,000
Hydrotreater	Spent catalysts	800
Hydrogen plant	Spent catalysts	50

Source: National Academy of Sciences, *Surface Mining of Non-Coal Minerals, Appendix II: Mining and Processing of Oil Shale and Tar Sands*, ISBN 0-039-03037-4 (1980).

Table 4.46

Average Concentration in Geothermal Brines and in Water Samples (mg/l)

Average Concentrations in Geothermal Brines, mg/l					
Ion	Salton Sea	Westmorland	Brawley	Heber	East Mesa
Na	52,000.	10,000.	22,000.	4,200.	2,600.
K	14,000.	1,400.	3,800.	260.	190.
Ca	24,000.	690.	8,100.	880.	130.
Mg	106.	188.	34.	5.4	3.4
Cl	145,000.	18,000.	46,000.	7,900.	3,900.
SO ₄	84.	57.		99.	155.
CO ₃	0.	130.	0.	3.3	33.
HCO ₃	140.	2,900.	49.	27.	490.
TDS	240,000.	37,000.	76,000.	14,000.	7,600.
pH	5.2	7.5	6.1	6.5	7.3
As	11.		2.6	0.1	0.16
B	350.	63.	140.	14.	5.4
Ba	433.		363.	3.8	2.2
Cu	4.	0.07	0.11	0.53	0.03
F	9.	2.24		1.6	2.0
Fe	2,300.	0.3	65.	22.	2.2
Li	211.	48.	100.	9.5	6.3
Mn	1,200.	2.8	190.	2.7	0.42
Ni	4.				0.03
Pb	100.	3.6	1.1	1.9	0.09
Se					1.2
	500.		340.	53.	38.
	660.	0.04	14.	0.83	0.07

Table 4.46 (cont.)

Average Concentrations in Water Samples in Salton Sea KGRA, mg/l						
Vail4 Canal	Sump 120	Sinclair 4	Sump 116	Vail4A Drain	Alamo River	Salton Sea
168.	1,080.	58,442.	2,470.	970.	607.	10,600.
6.3	20.	14,918.	247.	66.	15.	195.
93.	373.	26,992.	2,050.	437.	201.	850.
35.	187.	736.	385.	160.	120.	1,200.
158.	989.	154,590.	8,540.	1,870.	760.	14,700.
357.	1,990.	19.	1,590.	1,480.	960.	8,100.
15.	< 2.5		< 2.5	< 2.5	< 2.5	63.
152.	338.	0.	380.	330.	205.	143.
928.	5,030.	266,560.	17,700.	5,970.	3,000.	38,600.
8.2	7.	5.3	6.8	7.6	7.7	8.8
0.005	< 0.005	10.	0.005	0.005	0.007	< 0.01
0.25	1.1	332.	9.7	2.	0.76	6.8
0.09	0.097	1,100.	0.54	0.093	0.12	0.07
< 0.005	0.005	3.	0.075	0.007	0.014	0.08
0.5	0.57	14.	0.48	0.05	0.66	1.1
0.03	0.03	1,240.	0.26	0.08	0.045	0.24
0.08	0.31	344.	14.3	1.24	0.23	3.2
0.01	0.30	1,475.	47.	1.9	0.035	0.08
0.01	< 0.01	< 4.	0.31	< 0.01	< 0.01	< 0.2
< 0.01	0.01	60.	0.29	0.02	0.01	< 0.1
< 0.005	< 0.005		< 0.01	< 0.005	< 0.005	0.02
1.3	5.3	448.	38.	6.0	3.2	13.5
0.02	0.03	600.	7.8	0.12	0.02	0.03

Source: Primentel, K.D., R.R. Ireland and A. Tompkins, *Chemical Fingerprints to Assess the Effects of Geothermal Development of Water Quality In Imperial Valley*, presented at the 1978 Annual Meeting of the Geothermal Resources Council, Hilo, Hawaii (July, 1978).

CURRENT LEVELS OF SOLID WASTE GENERATION

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Table 4.47

**Projected Annual National Industrial Sludge Emissions
(millions of tons)**

Source	Base Year (1975)		2000 Low World Oil Price		2000 High World Oil Price	
	Value	Percent of Total	Value	Percent of Total	Value	Percent of Total
Energy						
Electric Utilities						
Oil	0	0	0	0	0	0
Gas	0	0	0	0	0	0
Coal	0.07	<1	36	42	41	39
Nuclear	0	0	0	0	0	0
Subtotal*	0.07	<1	36	42	41	39
Industrial Combustion						
Oil	0	0	0	0	0	0
Gas	0	0	0	0	0	0
Coal	0	0	15	17	17	16
Subtotal*	0	0	15	17	17	16
Other Energy						
Oil	0.06	<1	0.08	<1	0.06	<1
Gas	0	0	0	0	0	0
Coal	0	0	0	0	0	0
Nuclear	0	0	0.01	<1	0.01	<1
Synthetic Fuels	0	0	13	15	27	25
Subtotal*	0.06	<1	13	15	27	25
Energy Total	0.13	2	64	75	85	80
Non-Energy						
Asphalt	4.0	49	12	14	12	11
Iron and Steel	2.2	27	6.2	7	6.2	6
Stone & Clay Products	1.1	14	2.6	3	2.6	2
Other Non-Energy	0.71	9	1.0	1	0.97	1
Non-Energy Total*	8.0	99	22	25	22	20
TOTAL*	8.1	100	86	100	106	100

*Totals may not equal the sum of individual values; this results from the use of two figure accuracy.

Source: U.S. DOE, *National Energy Plan II, Appendix: Environmental Trends and Impacts*, ASEV (May, 1979).

Table 4.48

Projected Annual National Noncombustible Solid Waste Production
(millions of tons)

Source	Base Year (1975)		2000 Low World Oil Price		2000 High World Oil Price	
	Value	Percent of Total	Value	Percent of Total	Value	Percent of Total
Energy						
Electric Utilities						
Oil	0.13	<1	0.08	<1	0	0
Gas	0	0	0	0	0	0
Coal	42	54	94	44	108	14
Nuclear	0	0	0	0	0	0
Subtotal*	42	55	94	44	108	14
Industrial Combustion						
Oil	0.02	<1	0.05	<1	0.02	1
Gas	0	0	0	0	0	0
Coal	2.4	3	21		22	3
Subtotal*	2.4	3	21	4	22	3
Other Energy						
Oil	6.9	9	6.4	1	7.1	1
Gas	0	0	0	0	0	0
Coal	0.65	<1	0	0	0	0
Nuclear	0	0	0	0	0	0
Synthetic Fuels	0	0	384	68	576	74
Subtotal*	7.5	10	390	69	583	75
Energy Total	52	68	505	89	713	92
Non-Energy						
Stone & Clay Products	12	17	29	5.2	29	4
Asphalt	6	8	18	3.2	18	2
Iron and Steel	2.4	2	6.2	1.1	6.3	1
Other Non-Energy	4.4	6	8.5	1	8.4	1
Non-Energy Total*	25	32	62	11	62	8
TOTAL*	76	100	568	100	775	100

*Totals may not equal the sum of individual values; this results from the use of two-figure accuracy.

Source: U.S. DOE, *National Energy Plan II, Appendix: Environmental Trends and Impacts*, ASEV (May, 1979).

Table 4.49

Estimated Solid Wastes from Energy Related Activities (10⁶ tons)¹

Waste	1976	1985	1990	1995
Conventional Coal Boiler				
Utility - Ash	58.0	71.0	105.0	134.0
Lime/Limestone Scrubber Sludge	0.8	5.0	30.0	51.0
Industrial - Ash	7.0	24.0	33.0	46.0
Coal Gasification				
Coal Cleaning		0.2	0.7	1.8
Gasifier Ash		2.0	7.0	18.0
Boiler Ash		0.2	0.7	1.7
Boiler FGD Sludge		0.04	0.15	0.4
Biosludge		0.08	0.3	0.7
Acid Gas Clean-up		0.003	0.01	0.02
Spent Catalysts		N/A	N/A	N/A
Tar and Oil Sludges		N/A	N/A	N/A
Coal Liquefaction				
Coal Cleaning		2.0	2.0	18.0
Liquefaction Waste (Chars, Ash, Filter Cake)		0.9	0.9	8.0
Boiler Ash		0.025	0.025	0.2
Boiler FGD Sludge		0.03	0.03	0.3
Biosludge		0.09	0.09	0.8
Spent Catalysts		N/A	N/A	N/A
Acid Gas Clean Up		N/A	N/A	N/A
Tar and Oil Sludges		N/A	N/A	N/A
Oil Shale				
Raw Shale Dust		0.5	0.9	4.0
Spent Shale		19.5	39.0	173.0
Spent Shale Dust		0.04	0.08	0.35
Arsenic Waste		0.0002	0.0005	0.002
Nuclear				
High Level Waste (10 ⁶ × ft ³)	0.007	0.02	0.03	0.04
Low Level Waste (10 ⁶ × ft ³)	229.0	716.0	1030.0	1380.0

¹Solid waste figures are based on the following energy consumption and production figures:

	1976	1985	1990	1995
Utility coal (mmtons)	448.0	733.0	1066.0	1377.0
Industrial coal (mmtons)	62.0	212.0	289.0	404.0
Coal - derived gas (BCF)		88.4	313.4	786.0
Coal - derived oil (mmBls)		11.0	11.0	93.7
Oil shale (mmBls)		18.25	36.5	162.4
Nuclear (BKWH)	191.0	597.0	857.0	1151.0

1976 figures from Monthly Energy Review, DOE/EIA publication.

Future years from U.S. DOE/EIA Annual Report to Congress 1978, Volume 3, supplement 1, DOE/EIA - 0173/3-51.

Assumptions are from Series C - Medium supply, medium demand and medium costs.

Source: Crowther, M. A. and S. C. Morris, *Draft OTI White Paper on Environmental Aspects of Energy Related Solid Wastes*, Brookhaven National Laboratory (June, 1980).

Table 4.50

**Distribution of Ash Residuals by Degree of Utilization
(10⁶ tons¹)**

		2000	
	1975	High Scenario	Low Scenario
Electric Utilities			
Urban	13.1 (24%)	25.0 (26%)	20.7 (23%)
Intermediate	32.5 (62%)	58.0 (59%)	54.4 (61%)
Rural	7.1	14.5 (15%)	13.9 (16%)
TOTAL	52.7	97.5	88.0
Industrial Combustion			
Urban	3.9 (43%)	22.1 (53%)	21.7 (52%)
Intermediate	4.4 (48%)	17.3 (42%)	17.8 (43%)
Rural	0.7 (9%)	1.9 (5%)	1.9 (5%)
TOTAL	9.0	41.3	41.4

Notes: ¹Excluding flyash captured in wet FGD systems.

Source: Brookhaven National Laboratory, *RIIA - II Solid Waste Analysis, National Summary*, Draft DOE/RID (1980).

Table 4.51

Annual Solid Waste Production by Coal Gasification Facilities

Process Type	Size (Input)	Output	Annual Solid Wastes (tons/year) *	
High-Btu Fixed Bed	Appalachian Coal		430,000-489,000	Total Solid Wastes
	14,000 TPD			
	Eastern Interior Coal		438,000	Total Solid Wastes
	16-17,000 TPD		695,000	Total Solid Wastes
	Powder River, WY Coal		487,000	Total Solid Wastes
	22,820 TPD			
	Fort Union, ND Coal		715,000	Total Solid Wastes
	27,540 TPD			
	Four Corners, NM Coal		899,000	Total Solid Wastes
Low Btu		2.5×10^{11}	352,000	Total Solid Wastes
Lurgi-Medium Btu	Low S Coal	2.5×10^{11}	361,600	Gasifier Ash
	Stretford		86,900	Auxiliary Boiler Ash
	S Recovery		111,240	FGD Sludge
			13,900	Biopond Sludge
			7,000	WW Evaporator Residue
			580,640	Total Solid Wastes
Lurgi	24,520 TPD		802,900	Ash
			81,500	Unburned Coal
			332,750	Quench Water
			2,000	Water Treatment Sludge
			1,139,150	Total Solid Wastes
Lurgi	40,000 TPD	4.8×10^{11}	820,000-984,000	Coal Preparation Refuse
	6000 Btu/lb. Lignite		492,000-820,000	Ash
			163,000-328,000	Sulfur
			1,476,000-2,132,000	Total Solid Wastes
Lurgi		1.2×10^{11}	2,296,000-4,920,000	Total Wet Residuals
Hygas		1.2×10^{11}	1,312,000-2,624,000	Net Residuals

Table 4.51 (cont.)

Process Type	Size (Input)	Output	Annual Solid Wastes (tons/year)*	
Bygas		1.2×10^{11}	984,000-2,296,000	Total Wet Residuals
Synthane		1.2×10^{11}	1,630,000-2,296,000	Total Wet Residuals
Synthane	21,530 TPD	5.17×10^{11}	708,500	Ash
			433,000	Sudge
			1,141,000	Total Solid Wastes
Methanol from Coal	40-45,000 TPD		820,000-984,000	Coal Preparation Refuse
			492,000-820,000	Ash
			164,000-328,000	Sulfur
			1,476,000-2,132,000	Total Solid Wastes
Wellman-Galusha Low Btu		5×10^{11}	715,860	Gasifier Ash
			80,100	Cyclone Dust
			96,760	Sulfur
			892,720	Total Solid Wastes

*328 operating days per year

Source: McDonald, C. and N. Johnson, *Summary of Available Information on Quantity, Chemical Composition, and Hazardous Nature of Solid Wastes From Coal Gasification and Liquefaction Facilities*, System Consultants, Inc., Washington, D.C. (September 30, 1979).

Table 4.52

Annual Solid Waste Production by Coal Liquefaction Facilities

Process Type	Size (Input)	Output	Annual Solid Wastes (tons/year)*	
Exxon Donor Solvent	14,385 MTPD	3.8×10^{11} Btu/day	2,594,500	Coal Preparation Wet and Dry Refuse
		7950 m ³ /day	940,000	Ash Sludge from Hydrogen Generation
		50,000 bbl/day	765,000	Char and Ash from Process
			4,299,500	Total Solid Wastes
	21,820 MT/SD	4.5×10^{11} Btu/day	903,968	Solids from Flexicoker
		9540 m ³ /SD	883	Materials replaced every 3 mos. to 4 years
			904,851	Total Solid Wastes
H-Coal	17,400 MTPD	4.8×10^{11} Btu/day	364,100	Coal Preparation Wet and Dry Refuse
		7950 m ³ /day	682,900	Ash Sludge from Hydrogen Generation
		50,000 bbl/day	522,200	Char and Ash from Process
			1,569,200	Total Solid Wastes
Solvent Refined		2.5×10^{11} Btu/day	341,000	Total Solid Wastes
		35,000 bbl/day		
SRC-II	20,000 TPD	4.8×10^{11} Btu/day	328,000-492,000	Coal Refuse
			246,000-492,000	Ash
			82,000-164,000	Sulfur
			756,000-1,968,000	Total Solid Wastes
SRC-Refining	13,333 TPD	3.2×10^{11} Btu/day	656,000-1,968,000	Total Wet Solids
Synthoil		3.7×10^{11} Btu/day	328,000-1,312,000	Total Wet Solids

Table 4.52 (cont.)

Process Type	Size (Input)	Output	Annual Solid Wastes (tons/year)*	
Synthoil	24,183 MTPD	4.2×10^{11} Btu/day	462,500	Coal Preparation Refuse Wet and Dry
		7950 m ³ /day	201,400	Boiler Ash
		50,000 bbl/day	1,715,400	Scrubber Sludge } Auxiliary Boiler
			1,274,900	Ash Sludge from Hydrogen Generation
			74,500	Char and Ash from Process
			3,728,200	Total Solid Wastes
Fisher-Tropsch		2.8×10^{11} Btu/day	755,000	Total Solid Wastes
		50,000 bbl/day		
Liquefaction		2.8×10^{11} Btu/day	412,000	Total Solid Wastes
		50,000 bbl/day		

*328 operating days per year

MTPD - Metric Tons per Day, TPD - Tons per Day

Source: McDonald, C. and N. Johnson, *Summary of Available Information on Quantity, Chemical Composition, and Hazardous Nature of Solid Wastes from Coal Gasification and Liquefaction Facilities*, Systems Consultants, Inc., Washington, D.C. (September 30, 1979)

Table 4.53

**Solid Wastes Produced by the Colony Development Operation
at Grand Valley, Colorado**

Source of Solid Waste	Annual Production (tons)	Major Constituent
Pyrolysis Unit		
Processed shale	19,418,000	Processed Shale
Clarifier sludge from wet scrubbers- preheat systems	313,900	Raw Shale dust
Ball Circulation system	23,725	Processed shale dust
Processed shale moisturizing system	15,695	Processed shale dust
Crushing Unit		
Primary crusher	9,125	Raw shale dust
Final crusher	118,625	Raw shale dust
Shale storage silo	27,375	Raw shale dust
Upgrading Units (hydrotreaters)		
Naphtha	75	Spent HDN catalyst
Naphtha	60-80	Proprietary solid
Gas oil	230	Spent HDN catalyst
Gas oil	300-500	Proprietary solid
Hydrogen Unit		
Hydrodesulfurizer	18.3	Spent HDS catalyst
Guard bed	6.7	Spent ZnS catalyst
Shift converter (high temperature)	10	Spent Fe-Cr catalyst
Shift Converter (low temperature)	16.7	Spent Cu-Zn catalyst
Sulfur Unit		
Claus Unit	80	Spent alumina catalyst
Gas Treating Unit		
DEA filter	214.5	Diatomaceous earth
DEA filter	214.5	Deactivated carbon
Coker Unit	292,000	Green coke
Water Treatment	219	Lime and alum flocculants
	9	Proprietary coagulant aid

Source: National Academy of Sciences, *Surface Mining of Non-Coal Minerals, Appendix II: Mining and Processing of Oil Shale and Tar Sands*, ISBN 0-309-0307-4 (1980).

