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OIL SHALE
MINING ENVIRONMENTAL
RESEARCH PROGRAM OVERVIEW

PREPARED FOR

UNITED STATES DEPARTMENT OF THE INTERIOR
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By

THE AEROSPACE CORPORATION
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This report describes the direction and progress of the Bureau of Mines Oil Shale Mining Environmental Research Program as of January 31, 1979. The report focuses on the Bureau's role in environmental research supporting oil shale development with respect to the activities of other involved Government agencies and private industry. Environmental considerations in oil shale extraction, such as ecological disturbances, health and safety hazards, waste management, and socioeconomic impacts, are discussed along with the type of research known to be planned by organizations to ameliorate these problems.

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FOREWORD

This report was prepared by The Aerospace Corporation, Energy and Resources Division, 2350 East El Segundo Boulevard, El Segundo, California 90245, under the U.S. Bureau of Mines Contract Number J0255030. The contract was initiated under the Bureau of Mines Oil Shale Mining Environmental Research Program. It was administered under the technical direction of the Denver Mining Research Center, Denver, Colorado, with Mr. George R. Schottler acting as the Technical Project Officer. Mr. Larry L. Rock, Denver Mining Research Center, was the contract administrator for the Bureau of Mines. The report is a summary of work completed as part of this contract during the period September 1978 to June 1979. This report was submitted by the authors June 1979.

The description of the Bureau of Mines Oil Shale Mining Environmental Research Program was performed as part of an evaluation of the program undertaken by The Aerospace Corporation. The objective of this report is to illustrate the key role the USBM plays in the environmental research supporting oil shale development and to provide a base for an environmental benefit-cost analysis to be documented in a subsequent report. Ms. Cynthia Ogasawara was the principal author of this report with Mr. Guy F. Kuncir, the Principal Investigator of the program evaluation effort, and Mr. Don A. Lewis contributing to the effort.

The author wishes to acknowledge the assistance provided by various members of the USBM Denver Mining Research Center staff in supplying information required for this program documentation, and the material contributions, assistance and the guidance provided by Mr. George R. Schottler, Mining Engineer, Western Oil Shale Activities, Denver Mining Research Center.

DISCLAIMER

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1. INTRODUCTION

Oil shale is one of the most abundant, but undeveloped, energy resources in the United States. The potential synthetic fuel yield from high grade oil shales in the Green River Formation of Colorado, Utah and Wyoming is estimated at 600 billion barrels. Although this is approximately equivalent to the known world liquid petroleum reserves, no domestic oil shale industry exists today.

In several decades following World War I, serious interest was given to utilizing Green River oil shale as an energy source. Oil shale activities were experimental in nature and did not produce more than a few thousand barrels of shale oil. The tremendous demand for liquid fuels imposed by World War II brought on a new wave of interest in oil shale development, but this also did not precipitate an oil shale industry. Various factors have been singled out as contributing to the failure to produce a viable oil shale industry in the United States. Among these factors were (a) lack of sufficient technology and (b) economic conditions.

The recent energy crisis induced renewed interest in developing and exploiting the nation's oil shale reserves. The price of oil obtained by conventional petroleum engineering techniques has gone up, creating more favorable economic conditions for the development of an oil shale industry, while technology has advanced to pilot projects which demonstrate oil shale mining and processing. However, before commercialization can begin, numerous environmental problems must be researched and resolved. Environmental considerations in oil shale extraction include ecological disturbances, health and safety hazards, waste management, and socioeconomic impacts. This report discusses these concerns, giving an overview of the activities of various involved government agencies and private industry that address these issues.

To illustrate the key role the U.S. Bureau of Mines plays in the environmental research supporting oil shale development, a description of the direction and progress of the Bureau's Oil Shale Mining Environmental Research Program (MER) as of January 31, 1979 is presented in detail. This date, the day the bored shaft was put on standby basis, was selected because it represents the end of a major milestone in the MER program. An assessment of the environmental benefits resulting from the MER program will be performed in the future, and this report will provide a basis for that analysis.

2. ENVIRONMENTAL CONCERNS

Throughout most of this century, mineral development activities have proceeded with little or no thought to the environment. Today, however, the legislative climate affecting industry has changed. New development or expansion of existing activities requires careful consideration of the potential adverse impacts on the environment. Initiation of an oil shale industry must comply with regulations issued at federal, state and local levels.

Environmental legislation that affects the mining of oil shale includes the National Environmental Policy Act of 1969 -- NEPA (PL 91-190). The thrust of this act, as well as subsequent executive orders, Council of Environmental Quality (CEQ) guidelines, and numerous federal agency procedures, is to ensure that decision-making on major federal actions includes the integrated consideration of technical, economic, environmental, and social factors in a systematic and interdisciplinary approach. There are also numerous federal water and air quality regulations that affect mining operations. They establish a national policy for controlling and preventing air and water pollution. Appendix A summarizes the major federal environmental legislation governing water and air quality, many of which provide the impetus for research to help the mining industry attain compliance.

In response to this type of legislation, research programs have been developed to identify and solve the critical environmental problems confronting oil shale activities. Several problem areas have been defined and some work has been completed. The Bureau of Mines has done research in the areas of mine subsidence, mine safety, and waste management, the Environmental Protection Agency (EPA) has studied air and water quality in the Green River Formation area, the Geological Survey (USGS) has looked into the water availability and quality problem, and the Department of Energy (DOE) has concentrated its effort on determining the impact oil shale production, retorting, and upgrading would have on the environment. Sections 2.1-2.3 discuss major factors being considered, and the type of research known to be planned by organizations to ameliorate these problems. Appendix B shows the current and recent projects in oil shale environmental research, grouped by administering agency.

2.1 NATURAL ENVIRONMENT

The extraction and processing of oil shale could have an enormous effect on the natural environment of the are underlain by the Green River Formation, which covers a substantial portion of the states of Colorado, Utah and Wyoming. This impact will be magnified because of the fragility of the arid and semiarid area. A major potential disruption, such as development of the oil shale industry could destroy the stability of the existing ecosystem.

Anticipated problem areas in the natural environment include (a) water availability and quality, (b) air quality, (c) wildlife and agricultural grazing, (d) the rehabilitation of disturbed areas, and (e) the preservation of historic sites and antiquities. These are detailed in the following sections.

2.1.1 Water Availability and Quality

2.1.1.1 Areas of Concern

A prime concern for large scale oil shale development is water availability and quality. Water availability for oil shale development has been of special concern because of the lack of flexibility in siting mining operations and the generally more severe water constraints in the Colorado River Basin than in other watersheds. The critical constraints posed by water are oil shale mining and processing water demands, physical availability, and water rights.

The water quality of the Green River Formation area can be degraded by the aqueous wastes from both direct and indirect sources. Direct sources are waste waters generated from unit operations, including waste waters from retorting operations; waste water from upgrading operations; water from air emission control and gas cleaning systems; cooling water and boiler water blowdowns; water treatment systems residuals; mine dewatering waste water; and sanitary waste waters. Indirect sources include: leachate from retorted shale disposal areas; runoff and erosion resulting from construction and site use activities; and runoff from mining and transport activities. Water quality parameters that should be investigated are total dissolved solids, turbidity, temperature, dissolved oxygen, pH, hardness and major ion concentrations. This selection focuses on specific constituents because of their hazardous character, persistence, and concentration.

2.1.1.2 Research Efforts

To determine the water available to the oil shale industry, DOE, USGS, and the Bureau of Mines have compiled data describing existing water resources and their present use. Descriptions of major drainage basins, precipitation runoff, and the hydrology of surface water and groundwater resources were generated along with estimates of water demand. Also, an appraisal has been made of the economic and environmental implications of alternative water supplies.

Numerous agencies are conducting research in the area of water quality. The USGS is monitoring the surface and groundwater quality in the Piceance and Yellow Creek Basins, while EPA is developing procedures for quantitatively assessing the impact of individual mining projects on the hydrologic system of the area. A groundwater monitoring system has already been developed by the DOE to measure pre-operational, operational, and post-operational water quality levels near the Rock Springs Site 9 in Wyoming. DOE has also devised methods for the chemical characterization of aqueous effluents associated with the retorting processes with special attention to organic and trace metal components.

2.1.2 Air Quality

2.1.2.1 Areas of Concern

Principal uncertainties associated with air quality arise from a lack of knowledge of (a) the concentration of criteria effluents (e.g., carbon, nitrogen and sulfur oxides, hydrocarbons, particulate matter, photochemical oxidants), and the form and concentrations of noncriteria effluents (e.g., trace metals, polyaromatic hydrocarbons) from surface retorting and from below ground retorting conducted under positive pressures; (b) particulate matter and noncriteria pollutants associated with dusts from mining, crushing and resuspension of disposed spent shale; and (c) the geographical distribution and effects of these materials with time and differences in terrain and climate.

2.1.2.2 Research Efforts

The EPA has determined that ozone levels in the Piceance Creek Basin are surprisingly high, frequently exceeding the Federal Air Quality Standard by 50 percent. This contamination appears to be of natural origin due to high winds that cause turbulence and/or inversion. Likewise, terpenoids exuded by the vegetation can linger in the air in potentially carcinogenic concentrations. The SO_2 level is considerably below Federal Annual Average Standards and frequently below the limits of detection. Baseline CO, volatile hydrocarbons, and NO_2 are well below harmful limits, but surpass baseline levels when influenced by the activities associated with oil shale production. Presently, the EPA is in the process of collecting baseline data and meteorological information needed to predict the impact these emissions will have on the air quality.

2.1.3 Wildlife and Grazing

2.1.3.1 Areas of Concern

Oil shale development will cause surface disturbances and possible destruction of habitat. Mining activities may cause destruction of wildlife or cause displacement to other areas, while changes in the hydrology due to water use and disposal may affect the aquatic ecosystems as well as the natural plant communities. Construction, operation, or decommissioning could disrupt breeding activities or create a barrier of interruption in wildlife migration routes.

2.1.3.2 Research Efforts

The Fish and Wildlife Service and EPA have collected considerable data regarding the wildlife of the Green River Formation. These include the number of deer per acre as well as the number of deer days per acre--the greatest of which occurs on the plateau sage brush areas containing some 45 percent of the browse species' diet. Similar studies have been made of other large and small mammals, raptorial birds, reptiles, amphibians and fish as well as the various vegetation communities throughout the present edaphic climate range. None of the categories, or species within the categories, appears to be threatened as long as provision is made to correct the deleterious effects of oil shale activities. If the rehabilitated land will be used for agronomic purposes, grazing in this case, research has provided good information from which a viable selection of types of vegetation can be chosen.

2.1.4 Rehabilitation of Disturbed Areas

2.1.4.1 Areas of Concern

A principal adverse impact, as a result of oil shale development, will be the necessary land area for mining operations, facilities, and the storage of overburden or waste material from open pit, underground and modified in situ mining processes. 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 piles. Problems and uncertainties related to the rehabilitation of disturbed areas include water requirements, accumulation of toxic trace substances in the vegetation, long term stability and successional characteristics of the vegetation.

2.1.4.2 Research Efforts

Several vegetative stabilization studies are being sponsored by the EPA. Surface stability and salt movement in spent oil shales and soil covered spent shales will be investigated. A mathematical model of salt and water transport will be developed to estimate the long term water quality and quantity aspects of large scale disposal of spent shale residues. The Department of Agriculture (USDA) has also studied spent shale for revegetation, stabilization or improvement by the selection of improved plants. USDA's Surface Environment and Mining (SEAM) program is examining revegetation from the standpoint of developing new species for revegetation, studying treatment of processed shale for plant growth, and identifying the physical and chemical properties of shale and retort wastes.

The DOE is preparing a detailed characterization of the Piceance Creek Basin ecosystem to determine baseline conditions. A soil microbiology study was also initiated to establish new microbiological communities through natural mechanisms for innoculation.

2.1.5 Historic Sites and Antiquities

2.1.5.1 Areas of Concern

Another problem area is the preservation of historic sites and antiquities. The National Historic Preservation Act of 1966 (PL 89-665) and Executive Order 11593, Protection and Enhancement of the Cultural Environment, 16 USC 470 (Supplement 1, 1971) protects sites of historical significance. They require all federal agencies to develop internal procedures regarding the preservation and enhancement of historic and cultural properties in execution of their plans and programs. Identification of these sites will be necessary prior to oil shale development.

2.1.5.2 Research Efforts

Since NEPA requires an archaeological and cultural resource reconnaissance prior to any development by government or private industry, numerous archaeological teams have canvassed the Green River area, looking for ancient community sites and evaluating them to learn of the life patterns of mankind in that area.

2.2 LIVING AND WORKING ENVIRONMENT

There are several fundamental questions that must be resolved to ensure the health and safety of personnel in an oil shale mining environment and the proper evaluation of socioeconomic impacts to the surrounding community. Because of the limited oil shale mining experience, these questions are numerous, and very little information is available regarding the potential hazards.

2.2.1 Health Hazards

2.2.1.1 Areas of Concern

Health hazards associated with oil shale mining include the following:

- Silica levels in oil shale dust sufficient to cause pneumoconiosis, a fibrous induration of the lungs due to irritation caused by inhalation of dust
- Potential carcinogenic properties of the organic material in oil shale dust
- Inhalation of H_2S present in mines
- Hazards attributed to the volatility of kerogen in oil shale dust
- Carcinogenic fumes, skin irritants, toxic gases and vapors from retorting processes and shale oil.

2.2.1.2 Research Efforts

The Department of Defense-Navy is conducting a study to determine the oral, ocular, and dermal toxicity, and both the acute and chronic (120 day) inhalation toxicity of JP-5 aviation fuel derived from shale oil. Additional research in the area of health effects is being sponsored by the American Petroleum Institute. Bioassays are being performed on bacteria, yeast, mamallian cells, and rats exposed to raw shale dust, processed shale dust and retort oil to observe various biological responses. Acute and subacute toxicity as well as the mutagenic and teratogenic potential of oil shale will be assessed. After these health hazards are identified, medical surveillance procedures and protocols for their control will be developed.

The mortality rates and morbidity of oil shale workers are being studied by the National Institute of Occupational Safety and Health (NIOSH) of the Department of Health, Education and Welfare. Workers from the Bureau of Mines, Colorado School of Mines Research Institute, and the Union Oil Retort facility in Grand Valley, Colorado will be examined. A retrospective mortality study of approximately 60 men will be done while a cross-sectional evaluation of several morbidity aspects that may be associated with oil shale occupations will be completed.

The DOE, with pass through funds from EPA, obtained samples of potentially hazardous materials associated with oil shale mining and various processing stages to study both lethal and nonlethal toxic effects. Through tissue microscopy and biochemistry, the site and mode of toxic action will be determined and assessed in terms of existing or proposed acceptable exposure limits for oil shale workers and the general population. DOE will also attempt to develop a protozoan system to screen for mutagens in process and waste waters from shale oil processing.

2.2.2 Mine Safety

2.2.2.1 Areas of Concern

The safety problems involved in oil shale mining are much the same as those of other mining operations with the particular constraints imposed by the nature of the material, the applicable methods of mining, and the size of the mining operation needed to supply the predicted large tonnages. The major causes of accidents are related to roof, face, and rib falls and haulage equipment. Large mine openings will present ground control and support problems related to large roof spans, high face and ribs, and stability of supporting pillars. Large high speed mining and haulage equipment will present various machinery hazards, including noise.

Potential oil shale safety problems beyond those connected with routine mine operations are associated with the following:

- Oil shale dust explosibility
- Elaterite, a very flammable material found in deep oil shales, and
- Explosive gases such as methane.

2.2.2.2 Research Efforts

One of the major areas of research in the Bureau of Mines' MER program is concerned with mine safety. Several studies are being conducted to define the explosive properties and potential fire hazards of oil shale. Research efforts will provide the limits of explosibility of various grades of oil shale, indications of the basic physical and chemical mechanisms involved, and techniques for preventing propagation of oil shale dust explosions. The Bureau's experimental bored shaft provides an excellent site for research because large quantities of methane gas were encountered during the development of planned mine drifts, and a fire, believed to be caused by materials found with deep shales, was uniquely experienced in the deep shaft workings. Also, in anticipation of future oil shale mining needs, large diesel powered engines to be used in commercial oil shale operations will be tested to ensure that the Mine Safety and Health Administration (MSHA) requirements are met. The Bureau of Mines is also supporting research work in mine subsidence to reduce the hazards created by mine construction. Data collected will allow design of stable mine openings, while maintaining maximum extraction of resources.

2.2.3 Socioeconomic Impacts

2.2.3.1 Areas of Concern

Socioeconomic impacts will result from the immigration of oil shale mining, upgrading, and refining personnel and their support coincident with commercial scale development of oil shale deposits. There will be changes in population, traditional lifestyles, community coherence, traditional religious activities, and income levels.

2.2.3.2 Research Efforts

The Natural Resource Economic Division of the USDA is in the process of developing an integrated assessment of the socioeconomic consequences of oil shale development. This work will estimate the impact energy development has on employment, income, population, and local government finances and services. The costs of mined land reclamation and uses for land after mining will also be evaluated. A joint venture between the National Science Foundation (NSF), CEQ, EPA, and ERDA (now DOE) studied the socioeconomic impacts of western energy resource development in general terms.

2.3 WASTE MANAGEMENT

The disposal of spent shale and waste water represents one of the major issues in oil shale development. Spent shale occupies a 20 percent greater volume than the raw shale in place. The ultimate proportion of this volume that must be placed in some surface disposal area depends upon the extent to which byproducts are extracted from spent shale and whether mine backfilling techniques are employed. However, unless some means can be devised for utilizing all of the spent shale, a commercial scale operation will entail substantial engineering and environmental problems associated with waste management which will be difficult and costly to solve.

Water presents another sizable problem for the mining of oil shale. To date, no technical and economically feasible system or methods exist for coping with the water quality control problems which are expected. Mining activities will cut through both fresh and saline aquifers, and any water entering a mining area must be disposed of in an environmentally acceptable manner. Further, retort waters containing residual organics must also be disposed of without tainting potable water supplies.

2.3.1 Surface Disposal of Spent Shale

2.3.1.1 Areas of Concern

There will probably always be a requirement for permanent surface disposal due to the expansive nature of oil shale after it is crushed and retorted. Retorted shale contains varying quantities of inorganic and organic residuals, the form and solubility of which are dependent upon process, site, time, and climate variables. These may be leached to surface unless retorted shales are stabilized against erosion. The current approach to surface disposal in most proposed oil shale developments is to compact, leach, and establish a vegetation cover on the spent shale. However, there are unsolved problems with implementing this approach on an operational scale.

2.3.1.2 Research Efforts

The Bureau of Mines is sponsoring several projects which will study the properties of spent shale and analyze various aspects of surface disposal design. These efforts will culminate in a full scale surface waste impoundment. Also, under a working agreement with the Bureau of Mines, the Bureau of Reclamationd is conducting a study to test and analyze various retorted shale specimens to discover any physical properties which may lead to structural use of the material in disposal facilities and as mine backfill.

The DOE is presently investigating leaching of spent shale to identify leachable salts and organics. Also under investigation are the fate and transport of these overburden leachates through typical soil systems of the oil shale regions.