Table 4.54

Surface Disturbance Anticipated in Current Industrial Plans for Oil Shale Development

Developer or Tract	Plant Size (barrels per day)	Plant Area (acres)	Disposal Area (acres)	Technology
U-a/U-b	100,000	185	2,360	Underground mining, surface retorting
TOSCO	50,000	200	850	do.
Colony	50,000	200	800 - 1,000	do.
tion	9,000	5	320	do.
superior	11,500	380	65	Underground mining, Surface retorting, recovery of soda ash and alumina
C-a	76,000	Up to 300	Approx. 1,000	Modified in situ plus surface retorting
C-b	57,00	Up to 320	Up to 1,560	Modified in situ

Source: National Academy of Sciences, *Surface Mining of Non-Coal Minerals, Appendix II: Mining and Processing of Oil Shale and Tar Sands*, ISBN 0-309-0397-4 (1980).

Table 4.55

Retort Water Produced by Some Surface and In Situ Processes (modified from Farrier and Others, 1978)

Process	Ratio of Water to Oil (volume basis)
In situ retorts:	
True in situ	
Rock Springs site 9	22.2
Modified in situ with stream	
Occidental #5	11.5
Simulated in situ with stream	
Lawrence Livermore Laboratory 125 kg retort	2.30
True in situ	
Rock Springs site 7	0.66
Horizontal in situ	
Geokinetics #11	0.68
True in situ	
Rock springs site 4	0.40
Simulated in situ with nitrogen	
Lawrence Livermore Laboratory 125 kg retort	0.40
Surface retorts:	
Fischer Assay	0.15
TOSCO	0.10

Source: National Academy of Sciences, *Surface Mining of Non-Coal Minerals, Appendix II: Mining and Processing of Oil Shale and Tar Sands*, ISBN 0-309-037-4 (1980).

Table 4.56

**Production of Oil From Oil Shale as Indicated
by Current Industrial Plans (thousands of barrels per day)**

Year	Total	Surface Retorting	Modified in Situ	True in Situ
1985	96	10	85	up to 1
1990	298	160	133	5
2000	500	250	230	20

Source: National Academy of Sciences/National Research Council, *Surface Mining of Non-Coal Minerals, Appendix II: Mining and Processing of Oil Shale and Tar Sands*, (1980).

Table 4.57

Quantities of Existing Waste

High Level Waste (HLW), thousands of cubic feet

Commercial	80
Defense	9400

Transuranic Waste (TRU), contained TRU, Kilograms

Commercial	123
Defense	1100

Spent Fuel Discharged from Commercial Reactors

2300 metric tons of heavy metal (MTHM)

Low Level Waste (LLW), millions of cubic feet, buried

Commercial	15.8
Defense	50.8

Uranium Mill Tailings

140 million tons

Source: The Interagency Review Group on Nuclear Waste Management, *Report to the President on Nuclear Waste Management*, TID-29442, (1979).

Table 4.58

**Annual Waste Generation Rates
(normalized to an average 1000 MWe LWR)**

Spent Fuel Discharged (Ave.)	25.4 MTHM/yr (322 ft ³ /yr)
Low Level Waste, Generated Onsite ¹	
a) Present Experience	45,000 ft ³ /yr
b) Design Basis	15,000 ft ³ /yr
c) Advanced Volume Reduction ²	5,000 ft ³ /yr
Low Level Waste, Generated Offsite	
a) Uranium Mill, Tailings Solutions ³	254,000 MT/yr
Tailings Solids ³	96,000 MT/yr
b) UF ₃ Conversion	1,200 ft ³ /yr
c) Enrichment ^{3,4}	50 ft ³ /yr
d) Fuel Fabrication	750 ft ³ /yr
Transuranic Waste, Generated Onsite and Offsite	0

¹Roughly 40% of current volumes generated is contaminated trash.

²This estimate reflects the use of methods which are presently not economical. Current, allowable activity levels per package may preclude actual achievement of this level in the future.

³These wastes are currently disposed of at the processing facility site.

⁴This value is based on gaseous diffusion technology. The new centrifuge process could potentially generate more (up to 2900 ft³/yr).

Source: The Interagency Review Group on Nuclear Waste Management, *Report to the President on Nuclear Waste Management*, TID-29442, (1979).

Figure 4.2

Solid Waste Generation

Source: U.S. Department of Energy, *National Energy Plan II, Appendix, Environmental Trends and Impacts*, (May 1979).

EFFECTS AND METHODS OF SOLID/HAZARDOUS WASTE DISPOSAL

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Table 4.59

Summary of Energy Wastes and Relative Hazard Potential

Technology and Waste Stream	Chemicals of Concern	Potential Hazard (ranking)
Conventional Coal Boiler		
Ash	various trace elements	2
Lime/limestone scrubber sludge	various trace elements	2
AFBC		
Ash	various trace elements	2
Spent bed material	various pH, TDS, SO ₄ elements	1
Coal Gasification		
Coal cleaning	pH, trace organics and inorganics	3
Gasifier ash/char	fused aromatics, trace elements	3
Boiler ash	various elements	2
Boiler FGD sludge	various elements	2
Spent catalysts	Ni, Co, As, Cd, POM	3
Acid gas clean up and pollution control wastes	phenolics, aromatics, various elements	3
Tar and oil sludges	heterocyclics, PNA, other organics	3
Biosludges	heterocyclics, PNA, other organics	3
Coal Liquefaction	pH, trace organics and inorganics	3
Coal cleaning	pH, trace organics and inorganics	3
Liquefaction waste (chars, ash, filter cake)	fused aromatics, trace elements	3
Boiler ash	various elements	2
Spent catalysts	Ni, Co, As, Cd, POM	3
Acid gas clean up and pollution control wastes	phenolics, aromatics	3
Tar and oil sludges	heterocyclics, PNA, other organics	3
Biosludges	heterocyclics, PNA, other organics	3
Oil Shale		
Raw shale dust	respirable particulates	3
Spent shale	trace organics, PNA,	3
Shale oil coke	As, Se, PNA, other organics	3
API separator sludge	phenolics, trace elements	3
Process water and waste water	phenols, benzene, acetone	3
Spent catalysts	Ni, Co, As, Cd, trace organics	3
Activated carbon	organics	3
Elemental sulfur	trace inorganics	1
Water treatment chemicals		1

Table 4.59 (cont.)

Technology and Waste Stream	Chemicals of Concern	Potential Hazard (ranking)
Geothermal		
Drilling muds	bactericides, metals, organics	2
Geothermal fluid	As, Pb, K, F, TDS	2
Tar Sands Nuclear	similar to oil shale	3
Low level wastes	low radioactivity	1
High level wastes	high radioactivity	3
Oil Exploration		
Drilling muds	bactericides, metals, organics	2
Drilling brines	TDS	1

Notes: 1. low — concentrations of chemicals are known to be low, with few additional data necessary.

2. intermediate — concentrations of chemicals approach criteria and/or additional data may illustrate that concentration levels of chemical are high and/or additional data may identify new compounds of concern.

3. high — concentrations of chemicals exceed criteria and/or there is a high potential that additional data will illustrate severe problems associated with toxic chemicals present.

Source: Chiu, S. Y. et al., *Problems Associated with Energy Solid Wastes*, Argonne and Brookhaven National Labs. for Regional Impacts Division, U.S. Department of Energy, 1980.

Table 4.60

Composition of Ash Pond Liquors and Sluicing Waters (mg/l)

	Fly Ash Pond	Bottom Ash Pond	Ash Pond	Ash Pond Overflow	Ash Pond Overflow	Fly Ash Sluicing Water	Bottom Ash Sluicing Water
Aluminum (Al)	3.6-8.8	0.5-8.0	0.4	0.011-5.3	—	0.57-0.92	1.69-2.31
Antimony (Sb)*	—	—	0.007-0.012	—	0.003-0.3	0.004-0.021	0.034-0.41
Arsenic (As)*	<0.005-0.023	0.002-0.15	0.006- <0.12	—	0.003-0.02	<0.0001-0.001	0.004-0.008
Barium (Ba)	0.2-0.4	<0.10-0.30	<0.01-3.0	—	<0.3	<0.5- <0.6	<0.5-0.5
Beryllium (Be)	<0.01-0.02	<0.01	<0.002	—	0.001-0.003	<0.002-0.003	0.001-0.002
Boron (B)	—	—	1.0-24.67	—	0.233-1.03	0.5-2.41	0.25-2.46
Cadmium (Cd)	0.023-0.052	<0.001-0.002	0.005- <0.025	—	0.0001-0.04	0.001- <0.002	0.001-0.004
Calcium (Ca)	94-180	23-67	<200-563	—	—	46-114	45-785
Chlorine (Cl)	5-14	5-15	85-189	1-2415	—	14.9-17.2	15.7-27.7
Chromium (Cr)*	0.012-0.17	0.005-0.023	<0.02	0.0005-0.139	<0.0002-0.004	<0.05	<0.05
Cobalt (Co)	—	—	<0.001- <0.7	—	—	<0.003	0.004-0.005
Copper (Cu)*	0.16-0.45	<0.01-0.14	<0.003-0.05	0.005-0.06	<0.004-0.09	0.008-0.022	0.011-0.024
Fluorine (F)	—	—	1-14.85	—	0.35-10.4	0.023-0.70	0.25-16.2
Germanium (Ge)	—	—	—	—	0.02- <0.1	—	—
Iron (Fe)	0.33-6.6	1.7-11	<0.05- <0.2	0.001-2,894	—	0.01-1.38	0.31-2.25
Lead (Pb)*	<0.01-0.2	<0.01-0.031	0.0028-0.08	—	—	0.006-0.025	0.007-0.024
Lithium (Li)	—	—	0.4-0.08	—	—	—	—
Magnesium (Mg)	9.4-20	0.3-9.3	0.1-102	6-156	—	15.7-24.1	25.8-67.7
Manganese (Mn)	0.29-0.63	0.07-0.26	<0.005-0.49	0.0002-0.102	0.004-1.1	0.016-0.096	0.055-0.77
Mercury (Hg)*	<0.0002-0.0006	<0.0002-0.026	<0.001	0.0002	<0.001- <0.0022	<0.004- <0.0005	<0.0004-0.0005
Molybdenum (Mo)	—	—	0.030-0.49	—	0.004-0.10	<0.012-0.015	0.016-0.055
Phosphorus (P)	<0.01-0.06	0.01-0.23	—	0.1-0.41	—	—	—

Table 4.60 (cont.)

	Fly Ash Pond	Bottom Ash Pond	Ash Pond	Ash Pond Overflow	Ash Pond Overflow	Fly Ash Sluicing Water	Bottom Ash Sluicing Water
Potassium (K)	—	—	—	—	—	—	—
Selenium (Se)*	<0.001-0.004	<0.001-0.004	0.021- <0.05	—	0.003-0.15	0.001-0.004	0.001-0.031
Silicon (Si)	10-15	6.1-8.6	1-51	—	—	—	—
Silver (Ag)*	<0.01-0.01	<0.01	0.02	—	—	<0.0002	<0.0002-0.0004
Sodium (Na)	—	—	170-254	3,982	—	—	—
Strontium (Sr)	—	—	0.8	—	—	—	—
Tantalum (Ta)	—	—	<0.02	—	—	—	—
Titanium (Ti)	—	—	<0.02	—	<0.1	<0.1-0.1	—
Uranium (U)	—	—	—	—	—	0.004-0.005	0.003-0.005
Vanadium (V)	—	—	<0.02	—	<0.1-0.2	<0.005-0.072	<0.005-0.192
Zinc (Zn)*	1.1-2.7	0.02-0.16	<0.022-0.09	0.00013-0.17	0.02-2.5	0.008-0.028	0.013-0.075
Zirconium (Zr)	—	—	<0.07	—	—	—	—
Total Hardness (CaCO ₃)	185-520	—	—	25-736	—	—	—
pH	3.6-6.3	4.1-7.9	8.47	—	—	—	—
Dissolved Solids	141-820	69-404	1100-3335	40-3328	—	—	—
Suspended Solids	2-256	5-657	—	1-100	—	—	—
HCO ₃	—	—	31.0	—	—	—	—
SO ₄	—	—	580-2300	2.2-527	—	—	—

*On EPA list of 65 priority pollutants.

Source: Fred C. Hart Associates, Inc., *The Impact of RCRA (PL 94-580) on Utility Solid Wastes*, for Electric Power Research Institute, Palo Alto, CA, EPRI FP-878, TPS 78-779, (August, 1978).

Table 4.61

Trace Elements in Coal Ash Leachates (mg/l)

	Lurgi	H-COAL	FGD		FBC	
	Bottom Ash	Vacuum Still Residue	Bottom Ash	Precipitator Ash	Spent Stone	Fly Ash
pH	7.55	8.83	8.2	12.5	12.2	12.2
Ag	—	—	—	—	0.08	0.08
Al	ND ¹	3.0	—	—	—	—
As	ND	< 1	0.006	0.002	5.0	2.5
Ba	ND	< 0.1	0.3	40	—	—
Be	ND	< 0.01	0.00026	0.003	—	—
Ca	290	110	200	95	450	540
Cd	0.02	< 0.03	0.0011	0.001	—	—
Cr	ND	< 0.02	0.014	0.001	—	—
Co	ND	< 0.1	—	—	0.25	0.50
Cu	0.01	< 0.05	0.015	0.005	0.075	0.025
Fe	0.06	< 0.1	—	—	0.1	0.5
Ge	—	—	0.01	0.01	—	—
Hg	ND	< 0.0002	0.0003	0.0006	4.5	6.2
Li	1.8	< 0.01	—	—	—	—
Mg	10.5	< 0.5	10	5	22	96
Mn	0.45	< 0.02	0.002	0.002	0.05	0.025
Mo	ND	< 0.2	0.01	0.047	11.0	10.0
Ni	0.03	< 0.07	0.046	0.05	0.75	0.25
Pb	0.1	< 0.1	0.0063	0.0068	1.1	1.6
Sb	0.2	< 0.4	0.0087	0.006	—	—
Se	—	< 0.5	0.0005	0.009	—	—
Si	5	< 1	—	—	—	—
Sn	ND	< 1.0	—	—	—	—
Sr	1.8	0.2	—	—	—	—
Te	ND	< 0.5	—	—	—	—
Ti	ND	< 0.6	—	—	—	—
Tl	ND	< 0.4	—	—	—	—
V	ND	< 0.5	0.1	0.1	—	—
Zn	0.12	0.01	0.018	0.038	—	0.08

¹ND = not detectableSource: Chen, K. Y. et al, *Evaluation of Potential Impacts from Coal Utilization Wastes*, Draft, Argonne National Laboratory (December 1979);

Table 4.62

Equilibrium Concentrations of Trace Elements in Coal Ash Leachate

	Station Number					Water Quality Criteria ¹		
						Surface Water FWPCA (mg/l)	Irrigation FWPCA (mg/l)	Public Water Supply Intake EPA (mg/l)
	1	2	3	4	5			
Bottom Ash (wt %)	20	20	20	50	100			
Precipitator Ash (wt %)	80	80	80	50	—			
pH	12.5	9.5	12.2	12.0	8.2			
Element (ppm)								
Se	.006	.018	.033	.022	.0087	—	—	—
As	<.002	.084	.015	.072	.006	0.05	1.0	0.1
Ba	40	<.3	.3	.3	.3	1.0	—	—
Be	.003	.00064	.0007	.001	.00026	—	—	—
B	.03	16.9	.21	1.1	.048	1.0	0.75	1.0
Cd	<.001	.0025	.01	.001	.0011	0.01	0.005	0.01
Cr	<.001	.21	.11	1.0	.014	0.05	5.0	0.05
F	2.3	1.4	2.0	17.3	1.4	—	—	—
Ge	<.01	<.01	<.01	<.01	<.01	—	—	—
Hg	.0006	.0005	.015	.0003	.0003	—	—	0.002
Pb	.0068	.0027	.024	.0043	.0063	0.05	5.0	0.05
Mn	<.002	<.002	<.002	<.002	<.002	0.05	2.0	—
Mo	.047	.052	.05	.69	.010	—	0.005	—

Table 4.62 (cont.)

	Station Number					Water Quality Criteria ¹		
	1	2	3	4	5	Surface Water FWPCA (mg/l)	Irrigation FWPCA (mg/l)	Public Water Supply Intake EPA (mg/l)
Ni	.05	.015	.025	<.05	.046	—	0.5	—
Se	.009	.0005	.033	.47	.0005	0.01	0.05	0.01
V	<.1	<.1	<.1	<.2	<.1	—	10.0	—
Zn	.038	.025	.19	.005	.0175	5.0	5.0	5.0
Cu	<.005	.031	<.092	.013	.015	1.0	0.2	1.0

¹FWPCA = Federal Water Pollution Control Administration

Source: Holland, W. F., et al., *The Environmental Effects of Trace Elements in the Pond Disposal of Ash and Flue Gas Desulfurization Sludge*, Radian Corp., for the Electric Power Research Institute, Palo Alto, California, EPRI-202 (September 1975).

Table 4.63

Levels of Chromium and Lead in Combustion Solid Residues and Leachates as Compared to Solid Wastes from Selected Industries

	Waste Composition (mg/kg)		Leachate Composition (mg/l)	
	Lead	Chromium	Lead	Chromium
Petroleum Refining¹				
API sludge	.25-1,290	.10-6,790	—	1.9
DAF float	2.3-1,250	28-260	—	3.3
Slop oil emulsion solids	.25-580	1,750	—	—
Bundle sludge	—	310-311	—	—
Tank bottoms	158-1,420	—	—	—
Electroplating¹				
Wastewater treatment sludge (segregated zinc)	—	200	—	1.22
Primary Zinc Smelting and Refining¹				
Acid plant blowdown sludge				
Electrolytic	—	—	1.0-2.1	—
Pyrometallurgical plant	—	—	1.3	—
Anode slimes/sludges	—	—	2.0	—
Conventional Coal Combustion²				
Fly ash	4-130	3.7-300	1.6	0.001-1.0
Bottom ash	1-21	3.4-270	—	—
Water Quality Criteria				
Surface water (FWPCA)	—	—	0.05	0.05
Irrigation (FWPCA)	—	—	5.0	5.0
Public water supply intake	—	—	0.05	0.05

Sources: ¹Tamura, T. and W. J. Boegly, Jr., *Leaching Studies of Coal Gasification Solid Waste to Meet RCRA Requirements for Land Disposal*, paper presented at the Second Environmental Control Symposium, U.S. DOE, (April, 1980).

U.S. Environmental Protection Agency, *Applicability of Petroleum Refinery Control Technologies to Coal Conversion*, EPA 600/7-78-190 (October, 1978).

²Coles, D. G., R. C. Ragaini, and J. M. Ondov, 1978, *Behavior of Natural Radionuclides in Western Coal-Fired Power Plants*, Environmental Science and Technology, 12:442.

Chen, K. Y., et. al., *Evaluation of Potential Impacts from Coal Utilization Wastes*, DRAFT, Argonne National Laboratory, Argonne, Illinois, (December, 1979).

Table 4.64

**Chemical Composition of Lurgi Ash and Slurry Supernatant Solutions of the
Ash from an Illinois No. 6 Coal at Several pH's**

Consitutents	Chemical Composition of 10% Slurry Supernatant (mg/l)								Recommended Water Levels (mg/l)	Solid Ash Content (mg/kg)
	Air Atmosphere				Argon Atmosphere					
pH	7.55	5.10	3.82	2.68	8.82	7.20	5.35	3.79	6.0-9.0	—
Ag	—	—	—	—	—	—	—	—	.05	<.4
Al	ND	2	14	132	ND	ND	ND	92	.1	108,121
Au	—	—	—	—	—	—	—	—	—	.001
As	ND	ND	ND	ND	ND	ND	ND	ND	.1	3
B	4.0	4.5	4.5	5.5	4.5	3.0	4.5	8.0	.75	355
Ba	ND	ND	ND	ND	ND	ND	ND	ND	1.0	950
Be	ND	ND	.01	.03	ND	ND	ND	.01	.1	12
Br	—	—	—	—	—	—	—	—	—	<1.0
Ca	290	480	400	570	440	370	430	500	50	16,652
Cd	.02	.03	.03	.06	.01	ND	.02	.05	.01	<1.6
Ce	—	—	—	—	—	—	—	—	—	140
Cl	ND	ND	ND	ND	ND	ND	ND	ND	250	100
COD ^c	2	2	2	81	2	2	16	40	50	—
MCE ^d	28	28	0	23	10	3	6	4	—	—
Cr	ND	.02	.05	.12	.01	.01	.06	.16	.05	212
Co	ND	.05	.08	.19	ND	ND	ND	.17	.05	34
Cu	.01	.02	.13	.73	.01	.05	.01	.05	.2	57
Cs	—	—	—	—	—	—	—	—	—	11
Eu	—	—	—	—	—	—	—	—	—	1.9

Table 4.64 (cont.)

Constituents	Chemical Composition of 10% Slurry Supernatant (mg/l)								Recommended Water Levels (mg/l)	Solid Ash Content (mg/kg)
	Air Atmosphere				Argon Atmosphere					
F	.31	.30	.09	.04	.51	.34	.16	.02	1.0	<10
Fe _{Total}	.06	.19	.24	560	.06	.11	101	880	.3	143,780
Ga ₊₂	—	—	—	—	—	—	—	—	—	26
Fe	.03	.11	.10	533	.13	.05	110	365	—	—
Ge	—	—	—	—	—	—	—	—	—	7.0
Hf	—	—	—	—	—	—	—	—	—	6.1
Hg	ND	ND	ND	ND	ND	ND	ND	ND	.0002	0.5
K	42	49	51	25	39	43	48	61	5	14,611
La	—	—	—	—	—	—	—	—	—	47
Li	1.8	1.9	2.0	2.0	1.6	1.8	1.9	2.1	2.5	42
Lu	—	—	—	—	—	—	—	—	—	1.5
Mg	10.5	14	15	22	9.5	11	13.5	23	50	3,739
Mn	.45	1.94	2.7	3.8	.11	.90	2.3	3.7	.05	1,859
Mo	ND	ND	ND	ND	ND	ND	ND	ND	.01	30
Na	34	37	38	40	32	37	37	40	20	1,929
NH ₄	17	8	12	11	10	10	10	17	.02	—
Ni	.03	.13	.23	.50	ND	.04	.14	.42	1	89
Pb	.1	.1	.1	.2	ND	ND	.1	.2	.03	45
P	—	—	—	—	—	—	—	—	—	87
PO ₄	ND	ND	ND	ND	ND	ND	ND	ND	.05	—
S	ND	ND	ND	ND	ND	ND	ND	ND	.002	1,500
S _{Total}	—	—	—	—	—	—	—	—	—	6,100
Rb ₂	—	—	—	—	—	—	—	—	—	162
Sb	.2	.2	.3	.6	.3	.3	.3	.3	.05	4.2
SO ₄	—	943	8089	338	730	735	700	710	—	8,100

Table 4.64 (cont.)

Constituents	Chemical Composition of 10% Slurry Supernatant (mg/l)								Recommended Water Levels (mg/l)	Solid Ash Content (mg/kg)
	Air Atmosphere				Argon Atmosphere					
Sc	—	—	—	—	—	—	—	—	—	29
Se	—	—	—	—	—	—	—	—	.01	1
Si	5	29	60	130	4	9	27	120	—	229,946
Sm	—	—	—	—	—	—	—	—	—	10
Sn	ND	ND	ND	ND	ND	ND	ND	ND	—	—
Sr	1.8	1.9	2.1	2.9	1.5	1.7	1.9	2.6	50	370
Ta	—	—	—	—	—	—	—	—	—	1.1
Te	ND	ND	ND	ND	ND	ND	ND	ND	—	—
Th	—	—	—	—	—	—	—	—	—	21
Ti	ND	ND	ND	ND	ND	ND	ND	ND	—	6,295
Tl	ND	ND	ND	ND	ND	ND	ND	ND	—	4.6
U	—	—	—	—	—	—	—	—	—	17
V	—	—	—	—	—	—	—	—	0.1	184
W	—	—	—	—	—	—	—	—	—	1.5
Yb	—	—	—	—	—	—	—	—	—	2.9
Zn	.2	5.5	12	17	.01	.11	6.5	20	.2	400
Zr	—	—	—	—	—	—	—	—	—	170
EC (mnhos/cm)	1.17	1.50	1.95	5.60	1.20	1.39	1.80	5.20	18	—
Eb (electrode mvl)	+223	+246	+407	+349	+109	+161	+102	+243	—	—

¹Natural pH of supernatant.²Not detectable.³For low Na diet; 250 ppm for waste.

Source: Griffin, R. A., et. al., *Solubility and Toxicity of Potential Pollutants in Solid Coal Wastes*, prepared for the Symposium on Environmental Aspects of Fuel Conversion Technology, III, Hollywood, Fla., (September, 1977).

Table 4.65

Elements Exceeding Recommended Water Quality Levels

Constituent	Lurgi Ash Solubility	
	pH 3 (mg/l)	pH 8 (mg/l)
Al	132	0.5
B ¹	5.5	4.0
Ca ¹	570	290
Cd ¹	0.06	0.02
Cr	0.12	0.02
Ce	0.19	0.10
Cu	0.75	0.01
F	—	—
Fe	560	0.06
Ka	26	42
Mn ¹	3.80	0.45
NH ₄ ¹	11	17
Pb ¹	0.20	0.10
SO ₄ ¹	338	820
Sb ¹	0.60	0.20
Zn	17.00	0.12

¹Highest pollution potential

Source: Griffin, R. A., et. al., *Solubility and Toxicity of Potential Pollutants in Solid Coal Wastes*, prepared for the Symposium on Environmental Aspects of Fuel Conversion Technology, III, Hollywood, Florida, (September, 1977).

Table 4.66

**EPA-EP Leaching Results for Five Gasification/Liquefaction Solid Wastes
(ppb)**

Element	Waste 1	Waste 2	Waste 3	Waste 4	Waste 5	RCRA Standards¹
Arsenic	0.27	0.06	<1	<1	0.53	500
Barium	<200	<500	20	80	<500	10,000
Cadmium	0.054	0.97	<1	28	3.4	100
Chromium	1.6	0.44	<5	<5	0.13	500
Copper	2.7	3.7	10	10	0.94	2
Lead	<0.3	0.26	<10	<10	1.6	500
Mercury	0.64	0.03	<1	1	0.191	20
Selenium	<5	2	<1	<1	<1	100
Silver	<0.03	<0.03	<2	<2	0.07	500
Nickel	281	219	30	540	758	2
Zinc	63	10	13	2,240	385	2

¹RCRA standards were ten times the interim primary drinking water standards (12/18/78 regulations).

²No standards have been established for these elements at this time.

Source: Tamura, T. and W. J. Boegly, Jr., *Leaching Studies of Coal Gasification Solid Waste to Meet RCRA Requirements for Land Disposal*, paper presented at the Second Environmental Control Symposium, U.S. DOE, (April 1980).

Table 4.67
Chemical and Bioassay Test Results for Gasification Ash

Discharge Severity Range	Compounds Found from Chemical Analysis		Bioassay Test Results	
	Health	Ecological		
10 ³ - 10 ⁴	—	—	Health	
10 ² - 10 ³	Ba, Cr, Fe, Li, Mn, Ni	—	Ames RAM (EC ₅₀)	Negative <1000/ml of culture
10 - 10 ²	Fused polycyclic hydrocarbons ² , Be, Co, Cu, Pb, Se, Th, V, Zr	Cu, Fe, Ni	Potent Acute Toxicity (LD ₅₀)	<10 g/kg rat
1 - 10	Al, As, Bi, Cd, Ca, Hf, Mg, Si, Ag, Sr, Ti, Y	Alkenes, Cyclic Alkenes and Dienes, Aromatic Amines and Diamines, Ring Substituted Aromatics, Nitrophenols, Phthalate esters, Al, Ba, Cd, Cr, Pb, Li, Mn, Ti, V	Ecological Soil Microcosm	1

¹The soil microcosm test results cannot be interpreted in terms of a high, medium, or low potential for hazard but the gasifier ash was clearly more toxic than the cyclone dust.

²These categories of organic compounds are the worst case compounds which provide the largest discharge severity for the 38 µg/g of unidentified organics in the ash.

The worst case compounds corresponding to the categories are listed below:

Category	Compound
Fused Polycyclic Hydrocarbons	7, 12-Dimethylbenz (a) anthracene
Alkenes, Cyclic Alkenes and Dienes	Dicyclopentadiene
Aromatic Amines and Diamines	Aminonaphthalenes
Ring Substituted Aromatics	Dibromobenzene

Source: U.S. Environmental Protection Agency, *Environmental Assessment: Source Test and Evaluation Report-Wellman-Galusha (Glen Gary) Low-Btu Gasification*, EPA 600/7-79-185, 1st, 1979).

Table 4.68

Chemical and Bioassay Test Results for Gasification Cyclone Dust

Discharge Severity Range	Compounds Found from Chemical Analysis		
	Health	Ecological	Bioassay Test Results
$10^3 - 10^4$	Mn	—	Health
$10^2 - 10^3$	Fused Polycyclic Hydrocarbons ² , As, Ba, Cr, Fe, Pb, Li, Mi, Cu, Fe, Ni, Se	—	Ames RAM (EC ₅₀) Negative <1000/ml of culture
$10 - 10^2$	Be, Cd, Ag, Th, V, Zn	Alkenes, Cyclic Alkenes and Dienes, Aromatic Amines and Diamines, Ring Substituted Aromatics, Nitrophenols ² , Cd, Fe, Pb, Mn, Ni, Zn	Rodent Acute Toxicity (LD ₅₀) Ecological Soil Microcosm 1
1 - 10	Al, Sb, Ca, Co, Cu, F, Ga, Hf, Mg, Hg, Si, Sr, Ti, Tl, Y, Zr	Phthalate Esters, Al, Sb, As, Ba, Cr, Cu, Li, Mg, Hg, Se, Ti, V	

¹The soil microcosm test results cannot be interpreted in terms of a high, medium, or low potential for hazard but the cyclone dust was clearly more toxic than gasifier ash.

²These categories of organic compounds are the worst case compounds which provide the largest discharge severity for the 622 μ g/g of unidentified organics in cyclone dust.

The worst case compounds and their corresponding categories are listed below:

Category	Compound
Fused Polycyclic Hydrocarbons	7, 12-Dimethylbenz (a) anthracene
Alkenes, Cyclic Alkenes and Dienes	Dicyclopentadiene
Aromatic Amines and Diamines	Aminonaphthalenes
Ring Substituted Aromatics	Dibromobenzene
Nitrophenols	Dinitrophenols

Source: U.S. Environmental Protection Agency, *Environmental Assessment: Source Test and Evaluation Report-Wellman-Galusha (Glen Gary) Low-Btu Gasification*, EPA 600/7-79-185, (August, 1979).

Table 4.69

Chemical and Bioassay Test Results for Gasification Cyclone Dust Leachate

Discharge Severity Range	Compounds Found from Chemical Analysis		Bioassay Test Results	
	Health	Ecological		
$10^2 - 10^3$	Fused polycyclic hydrocarbons ¹	Mn, Zn	Ames	Negative
$10 - 10^2$	Mr.	Alkenes, Cyclic Alkenes, Dienes Nitrophenols, ^a Pb	W-38 (EC ₅₀) ¹	<500/ml of culture
1 - 10	Pb, Li	Al, Cd, Co, Cu Fe, Li	Rodent Acute Toxicity	NA
			Scil Microcosm	NA

NA = test was not applied

¹The 5,400 g/ of unidentified organics was assumed to contain the worst case compounds which provide the largest discharge severity. The worst case compounds and their corresponding categories are listed below:

Category	Compound
7, 12-Dimethylbenz (a) anthracene	Fused Polycyclic Hydrocarbons
Dicyclopentadiene	Alkenes, Cyclic Alkenes and Dienes
Dinitrophenols	Nitrophenols and Diamines

Source: U.S. Environmental Protection Agency, *Environmental Assessment: Source Test and Evaluation Report-Wellman-Galusha (Glen Gary) Low-Btu Gasification*, EPA 600/7-79-185, (August, 1979).

Table 4.70

Acute Toxicities of Lurgi Ash Leachates to *Daphnia Magna*

Source Coal	Leachate Column Volume	pH	Heavy Metals Concentration ¹ (mg/liter)	48-h LC ₅₀ ² (%)	95% Confidence Interval	
					Upper	Lower
Rosebud	1	6.8	2.5	no mortality		
	2	8.8	0.3	no mortality		
	3	9.5		no mortality		
	4	10.0		49.1	35.1	82.9
is #5	1	4.5	51.0	45.0	not determined	
	2	5.2	12.4	no mortality		
	3	5.6		no mortality		
	4	5.1		52.4	36.0	264.3
Illinois #6	1	3.2	312.2	5.5	3.7	10.1
	2	3.9		16.8	10.3	33.9
	3	4.3		60.0	26.7	1307.0
	4	5.1		no mortality		

¹Includes Zn, Fe, Ni, Mn, Cu, Al, Hg, As, Se, Pb, Cd

²48-h LC₅₀ = the percent dilution of the leachate in spring water which caused a 50% mortality in 48 hours.

Source: Shiner, D.S., et. al., *Physical, Chemical, and Ecological Characterization of Solid Wastes from a Lurgi Gasification Facility*, in Symposium on Potential Health and Environmental Effects of Synthetic Fossil Fuel Technologies, (September, 1978).

Table 4.71

Toxicity of Lurgi Ash Leachates to *Raphanus Sativus* L¹

Source Coal	Leachate Column Fraction	Concentration (%)	pH	Reduction of Growth (%)
Rosebud	1	100	6.5	18
		50	6.5	18
		10	5.5	0
	2	100	9.2	52 ²
		50	9.2	14
	3	100	9.5	38 ²
		50	9.5	19
		50	9.3	9
	4	100	10.0	31 ²
		50	9.8	16
		10	9.5	9
Illinois #5	1	100	4.5	48 ²
		50	4.5	24 ²
		10	5.5	0
	2	100	5.2	11
		50	5.2	0
	3	100	5.6	12
		50	5.6	0
	4	100	5.1	86 ²
		50	5.2	72 ²
		10	5.4	0
Illinois #6	1	100	3.2	75 ²
		50	3.2	75 ²
		10	3.6	62 ²
		1	3.6	0
	2	100	3.9	45 ²
		50	4.1	55 ²
		10	4.6	6
	3	100	4.3	0
	4	100	5.1	9

¹Includes Zn, Fe, Ni, Mn, Cu, Al, Hg, As, Se, Pb, Cd

²48-h LC₅₀ = the percent dilution of the leachate in spring water which caused a 50% mortality in 48 hours.

Source: Shiner, D.S., et. al., *Physical, Chemical, and Ecological Characterization of Solid Wastes from a Lurgi Gasification Facility*, in Symposium on Potential Health and Environmental Effects of Synthetic Fossil Fuel Technologies, (September 1978).