2.3.2 Underground Disposal of Spent Shale

2.3.2.1 Areas of Concern

A partial solution to the environmental problems created by the surface disposal of spent shale can be afforded by returning the waste to mined out underground workings. In addition to providing an unobtrusive storage area which eliminates many environmental, health, safety and social problems associated with surface disposal, underground storage can provide several secondary benefits to the mining process. The support potential of spent shale can be exploited to reduce mining support costs, control subsidence, or provide a working platform from mining thick seams. The issue of immediate concern, however, is to determine the technical and economical feasibility of transporting and stowing the waste underground. Consideration must be given to the physical properties of materials, the structural strengths obtainable, and the environmental problems connected with disposal in areas of restrictive containments.

2.3.2.2 Research Efforts

The Bureau of Mines has directed efforts to determine the economic feasibility of alternative underground waste disposal techniques with respect to specification of equipment and operational requirements for handling and stowing wastes, the density and strengths obtainable, and the environmental problems that may be encountered such as leaching, and gas or heat liberation. As a result of this comparative study, conveyor transport and stowing has been selected as the most feasible system for underground disposal of retorted oil shale using either chamber and pillar mining or sublevel stoping. The design and demonstration of a complete backfilling operation is scheduled in the future.

The design and demonstration of an underground waste disposal system for rubblized in situ oil shale retort mining methods is also being investigated by the Bureau of Mines. Attempts will be made to inject a slurry into the coarse rubble in the in situ retort with oil shale waste material removed from the mine and retorted on the surface.

2.3.3 Water Management

2.3.3.1 Areas of Concern

The first generation oil shale mines in the Green River Formation will probably be developed in the Mahogany Zone of the Piceance Creek Basin of Colorado because of its easily accessible rich shales. Exploiting this zone from the surface, underground, or by modified in situ methods will require control of influxing water from aquifers above and below the upper oil shale sequence. Surface water shortages in the Piceance Creek Basin, and restricted use of water from the Colorado River, will make it necessary to use groundwater for mining, disposal, upgrading, power generation, revegetation, sanitary and domestic purposes. Limited testing indicates that some of this groundwater is of high quality, but much is saline. A possible method to dispose of this saline water is to pump it back into the aquifers from which it originated. However, adequate safeguards against pollution of underground water systems must be provided.

2.3.3.2 Research Efforts

Water management in oil shale mining is being investigated by the Bureau of Mines. Three specific sites in the Piceance Creek Basin were investigated, and optimal water management systems for both conventional and in situ extraction processes were generated. The Bureau has also planned a project which will develop economical and technically feasible procedures for handling and treating water from various mining and processing operations.

3. U.S. BUREAU OF MINES OIL SHALE MINING ENVIRONMENTAL RESEARCH PROGRAM OVERVIEW

The immediate predecessor of the U.S. Bureau of Mines Oil Shale Mining Environmental Research program was the Advancing Mining Technology-Oil Shale program initiated in the latter part of FY 1974*, when three contracts were awarded for the technical and economic evaluation of surface, underground, and modified in situ mining methods for deep oil shale deposits. Simultaneously, goals and objectives were established for the program, and a multiyear inhouse/contract research program was planned to address the major extraction and environmental problem areas expected to be encountered in commercial oil shale mining. This program was incorporated in the Bureau's overall energy extraction research and development program within the Division of Mining Research-Resources of the Office of the Assistant Director--Mining. Starting in 1978, the Bureau's oil shale research program, originally both production and environment oriented, was redirected to specifically address the environmental problems only and was redesignated as the Oil Shale Mining Environmental Research Program to reflect this change.

3.1 ADVANCING MINING TECHNOLOGY-OIL SHALE PROGRAM (1974-1977)

The goal of the Bureau's Oil Shale Research Program during the period from 1974 through 1977 was to test, demonstrate, and then transfer to industry improved low cost mining and waste management methods and equipment for the production of large tonnages of oil shale and shale oil by 1980. At the end of 1974, three baseline study contracts were awarded for the technical and economic evaluation of open pit, underground and modified in situ mining systems. The purpose of these studies was to supply government and industry with information for management decisions and provide data for planning and programming subsequent development and demonstration investigations. A crucial element in the program was the development of a proposed Pilot Demonstration Mine. Consequently, in 1975 a major effort was effected to obtain the basic geologic and hydrologic data needed for the selection of a suitable site for the proposed mine. Special land use permits were obtained from the Bureau of Land Management (BLM), as were other permits required by the State of Colorado before exploratory core holes were drilled. These core holes were required to verify the geologic and hydrologic conditions of the site. In addition to the proposed Pilot Demonstration Mine, several projects were initiated in areas of extraction and environmental research.

In FY 1976 and the 1976 transition quarter, the Bureau's Oil Shale Research Program significantly increased in magnitude with 20 contracts and five inhouse projects started. Again the major effort was directed toward the development of the Pilot Demonstration Mine. A proposed site for the mine was selected, three exploratory

*Unless otherwise noted, all years pertain to FY.

core holes were drilled, and extensive geologic, hydrologic and geophysical tests were conducted to determine suitability of ground conditions. An intra-agency cooperative research agreement was negotiated with the BLM for use of the 2643 acre proposed mine site and preparation of an environmental assessment report (EAR). An archaeological study was conducted to support the EAR. Detailed mine development plans were completed, and work on the design and layout of the proposed Pilot Demonstration Mine was initiated at that time.

A bored shaft was planned as a secondary access and ventilation shaft for the mine. In 1976, the site for the 120 inch diameter bored shaft was selected. An exploratory pilot hole was drilled to provide the geologic and hydrologic data necessary for shaft construction. Plans and specifications for the bored shaft were prepared, and contracts were awarded for drilling and casing the shaft. In addition to the progress made on the proposed Pilot Demonstration Mine in 1976 and the 1976 transition quarter, the three baseline technical and economic studies of open pit, underground, and modified in situ mining methods were completed and the Phase I reports for each published. These studies generated several promising concepts for large scale, low cost mining systems for economical recovery of the deep, thick oil shale deposits typical of the central Piceance Creek Basin, Rio Blanco County, Colorado.

In 1977, actual construction of the 2352 foot deep, 120 inch outer diameter bored shaft was started following site preparation work. The 96 inch inside diameter casing for lining the shaft was manufactured and delivered to the shaft site, as were two sets of 96 inch casing elevators. Shaft boring was completed on October 2, 1977 and installation and cementing of the casing was completed on December 27, 1977. A contract was awarded late in 1977 to install the necessary hoisting, ventilation and service systems in the shaft and to extract bulk samples from several mining levels of interest to the Bureau of Mines for metallurgical testing and process development. A five year research plan was prepared under another contract for conducting research studies from the bored shaft. Other projects were completed early in 1977 to provide additional geologic information prior to commencement of the shaft boring operation. These included the geotechnical evaluation of geophysical data obtained from a pilot hole drilled at the shaft site and correlation of the data with adjacent core holes drilled prior to 1977.

Several projects in the environmental component of the research program were completed in 1977 and reports on the work were published. These included a study on the disposal of retorted oil shale, and an analysis of water seepage through spent shale. Both of these efforts contribute significantly to definition of the potential waste disposal problems likely to be encountered by a commercial oil shale mining and retorting operation.

In summary, since the Bureau of Mines Advancing Mining Technology-Oil Shale (AMT-OS) Program was initially funded near the end of 1974, until the end of 1977 more than 35 contracts were awarded for research on a broad spectrum of oil shale extraction and environmental problems, as well as special studies such as the feasibility of oil mining. Eleven inhouse research projects were also conducted within the program, utilizing the expertise of Bureau personnel in research areas, such as rock mechanics, dust explosion and fire hazards, waste disposal systems design, and bit and cutter testing evaluation for mechanical excavation of mine entries. In addition to the funded oil shale research projects, the Bureau of Mines entered into eight no cost cooperative research agreements with commercial oil shale firms and cooperative agreements with the Environmental Protection Agency, U.S. Geological Survey and the Energuy Research and Development Administration. Through these cooperative agreements, the Bureau has been able to establish and maintain close working relationships with all major commercial oil shale projects currently active.

Figure 1 (see foldout in back) illustrates the overall Advancing Mining Technology-Oil Shale Program as developed from 1974 through the end of 1977. The chart shows individual projects in the areas of Surface Mining Systems, Underground Mining Systems, Modified In Situ Systems, Natural Environment, Living and Working Environment, Waste Management, Special Studies, and Program Management.

3.2 MINING ENVIRONMENTAL RESEARCH PROGRAM (1978-1983)

In early 1978, coincident with formation of DOE, the Bureau was directed to phase out the ongoing production type projects and expand environmental research. The contract for designing the proposed experimental mine, which was well underway, was continued to completion to provide a planning document for any future production type work by industry or other government agencies.

The major thrust of the new oil shale program is directed toward the environmental factors connected with the thick, deep deposits in the Saline Zone containing the major portion of the mineral resource. The purpose of these studies is (a) investigation of the potential effects of oil shale extraction on both the natural environment and the living and working environment, and (b) the study of the problems of oil shale waste management by conducting baseline studies and designing and demonstrating improved waste management methods. The results of this research and development effort will provide government and industry with the information necessary for making sound management decisions related to environmental and waste management aspects of oil shale mining.

3.2.1 Program Goals and Objectives

The goals of the Oil Shale Mining Environmental Research Program from 1978 through 1983 are to provide:

- Technology required to reduce the environmental effects of oil shale mining/shale oil extraction and ultimately to eliminate the adverse effects

- Environmental baseline data for use by government and industry in the sound planning, management and control of mining impacts.

Objectives that will ensure achievement of these basic goals are listed in the following:

- Develop, test and demonstrate technology to minimize/eliminate surface subsidence caused by underground mining or modified in situ extraction methods

- Develop, test and demonstrate technology to manage processed (spent) shale waste

- Develop, test and demonstrate technology to manage mine water, including pollution abatement, water treatment, and water distribution

- Determine the nature and extent of hazards associated with the living and working environment in the oil shale industry to ensure health and safety of the miners

- Conduct mining environmental engineering studies to define environmental problems caused by mining and to develop mitigating techniques

- Conduct assessments of the natural environment to provide pre-mining baseline data.

3.2.2 Program Structure and Rationale

The program is structured with emphasis on solving mining induced environmental problems, as opposed to achieving advancement of environmental science. Technology transfer is a key underlying element in the program, as defined in Section 3.2.3. Efforts will be integrated with environmental results of past mining research, development, and technology transfer activities. The program, as indicated in the overview presented in Figure 2 (see foldout in back), is segregated into three major categories: Environmental Engineering Systems, Environmental Control Technology, and Mined Land Reclamation Technology. Projects within these broad categories will be conducted in the following research areas:

Mining/Environmental Engineering

Environmental Assessment

Mine Subsidence

Mining Waste Management

Water Management

Living and Working Environment

Special Studies

Program Management.

3.2.3 Technology Transfer

Transfer of newly developed technology from research laboratories into practical industrial use is as necessary to the total success of the program as is the accomplishment of the initial research goal. The program places significant emphasis on technology transfer. It uses periodic and special publications, seminars, exhibits, demonstrations, cost sharing contracts, cooperative agreements, and other activities as required to expedite new developments into the industry. Equally important are the communications of technological feedback from all segments of the mining industry. Obviously, this is crucial in directing ongoing and future projects toward the most important problem areas.

3.2.4 Program Strategy

The Bureau will accomplish the objectives set forth in this program by using a combined contract and inhouse research program to advance simultaneously all areas of investigation in the program. Because no one area can be singled out as the most important factor influencing the interaction of mining with the environment, the Bureau has decided to support research only in areas where it has expertise and demonstrated capabilities. Areas outside the Bureau's normal range of inhouse activities will be advanced by contract. The program structure allows for investigation of short range solutions and more comprehensive, longer range solutions depending on the level of effort afforded the program. Principal emphasis will be placed on obtaining cost sharing agreements with mining companies for eventual demonstration of new equipment and techniques developed under the program. The alternative would have been to rely on the mining industry or other government agencies to perform the needed research and development. However, because industry has not demonstrated a willingness to perform this role, this alternative has been rejected. Similarly, although other government agencies are conducting environmental research related to oil shale mining, the Bureau possesses unique capabilities to develop a successful program that will solve the critical environmental problems facing mining operations in the 1980s and beyond.

4. OIL SHALE MINING ENVIRONMENTAL RESEARCH PROGRAM

4.1 ENVIRONMENTAL ENGINEERING SYSTEMS

4.1.1 Mining/Environmental Engineering

The Bureau of Mines' mining/environmental engineering element consists of projects aimed at developing a bored shaft. The aim of this shaft development work is to construct a mining environmental research facility for studying the environment related effects of future deep mining of oil shale. The construction of the bored shaft involves the nine projects shown in Figure 3, three of which are not projects in the true sense of the word, but purchases of equipment and services required for the shaft. They are: (a) elevators for mine shaft casing, (b) equipment for drilling and casing shaft, and (c) BOM-DNA loan agreement. The six remaining projects are to prepare the bored shaft for the environmental studies to follow.

A 10-foot diameter shaft was bored from the surface to a depth of 2371 feet and lined with an eight foot inside diameter steel casing. After the shaft was equipped a 400-ton bulk sample of oil shale containing dawsonite was mined from the No. 5 level at a depth of 2079 feet below the shaft collar. Subsequently, a 35 ton sample of oil shale containing nahcolite was mined from No. 3 level at a depth of 1844 feet. Proposed environmental studies utilizing the bored shaft include gathering geotechnical data for mine design purposes and analysis of samples of oil shale, nahcolite and dawsonite obtained from levels 3 and 5. Correlation between the surface geology and geology at depth will also be sought. A fourth proposed project to be conducted at the Mining Environmental Research Facility will consist of rubblization experiments in a simulated modified in situ retort.

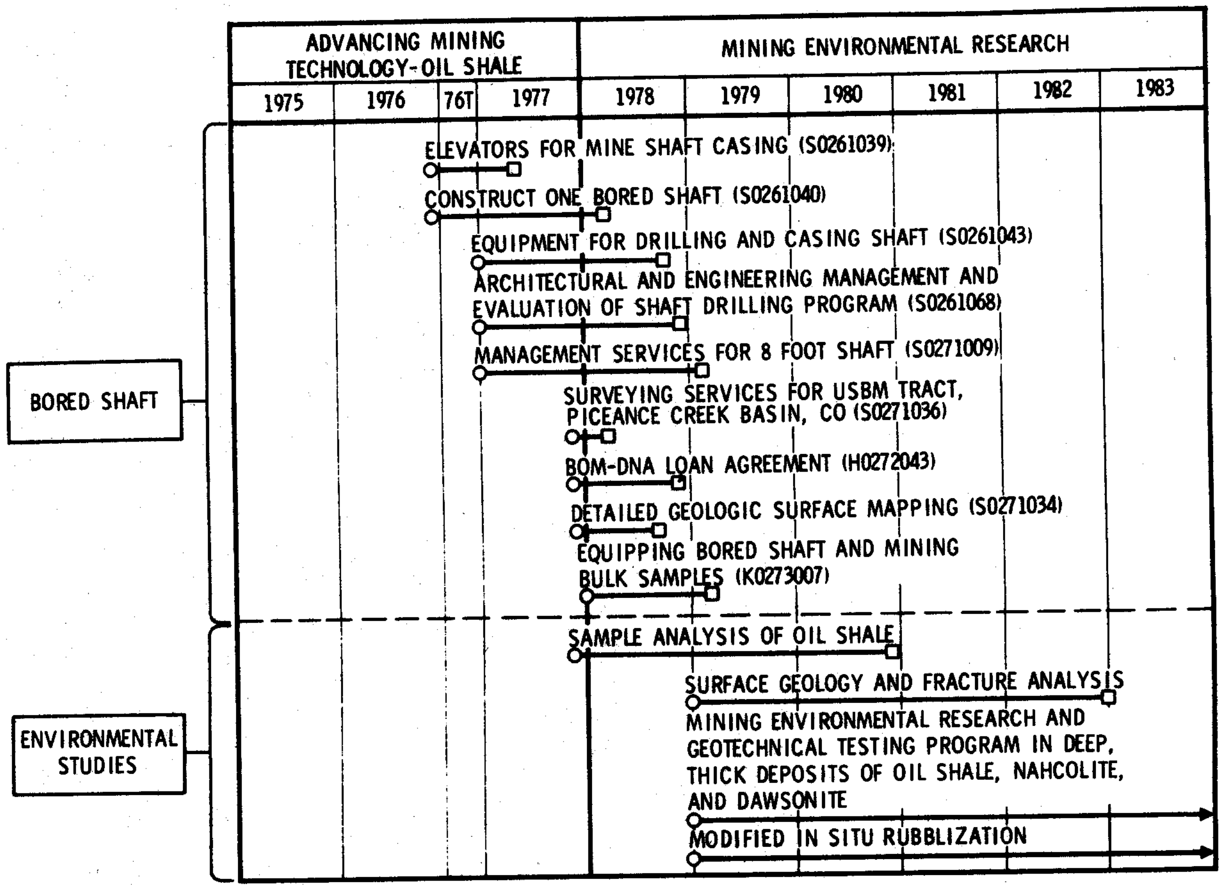
4.1.1.1 Construction of One Bored Shaft (120 Inch)

Rowan Drilling was contracted to drill and case the shaft at the proposed demonstration mine site. This was only for drilling services. The contractor (as indicated in Section 3.1) moved onto a preconstructed drilling pad, bored a 120 inch hole which bottomed out at a depth of 2371 feet, set a 96 inch ID casing to 2352 feet and cemented it in place, rigged down, cleaned up the site, and removed drilling equipment. The project was delayed in July 1977 while fishing operations were conducted to recover the cutter head which had sheared off and lodged in the hole 1245 feet from the surface. The cutter head was lost when boring had progressed to a depth of 1781 feet. Construction started in June 1976 and ended December 1977. The total cost was $2.099 million.

Completion of this blind bored shaft demonstrated successful boring into the deep oil shales of the Piceance Creek Basin, Rio Blanco County, Colorado. This pioneer shaft allowed access for the first time to the deep shales for research studies. Information about this unique project was transferred to industry, other government agencies, other organizations interested in oil shale and the general public by means of news media, technical papers, briefings, and onsite visits. Over 2000 persons visited and observed the project.

Figure 3.

Mining/Environmental Engineering



4.1.1.2 Architectural and Engineering Management and Evaluation of Shaft Drilling Program

The architectural and engineering services project was conducted by Fenix and Scisson, Inc. They developed a detailed site and shaft development plan with instructions on the drilling and casing of the shaft and the mining of the bulk ore samples. Anticipated construction problems were identified, materials and procedures were described, and cost estimates were prepared. Recommended procedures were modified as required to compensate for the unforeseen problems which were encountered when the shaft was bored.