Table 4.72

Comparison of Process Wastewaters From Coal Conversion and Coke Making Processes (mg/l)

	Coke Plant Ammonia Liquor	Synthane	Lurgi	Koppers Totzek	SRC-1
pH	8.4	8.6	8.9	8.9	8.0
Suspended Solids	4000	600	5000	50	300
Phenol	1000	N.A.	3500	N.A.	45000
COD	10000	150000	12500	70	15000
thiocyanate	1000	152	N.A.	N.A.	N.A.
yanide	50	N.A.	N.A.	0.7	N.A.
Ammonia	5000	8100	11200	25	5600
Chloride	6000	500	N.A.	600	N.A.
Carbonate	N.A.	6000	10000	1200	N.A.
Sulfide	1250	1400	N.A.	N.A.	4000

Source: U.S. Environmental Protection Agency, *Applicability of Coke Plant Control Technologies to Coal Conversion*, EPA-600/7-79-184, (August, 1979).

Table 4.73

**Known or Suspected Carcinogens
Which May Be in the Effluent Streams of Coal Liquefaction Plants**

Compound Type	Example
bicyclic compounds	benzidine
nitrosamines	
nickel	
chromium	chromic trioxide or chromate salts
beryllium	beryllium oxide
arsenic	tricalcium arsenate
selenium	selenide salt
cobalt	cobalt sulfide
lead	lead chromate
zinc	zinc chromate
mercury	elemental mercury
cadmium	cadmium sulfide
anthracenes	anthracene and 9, 10-dimethylantracene
chrysenes	5-methyl cystein
benzanthracenes	benzo (a) anthracene
fluoranthene	benzo (j) fluoranthene benzo (b) fluoranthene
cholanthrenes	20-methylcholanthrene
benzopyrenes	benzo (e) pyrene and benzo (a) pyrene
dibenzophrenes	dibenzo (a,1) pyrene, dibenzo (a,n) pyrene dibenzo (a,i) pyrene dibenzo (a,h) pyrene
mono- & dibenzacridines	dibenz (a,h) acridine
benzocarbazoles	7H-benzo (a,h) acridine
dibenzocarbazoles	7H-benzo (c,g) carbazole
benzanthronos	benzo (a) anthrone and 7H-benz (d,e) xanthracene-7-one
aminobenzene	4-dimethylaminoazobenzene
acenaphthenes	acenaphthene
naphthylamines	alpha-naphthylamine beta-naphthylamine
fine particulates	sulfur, coke
amines	diethyl amines methylethyl amines
monoaromatic	benzene
pyrenes	cyclopenta (c,d) pyrene indeno (1,2,3-c-d) pyrene

Source: U.S. Environmental Protection Agency, *SRC-Site Specific Pollutant Evaluation, Volume I Discussion*, EPA-600/7-78-223a, (November 1978).

Table 4.74

Quantitative Comparison of Selected Organic Compounds in Aqueous Energy-Related Effluents

Compound	Energy Process ^{1,2}						
	EP-1	EP-2	EP-3	EP-4	EP-5	EP-6	EP-7
Oxygenated Compounds							
Acetone	ND	1234 ± 0	16.17 ± 5.2	2226 ± 334	250 ± 50	126 ± 40	40 ± 10
Methyl ethyl ketone	ND	645 ± 33	10.59 ± 7.25	44 ± 5	22 ± 8	76 ± 3	T
Methyl isopropyl ketone	ND	55 ± 5	ND	89 ± 33	ND	20 ± 12	ND
2-Pentanone	ND	124 ± 111	ND	846 ± 4	12 ± 5	197 ± 72	ND
3-Pentanone	ND	55 ± 0	ND	297 ± 4	T	26 ± 14	ND
2-Methyl-3-pentanone	ND	ND	ND	68 ± 8	93 ± 42	62 ± 30	ND
3-Methyl-2-pentanone	ND	ND	ND	79 ± 25	446 ± 222	12 ± 2	ND
4-Methyl-2-pentanone	ND	ND	ND	ND	78 ± 33	105 ± 70	ND
2-Hexanone	ND	ND	ND	7 ± 6	202 ± 67	53 ± 22	ND
3-Hexanone	ND	27 ± 8	ND	61 ± 6	86 ± 37	25 ± 17	ND
2-Heptanone	ND	5 ± 0	ND	40 ± 7	195 ± 50	224 ± 100	ND
2-Octanone	ND	ND	ND	29 ± 5	188 ± 100	126 ± 42	ND
2-Decanone	ND	ND	ND	7 ± 2	T	ND	ND
3-Decanone	ND	ND	ND	ND	139 ± 67	ND	ND
Cyclopentanone	ND	32 ± 9	ND	110	56	5 ± 3	ND
2-Methylcyclopentanone	ND	101 ± 10	ND	56 ± 36	72	8 ± 3	ND
3-Methylcyclopentanone	ND	ND	ND	50 ± 21	ND	ND	ND
Diisopropyl ketone	ND	ND	ND	ND	T	ND	ND
n-Butyric acid	ND	90	ND	ND	ND		
n-Pentanoic acid	ND	1060	ND	ND	ND	5	4
n-Hexanoic acid	ND	1470	ND	ND	ND	38	5
n-Heptanoic acid	ND	870	ND	ND	ND	79	54
n-Octanoic acid	ND	110	ND	ND	ND	14	115
n-Nonanoic acid	ND	ND	ND	5	ND	493	132
n-Decanoic acid	ND	ND	ND	3	ND	ND	123
n-Undecanoic acid	ND	ND	ND	5	ND	ND	2
Isopentanoic acid	ND	170	ND	ND	ND	8	3
Isohexanoic acid	ND	190	ND	ND	ND	ND	3
Isoheptanoic acid	ND	30	ND	ND	ND	ND	4
2-Methylpentanoic acid	ND	260	ND	ND	ND	4	3
C ₈ H ₁₀ O ₂ carboxylic acid	ND	T	ND	ND	ND	ND	ND

Table 4.74 (cont.)

Compound	Energy Process ^{1,2}						
	EP-1	EP-2	EP-3	EP-4	EP-5	EP-6	EP-7
C ₈ H ₁₆ O ₂ carboxylic acid	ND	78	ND	ND	ND	ND	ND
Furan	ND	ND	ND	ND	7 ± 4	ND	ND
2-n-Pentylfuran	ND	T	ND	ND	ND	ND	ND
Benzofuran	0.05 ± 0.01	111 ± 16	4.89 ± 2.0	6 ± 2	267 ± 67	ND	ND
Methylbenzofuran isomer	ND	28 ± 4	0.39 ± 0.2	29 ± 5	391 ± 20	ND	ND
Dimethylbenzofuran isomer	ND	148 ± 22	ND	21 ± 3	T	ND	ND
Dibenzofuran	ND	ND	ND	T	72	29	ND
Anisole	ND	100	0.59 ± 0.4	5.7 ± 1.7	5 ± 2	ND	ND
p-Methylanisole	ND	T	ND	ND	ND	ND	ND
Acetaldehyde	ND	ND	ND	60 ± 9	92 ± 53	NQ	3 ± 1
Propanal	ND	NQ	ND	ND	8 ± 4	ND	ND
Butanal	ND	NQ	ND	NC	42 ± 33	ND	ND
Benzaldehyde	0.05 ± 0.03	ND	ND	19.7	T	ND	ND
Phenyl acetate	ND	ND	ND	4	ND	ND	ND
p-Cresyl methyl ether	ND	13	ND	NC	ND	ND	ND
Phenol	22	270000	15	50000 ³	280	461	459
o-Cresol	192	NQ	132	8000 ³	4330	ND	T
m-Cresol	ND	850	ND	NQ	4490	ND	561
p-Cresol	ND	10200	ND	NQ	40	779	ND
Dimethylphenol isomer	279	990	360	40000	2440	15	3
	T	8400	T	425 ³	4390	T	552
	17	60	T	3800 ³	ND	T	9
C ₃ Alkylphenol isomer	T	170	T	T	42	ND	T
	T	180	T	T	T	ND	9
	ND	850	T	400 ³	84	ND	107
	ND	6	ND	600 ³	36	ND	T
	ND	ND	ND	350 ³	30	ND	1
	ND	ND	ND	20 ³	10	ND	ND
	ND	ND	ND	25 ³	T	ND	ND
Ethylphenol isomer	35	18	6	455 ³	1360	69	17
Nitrogenous Compounds							
Acetonitrile	ND	620 ± 60	ND	1246 ± 150	ND	42 ± 11	ND
Propionitrile	ND	382 ± 47	NC	175 ± 22	NC	27 ± 7	ND

Table 4.74 (cont.)

Compound	Energy Process ^{1,2}						
	EP-1	EP-2	EP-3	EP-4	EP-5	EP-6	EP-7
n-Butyronitrile	ND	267 ± 13	ND	ND	ND	13 ± 3	ND
n-Pentyl nitrile	ND	53 ± 0	ND	38 ± 13	ND	11 ± 4	ND
n-Hexyl nitrile	ND	ND	ND	41 ± 14	ND	10 ± 6	ND
n-Heptyl nitrile	ND	ND	ND	ND	ND	5 ± 6	ND
Isobutyronitrile	ND	53 ± 16	ND	34 ± 11	ND	5 ± 1	ND
a-Methylbutyronitrile	ND	32 ± 9	ND	T	ND	30 ± 14	ND
Methacrylonitrile	ND	ND	ND	T	ND	ND	ND
4-Methylpentyl nitrile	ND	ND	ND	ND	ND	T	ND
Benzonitrile	ND	44 ± 5	ND	24 ± 5	ND	235 ± 155	ND
Tolunitrile	ND	ND	ND	ND	ND	11 ± 5	ND
Pyrrole	ND	208 ± 21	ND	111 ± 11	ND	23 ± 15	ND
N-Methylpyrrole	ND	2 ± 0	ND	12 ± 4	ND	ND	ND
2-Methylpyrrole	ND	24 ± 2	ND	27 ± 7	ND	ND	ND
3-Methylpyrrole	ND	46 ± 4	ND	12 ± 6	ND	ND	ND
Dimethylpyrrole isomer	ND	7 ± 1	ND	17 ± 6	ND	ND	ND
1,3,5-Trimethylpyrazole	ND	ND	ND	ND	ND	14 ± 6	ND
Pyridine	ND	ND	ND	ND	ND	152 ± 62	ND
2-Methylpyridine isomer	ND	120 ± 11	ND	33 ± 3	ND	30 ± 6	ND
3-Methylpyridine isomer	ND	ND	ND	16 ± 2.3	ND	6 ± 3	ND
4-Methylpyridine isomer	ND	ND	ND	T	ND	ND	ND
Methyl ethyl pyridine isomer	ND	ND	ND	ND	ND	ND	ND
2-Ethylpyridine	ND	ND	ND	ND	ND	T	ND
Dimethylpyridine isomer	ND	74 ± 15	ND	T	ND	16 ± 6	ND
	ND	417 ± 7	ND	ND	ND	ND	ND
Trimethylpyridine isomer	ND	40 ± 2	ND	ND	ND	ND	ND
C ₃ Alkylpyridine isomer	ND	15 ± 3	ND	ND	ND	15 ± 4	ND
	ND	ND	ND	ND	ND	63 ± 14	ND
C ₃ Alkylthiophene isomer	ND	38 ± 16	3.5 ± 1.2	5 ± 2	T	ND	ND
	ND	15 ± 0	ND	ND	20 ± 5	ND	ND
	ND	ND	ND	ND	NQ	ND	ND
C ₄ Alkylthiophene isomer	ND	ND	ND	ND	T	ND	ND
	ND	ND	ND	ND	T	ND	ND
Ethylthiophene	ND	ND	ND	ND	83 ± 42	ND	ND
Thiacyclopentane	ND	ND	ND	ND	ND	6 ± 3	ND
Thiacyclohexane	ND	ND	ND	ND	ND	5 ± 2	ND

Table 4.74 (cont.)

Compound	Energy Process ^{1,2}						
	EP-1	EP-2	EP-3	EP-4	EP-5	EP-6	EP-7
Methylthiacyclohexane isomer	ND	ND	ND	ND	ND	T	ND
2-Methylthiacyclopentane	ND	ND	ND	ND	ND	3 ± 0.2	ND
2,5-Dimethylthiacyclopentane	ND	ND	ND	ND	ND	4 ± 1	ND
Dimethylthiacyclopentane	ND	ND	ND	ND	ND	0.3 ± 0.2	ND
3-Methylisothiazole	ND	ND	ND	ND	ND	ND	ND
Benzothiophene	ND	118 ± 6	ND	ND	52 ± 20	ND	ND
Aromatics							
Benzene	ND	607 ± 6	192.5 ± 3.3	4318 ± 1154	1214 ± 325	134 ± 3	4 ± 1
Toluene	2.5 ± 1	556 ± 200	67.8 ± 32	1081 ± 298	121 ± 44	7 ± 1	19 ± 6
p-Xylene	0.35 ± 2.5	561 ± 60	4.7 ± 1.3	121 ± 14	61 ± 25	ND	T
m-Xylene	0.01 ± 0.10	NQ	ND	NQ	NQ	40 ± 7	ND
o-Xylene	ND	472 ± 37	6.5 ± 1.5	82 ± 22	181 ± 17	6 ± 3	ND
Ethylbenzene	1.7 ± 0.60	222 ± 27	1.88 ± 0.4	41 ± 14	104 ± 42	2 ± 1	ND
Styrene	1.2 ± 0.50	58 ± 6	3.80 ± 1.2	55 ± 27	83 ± 48	ND	T
n-Propylbenzene	0.5 ± 0.03	28 ± 3	104 ± 30	7 ± 2	T	ND	ND
n-Butylbenzene	T	9 ± 3	0.5 ± 0.2	ND	T	ND	ND
n-Pentylbenzene	T	12 ± 1	T	ND	60 ± 20	ND	ND
n-Hexylbenzene	T	ND	0.15 ± 0	T	18 ± 5	ND	ND
n-Heptylbenzene	ND	26 ± 5	T	ND	25 ± 5	ND	ND
m-Ethyltoluene	0.1 ± 0.3	184 ± 16	ND	55 ± 6	278 ± 6	ND	ND
p-Ethyltoluene	0.05 ± 0.3	61 ± 7	ND	NQ	ND	ND	ND
o-Ethyltoluene	0.04 ± 0.01	67 ± 17	ND	34 ± 7	148 ± 17	ND	ND
1,2,3-Trimethylbenzene	0.1 ± 0.5	ND	ND	42 ± 14	361 ± 200	ND	ND
1,2,4-Trimethylbenzene	0.03 ± 0.02	267 ± 27	ND	35 ± 5	198 ± 100	ND	ND
1,3,5-Trimethylbenzene	0.01 ± 0.01	ND	ND	27 ± 7	139 ± 17	ND	ND
2,4,6-Trimethylpyridine	ND	ND	ND	ND	ND	T	ND
C ₈ Alkylpyridine isomer	ND	ND	ND	ND	ND	T	ND
	ND	ND	ND	ND	ND	T	ND
	ND	ND	ND	ND	ND	T	ND
	ND	ND	ND	ND	ND	T	ND
	ND	ND	ND	ND	ND	T	ND
C ₉ Alkylpyridine isomer	ND	ND	ND	ND	ND	T	ND
	ND	ND	ND	ND	ND	T	ND
	ND	ND	ND	ND	ND	T	ND

Table 4.74 (cont.)

Compound	Energy Process ^{1,2}						
	EP-1	EP-2	EP-3	EP-4	EP-5	EP-6	EP-7
C ₆ Alkylpyridine isomer	ND	ND	ND	ND	ND	T	ND
	ND	ND	ND	ND	ND	T	ND
	ND	ND	ND	ND	ND	T	ND
	ND	ND	ND	ND	ND	T	ND
	ND	ND	ND	ND	ND	T	ND
	ND	ND	ND	ND	ND	T	ND
	ND	ND	ND	ND	ND	T	ND
C ₇ Alkylpyridine isomer	ND	ND	ND	ND	ND	T	ND
	ND	ND	ND	ND	ND	T	ND
	ND	ND	ND	ND	ND	T	ND
C ₈ Alkylpyridine isomer	ND	ND	ND	ND	ND	T	ND
Aniline	ND	3460	ND	ND	ND	497	ND
Quinoline	ND	ND	6	ND	ND	99	ND
2-Methylbenzimidazole	ND	ND	ND	T	58 ± 16	ND	ND
5,6-Dimethylbenzimidazole	ND	ND	ND	ND	T	ND	ND
2-Isopropylbenzimidazole	ND	25 ± 2	ND	ND	ND	ND	ND
Sulfur Compounds							
Thiophene	ND	620 ± 6	6.59 ± 1.3	241 ± 29	59 ± 6	20 ± 6	ND
2-Methylthiophene	ND	NQ	11.74 ± 6.5	56 ± 7	134 ± 17	T	ND
3-Methylthiophene	ND	ND	120.0 ± 56	50 ± 11	107 ± 23	T	ND
Dimethylthiophene isomer	ND	15 ± 0	1.3 ± 0.6	14 ± 4	14 ± 3	ND	ND
	ND	52 ± 3	1.2 ± 3	13 ± 3	28 ± 3	ND	ND
	ND	ND	8.0 ± 2.5	5 ± 2	14 ± 3	ND	ND
	0.02 ± 0.01	11 ± 0	ND	T	26 ± 5	ND	ND
Isopropylbenzene	T	6 ± 2	6.0 ± 2.0	25 ± 2	T	ND	ND
	0.65 ± 0.04	9 ± 3	0.5 ± 0.2	4 ± 3	T	ND	ND
	0.01 ± 0.01	71 ± 20	0.25 ± 0.2	T	T	ND	ND
	T	20 ± 2	6.31 ± 2.4	T	ND	ND	ND
	T	22 ± 11	0.12 ± 0	ND	ND	ND	ND
C ₆ Alkylbenzene isomer	T	139 ± 21	0.10 ± 0	ND	T	ND	ND
	T	69 ± 13	T	ND	T	ND	ND
C ₆ Alkybenzene isomer	T	162 ± 15	T	ND	T	ND	ND
	ND	56 ± 4	0.15 ± 0	ND	T	ND	ND
	ND	17 ± 1	ND	ND	T	ND	ND
	ND	NQ	ND	ND	3 ± 1	ND	ND

Table 4.74 (cont.)

Compound	Energy Process ^{1,2}						
	EP-1	EP-2	EP-3	EP-4	EP-5	EP-6	EP-7
C ₇ Alkylbenzene isomer	ND	ND	T	ND	T	ND	ND
	ND	ND	T	ND	T	ND	ND
	ND	ND	ND	ND	T	ND	ND
sec-Butylbenzene	ND	ND	ND	ND	83 ± 17	ND	ND
Indan	ND	234 ± 33	ND	240 ± 17	247 ± 47	ND	ND
Indene	0.03 ± 0.03	272 ± 32	ND	79 ± 29	363 ± 75	ND	ND
Methylindene isomer	0.01 ± 0.01	196 ± 31	ND	38 ± 9	222 ± 40	ND	ND
	T	184 ± 164	ND	ND	209 ± 78	ND	ND
Methylindan isomer	T	126 ± 15	ND	ND	T	ND	ND
	T	NC	ND	ND	52 ± 19	ND	ND
C ₂ Alkyl indan isomer	0.03 ± 0.03	T	ND	7 ± 2	T	ND	ND
	0.06 ± 0.05	162 ± 15	ND	5 ± 3	T	ND	ND
C ₃ Alkyl indan isomer	T	22 ± 0	ND	13 ± 6	20 ± 3	ND	ND
	ND	94 ± 7	ND	ND	T	ND	ND
C ₄ Alkyl indan isomer	ND	ND	ND	ND	T	ND	ND
	ND	ND	ND	NC	ND	ND	ND
Naphthalene	2.7 ± 0.15	640 ± 32	0.35 ± 0.2	1707 ± 79	5121 ± 1336	29 ± 18	T
B-Methylnaphthalene	177 ± 33	345 ± 7	ND	66 ± 12	960 ± 225	ND	ND
Ethylnaphthalene isomer	T	39 ± 9	ND	20 ± 7	ND	ND	T
Dimethylnaphthalene isomer	T	195 ± 17	ND	55 ± 9	12 ± 3	199	T
Dimethylnaphthalene isomer	0.2 ± 0.20	135 ± 52	ND	13 ± 2	24 ± 5	ND	T
C ₃ Alkyl naphthalene isomer	ND	7 ± 1	ND	T	530	ND	T
	ND	5 ± 1	ND	T	2	ND	T
	ND	7 ± 0	ND	6 ± 3	T	ND	ND
	ND	T	ND	12 ± 4	ND	ND	ND
C ₄ Alkyl naphthalene isomer	ND	ND	ND	NQ	ND	ND	ND
	ND	ND	ND	NQ	ND	ND	ND
Dimethylnaphthalene isomer	0.15 ± 0.15	47 ± 14	ND	74 ± 17	9 ± 3	ND	ND
Trimethylnaphthalene isomer	ND	7 ± 1	ND	48 ± 6	5 ± 3	ND	ND
	ND	ND	ND	ND	11 ± 4	ND	ND
	ND	ND	ND	ND	ND	ND	ND
	ND	ND	ND	ND	ND	ND	ND
	ND	ND	ND	ND	ND	ND	ND
Isopropyl naphthalene isomer	ND	-	ND	ND	ND	ND	ND

Table 4.74 (cont.)

Compound	Energy Process ^{1,2}						
	EP-1	EP-2	EP-3	EP-4	EP-5	EP-6	EP-7
Methyldihydronaphthalene isomer	ND	ND	ND	ND	118 ± 50	ND	ND
	ND	ND	ND	ND	18 ± 3	ND	ND
	ND	ND	ND	ND	42 ± 16	ND	ND
Biphenyl	T	114 ± 12	ND	31 ± 10	ND	ND	ND
Biphenylene	ND	ND	ND	21 ± 2	ND	ND	ND
Acenaphthene	ND	612 ± 9	ND	32 ± 5	10	188	ND
Fluorene	ND	ND	ND	18 ± 17	24	7	ND

¹EP-1 = ground water sample, well 5, Hanna II, prior to in situ coal gasification, Hanna, Wyo.

EP-2 = product water sample from Hanna II, wells 5-6 in situ coal gasification, Hanna, Wyo.

EP-3 = aqueous sample from dewatering well 5 prior to in situ coal gasification, Gillette, Wyo.

EP-4 = process water from in situ coal gasification, Gillette, Wyo.

EP-5 = aqueous condensate from low-Btu gasification of Rosebud coal, Morgantown, W. Va.

EP-6 = Omega-9 retort water from in situ oil shale processing, Rock Springs, Wyo.

EP-7 = boiler blowdown water from in situ oil shale processing, DeBeque, Colo.

²Values are in ppb; ± indicate duplicate analyses; ND = not detected, NQ = not quantified, T = trace
Limit of detection was 0.1 ppb.

³Values are in ppm.

Source: Pellizzari, E.D., et al. *Identification of Organic Components in Aqueous Effluents from Energy-Related Processes*, Special Technical Publication 686, ASTM (1979).

Table 4.75

Bioassay Test Results for Crude Tar Samples and Fractions

Sample	Coal	Potential Mutagenicity
Base Fraction	W.Ky. No.9	High
	Wyo. Subbituminous	High
	N.D.Lignite	High
	Ill.No.6	Medium
Acid Fraction	W.Ky.No.9	Negative
	Ill.No.6	Negative
	Wyo.Subbituminous	Negative
	N.D.Lignite	Negative
PNA Fraction	W.Ky.No.9	High
	Ill.No.6	Medium
	Wyo.Subbituminous	Medium
	N.D.Lignite	Medium
Polar Neutral Fraction	Ill.No.6	High
	W.Ky.No.9	Medium
	Wyo.Subbituminous	Medium
	N.D.Lignite	Medium
Non-Polar Neutral Fraction	W.Ky.No.9	Negative
	Ill.No.6	Negative
	Wyo.Subbituminous	—
	N.D.Lignite	Negative
Crude Tar	W.Ky.No.9	High
	Ill.No.6	High
	Wyo.Subbituminous	Medium
	N.D.Lignite	Medium

Notes: Two additional Western Kentucky No. 9 (Insolubles and XAD-2) both showed negative potential mutagenicity. These same fractions from the other coal types were not tested.

Source: Brusick, D.J., *In Vitro Mutagenesis Assays as Predictors of Chemical Carcinogenesis in Mammals*, Clinical Toxicology, Vol. 10 (1977).

Table 4.76

PAH Concentration in Cresote and Coal Tar (g/Kg)

PAH	Creosote		Coal Tar	
	Sample 1	Sample 2	Sample 1	Sample 2
Anthracene	12.1	12.0	2.88	4.35
Benz[α]anthracene	2.77	2.94	6.24	6.98
Benzo[β]chrysene	0.03	0.06	0.93	0.80
Benzo[ζ]fluoranthene	0.29	0.29	0.45	
Benzo[κ]fluoranthene	0.30	0.11	1.08	1.07
Benzo[λ , η , i]perylene			1.23	1.89
Benzo[α]pyrene	0.14	0.22	2.08	1.76
Benzo[ϵ]pyrene	0.18	0.15	1.85	1.88
Carbazole	2.20	1.42	1.32	1.27
Chrysene	1.34	0.94	2.13	2.86
Dibenz[α , η]anthracene			0.30	0.23
Fluoranthene	24.8	22.2	17.7	17.8
Perylene	0.04	0.04	0.70	0.76
Phenanthrene	39.9	33.3	13.6	17.5
Pyrene	9.1	6.8	7.95	10.6

Source: Braunstein, H.M., et. al., *Environmental Health, and Control Aspects of Coal Conversion: An Information Overview*, Oak Ridge National Laboratory, prepared for the U.S. ERDA, ORNL/EIS-94, OC-11, -41, -48, -90i, (April, 1977).

Table 4.77

Polynuclear Aromatic Hydrocarbons in Coal Tars and Bottom Sediment Sludge from a Wood Preserving Plant (g/Kg)

PAHs	Coal Tar	Bottom Sediment Sludge from Wood Preserving Plant
Benz(a)anthracene	6.24-6.98	1.25
Chrysene	2.13-2.86	9.28
Benzo(a)pyrene	1.76-2.08	5.98

Source: ¹Braunstein, H.M., et. al., *Environmental, Health, and Control Aspects of Coal Conversion: An Information Overview*, Oak Ridge National Laboratory, prepared for the U.S. ERDA, ORNL/EIS-94, UC-11, -41, -48, -90i, (April, 1977).

²U.S. Environmental Protection Agency, *Draft Background Document; Sections 261.31 and 261.32: Listing of Hazardous Wastes*, Washington, D.C., Office of Solid Waste (May, 1980).

Table 4.78

**Estimated Composition of Leachates from Surface and Simulated
In Situ Processed Shales and from Raw Oil Shale (milligrams
per 100 grams of material leached)**

	Processed Shale from in Situ Retorts	Processed Shale from Surface Retorts	Raw Oil Shale
Al	0095-2.8	—	—
As	—	0.005-0.013	0.015
B	0.075-0.14	0.2-1.2	0.019-0.7
Ca	3.6-210	42-327	5.2-10
Cl	5.6	5-33	2.2-4.5
CO ₃	30-215	21	11-15
Cr	0.002-1.8	—	—
F	1.2-4.2	3.4-5.5	1.7-6.5
Fe	0.0004-0.042	—	—
HCO ₃	22-40	20-38	37-75
K	0.76-18	10-625	0.6-24
Li	0.020-0.42	—	—
Mg	0.002-8.0	3.5-91	1.0-1.6
Mo	Trace	0.2-0.8	0.1-0.3
Na	8.8-235	165-2,100	1.4-48
NO ₃	0.2-2.6	5.1-5.6	0.2-2.0
OH	22-40	—	1.7
Pb	0.014-0.017	—	—
Se	—	0.005-0.006	0.009
Si	25-88	—	0.9-2.8
SO ₄	50-130	600-6,230	1.2-79
Sr	0.004-8.7	—	—
Zn	0.001-0.025	—	—
TDS	0-2800	600-10,011	61-277
TOC	1.0-38	—	1
Organic N	0.06-0.14	—	—
Phenols	0.02-0.04	—	—
pH	7.76-12.7	7.78-9.94	8.15-9.8

Source: National Academy of Sciences, *Surface Mining of Non-Coal Minerals, Appendix II: Mining and Processing of Oil Shale and Tar Sands*, ISBN 0-309-037-4 (1980).

Table 4.79

**Quality of Ground Water in the Piceance Creek Basin as Compared with Leachate from In Situ Retorts
and Water Quality Criteria Recommended by the U.S. Environmental Protection Agency**

Constituent	Water Quality Criteria ¹			Predevelopment Ground Water Quality ²		Postdevelopment Ground Water Quality (mg/l)
	Domestic Water Supplies (mg/l)	Livestock Watering, (mg/l)	Irrigation, (mg/l)	Average Concentration of Upper Aquifer (mg/l)	Average Concentration of Lower Aquifer (mg/l)	
Aluminum (Al)	—	5.0	5-20	0.14	0.24	0.7-50
Baron (B)	(3)	5.0	0.75-2.0	0.33	0.84	1-3
Chloride (Cl)	250	—	(3)	12	22	50-130
Chromium (Cr)	0.05	1.0	0.1-1.0	0.01	<0.01	0.02-35
Fluoride (F)	1.4-2.4	2.0	1-15	0.41	15	8-90
Iron (Fe)	0.3	None	5-20	5.0	0.78	1-6
Lead (Pb)	0.05	0.1	5-10	0.17	0.21	0.03-0.5
Lithium (Li)	—	—	0.075-25	0.13	0.13	0.3-8
Nitrate/nitrogen	10	100 ^d	None	0.9	0.4	2-50
Phenols	0.001	—	—	0.003	0.002	0.1-0.8
Sodium (Na)	—	—	(3)	212	397	340-4840
Sulfate (SO ₄)	250	—	—	325	112	500-2800
Total dissolved solids (TDS)	—	—	(3)	905	1075	905-54,000
Zinc (Zn)	5	25	2-10	0.26	0.24	0.3-0.7

¹Guidelines recommended by the U.S. Environmental Protection Agency

²Vicinity of lease tract C-a

³Variable; depends on soil condition.

Source: National Academy of Sciences, *Surface Mining of Non-Coal Minerals, Appendix II: Mining and Processing of Oil Shale and Tar Sands*, ISBN 0-309-037-4 (1980).

Table 4.80

**Increases in Total Dissolved Solids, Sodium, and Total Organic Carbon in Streams of the
Upper Colorado River Basin from Discharge of In Situ Leachates as Base Flow into
Piceance Creek and Yellow Creek, Assuming a 100,000 Barrel-Per-Day Industry.**

Watercourse	Average Annual Discharge (acre-ft/yr)	Maximum Possible Increase in TDS Due to Discharge of in Situ Leachate into Piceance Creek and Yellow Creek (mg/l)	Maximum Possible Increase in Na Due to Discharge of in Situ Leachate into Piceance Creek and Yellow Creek (mg/l)	Maximum Possible Increase in TOC Due to Discharge of in Situ Leachate into Piceance Creek and Yellow Creek (mg/l)
Piceance Creek at White River	14,500	700-42,000	260-3,800	12-180
White River near Watson, Utah	532,000	20-1,270	8-110	0.4-5
Green River near Green River, Utah	4,427,000	3-150	1-14	<0.05-0.7
Colorado River at Lees Ferry, Arizona	12,426,000	1-50	0.3-5	<0.05-0.2

Source: National Academy of Sciences, *Surface Mining of Non-Coal Minerals, Appendix II: Mining and Processing of Oil Shale and Tar Sands*, ISBN 0-309-0307-4 (1980).

Table 4.81

Acute Studies of Shale Oil and Shale Oil Products

Sample	Test	Results
Crude Shale Oils (4)	Oral LD50 (Rat)	8-10 g/kg
Crude Shale Oils (4)	Dermal LD50 (Rabbit)	5 ml/kg
Crude Shale Oils (4)	Eye Irritation (Rabbit)	Minimal, reversible
Raw Shales (3)	Eye Irritation (Rabbit)	Negative
Spent Shales (4)	Eye Irritation (Rabbit)	Irritating, reversible
Crude Shale Oils (4)	Dermal Irritation (Rabbit)	0.5 g in 72 hour abraided-unabraided
Crude Shale Oils (4)	Sensitization (Guinea Pig)	Negative
Raw Shales (3)	Sensitization (Guinea Pig)	Negative
Spent Shales (4)	Sensitization (Guinea Pig)	Negative

Source: Weaver, N.K., and R.L. Gibson, *The U.S. Oil Shale Industry: A Health Perspective*, presented at American Industrial Hygiene Conference, Los Angeles, California, (May, 1978).

Table 4.82

The Number and Types of Abnormality Found in Rabbit Embryos After Oral Doses of Spent Shale

	Number of Litters	Number of Implants	Location of Abnormality					
			Number Dead or Resorbed	Ribs	Skull	Vertebra	Limbs	Others
Control	4	41	4	4				
Carbon 250	8	67	10	8	1			2
Carbon 500	4	50	6	3	1	4	1	1
Shale 250	10	84	9	7	2	8	1	3
Shale 500	15	129	9	17	13	7	1	1

Source: Barkley, W., et. al., *The Toxicology and Carcinogenic Investigation of Shale Oil and Shale Oil Products*, in: Symposium on Potential Health and Environmental Effects of Synthetic Fossil Fuel Technologies, (September, 1978).

Table 4.83

Mutagenicity of Chemicals Identified in Shale Oil Using Salmonella Tester Strains

Chemical Name	CAS Registry No.	Strain	Mutagenicity
Phenol and aniline derivatives			
Phenol	108-95-2	98, 100	—
Phenol, dimethyl (xlenol)	1300-71-6	98, 100	—
2,3	526-75-0	98, 100	—
2,4	105-67-9	98, 100	—
2,5	95-87-4	98, 100	—
2,6	576-26-1	98, 100	—
3,4	95-65-8	98, 100	—
3,5	108-68-9	98, 100	—
Phenol, ethyl	25429-37-2	98, 100	—
2	90-00-6	98, 100	—
4	123-07-9	98, 100	—
Phenol, 2,4,6-trimethyl (mesitol)	527-60-6	98, 100	—
Aniline	62-53-3	98, 100	—
Aniline, dimethyl (xyldine)			
2,3	87-59-2	98, 100	—
2,4	95-68-1	98, 100	—
2,5 ^b	—	98	+
Aniline, 2,4,6-trimethyl	88-05-1	98, 100	—
Aniline, ethyl			
2	578-54-1	98, 100	—
3	587-02-0	98, 100	—
Polycyclic fused aromatic hydrocarbons			
Acenaphthene	83-32-9	98, 100	+
Anthracene	120-12-7	98, 100	—
Benz[a]anthracene	56-55-3	100	+
Benz[a]anthracene, 7,12-dimethyl	57-97-6	100	+
Benzo[a]fluorene	238-84-6	100	+
Benzo[a]pyrene	50-32-8	98	+
Chrysene	218-01-8	100	+
Fluoranthene	206-44-0	98	+
Naphthalene	91-20-3	98, 100	—
Phenanthrene	85-01-8	98	+
Pyrene	129-00-0	1537	+
Triphenylene	217-59-4	98	+
1,2,2,4-Dibenzanthracene ¹	—	100	+
1,2,5,6-Dibenzanthracene ¹	—	100	+
Polycyclic fused heterocycles			
Acridine	260-94-6	1537	+
Carbazole	86-74-8	100	—
Isoquinoline ¹	—	98, 100	—
Quinoline	91-22-5	98	+
Quinoline, methyl			
7 ¹	—	100	+
8 ¹	—	100	+
Quinoline, Dimethyl			
2,6 ¹	—	98, 100	—
Quinoline, hydroxy			
8 (sulfate) ¹	134-31-6	100	+
Quinoline, nitro			
8 ¹	607-35-2	100	+
Quinoline, amino			
8 ¹	578-66-5	1537	+
α -Naphthylamine ¹	—	100	+
2-Acetamidofluorene	53-96-3	98	+

¹Compounds not identified in shale oil, but predicted to occur in the same or modified chemical form.