The contractor managed all phases of the construction of the bored shaft and supplied necessary materials, supplies and services. In particular, the contractor performed the following:

- Managed construction and drilling services
- Designed engineering, as required, for access roads and pits, miscellaneous drilling equipment, water well completion, etc.
- Purchased and controlled bits, cement, geophysical logging, pipe and casing, support services, drilling mud and additives, and all other supplies and services necessary to drill and complete the shaft, except for those purchased and furnished by the government or the drilling contractor
- Rented and supplied equipment, supplies and services necessary to drill and complete the shaft.

Funding for this project was $4.412 million. The project was initiated in September 1976 and ended September 1978. The final report, entitled "Drilling and Casing a 96 Inch ID by 2371 Foot Deep Shaft in Oil Shale," was submitted on September 29, 1978.

4.1.1.3 Management Services for 96 Inch ID Shaft

William Brothers Process Services, Inc., under the management services contract, provided an onsite program manager for the bored shaft construction program. The manager's duties included:

- Onsite representation for the Bureau of Mines during bored shaft construction
- Coordination and management of program activities between all contractors and subcontractors
- Review and recommendation of appropriate action to the Bureau of Mines regarding: specifications, estimates of costs, and justification statements for contract modifications, contractor claims and proposals, contract billings, and reports on tests of materials and equipment
- Design and supervision of the pouring of the concrete drill pad
- Review of casing, welding, and radiographic packages.

After the field work was completed in January 1978, Williams Brothers Process Services, Inc., continued to assist in review of final reports and vouchers, and checking on the return of loaned equipment. The total cost of the project was $138,000.

4.1.1.4 Surveying Services for USBM Tract, Piceance Creek Basin, Rio Blanco County, Colorado

Kucera and Associates, Inc., were contracted to provide detailed topographic maps, and color and color infrared aerial photography of the 2460 acre USBM Oil Shale Tract located in Rio Blanco County, Colorado. Permanent ground control monuments were placed throughout the tract for future surveying reference and subsidence studies. Detailed surveying services, such as those provided under this project, follow good engineering practice. The project performance period was from August 1977 to December 1977, and the project funding was $24,000.

4.1.1.5 Detailed Geologic Surface Mapping

Detailed surface geologic maps of the USBM Oil Shale Tract, Piceance Creek Basin, Colorado were provided by Amuedo and Ivey. These maps were placed on open file for use by other interested parties. Work started in September 1977 and was completed in May 1978 at a cost of $22,000.

4.1.1.6 Equipping Bored Shaft and Mining Bulk Samples

One of the primary initial objectives of the oil shale MER program was to equip the bored shaft and obtain bulk samples of oil shale, nahcolite and dawsonite for metallurgical research and process testing. A contract was awarded to Harrison-Western Corporation at the end of 1977 to accomplish this objective. Beginning in April 1978, the contractor erected a headframe and surface plant, and equipped the shaft with necessary hoisting, ventilation, manway and service lines.

When the shaft was operable, attempts were made to cut a station at the No. 2 level 1675 feet below the surface. When holes were drilled through the shaft casing, large quantities of water and methane gas were encountered. The water was drained and grout injected into the void outside the casing. The decision was made to seal the drill holes at level 2, and proceed with the development of level 5 (2079 ft) and level 3 (1844 ft). Level 5 was developed first, and a 10 ft x 10 ft drift was driven approximately 90 feet from the shaft resulting in the recovery of a 400 ton bulk sample of dawsonitic oil shale. Large quantities of methane were encountered. A fire in the drift required that mining operations be terminated on level 5. With remaining contract funds, initial development of level 3 was begun. Approximately 35 tons of oil shale containing bedded and nodular nahcolite were brought to the surface before contract funds ran out and work stopped in January 1979. The shaft was placed in standby status effective January 31, 1979. Funding for this contract was $1.219 million in 1977 (AMT funds), $840,000 in 1978, and $275,000 in 1979.

4.1.1.7 Sample Analysis of Oil Shale

Under the contract for equipping bored shaft and mining bulk samples, large bulk samples of oil shale, nahcolite and dawsonite were mined. These and core samples will be analyzed under this project by Colorado School of Mines to evaluate the economic potential of oil shale mining. The tests will consist of saline analysis by wet chemical techniques and Fischer assays to determine shale oil content. Analysis started in August 1978 and is scheduled to be completed by September 1980.

4.1.1.8 Surface Geology and Fracture Analysis

Upon completion of the current contracts, five levels in the deep saline oil shale were to have been mined to a distance of 100 feet from the shaft, but only levels 3 and 5 were developed. These levels offer the first opportunity to actually examine these oil shales as they exist at depth. Fracture and geologic maps of these levels would offer a unique opportunity to study the relationship between the surface geology and the geology at depth, particularly with respect to fractures.

The objective of this project is to determine the feasibility of predicting subsurface fracture and joint patterns from surface observations of such patterns and from drill core analysis. If it can be determined that there is definitive predictable correlation, many of the problems in underground mine design can be ameliorated. The development and utilization of a predictive computer model using such correlations could be used prior to the start of mining opertions and would allow the design of a safer, more economical mine and would probably enhance recovery of the resource. Project duration is from 1979 through 1982.

4.1.1.9 Mining Environmental Research and Geotechnical Testing Program in Deep, Thick Deposits of Oil Shale, Nahcolite and Dawsonite

Following the boring and casing of a small diameter shaft through the deeper deposits of the Basin, geotechnical tests will be conducted under this project. The geotechnical data to be gathered are needed to verify and supplement design data from surface core holes, and to design environmentally acceptable systems for the extraction of the thick deposits of oil shale, nahcolite and dawsonite.

This research and testing program is scheduled to start in January 1979 or at the end of the equipping bored shaft and mining bulk samples project. Detailed plans and specifications for this multiyear program have been prepared by the Denver Mining Research Center (DMRC) and by the Cleveland-Cliffs Iron Company under a modification to contract J0265020.

4.1.1.10 Simulated Modified In Situ Rubblization

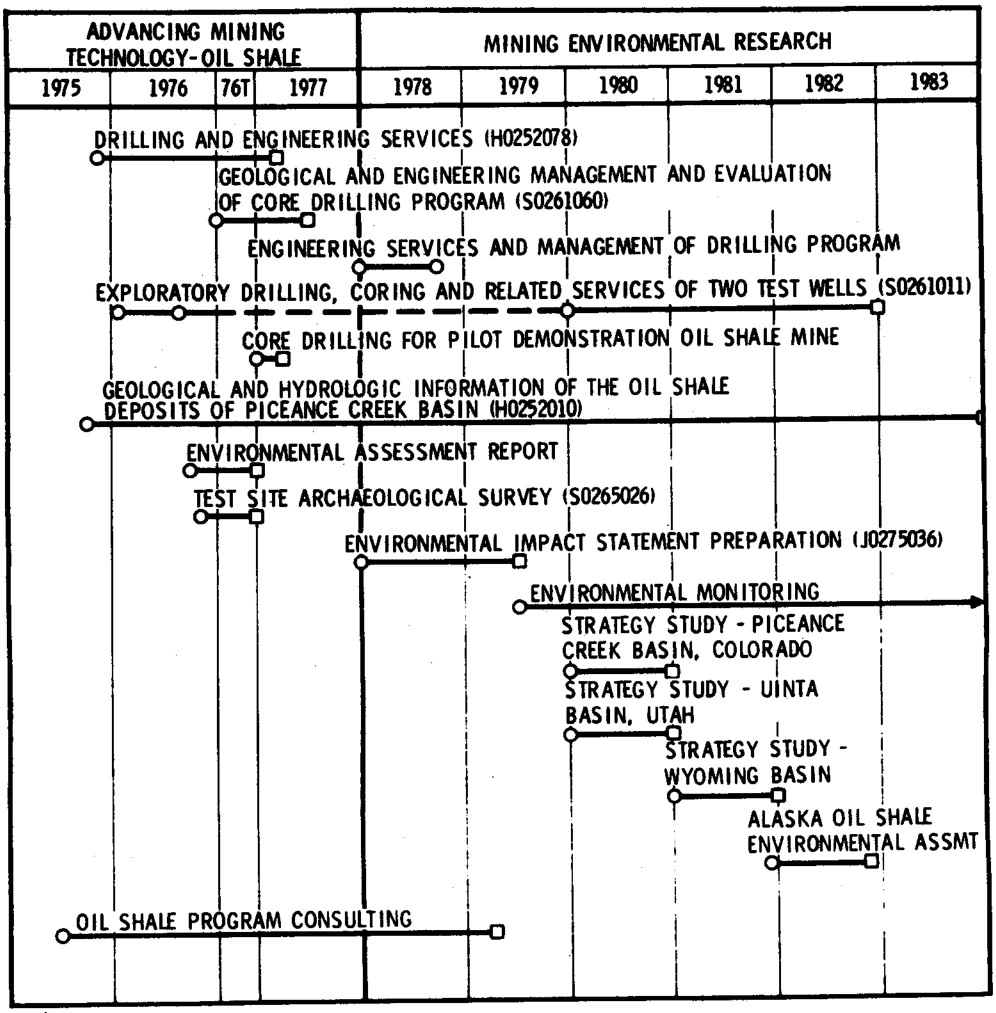
The objective of this proposed contract is to construct a simulated modified in situ retort at the Bureau's Oil Shale MER Facility at the Piceance Creek Basin. This simulated modified in situ retort would be used for fragmentation experiments and subsequent permeability tests. No retorting of oil shale would be done. The research would result in a better understanding of the mechanics and control of in situ rubblization of oil shale, permitting development of improved rubblization techniques which, in turn, would improve recovery of oil from oil shale. The term of the contract is from March 1979 to February 1983.