Source: Epler, J.L., T.K. Rao, and M.R. Gverin, *Evaluation of Feasibility of Mutagenic Testing of Shale Oil Products and Effluents*, Environmental Health Perspective Vol. 30, (June, 1979).

Table 4.84

Levels of Benzo(a)pyrene (BaP) Reported in Oil Shale and Natural and Industrial Materials

Substrate Material	Benzo(a)pyrene (parts per billion)
Natural Materials	
Coconut oil	43.7
Peanut oil	1.9
Oysters (Norfolk, VA)	10 to 20 (based on dry weight)
Forest soil	4 to 8
Farm field near Moscow	79
Oak leaves	300 max
Petroleum and Petroleum Products	
Libyan crude oil	1,320
Cracked residuum (API Smpl 59)	50,000
Cracked sidestream (API Smpl 2)	2,000
West Texas paraffin distillate	3,000
Asphalt	1×10^4 to 1×10^5
Oil Shale Related Materials	
TOSCO II retorted shale	13 - 100
GCR retorted shale	15
Raw shale oil (Colorado)	30,000 - 40,000
Crude shale oil (TOSCO II)	3,130
Hydrotreated shale oil (0.25%N)	6,900
Hydrotreated shale oil (0.05%N)	690
Coals	
High volatile bituminous	4,200
Low volatile bituminous	3,150
Lignite	1,200
Coal tar	3×10^4 to 8×10^4

Source: Connes, R.M., *The Health Effects of Oil Shale Processing*, 9th Oil Shale Symposium, Colorado School of Mines, Golden, Colorado, (April 29-30, 1976).

Table 4.85

Carcinogenic Potency of Two Raw Shale Oils

	Strain of Mice	Dosage	Number of Mice	Final ¹ Effective Number	BaP (%)	Number of Mice Developing Tumors		Average Time of Appearance of Papillomas (weeks)
						Malignant	Benign	
Shale oil #1. Heat transfer process	C3H	50 mg. twice weekly	15	12	<0.00001	8	3	43
Shale oil #2. Retort combustion process	C3H	50 mg. twice weekly	15	12	<0.00001	8	2	43

¹The final effective number is the number of mice alive at the time of appearance of the median tumor plus those mice that may have died with tumors.

Source: Barkley, W., et. al., *The Toxicology and Carcinogenic Investigation of Shale Oil and Shale Oil Products*, In: Symposium on Potential Health and Environmental Effects of Synthetic Fossil Fuels Technologies, (September, 1978).

Table 4.86

Benzo(a)pyrene Content of Shale Oil Products

Sample	BaP Concentration
Raw Shale Oil	< 0.00005%
Upgraded Oil	0.0006%
Processed Shale	< 0.000005%
Processed Water	1 ppb
Native Grass	< 0.000065%
Leached Water	1 ppb
Raw Shale	< 0.000005%
Native Soil	< 0.000005%

Source: Barkley, W., et. al., *The Toxicology and Carcinogenic Investigation of Shale Oil and Shale Oil Products*, In: Symposium on Potential Health and Environmental Effects of Synthetic Fossil Fuel Technologies, (September, 1978).

Table 4.87

Carcinogenic Potency of Shale Oils and Shale Oil Products¹

Sample	Strain of Mice	Dosage	Number of Mice	Final ¹ Effective Number	BaP (%)	Number of Mice Developing Tumors		Average Time of Appearance of Papillomas (weeks)
						Malignant	Benign	
Raw oil #1	C3H	50 mg. twice weekly	50		0.00018	11	19	28.6
Raw oil #2	C3H	50 mg. twice weekly	50		0.00018	30	1	19.1
Raw oil #3	C3H	50 mg. twice weekly	50		0.00012	27	10	26.3
Raw shale 101	C3H	50 mg. twice weekly	50		0.00042	27	11	24.9
Raw shale 102	C3H	50 mg. twice weekly	50		<0.00001	0	0	
Raw shale 103	C3H	50 mg. twice weekly	50		<0.00001	0	0	
Spent shale 201	C3H	50 mg. twice weekly	50		<0.00001	0	0	
Spent shale 202	C3H	50 mg. twice weekly	50		<0.00001	0	0	
Spent shale 203	C3H	50 mg. twice weekly	50		<0.00001	0	0	
Spent shale 204	C3H	50 mg. twice weekly	50			0	0	
Control - no treatment	C3H	50 mg. twice weekly	50		<0.00001	0	0	
Control - mineral oil only	C3H	50 mg. twice weekly	50			0	0	
0.05% BaP in mineral oil	C3H	50 mg. twice weekly	50		0.05	40	6	37.8
0.15% BaP in mineral oil	C3H	50 mg. twice weekly	30		0.15	29	1	27.4

¹Incomplete: 54 weeks durationSource: Barkley, W., et. al., *The Toxicology and Carcinogenic Investigation of Shale Oil and Shale Oil Products*, In: Symposium on Potential Health and Environmental Effects of Synthetic Fossil Fuel Technologies, (September, 1978).

Table 4.88

Types and Amounts of Ocean Disposal by Geographic Area, 1973-78 (in approximate tons)

Waste Type	Atlantic					
	1973	1974	1975	1976	1977	1978
Industrial waste	3,642,800	3,642,000	3,322,300	2,633,200	1,783,600	12,548,000
Sewage sludge	4,898,000	5,010,000	5,039,600	5,270,900	5,134,000	25,535,000
Construction and demolition debris	973,700	770,400	395,900	314,600	379,000	241,000
Solid waste	0	0	0	0	100	0
Explosives	0	0	0	0	0	0
Incinerated (wood)	10,800	15,800	6,200	8,700	15,100	18,000
Incinerated (chemicals)	0	0	0	0	0	0
Total	9,526,200	9,438,200	8,764,000	8,227,400	7,311,700	8,342,000
Waste Type	Gulf					
	1973	1974	1975	1976	1977	1978
Industrial waste	1,408,000	937,700	119,600	108,300	60,200	173
Sewage sludge	0	0	0	0	0	0
Construction and demolition debris	0	0	0	0	0	0
Solid waste	0	0	0	0	0	0
Explosives	0	0	0	0	0	0
Incinerated (wood)	0	0	0	0	0	0
Incinerated (chemicals)	0	12,300	4,100	0	17,600	0
Total	1,408,000	950,000	123,700	108,300	77,800	173
Waste Type	Pacific					
	1973	1974	1975	1976	1977	1978
Industrial waste	0	0	0	0	0	0
Sewage sludge	0	0	0	0	0	0
Construction and demolition debris	0	0	0	0	0	0
Solid waste	240	200	0	0	0	0
Explosives	0	0	0	0	0	0
Incinerated (wood)	0	0	0	0	0	0
Incinerated (chemicals)	0	0	0	0	12,100	0
Total	240	200	0	0	12,100	0

¹Increase in industrial waste over last year due to an extended strike at NL Industries during 1976-77 during which time the plant was completely shut down.

²Increase in sewage sludge primarily due to the upgrading of sewage treatment plants to secondary treatment in New York, Middlesex County, and Joint Meeting.

Source: Council on Environmental Quality, *The Tenth Annual Report of the Council on Environmental Quality* (December, 1978).

SOLID/HAZARDOUS WASTE DISPOSAL SITES

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Table 4.89

Existing High Level Waste (HLW)¹, 10/1/77¹
(thousands of cubic feet)

DOE	Total	Liquid	Slat Cake	Sludge	Calcine	Cs;Sr Capsules
Savannah River	2900	1700	900	300	0	0
Idaho	404	350	0	0	54	0
Hanford	6102.5	1600	2800	1700	0	2.5
Sub	9406.5	3650	3700	2000	54	2.5
West Valley (NFS)²						
Neutralized (600,000 gal.)	80.2	80.2	0	0	0	0
Acidic (12,000 gal.)	1.6	1.6	0	0	0	0
Sub	81.8	81.8	0	0	0	0
Total	9488.3	3731.8	3700	2000	54	2.5

¹This reflects the present form of the existing waste, not necessarily the form that would be placed in permanent disposal.

²The neutralized waste is stored in a 750,000 gal. carbon steel tank while the acidic waste is in a 15,000 gal. stainless steel tank. There is a spare tank for each in case of leaks.

Source: The Interagency Review Group on Nuclear Waste Management, *Report to the President by the Interagency Review Group on Nuclear Waste Management*, TID-29442 (March 1979).

Table 4.90

**Existing Commercial Transuranic
(TRU) Waste, 1/1/77 (Kg)**

Site	Buried Transuranic Quantities ¹
Barnwell, SC	0
Beatty, NV	14.1
Hanford, WA	22.7
Maxey Flats, KY	69.1
Sheffield, IL	13.4
West Valley, NY	3.6
	123.1

¹The associated volumes of TRU waste are not known. The only site presently receiving commercial TRU waste for burial is Hanford.

Source: The Interagency Review Group on Nuclear Waste Management, *Report to the President by the Interagency Review Group on Nuclear Waste Management*, TID-29442 (March 1979).

Table 4.91

Existing DOE TRU Waste, 1/1/77
(millions of cubic feet)

	Buried¹	Retrievably² Stored	Total
Hanford, WA	5.40	0.27	5.67
Idaho Falls, ID	2.30	1.28	3.58
Los Alamos, NM	4.10	0.06	4.16
ORNL, TN	0.02	0.05	0.25
Savannah River, SC	1.00	0.06	1.06
Nevada Test Site	< 0.01	< 0.01	< 0.01
Total	12.82	1.72	14.72
Transuranic Content (Kg)	(> 700)	(374)	(> 1100)

¹These are approximate volumes of TRU waste included in the buried LLW. Burial of DOE TRU waste ceased in 1974 (most sites in 1970).

²Do not reflect any potential volume reduction.

Source: The Interagency Review Group on Nuclear Waste Management, Report to the President by the Interagency Review Group on Nuclear Waste Management, TID-29442 (March 1979).

SOLID WASTE UTILIZATION

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Table 4.92

Estimated Composition of Residential and Commercial Post-Consumer Solid Waste, 1977 (as generated wet weight in millions of tons and percents)

Materials	Millions of Tons	Percent of Total
Paper	49.5	33.5
Glass	14.7	9.9
Metals	13.6	9.2
Ferrous	(11.8)	(8.0)
Aluminum	(1.4)	(0.9)
Other nonferrous	(0.4)	(0.3)
Plastics	6.3	3.6
Rubber & leather	3.9	2.6
Textiles	3.0	2.0
Wood	4.7	3.2
Total nonfood products	94.7	64.0
Total nonfood products	94.7	64.0
Total waste	25.2	17.0
Yard waste	25.9	17.5
Miscellaneous inorganics	2.2	1.5
Total generation	148.0	100.0

Source: Council on Environmental Quality. *The Tenth Annual Report of the Council on Environmental Quality* (December, 1979).

Table 4.93

Wastes-as-Fuel Facilities as of March, 1978

Location	Type ¹	Capacity (TPD)	Products/Markets	Start-up Date
IN OPERATION:				
Ames, Iowa	RDF	400	RDF-Utility, Fe, Al	1975
Baltimore, Md. (D)	Pyrolysis	700	Steam heating & cooling, Fe	1975
Baltimore County, Md. (D)	RDF	550	RDF, Fe, Al, glass	1976
Blytheville, Ark.	MCU	50	Steam process	1975
Braintree, Mass.	WWC	240	Steam process	1971
E. Bridgewater, Mass. (D)	RDF	160	RDF-utility	1974
Groveton, N.H.	MCU	30	Steam process	1975
Milwaukee, Wis.	RDF	1000	RDF-utility, paper Fe, Al	1977
Nashville, Tenn.	WWC	720	Steam heating & cooling	1974
Norfolk, Va.	WWC	360	Steam (Navy Base)	1967
Oceanside, N.Y.	RWI/WWC	750	Steam	1965/74
Palos Verdes, Calif.	Methane recovery		Gas-utility & Fe	1975
Saugus, Mass.	WWC	1200	Steam process	1976
Siloam Springs, Ark.	MCU	20	Steam process	1975
South Charleston, W. Va. (D)	Pyrolysis	200	Gas, Fe	1974
UNDER CONSTRUCTION: STARTUP:				
Akron, Ohio	RDF/WWC	1000	Steam heating & cooling	1978
Bridgeport, Conn.	RDF	1800	RDF-utility, Fe, Al, glass	1978
Chicago, Ill.	RDF	1000	RDF-utility, Fe	1976
Hempstead, N.Y.	Wet pulp/WWC	2000	Electricity, Fe, Al, glass	1978
Lane County, Ore.	RDF/WWC	750	RDF-institution, Fe	1978
Monroe County, N.Y.	RDF	2000	RDF-utility, Fe, Al, glass	1978
Mountain View, Calif. (D)	Methane recovery		Gas-utility	1977
Niagara Falls, N.Y.	RDF/WWC	2200	Steam industry, Fe	—
North Little Rock, Ark.	MCU	100	Steam process	1977
Portsmouth, Va.	WWC	160	Steam loop	1976
San Diego, Calif. (D)	Pyrolysis	200	Liquid fuel-utility, Fe, Al, glass	1977

¹RDF = Refuse-derived fuel; WWC = Waterwall combustion; RWI = Refractory wall incinerator with waste heat boiler; MCU = Modular combustion unit; RDF/WWC = Waterwall combustion using processed waste; D = Pilot or demonstration facility.

Source: Environmental Protection Agency, EPA SW/3004, (1978).

Table 4.94

Estimates and Projections of Recovery of Residential and Commercial Post-Consumer Solid Waste¹, Selected Materials, 1969-85 (in thousands of tons, as generated wet weight)

Material	1960	1970	1977	1985
Ferrous metals				
Source separation	—	—	35	50
Magnetic separation ¹	50	150	200	200
Mixed-waste processing	—	—	50	400
Total	50	150	285	650
Aluminum				
Source separation	—	10	140	225
Mixed-waste processing	—	—	—	5
Total	—	10	140	230
Paper				
Source separation	5,575	7,115	10,180	12,150
Glass				
Source separation	100	160	500	865
Mixed-waste processing	—	—	—	5
Total	100	160	500	870
Rubber				
Source separation	330	255	160	170
Total Materials Recovery				
Source separation	6,005	7,540	11,015	13,460
Magnetic separation ¹	50	150	200	200
Mixed-waste processing	—	—	50	410
Total	6,055	7,690	11,265	14,070
Energy recovery from combustibles	—	—	750	9,400
Total recovery	6,055	7,690	12,015	23,470
Total gross discards	87,000	131,000	148,000	175,000
Percent recovered	7	6	8	13
Percent source separated	7	6	7	8

¹Includes systems magnetically separating ferrous scrap, but doing no other resource recovery.

Source: Council on Environmental Quality. *The Tenth Annual Report of the Council on Environmental Quality* (December, 1979).

Table 4.95

Material Recovery Efficiencies at Centralized Waste Processing Facilities

Material/Technology	Estimated Achievable Efficiency of Recovery Technology (in percent)
Ferrous/magnetic	90-97
Paper/wet slurry	50
Aluminum/magnet	65
Glass/froth flotation	65-70
Glass/optical sorting	50

Source: Council on Environmental Quality. *The Tenth Annual Report of the Council on Environmental Quality* (December, 1979).

Table 4.96

Comparison of Energy Recovery Efficiencies for Selected Solid Waste Energy Recovery Processes

Process	Net Energy in Fuel Produced ¹	Net Energy Available as Steam ²
Fluff RDF	³ 70	³ 49
Dust RDF	80	63
Wet RDF	76	48
Waterwall combustion furnace	—	59
Modular incinerator	—	³ 25-50
Purox gasifier	64	58
Monsanto gasifier	78	42
Torrax gasifier	84	58
Occidental Petroleum Co. pyrolysis	26	23
Biological gasification ⁴	³ 33	29

¹This is the higher heating value of the fuel product less the heat value of the energy used to operate the system (in the case of electric power consumption it was assumed that the electricity was produced on site using the system's fuel product), expressed as a percent of the heat value of the solid waste.

²In order to compare all the processes on an equal basis, the net energy available as steam was calculated using the boiler efficiency for each fuel product.

³Updated figure drawn from U.S. Congress, Office of Technology Assessment, Materials and Energy from Waste, final draft (Washington, D.C., June 1978), pp. 6-12.

⁴Includes energy recovered from sewage sludge.

Source: Council on Environmental Quality. *The Tenth Annual Report of the Council on Environmental Quality* (December, 1979).

Table 4.97

Electric Utility Ash Utilization Pattern

	1966	1973	1974	1975	1976	1977
Ash Collected						
Fly ash	17.1	34.6	40.4	42.3	42.8	48.5
Bottom ash	8.1	10.7	14.3	13.1	14.3	14.1
Boiler slag		4.0	4.8	4.6	4.8	5.2
Total ash collected - tons $\times 10^6$	25.2	49.3	59.5	60.0	61.9	67.8
Ash Utilized						
Fly ash	1.4	3.9	3.4	4.5	5.7	6.3
Bottom ash	1.7	2.3	2.9	3.5	4.5	4.6
Boiler slag		1.8	2.4	1.8	2.2	3.1
Total ash utilized - tons $\times 10^6$	3.1	8.0	8.7	9.8	12.4	14.0
Percent of Ash Utilized						
Percent fly ash	7.0	11.4	8.4	10.6	13.3	13.0
Percent bottom ash	21.0	21.9	20.3	26.7	31.5	32.6
Percent boiler slag		44.3	50.0	40.0	45.8	60.0
Percent of total ash utilized	12.1	16.3	14.6	16.4	20.0	20.7

Source: Price J.D., et al., *Potential for Energy Conservation Through the Use of Slag and Fly Ash in Concrete*, Gordian Associates Inc., Washington, D.C., SAN-1699-TI (1978).

Table 4.98

Known Miscellaneous Uses for Ash and Slag

Oil well cementing	Oil well drilling
Mine fire control	Industrial testing
Mine subsidence control	Vanadium recovery
Neutralization of acid mine drainage	Ice control
Cleaning abrasive	Outdoor school tracks
Spontaneous combustion control	Asphalt shingles
Highway bridges	Sandblasting grit
Test caps	Filler for glass
Refractory add mix	Filler for fertilizer
Insulating cement	Filler for paint
Grouting	Filler for plastics
Snow sanding	Dike repair and buildings
Pipe coating	Drainage filter
Foundries	Aggregate
sand	Landfill
manufacturer products	Agriculture
Chemical products	Dust control
Poz-O-Pac ¹	Seal coating
Sewage treatment plants (filtration)	Roofing granules
Substrate course (heavy construction)	Railroad base
Ready Mix	Mineral wool production

¹A pozzolan.

Source: Ralph Stone and Co., Inc., *Environmental Assessment of Solid Residues from Fluidized - Bed Fuel Processing*, EPA-600/7-78-104 (June 1978).

Table 4.99

Commercial Utilization of Ash in the U.S. in 1975¹
(thousands of tons)

Use	Fly Ash	Bottom Ash	Boiler Slag
Type 1-P cement	225	70	36
Partial substitute for cement	945	—	—
Lightweight aggregate	90	35	—
Stabilization and roads	450	525	72
Filler in asphalt mix	135	—	—
Ice control	—	280	54
Blast grit and roof granules	—	420	864
Miscellaneous	180	350	414
Ash removal at no cost to utility ²	1,080	875	270
Ash utilized ² from disposal sites	1,395	945	90
1975 total utilized	4,500	3,500	1,800

¹Compiled by the National Ash Association and Edison Electric Institute.

²Specific end use not known.

Source: U.S. Department of Energy, Final Environmental Impact Statement Fuel Use Act, DOE/EIS-0038 (April 1979).

Table 4.100

Ash Collection and Utilization, 1971

	Fly Ash (kkg)	Bottom Ash (kkg)	Boiler Slag (kkg)
Ash utilized:			
Mixed with raw material before forming cement clinker	94,550	NA	83,440
Mixed with cement clinker or mixed with cement (pozzolan cement)	15,001	NA	NA
Partial replacement of cement			
Concrete products	160,725	32,094	68,551
Structural concrete	168,256	NA	NA
Dams and other massive concrete	64,784	NA	NA
Lightweight aggregate	162,294	12,648	NA
Fill material for roads, construction sites, etc.	329,003	484,156	2,384,924
Stabilizer for road bases, parking areas, etc.	33,511	7,149	44,964
Filler in asphalt mix	133,953	2,570	74,118
Miscellaneous	89,633	431,299	388,305
Total	1,252,370	969,916	3,044,302
Ash removed at plant site at no cost to utility but not covered in categories listed under "ash utilized"	1,698,938	492,514	346,346
Total ash utilized	2,951,308	1,462,430	3,390,648
Ash removed to disposal areas at company expense	22,224,448	7,663,065	1,117,941
Total ash collected	25,175,756	9,125,495	4,508,589
Estimated 1976 ash production	33,561,352	10,651,580	2,284,060

Note: NA = Not Applicable.

Source: Ralph Stone and Co., Inc., *Environmental Assessment of Solid Residues from Fluidized - Bed Fuel Processing*, EPA-600/7-78-104 (June 1978).

Table 4.101

Potential Sulfur Production by Energy Technologies and Total Sulfur Sold in the U.S.

Technology	Facility Size	Sulfur Production per Plant per Year (tons)
Coal utility with regenerable FGD ¹	1000 MW	42,000
AFBC with bed regeneration	600 MW	36,000
Lurgi Coal Gasification	250 × 10 ⁹ Btu/day	150,000
SRC II Liquefaction	250 × 10 ⁹ Btu/day	120,000
Total U.S. Sulfur Sales (1976)	—	10,768,000

¹With magnesium oxide scrubbers.

Sources: TRW, Inc., *Environmental Data Base for High-Btu Gasification Technology: Volumes I-III*, EPA-600/7-78-186a-c (1978).

Mesko, J.E., *Multicell Fluidized - Bed Boiler Design, Construction, and Test Program*, NTIS #PB 236 254 (1974).

Mitre Corporation, *Background Material for the Workshop on Health and Environmental Effects of Coal Gasification and Liquefaction Technologies*, M78-58, McLean, Virginia.

Ralph Stone, Inc., *Environmental Assessment of Solid Residues from Fluidized - Bed Fuel Processing*, EPA-600/7-78-104 (June 1978).

5. GLOSSARY

Acid sludge: the residue left after treating petroleum oil with sulfuric acid for the removal of impurities. It is a black, viscous substance containing the spent acid and impurities that have been separated from the oil.

Actinium (Ac): A radioactive element whose atomic weight is 227 and atomic number is 89.

Acute toxicity: any poisonous effect produced within a short period of time, usually up to 24-96 hours, resulting in severe biological harm and often death.

Aerosol: a suspension (in a body of gas) of liquid or solid particles of such size that they tend to remain suspended for an indefinite period.

Alicyclic: a group of organic compounds characterized by arrangement of the carbon atoms in closed-ring structures. These compounds have properties resembling those of aliphatics. Three alicyclic subgroups are cycloparaffins (saturated), cycloolefins, and cycloacetylenes (cyclynes), having a triple bond.

Aliphatic: one of the major groups of organic compounds characterized by straight-chain arrangement of the constituent carbon atoms. Aliphatic hydrocarbons include three subgroups: paraffins (alkanes), which are saturated and unreactive; olefins (alkenes and alkadienes), which are unsaturated and quite reactive; and acetylenes (alkynes), which contain a triple bond and are highly reactive. In complex structures, the chains may be branched or cross-linked.

Alkadiene: (diolefin, diene); an olefinic compound containing two double bonds, either adjacent or conjugated.

Alkene: An aliphatic hydrocarbon compound containing one double bond, such as ethylene.

Allochthonous coal: coal that originated from accumulations of plant debris that had been transported from their place of growth and deposited elsewhere.

Ambient air: any unconfined portion of the atmosphere; the outside air.

Anacrobic: refers to an organism or life process that does not use, or cannot exist in the presence of oxygen.

Anthracite (hard coal): generally a hard, black, lustrous coal containing a high percentage of fixed carbon and a low percentage of volatile matter; a high-rank coal.

Anthraxylon: the vitreous-appearing components of coal which, in thin section, are shown to be derived from the woody tissues of plants (such as stems, limbs, branches, twigs, and roots), which are changed and broken into fragments of greatly varying size through biological decomposition and weathering during the peak stage, and later are flattened; and transformed into coal through the coalification process; the woody tissues still remain as definite units.

API Separator: gravity separators used in the treatment of oily waste waters.

Aquifer: an underground formation containing water.

Aromatic (arene): a major group of unsaturated cyclic hydrocarbons containing one or more rings (e.g., benzene). These highly reactive and chemically versatile compounds have a strong, but not unpleasant, odor—thus the name aromatic.

Ash: inorganic residue remaining after ignition of combustible substances.

Asphaltene: any of the components of a bitumen (as asphalt) that are soluble in carbon disulfide, but not in paraffin naphtha and that constitute the solid dispersed particles of the bitumen and consist chiefly of high-molecular weight hydrocarbons.

Attenuation: the soil's capacity to weaken or reduce the adverse impacts of water-borne effluents.

Autochthonous coal: coal believed to have originated from accumulations of plant debris located at the place where the plants grew. (Two modes of origin can be distinguished: terrestrial and aquatic.)

Autotrophs: organisms capable of using (oxidizing) simple chemical elements or compounds, such as iron, sulfur, or nitrates, to obtain energy for growth.

Background concentration: those pollutant concentrations that are due to natural sources.

Banded coal: the common variety of bituminous and subbituminous coal. Banded coal consists of a sequence of irregularly alternating layers or lenses: homogeneous black material having a brilliant vitreous luster; grayish black, less brilliant, striated material, usually of silky luster; and generally thinner bands or lenses of soft powder and fibrous particles of mineral charcoal.

BAT: the best available technology economically achievable, under Section 304(b)(2)(B) of the Clean Water Act.

Benzene (C₆H₆): a colorless, liquid hydrocarbon that is made from coal tar and by catalytic reforming of naphthalenes. (Benzene is used in the manufacture of phenol, styrene, nylon, detergents, aniline, phthalic anhydride, and other compounds; as a solvent; and as a component of high-octane gasoline.)

BCT: the best conventional pollutant control technology, under Section 304(b)(4) of the Clean Water Act.

Bi-Gas: a process for coal gasification being developed by the Office of Coal Research and the American Gas Association.

Bioaccumulation: the ability of an organism to continue to concentrate a substance throughout its active metabolic lifetime so that the concentration factor, if calculated, would be continuously increasing during the lifetime of the organism.

Bioassay: an assay method using a change in biological activity as a qualitative or quantitative means of analyzing.

Biochemical oxygen demand (BOD): the quantity of oxygen used in the biological oxygen of organic matter, in a specified time and at a specified temperature, determined by its availability to serve as food for microorganisms. BOD can be related to the

oxygen resources of a stream; for example, after dilution and mixing in a stream, one part of BOD will consume one part of oxygen in the stream.

Bioconversion: the conversion of one form of energy into another by plants or microorganisms. (Digestion of solid wastes or sewage sludge by microorganisms to form methane is bioconversion of one form of stored chemical energy into another more useful form.)

Biological half-life: the time required for a biological system (such as human or animal) to eliminate, by natural processes, half of the amount of a substance (such as a radioactive material) that has entered that system.

Biosludge: produced when biological processes are employed for the treatment of aqueous wastes, resulting in the degradation of organics and the physical entrapment and settling of suspended particles.

Bitumen: a general name for various solid and semisolid hydrocarbons: a native substance of dark color that is comparatively hard and nonvolatile and is composed principally of hydrocarbon.

Bituminous coal (soft coal): the most important and plentiful rank (type) of coal. Bituminous coal is the chief fuel in steam-electrical plants: other important industrial uses include provision of coke for the steel industry, use as raw material for thousands of coke by-products (including gas, light oils, and chemicals), use in aluminum, cement, food, paper, and textile production, and heat source for homes and buildings. Large deposits of bituminous coal are found in many states, both east and west of the Mississippi River. The most important bituminous coal beds in the United States are located in a region west of the Appalachian Mountains, which extends southwest from Ohio and Pennsylvania to Alabama. Nearly three of every four tons of bituminous coal mined in the United States each year come from this eastern coal area.

Block coal: a peculiar kind of coal that breaks into large cubical blocks; a variety of tough coal.

Boghead coal: a nonbanded coal having translucent attritus that consist predominantly of algae.

Boiling fluidized bed: a fluidized bed through which part of the fluidizing medium passes in the form of bubbles of a

size approximately equal to the size of the solid particles, but very small relative to the dimensions of the containing vessel.

Bright coal (anthraxylon): the constituent of banded coal that is of a jet-black pitchy appearance, is more compact than dull coal, breaks with a conchoidal fracture visible when viewed microscopically, and in thin section, always shows preserved cell structure of woody plant tissue.

British thermal unit (Btu): the quantity of heat necessary to raise the temperature of 1 lb water 1 degree F (One Btu equals 252 cal/g(mean), 778 ft-lbs, 1055 J., and 0.293 Whr).

Brown coal: lignite.

Brown lignite: a lignite lower in rank than black lignite.

By-products (residuals): secondary products (possibly of commercial value) obtained from the processing of raw material. By-products may be the residues of the gas production process (such as coke, tar, and ammonia), or they may be the result of further processing of such residues (such as ammonium sulfate).

By-product stream: material streams within the coal-conversion plant that are of secondary resale value as compared with the product stream (e.g., sulfur, ammonia, gypsum, phenols).

Cannel coal: a massive, noncoking, tough, clean, block coal of fine, even, compact grain, dull luster, and commonly conchoidal cross fracture; a nonbanded coal consisting predominantly of spores. Cannel coal, typically, has a low fuel ratio and contains a high percentage of hydrogen. It is easily ignited; burns with a long, yellow flame; leaves a moderate amount of ash; and is pulverulent in burning.

Cascading heat: the direct use of a geothermal stream to perform a variety of successive tasks requiring successively lower temperatures.

Catalyst: a substance that accelerates the rate of a chemical reaction without itself undergoing a permanent chemical change.

Catalytic hydrogenation process: a method for adding hydrogen to substances using a catalyst to promote the reaction. It can be used to convert coal to a liquid and/or to remove sulfur from residual oil, coal, crude coal liquids (such as coal tar), and coal extracts. Catalytic cracking (Cat-Cracker): a process of cracking in which the catalyst supplements heat and pressure; also, the conversion of high-boiling hydrocarbons

into lower-boiling substances by means of a catalyst. (Feedstocks may range from naphtha cuts to reduced crude oils.)

Char: the solid, carbonaceous residue that results from incomplete combustion of organic material. Char can be burned for its energy content or, if free from large amounts of impurities, processed further for production of activated carbon for use as a filtering medium. Char produced from coal is generally called coke, whereas that produced from wood or bone is called char-coal.

Char-Oil-Energy Development process (COED): a process being developed by the Office of Coal Research for low-temperature distillation of coal-carbonization products. The process is designed to produce clean liquids, gases, and char for fuel, the product balance depending upon economic factors.

Clarain: an ingredient of banded coal that appears, megascopically, as thin or very thick bands intrinsically stratified parallel to the bedding plane, most often has a silky luster, and has scattered or diffuse reflection markedly less intense than the specular reflection of vitrain under the same illumination.

Coal: a solid, combustible, organic material formed by the decomposition of vegetable material without free access to air. Chemically, coal is composed chiefly of condensed, aromatic ring structures of high molecular weight; thus, it has a higher ratio of carbon-to-hydrogen content than does petroleum.

Coal alkylation: a process being developed by the Bureau of Mines to convert sulfur-bearing coal into a nonpolluting fuel.

Coal conversion: the conversion of coal to a liquid or gas suitable for uses as a fuel.

Coal gas: the gas that comes from retorts, mufflers, or ovens during the distillation of coal. Coal gas has a high illuminating value and is a relatively suitable engine fuel. Large quantities of coal gas are produced when coal is used to make coke, coal tar, benzoin, toluene, ammonia, and other products.

Coal-gasification (high-Btu gas): two existing commercial processes (Lurgi, and Koppers-Totzek) that should be able to produce a synthetic pipeline gas once the methanation processes step has been proven on a large scale.

Coal-gasification (low-Btu gas): production of gas from coal with air, as distinct from oxygen. (The Btu content will range from 150 to 175 Btu/cu ft, which prevents any storage of the gas between producer and boiler.)

Coalification: those processes involved in the genetic and metamorphic history of coal beds. The three essential processes of coalification are incorporation, vitrification, and fusinization.

Coal liquefaction (coal hydrogenation): the conversion of coal into liquid hydrocarbons and related compounds by hydrogenation.

Coal oil: oil obtained by the destructive distillation of bituminous coal; also an archaic term for kerosene made from petroleum.

Coal preparation: a collective term for physical and mechanical processes applied to coal to make it suitable for a particular use.

Coal seam: a bed of coal usually thick enough to be mined with profit.

Coal-slurry pipeline: a pipeline that transports pulverized coal suspended in water.

Coal tar: a gummy, black substance produced as a by-product of distillation of bituminous coal.

Coarse particulates: suspended solids having a Svedberg coefficient greater than 20,000 S, corresponding to a diameter larger than 0.15 microns for a particle of 2.65 specific gravity.

COED: Char-Oil-Energy-Development; the development of liquid fuel from coal char (see Char-Oil-Energy-Development process).

Coke: a porous, solid residue that results from the incomplete combustion of coal heated in a closed chamber, or oven, with a limited supply of air. Coke is largely carbon and is desirable fuel in certain metallurgical industries.

Coke-oven gas: the gas secured from coke ovens during the production of coke. The properties of this gas are identical to coal gas, and the two products are interchangeable. Coke is particularly useful in making iron and steel and as an industrial fuel.

Coking: one of the processes used to upgrade shale oil and improve its transportation properties. The oil is thermally decomposed at high temperatures, forming coke as a solid product.

Coking coal: the most important of the bituminous coals, which burns with a long yellow flame and creates an intense heat when properly attended.

Colloidal particulates: suspended solids having a Svedberg value greater than 100 S and less than 20,000 S, corresponding to a diameter between 0.01 μ and 0.15 μ for a particle having a specific gravity of 2.65.

Conversion type process: a method of removing potential pollutants from a fuel by converting it to a clean-burning fuel (e.g., elimination of sulfur from residual oil by hydrogenation; conversion of coal to a low-sulfur fuel).

Crushed coal: usually, coal that has been crushed for use in a cyclone furnace (as opposed to pulverized coal). Normally 90 to 97.5 percent passes a number 4 screen and 7 to 13 percent passes a number 200 screen (fine-hole U.S. standard series).