4.1.2 Environmental Assessment

Eleven projects presently compose the environmental assessment program. They are illustrated in Figure 4 along with four projects sponsored by the AMT-OS program. The first six projects support core drilling and the evaluation of the geology and hydrology at the bored shaft site. The core holes are exploratory in nature and directed at determining the suitability of the proposed site by acquiring the geologic, physical and hydrologic data, such as lithology, fractures and porosity, water quality and water quantity. The "Geological and Engineering Management and Evaluation of Core Drilling Program" and "Core Drilling for Pilot Demonstration Oil Shale Mine" projects were completed under the AMT-OS program.

Figure 4.

Environmental Assessment



The next eight projects are in keeping with the dictates of the National Environmental Policy Act of 1969 and various other clean air and water laws. The AMT-OS program provided an environmental assessment report (EAR) describing the potential impacts that may result from the Bureau's oil shale activities and a reconnaissance survey which described the location, extent and significance of historically important archaeological sites in the area of the Bureau's research facility at the Basin. An environmental impact statement (EIS) followed these projects to provide an analysis of the potential environmental impacts resulting from the activities conducted in the bored shaft. Monitoring of environmental factors is scheduled to detect any adverse impacts which may occur as a result of these proposed activities. Regional programmatic environmental assessments are also planned in the future for the Piceance Creek Basin of Colorado, Uinta Basin of Utah, Wyoming Basin and Alaska. They are to ensure that oil shale development in these areas is done in an orderly and environmentally safe fashion.

The objective of the last project in this program is to initiate a cooperating effort between the Bureau of Mines and other government agencies active in oil shale mining environmental activities.

4.1.2.1 Drilling and Engineering Project

Engineering services, materials, supplies and equipment during the drilling, testing and completion of two boreholes at the demonstration mine site in the Piceance Basin were provided under a Memorandum of Understanding with the U.S. Energy Research and Development Administration (ERDA, now DOE) - Nevada Operations. Initially, ERDA prepared a drilling plan, cost estimates, drilling specifications, and a preliminary feasibility study for the boreholes. After drilling contractor selection, ERDA (a) supervised site preparations, (b) provided facilities for drilling contractor personnel, (c) provided technical direction during the test borehole drilling, and (d) supplied casing, tubing, and other materials and equipment needed to complete the wells. Technical direction included (a) supervision of drilling and coring, (b) recommendation of casing programs and completion practices, (c) monitoring installations of pumping equipment and tubing, and (d) general liaison with the drilling contractor. ERDA also supervised site cleanup activities.

The drilling technology, lithology, and hydrologic conditions encountered during the drilling operations were transferred to and used by mining companies, oil companies, universities, consultants, research centers and others with an interest in the conditions to be encountered in deep oil shale formations. The work started in May 1975 and was completed in November 1977. Funding for the drilling and engineering project was $415,000.

4.1.2.2 Engineering Services and Management of Drilling Program

Geological and engineering management services for a core drilling program at the field test site must be provided. There is a need for supervision of coring and hydrologic testing operations, preparation of well history and geologic reports, and a detailed analysis of the geology and hydrology as they affect the proposed site. These services began in September 1977 and ended in December 1977. $27,000 was allocated for this task.

4.1.2.3 Exploratory Drilling, Coring, and Related Services of Two Test Wells

The purpose of this contract is to drill, core and test two core holes required to provide information as to geology, fracture patterns and orientation, hydrology, mineral content, etc., of formations underlying the MER Facility tract. This project is a logical follow-on to a drilling program started in 1976 which outlined the areas where shaft sinking would occur, defined hydrologic conditions, local dip and strike of the formation at the proposed mining horizon, and provided more detailed knowledge of fractures, joints and faults present in the rocks at the horizon. The data obtained under this contract will be obtained in the areas where actual underground openings are planned. Drilling operations are expected to start in January 1979 and continue until October 1982.

4.1.2.4 Geologic and Hydrologic Information of the Oil Shale Deposits of Piceance Creek Basin, Installing, Maintaining, and Monitoring a Water Measuring Station

In support of the environmental assessment phase of the program, the geologic and hydrologic information project is being performed by the USGS. Its objective is to provide geologic and hydrologic characteristics of the oil shale formations at the Piceance Creek Basin mine site. In particular, the study is directed to obtaining information regarding the quality, quantity, and capacity of deep aquifers above and below the Mahogany Zone. This information was required before a demonstration mine design could begin.

The USGS conducted onsite studies and tests of the geologic and hydrologic characteristics of the formations to be encountered in a demonstration mine. Survey personnel monitored the drilling of cores, log samples, and conducted hydrologic tests in the core holes. Samples and cores were analyzed and detailed lithologic logs were prepared.

Data collection started in March 1975 and was completed. All work was done under an Interagency Working Fund Agreement and $275,000 was spent.

The analytical reports describing water quality, water quantity, and formation capacity were used as baseline information in the EIS being prepared for the demonstration mine site. The water data will be published in Bureau reports and will be available to oil companies, mining companies, universities and others interested in the geology and hydrology of the deep oil shale deposits.

4.1.2.5 Environmental Impact Statement Preparation

In April 1976 an EAR was prepared by the BLM under the AMT-OS program to determine whether the impacts resulting from an underground demonstration mine were sufficient to require the preparation of a full EIS before a construction permit could be granted. Also, in direct support of the EAR, the AMT-OS program sponsored a project to conduct an archaeological reconnaissance of the proposed underground mine demonstration site in the Piceance Creek Basin of Colorado to determine the location, extent and significance of any historically important archaeological sites in the proposed mining withdrawal area. The EAR made two recommendations. The first recommendation was that the proposed mine demonstration project be permitted to proceed to gain additional information from geophysical work and core drilling at the shaft site. However, it further recommended deferring additional action on mine development until an EIS had been prepared which would provide more quantitative site specific data for the analysis of resulting impacts. The second recommendation suggested that the demonstration project be permitted to proceed and be subject to reviews to be held at key stages of the development, such as at the completion of the geophysical and core drilling program, and at the completion of the 96 inch ID shaft.

The Bureau elected to follow the first recommendation and awarded a contract to VTN-Colorado for "Preparation of an EIS for the Bureau of Mines Experimental Oil Shale Mine." With the advent of the new MER program in 1978, the original contract was modified and limited to the research work planned from the bored shaft. VTN-Colorado, Inc., started work on this project in September 1977. A preliminary draft of the environmental report was completed in November 1978 and the draft EIS was completed in February 1979. Funding for this project was $155,000.

4.1.2.6 Environmental Monitoring

After the baseline EIS has been accepted, it will be necessary to monitor critical environmental factors on a continuing basis at the site of the oil shale MER facility during its development and operation to ensure minimal adverse impact of the facility on the existing environment. Critical environmental factors, such as water and air quality and plant and animal life, will be kept under constant surveillance. Any adverse impacts created by development activities will be assessed so that necessary mitigating measures can be undertaken. The data obtained from this project will also be useful in planning for rehabilitation of disturbed areas on the site as soon as possible following the Bureau's use of the area for mining environmental research purposes.

The planned program will begin in 1979 (after the completion of the EIS), and extend throughout the program, to 1987 and beyond, until the research facility is either leased to industry or abandoned after a supervised reclamation.

4.1.2.7 Strategy for Oil Shale Mining Development and Environmental Safekeeping of the Piceance Creek Basin of Colorado

All major investigations of oil shale mining in the Piceance Creek Basin have been limited to one method and one proposed mine site. The notable exception to this is the Final Environmental Statement for the Prototype Oil Shale Leasing Program (USDI, 1973) which addressed several mining methods and six sites throughout Colorado, Wyoming, and Utah. No long range plan exists for the orderly development of this valuable resource. Such a long range development plan is needed to provide government and industry planners with guidelines upon which to base management decisions and alternative strategies.

Based on present mining technology in relation to the socioeconomic and environmental constraints of the Basin, a total mining strategy throughout the Piceance Creek Basin for the optimum resource recovery of the oil shale deposits will be developed under this project. Different mining methods (surface, underground, and in situ) and various waste management techniques will be needed in accordance with site specific conditions, due to the diversity of geologic, hydrologic, topographic, and other conditions of the Basin. However, environmental issues resulting from the use of these methods are relatively consistent regardless of the area of their application. The environmental issues demanding solution are resource management, environmental safeguards, mine development scheduling, health and safety regulations and leasing policies. A basinwide programmatic EIS can discuss and analyze these issues, as well as provide an accurate information resource which may be used to enhance required site specific impact analyses as they are prepared in step with Basin development.

4.1.2.8 Strategy for Oil Shale Mining Development and Environmental Safekeeping of the Uinta Basin of Utah

A study will be made, under this contract, to evaluate the best mining methods for all the areas in the Uinta Basin of Utah that are adaptable for mining oil shale based on the socioeconomic and environmental constraints of the area. Technical and economic feasibility studies of three methods of mining oil shale and extracting shale oil from the deeply deposited oil shale beds of the Piceance Creek Basin have been completed under the AMT-OS program. The results of these and other studies will be analyzed for their application within the Uinta Basin and synthesized to develop the total strategy for mineral production from the Basin. The results of the study will allow priorities to be established by government and industry for various stages of the resource development in relation to demand. This study will be conducted in 1979.

4.1.2.9 Strategy for Oil Shale Mining Development and Environmental Safekeeping of the Wyoming Basin

The Wyoming Basin will be assessed for socioeconomic and environmental constraints under this project. In Wyoming, the Tipton member of the Green River Formation shows the greatest potential for development. Total resources of oil shale are estimated to be the equivalent of 730 billion barrels of oil. A basinwide programmatic EIS similar to those prepared for the Piceance Creek Basin of Colorado and Uinta Basin of Utah will be conducted in 1980.

4.1.2.10 Alaska Oil Shale Environmental Assessment

Increasing pressures are being exerted to develop rapidly and mine areas of the country, such as Alaska, where impact effects of mining on the environment have had minimal documentation. Alaska has soil and climate conditions that differ from most mining districts in the lower 48 states so that existing regulations concerning replacement of spoil and ensuing efforts for revegetation may have to be amended.

This project proposes to examine the unique environmental and socioeconomic constraints of Alaska oil shale mining. The proposed starting date for this year long project is September 1981.

4.1.2.11 Oil Shale Program Consulting

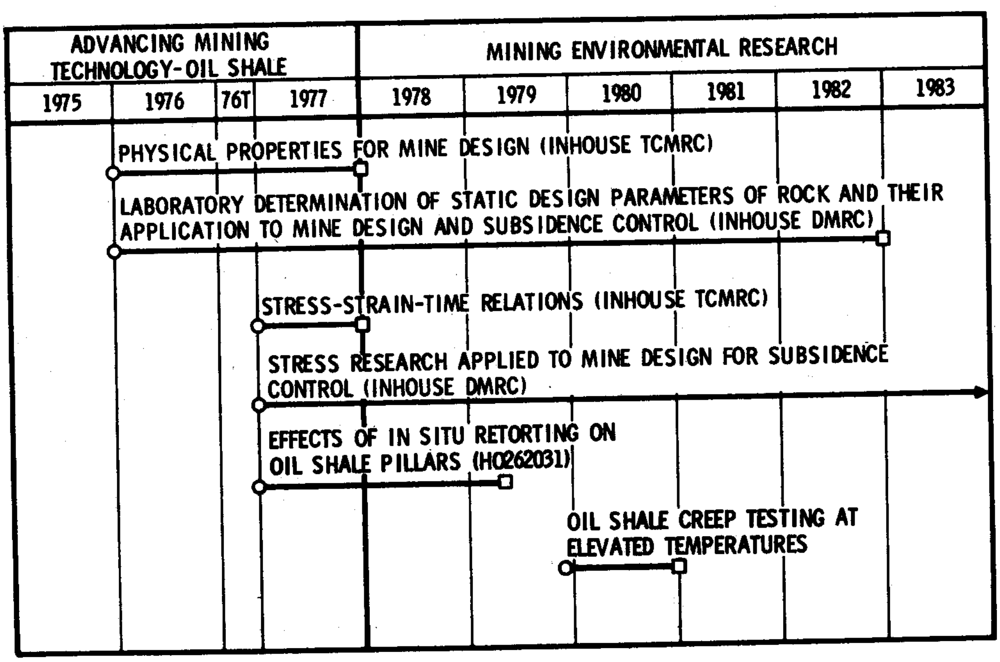
Several government agencies have programs dealing with the environmental concerns of oil shale mining, as discussed in Section 2. This project is designed to maintain a cooperative effort between the USBM and these other agencies, specifically the Environmental Protection Agency. Duplication of work and insufficient research in other area of study will be eliminated through such efforts. Technology transfer will also be greatly enhanced.

4.1.3 Mine Subsidence

The overall goal of this portion of the program is to minimize the adverse environmental effects of mining induced subsidence, while maintaining maximum extraction of resources. The six projects illustrated in Figure 5 are directed at the accumulation of various physical and mechanical property data for mine design. Without the benefit of a thorough knowledge of these rock properties, conservative engineering design tends to reduce ultimate resource recovery by maximizing structural support members.

Figure 5.

Mine Subsidence



The AMT-OS program initiated the first five projects and completed two. The physical properties for mine design project determined the physical and mechanical properties of oil shale deposits in the Parachute Creek Member of the Green River Formation, while the stress-strain-time relations project analyzed the effect of strain rates on the mechanical properties of oil shale through time. In keeping with an environmental focus, the MER program continued to study the static design parameters of rock and their application to mine design and subsidence control, stress research applied to mine design for subsidence control, and the effects of in situ retorting on oil shale pillars. The effects of in situ retorting projects revealed that time dependent deformation, or creep, does exist at elevated temperatures, so an additional project was added to this element.

4.1.3.1 Laboratory Determination of Static Design Parameters of Rock and Their Application to Mine Design and Subsidence Control

The laboratory determination of static design parameters project will acquire information needed for the entire oil shale industry. A better understanding of subsidence control, mine design, and the behavior of rock material will be gained from this project. Rock samples were obtained by members of the DMRC from various mining areas in Colorado and Utah, and static design parameters, fractured and unfractured, were developed under simulated field conditions on models made from the prototype rock. This information is essential for the evaluation of permissible subsidence, extraction ratios, safety factors and the definition of optimum design criteria for use in the recovery of oil shale. Funding for this project to date is $459,000 and the term of this inhouse project is from July 1975 to October 1982.

Oil shale cores from various sites were tested and functional relationships were established relating Fischer assays to compressive strength, apparent specific gravity, and Young's modulus. Also determined were the effects of different levels of dawsonite and nahcolite on these mechanical properties. Results show that a larger percentage than 10 percent nahcolite tended to lower the compressive strength and to increase Young's modulus.

Several preliminary load compaction tests were run on surface retored oil shale from the Logan Wash area of Utah. Also, uniaxial, triaxial, Brazilian and modulus of rupture tests were completed on cores obtained in the air room pillars of Occidental Retort No. 6 at DMRC. Long term creep testing of materials from these pillars was also initiated, since time dependent data will be significant in estimating the magnitude of surface subsidence.

4.1.3.2 Effects of In Situ Retorting on Oil Shale Pillars

In situ retorting is a promising technique for developing low grade, deep oil shale beds. However, there is a lack of adequate test data on the thermal properties and thermal response of oil shale. Thermal measurements are necessary to quantify the effect of retorting temperatures on (a) the recovery of kerogen from pillars between in situ retort, (b) the strength of support pillars, and (c) the possible distortion of underground and surface formations above the retorted ore body. Work done by the Colorado School of Mines (CSM) under this contract identified, measured and analyzed properties of importance to in situ retorting.

The immediate effort of this project was confined to the oil shale in the leached zone (dry) containing less than 30 gallons of oil/ton. This zone is a prime candidate for in situ retorting operations. Work involved the measurement and evaluation of shale properties at several temperature levels from ambient to 500°C. Properties measured included thermal conductivity, thermal diffusivity, thermal expansion and strength. Project emphasis is directed towards determining the kerogen recovery from support pillars, the extent that support pillars weaken due to retort heat effects, the use of rubble as pillar support to prevent subsidence, and the extent of surface or subsurface subsidence which can be attributed to retort heat effects. Duration of this project was from June 1976 to August 1978 and $402,000 was spent.

4.1.3.3 Stress Research Applied to Mine Design and Subsidence Control

The objectives of this project are to: (a) maintain inhouse capability for determining accurately the state of stress in rock, (b) determine in situ stresses and loading conditions in mines and mine structures, (c) investigate relationships between existing in situ rock stresses and ground control problems, and (d) input this into the mine design process. The project will lead to a better understanding of the effects of underground mining and mine design on the surface environment, specifically pertaining to subsidence and long term stability of surface areas.

The study includes the measurement of the applied stress field, the variation of the stress field due to changes in geology, structure, depth and temperature, stresses in zones of concentration, arching effects near underground openings, and the monitoring of stress changes near those openings. Measured in situ stresses will be used as input to both theoretical and finite element analysis of mine design and structural problems. These include (a) the determination of the stress field at sites in Utah and Colorado so that these values can be used in initial designs for oil shale mine planning and (b) the study of stresses and distributions near modified in situ retort experiments for use in future planning of retorting programs.

This project has provided technical assistance and guidance to mining companies, contractors, other government agencies, schools, and foreign governments who desire and need stress information for better planning, control and design of underground openings. However, the primary mode of technology transfer was to accompany personnel on the site during the field testing program and demonstrations. The group of cooperating organizations has included: Western Oil Shale Corporation, Superior Oil Company, White River Shale Project, Union Oil Company, and Colony Oil Shale Development Company. DMRC has been conducting this study since October 1976 and $243,000 has been spent thus far.

4.1.3.4 Oil Shale Creep Testing at Elevated Temperatures

In the course of strength tests conducted under the "Effects of In Situ Retorting on Oil Shale Pillars" contract, time dependent deformation, or creep, was observed to increase to very significant levels with even small increases in temperature. Large deformations resulting from creep can have severe consequences on mine structures and the environment as it relates to surface subsidence. An understanding of the effect of heating on oil shale creep and its magnitude is therefore essential for a valid in situ mine design.

Under this project, four grades of oil shale will be creep tested at several temperatures up to approximately 250°C. The results of these creep tests will be included with the thermal and thermophysical properties obtained from the effects of in situ retorting on oil shale pillars project in a mathematical model for pillar design and subsidence prediction. This year long project will begin in September 1979.