Cyclone: a separator that depends upon centrifugal force to separate particles or droplets from the stream (used to separate solids from gases and water from steam).

Cycloolefin (cycloalkene): an alicyclic hydrocarbon having two or more double bonds.

Cycloparaffin (naphthene): an alicyclic hydrocarbon in which three or more of the carbon atoms in each molecule are united in a ring structure and each of these ring carbon atoms is joined to two hydrogen atoms or alkyl groups.

daf: dry, ash-free (usually coal).

DAF float (Dissolved air flotation float): used in lieu of or as a supplement to conventional gravity separation for the removal of separable oils from oily wastewaters.

Deposit: a natural accumulation; e.g., of coal, iron ore, or oil shale.

Devolatilization: progressive loss of volatiles by the substance undergoing the gasification process: also, treatment of coal, usually by controlled heating, to remove all or part of the volatile constituents.

Direct-use geothermal applications: any non-electric use of geothermal energy, for space heating, water heating, or processing.

Dissolved solids: the total amount of dissolved material, organic and inorganic, contained in water or wastes.

District heating: a centralized heating system employing a regionally available energy resource (centralized wasteburning system, hydrosystems, geothermal well,

etc). Provides heat energy for a variety of direct-use applications for a number of buildings and establishments in a given area.

Dry steam: a rare geothermal resource consisting of hot steam with no condensate (water content). Found principally at The Geysers and Yellowstone National Park.

Dust: a general term used to describe solid particles that are in the micron size range (e.g., fly ash, coarse dirt, and mechanically produced particles).

ED-50: ecological dose; amount of contaminant added to a culture system, regardless of whether all of it solubilizes; behaves as a toxicant and causes 50 percent abnormality in a culture of oyster larvae.

Environmental fate: the result of the physical, biological, and chemical interactions of a substance released to the environment.

Environmental transport: the movement through the environment of a substance (chemical, trace elements, etc.), including the physical, biological, and chemical interactions undergone by the substance.

ESP: electrostatic precipitators.

Exinite: the series of genetically related macerals forming a portion of the hydrogen-rich fraction of coal seams and derived from the waxy cell secretions represented by plant cuticles and from spore and pollen exines.

Filter cake: mineral matter (ash and char) and some unreacted insoluble carbon separated from crude liquefaction oil products.

Fines: in general, the smallest particles of coal or mineral in any classification, process, or sample of material; especially those elutriated from the main body of material in the process.

Fischer assay: small samples of crushed oil shale are heated to 932°F (500°C) under carefully controlled conditions. The ore yield by this method is the standard measure of oil shale quality.

Fixed bed: a bed in which the individual particles or granules of a solid are motionless and supported by contact with each other.

Fixed carbon: for coal, coke, and other bituminous materials, the solid residue, other than ash, obtained by destructive distillation and determined by prescribed methods.

Flashing: a system of converting geothermal liquid to steam vapor by decreasing the pressure. The vapor is then used to run a turbine generator.

Flocculation: the aggregation or clumping together of individual, tiny soil particles, especially fine clay, into small groups or granules.

Flotation: a process for separating minerals from waste rock or solids of different kinds by agitating the pulverized mixture of solids with water, oil, and special chemical, which causes preferential wetting of solid particles of certain types by the oil. The unwetted particles are carried to the surface by the air bubbles and, thus, are separated from the wetted particles. A frothing agent is also used to stabilize the bubbles in the form of a froth, which can be easily separated from the body of the liquid (froth flotation).

Flue gas desulfurization: the removal of sulfur from gaseous combustion products.

Fluidization: a condition in which the individual particles or granules of a solid are suspended by a gas or liquid passing through them at a velocity sufficient to cause them to be disengaged somewhat from each other.

Fluidized bed: a bed of suitable sized solid particles through which fluid (usually a gas) flows at a velocity high enough to buoy the particles, to overcome the influence of gravity, and to impart to them an appearance of great turbulence.

Fluidized-bed boilers: a method of power generation using the technique of moving powdered fuel (coal) into a combustion chamber in a liquidlike stream by use of air or other gases.

Flue gas, stack gas: synonymous terms for the gases resulting from combustion of a fuel.

Fly ash: the fine, solid particles of noncombustible material residue carried from a bed of solid fuel by the gaseous products of combustion.

Fracturing: breaking up a deposit by means of chemical explosives, electricity, or injecting high pressure air and water to increase its permeability to fluid flow.

Fuel oil: any liquid or liquefiable petroleum product that is burned for the generation of heat or engine power. Includes: residual fuel oils (oil from the bottom of the crude oil barrel that cannot be further refined; viscous residual that, unless heated to temperatures of 120 to 160°F, will remain

solids), distillate fuels (derived directly or indirectly from crude), and blended fuels (no. 3, 4, or 5, produced by blending residual and middle distillate fuel oils).

Gas scrubbing: crude gas is scrubbed and cooled with water, which removes tar and oil by-products and phenolic waters. The phenolic waters are subsequently processed for recovery of by-product phenols.

Gas synthesis: a method of developing liquid fuels from coal by oxidation (e.g., the Fischer-Tropsch process). The first step is to convert pulverized coal into a gas by exposing the coal to oxygen and superheated steam. The gas, a mixture of carbon monoxide and hydrogen, is then passed over various solid catalysts to change into useful products.

Gasification: in the most commonly used sense, refers to the conversion of coal to a high-Btu synthetic natural gas under conditions of high temperatures and pressures; in a more general sense, conversion of coal into a usable gas.

Geopressed resources: sedimentary basins, located principally along the Texas and Louisiana Gulf Coast, which contain water and dissolved methane at moderately high temperatures under very high pressure.

Geothermal energy: the heat energy available in rocks, hot water, and steam in the earth's subsurface.

Geothermal gradient: procedure for estimating the temperature of a geothermal resource; consists of measuring the rate of increase of temperature in the earth as a function of depth. Average temperature increase is 1 degree F every 75 feet. Above-average gradients indicate possible geothermal resources.

Gilsonite: a solid hydrocarbon that looks like black glass but is as brittle as dried mud (probably formed from conventional crude oil that flowed upward through subsidence fissures where the lighter fractions evaporated).

Hard coal: in U.S. usage, anthracite or semianthracite; in European usage, a coal having a calorific value greater than 10,260 Btu/lb on a moist, ash-free basis.

H-Coal process: one method to convert coal to a clean (low-sulfur, low-ash) fuel by catalytic hydrogenation.

HDS (Hydrodesulfurization, a copyrighted trademark): desulfurization by use of hydrogen and catalyst treatment.

Heterocyclic: a cyclic or ring structure in which one or more of the atoms in the ring is an element other than carbon.

High-sulfur coal: generally, coal that contains more than 1 percent sulfur by weight.

Hot dry rock resources: abnormally hot rock formations at accessible depths which contain little or no water and are relatively unfractured. Power generation from these resources requires fracturing the rock and introducing and circulating a heat transfer fluid.

Humin-ulmins: the products of decay of vegetable matter and their prototypes that occur in coal as a gel.

Hydrocarbons: organic compounds containing only carbon and hydrogen.

Hydrothermal resources: underground systems of hot water and/or steam trapped in fractured rocks or sediments, classified as hot water or vapor-dominated (steam) according to the state of the subsurface fluid.

HYGAS: a process to produce pipeline quality gas by hydrogasification of coal.

Incorporation: a process by which material contributing to coal responds to diagenetic and metamorphic agencies of coalification and becomes a part of the coal without undergoing any material modification.

In situ: in its original place: e.g., underground gasification of a coal seam.

Ion exchange: a reversible chemical reaction between a solid (ion exchanger) and a fluid (usually a water solution) by means of which ions may be interchanged from one substance to another without affecting the superficial physical structure of the solid.

Kerogen: a resinous hydrocarbon material, the chief organic constituent of oil shale.

LC₅₀: median lethal concentration.

LD₅₀: median lethal dose.

Leachate: liquid that has percolated through solid waste or other media and has extracted dissolved or suspended materials from it.

Leaching: the process of extracting a soluble component from a mixture by percolation of the mixture with a solvent, usually water, resulting in the solution and later separation of the soluble component.

Lignite: a brownish black coal in which the alteration of vegetal material has proceeded further than in peat but not so far as in sub-bituminous coal.

Liquefaction of coal: the conversion of coal to liquid fuels, a method for making large amounts of gasoline and heating oils.

Liquefied gases: ethane, propane, butanes, ethylene, propylene, and butylenes; derived by refining, or other processing, of natural gas, crude oil, or unfinished oils.

Liquefied natural gas (LNG): natural gas that has been changed into a liquid by cooling to about -260 degrees F, at which point it occupies about 1/600 of its gaseous volume at normal atmospheric pressure.

Liquefied refinery gas (LRG): a product of petroleum; includes butane, propane, and butane-propane mixtures.

Liquid Petroleum gas (LPG) bottled gas: consists primarily of propanes and butanes, highly volatile gases that are extracted from refinery and natural gases. Under moderate pressure, LPG becomes liquid and can easily transported by pipelines, railroad tank cars, or trucks. Released from its storage tank, LPG reverts to vapor form, burning with high heat value and a clean flame.

Lithotype: refers to any of the four microscopically recognizable constituents of banded coal: vitrain, clarain, durain, fusain.

Low-Btu gas: fuel gas having a higher heating value of 350 to 450 Btu/scf or less.

Lurgi process: a commercially available process for coal gasification.

Maceral: any of the elementary microscopic constituents of coal. Three groups are recognized: vitrinites, exinites, inertinites.

Magma source: molten rocks within the earth from which geothermal fluids derive their heat.

Metallurgical coal: coal with strong or moderately strong coking properties that contain no more than 8 percent ash and 1.25 percent sulfur, as mined or after conventional cleaning.

Micelle: an electrically charged colloidal particle, usually organic in nature, composed of aggregates of large molecules.

Micrinite: the series of genetically related macerals forming a portion of the attrital fraction of coal seams and that are formed by the granulation and subsequent metamorphosis of plant cell wall-derived materials.

Microlithotype: typical microscopic association of macerals in coal.

Mine-mouth plant: a steam-electric plant or coal gasification plant built close to a coal mine, usually associated with delivery of

output via transmission lines or pipelines over long distances, as contrasted with plants located nearer load centers and at some distance from sources of fuel supply.

Moving bed: a body of solids in which the particles or granules of a solid remain in mutual contact but in which the entire bed moves in piston-like fashion with respect to the containing walls.

Mutagenesis: the condition in which inheritable genetic changes are passed on from parent to offspring.

Naphthalene: an aromatic hydrocarbon that is the most abundant component of coal tar.

NESHAPS: National Emission Standards for Hazardous Air Pollutants.

Nonbanded coal: coals that do not display a striated or banded appearance on the vertical face.

NPDES: National Pollutant Discharge Elimination System.

Oil shale: a sedimentary rock containing solid organic matter from which oil can be obtained when the rock is heated to a high temperature.

Olefin (alkene): a class of unsaturated aliphatic hydrocarbons containing one or more double bonds, chemically reactive. Those containing one double bond are alkenes; those containing two are alka-dienes or diolcfins.

PAH: polycyclic aromatic hydrocarbons.

Paraffin (also called alkane): a class of aliphatic hydrocarbons characterized by a straight carbon chain. Their physical form varies with increasing molecular weight from gases (methane) to waxy solids. Occur principally in Pennsylvania and midcontinent petroleum.

Particulate fluidized bed: a bed in such a condition of fluidization that the individual particles are discretely separated from each other and the volumetric concentration of solid particles is uniform throughout the bed.

Particulate matter: solid particles, such as ash, that are released in exhaust gases from the combustion process at fossil-fuel plants.

Particulates: small particles of solid material produced by the burning of fuels.

Peat: one of the earliest stages of coal in which the remains of plants that have been preserved may be clearly seen.

Petroleum: an oily, flammable bituminous liquid that may vary from almost colorless

to black, that occurs in many places in the upper strata of the earth; a complex mixture of hydrocarbons containing small amounts of other substances that is prepared for use as gasoline, naphtha, or other products by various refining processes.

Petroleum coke: a solid residue; the final product of the condensation process in cracking, consisting mainly of highly polycyclic aromatic hydrocarbons very poor in hydrogen.

Petroleum naphtha: a generic term applied to refined, partially refined, or unrefined petroleum and liquid products of natural gas.

Petroleum refinery: a plant that converts crude petroleum into the many petroleum fractions.

Petroleum tar: a viscous black or dark brown product obtained in petroleum refining that will yield a substantial quantity of solid residue when partly evaporated or fractionally distilled.

pH: a means of expressing the acidity or alkalinity of a solution. At normal temperatures, pure water has a pH of about 7 (neutral); the pH of a strong acid is about 1 and that of a strong base about 14.

Phenols: a group of aromatic hydrocarbons having the hydroxyl (OH) group directly attached to the benzene ring.

PIFUA: Powerplant and Industrial Fuel Use Act.

Pitch of tar: a black or brown solid or semisolid residue obtained by partial evaporation or fractional distillation of tars and tar products.

POM: polycyclic organic matter.

Pressure gasification: the process by which coal, steam, and oxygen are caused to react under controlled conditions of temperature and pressure to produce a crude gas containing methane, hydrogen, carbon monoxide, carbon dioxide, excess steam, and various by-products and impurities.

Process stream: any material stream within the coal-conversion processing area.

Product stream: streams within the coal conversion plant that contain the material for which the plant was built.

Pulverized coal: coal that has been reduced to a fine dust (75 to 95 percent will pass a 200-mesh screen) by grinding mills.

Pyrolysis: the transformation of a substance into another compound or compounds by the application of heat alone.

Radioactive waste: liquid, solid, or gaseous waste resulting from mining of radioactive ore, production of reactor fuel materials, reactor operation, processing of irradiated reactor fuels, and related operations, and from use of radioactive materials in research, industry, and medicine.

Radionuclide: a radioactive atom.

Rank: those differences in the pure coal material due to geological processes designated as metamorphic, whereby the coal material changes from peat through lignite and bituminous coal to anthracite or even graphite; the degree of coal metamorphism.

RCRA: Resource Conservation and Recovery Act.

Reinjection well: the remaining components that are not removed as distillates that can be used as fuel or residual fuel oil or for asphalt manufacture.

Resinite: the series of genetically related macerals forming a portion of the hydrogen-rich fraction of coal seams and derived from resinous secretions and excretions of plant cells.

RIIA: Regional Issue Identification and Analysis Program.

Run-of-mine: coal that is taken from the mine.

Sediment: soil and mineral solids of small particle conveyed in water.

Settleable solids: settling solids; suspended solids that will settle out in a reasonable period of quiescence (arbitrarily taken to be 2 hrs).

Silt: finely divided particles of soil or rock, which are often carried in cloudy suspension in water and eventually deposited as sediment.

SIP: State Implementation Plan.

Slag: ash and other residue remaining after fuel combustion; usually used to indicate a hot molten state; solidification from this state.

Slop oil emulsion: a process waste stream consisting of oil, water and solids produced in petroleum refining.

Sludge: a solid waste fraction precipitated by a water treatment process.

SNG: substitute or synthetic natural gas; a manufactured gas that contains about 97 percent methane, has a higher heating value of about 1000 Btu/scf, and meets the same end-use specifications as pipeline natural gas.

Solvent extraction process: a method to convert coal and hydrogen under pressure to a clean (low-sulfur, low-ash) fuel by dissolving most of it, then separating the undissolved coal and mineral matter (ash) from the extract.

Solvent naphtha: a flammable liquid distillate containing, principally, xylenes and higher aromatic hydrocarbons.

Solvent-Refined Coal process: a process to remove ash, sulfur, and other impurities from coal.

Soot: agglomerations of tar-impregnated carbon particles that form when carbonaceous material does not undergo complete combustion.

Sorption: a term including both adsorption and absorption. Sorption is basic to many processes used to remove gaseous and particulate pollutants from an emission and to clean up oil spills.

Spent shale: the retorted residual material after the oil and gas products are removed. Its properties vary with the type of retorting procedure used; indirectly heated retorts produced a carbonaceous spent shale, while directly heated retorts produce a material essentially stripped of carbon.

Stoichiometry: quantitative chemical properties and composition especially as a factor in processes of chemical or physical change.

Strip mining: the mining of coal by removing covering material (the overburden) and stripping away the entire underlying coal seam.

Subbituminous coal: coal of intermediate rank (between lignite and bituminous); weathering and nonagglomerating coal having calorific values in the range of 8300 to 13,000 Btu, calculated on a moist, mineral-matter free basis.

Suspended solids: solids that either float on the surface or remain suspended in liquids; removed by filtering.

Svedberg coefficient(s): a numerical value related to the settling velocity of a spherical particle, which is a function of particle density, particle diameter, and fluid viscosity.

Syngenetic: a term generally applied to mineral or ore deposits formed contemporaneously with the enclosing rocks.

Synthane: a coal gasification process being developed by the Bureau of Mines to produce pipeline quality gas.

Tank bottoms: the solid waste formed through the separation and cooling of petroleum products in storage tanks.

Tar sands: sedimentary rocks that contain viscous, heavy petroleum that cannot be recovered by conventional methods of petroleum production.

Teratogenesis: the process that produces birth defects.

Threshold dose: the minimum dose of a given substance necessary to produce a measurable physiological or psychological effect.

Transuranic waste: those wastes contaminated with long-lived alpha-emitting radionuclides including ^{233}U and its daughter products, plutonium and transplutonium nuclides (those with atomic number 94) except ^{238}Pu and ^{241}Pu .

TSCA: Toxic Substances Control Act.

Upgrading: the treatment of crude shale oil to improve it to a transportable refinery feedstock; e.g., hydrotreating.

Uranium: a metallic element; highly toxic and radioactive; ignites spontaneously in air and reacts with nearly all nonmetals; used in nuclear fuel as the source of U^{235} and plutonium.

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