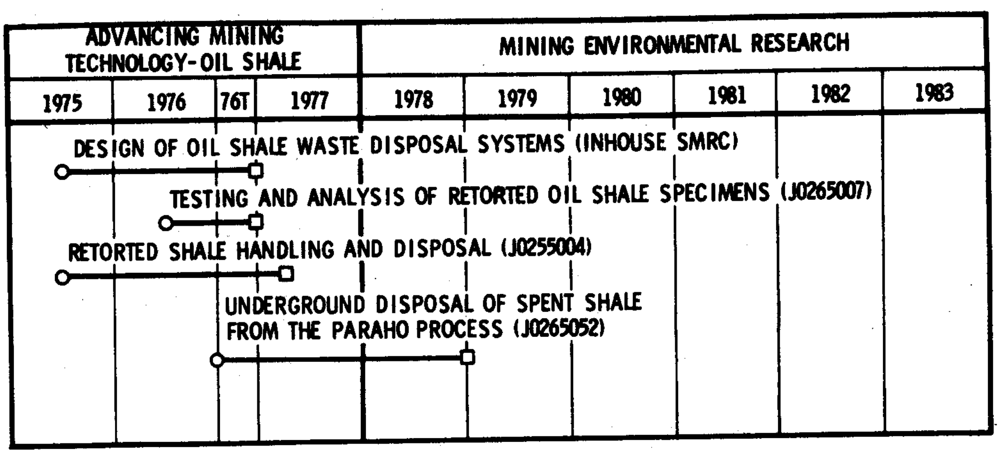
4.1.4 Mining Waste Management

The disposal of spent shale represents one of the major environmental issues in oil shale development. The engineering and environmental problems connected with the large volumes of solid wastes anticipated in a full scale operation will be difficult and costly to solve. If these problems cannot be answered, waste disposal may be the deciding factor in determining the economic feasibility of a viable oil shale industry. The four projects listed in Figure 6 are designed to address these problems.

The design and construction criteria required for developing shale waste disposal systems are provided in the first project, while information on the properties of the retorted shale is given in the "Testing and Analysis of Retorted Oil Shale Specimens" project. The handling and underground disposal of spent shale from the Paraho process is addressed in the third and fourth projects. The first three projects were conducted under the AMT-OS program.

Figure 6.

Mining Waste Management



4.1.4.1 Underground Disposal of Spent Shale from the Paraho Process

The objective of this project was to determine the most desirable systems for underground disposal of spent shale from the Paraho process based on mining methods most likely to be employed by the oil shale industry. The economic feasibility of alternative underground waste disposal plans was considered with respect to specification of equipment and operational requirements for handling and stowing the waste, the density and strengths obtainable, and the environmental problems that may be encountered, such as leaching, gas or heat liberation, etc. The investigation examines the following variables: material properties, methods of transportation (mechanical or hydraulic, or pneumatic), placement methods (wet and dry), strengthening schemes (compaction or additives), and mining methods (chamber and pillar, or sublevel stoping).

As a result of this comparative study, conveyor transport and stowing has been selected as the most feasible system for underground disposal of retorted oil shale using either chamber and pillar mining or sublevel stoping. This analysis was based on a deep mine in the Piceance Creek Basin and the use of retorted shale from the Paraho direct heating mode of retorting. When compared to the other alternatives, this system has the following advantages: (a) highest fill density, (b) most retorted shale placed underground, (c) highest pillar support potential, (d) lowest energy requirement, (e) lowest capital and operating costs, (f) least potential for ground water contamination, (g) least surface disruption, (h) least environmental degradation, and (i) safest overall method. The Cleveland-Cliffs Iron Company conducted this project from July 1976 to October 1978 at a cost of $304,000.

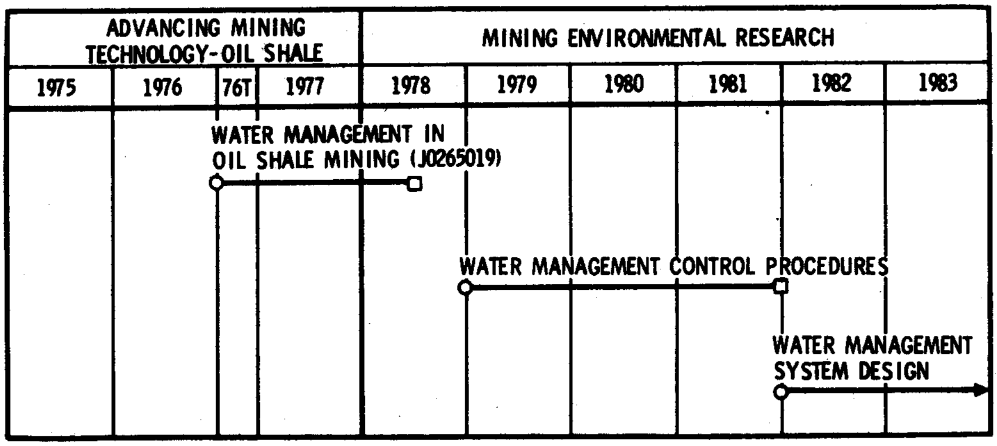
4.1.5 Water Management

Water presents a sizable problem for commercial oil shale resource developments. To date, no technical and economically feasible systems or methods exist for coping with the water supply and quality control problems which are expected. Mining activities will cut through both fresh and saline aquifers and any water entering a mining area must be disposed of in an environmentally acceptable manner. Further, retort waters containing residual organics must also be disposed without contamination of potable water supplies. In addition to waste water disposal needs, the water supply requirements of oil shale mining related reclamation and support activities must be met consistent with governing federal and state regulations and a continued source of these waters must be assured.

Figure 7 illustrates the three projects in the water management program. The first of these projects surveyed water management requirements and proposed control procedures. The second project in the series will expand upon this work, and the final project will design a water management system for a specific site.

Figure 7.

Water Management



4.1.5.1 Water Management in Oil Shale Mining

The water management in oil shale mining project was directed to develop methods of management which are technically feasible and environmentally acceptable within the Piceance Creek Basin. Three specific sites were investigated, and optimal water management systems for both conventional and in situ extraction processes were generated. Water related legal and environmental constraints on development were identified, and the water management schemes were developed in compliance with these regulations.

The final report gives a range of possible water management cases by presenting three systems: conventional, minimum in situ, and maximum in situ. Limitations on shale oil production implied by limited water supplies were also evaluated. Through use of a computer model, potential basinwide effects of development were assessed. It was found that there are no major negative postmining impacts upon the hydrology of the Basin which cannot be economically mitigated by appropriate activities during the mining phase. Recommendations for additional investigation and analyses are also presented. Golder Associates worked under this contract from June 1976 to April 1978. Funding was $116,000.

4.1.5.2 Water Management Control Procedures

The planned water management control procedures project will conduct studies which were recommended in the water management in oil shale mining project. The objective of the project will be to develop economical and technically feasible procedures for handling and treating water from various mining and processing operations. The general hydrology of the selected mining site will be considered, including the expected influx of water due to mining and the techniques used to control this influx. Water requirements for the following will be determined by: (a) spent shale disposal (hydraulic transport, compaction), (b) dust control (conveyors, haul roads, mining, crushers), (c) retorting and upgrading, and (d) reclamation work. The need and requirements for water recycling or water treatment will be discussed. This project began in 1978 and will continue until 1981.

4.1.5.3 Water Management System Design

Under the water management system design project, the results of previous studies will be integrated into a water management program for a specific site. Required capital equipment, installation and operational procedures will be defined, and a water management program will be outlined which complements the series of planned mining method tests and the underground disposal demonstration. Detailed costs will be provided for future equipment procurement. Work on this project will begin when the water management control procedures project is completed in 1981.

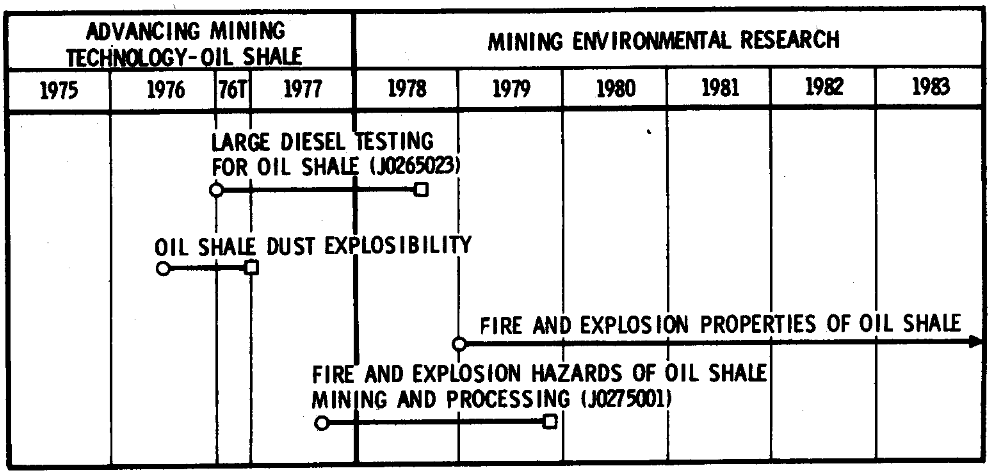
4.1.6 Living and Working Environment

The living and working environment program addresses fundamental questions that must be resolved to ensure the health and safety of personnel in an oil shale mining environment. Because of limited oil shale mining experience, these questions are numerous. Ultimately, as a result of planned investigations, equipment specifications and operating procedures will be formulated and required technology developed to provide for safe, healthy working conditions in all oil shale mining facilities.

Four projects are included within the program. They are depicted in Figure 8. In anticipation of future oil shale mining needs, the first project was conducted to evaluate the applicability of large diesel powered engines for use in commercial oil shale operations and to modify them, when necessary, to conform to the Mine Safety and Health Administration (MSHA) requirements. In the second project, Pittsburgh Mining and Safety Research Center (PMSRC) investigated the potential explosibility of oil shale dust (under the AMT-OS program), and later added the fire and explosion properties of oil shale, and fire and explosion hazards of oil shale mining and processing projects to the MER program. Results of these studies will give the limits of explosibility of various grades of oil shale, indications of the basic physical and chemical mechanisms involved, and techniques for preventing propagation of oil shale dust explosions.

Figure 8.

Living and Working Environment



4.1.6.1 Large Diesel Testing for Oil Shale

The successful movement of extremely large tonnages of oil shale associated with a mature oil shale industry will probably necessitate the use of large diesel powered equipment. The objective of this project was to evaluate the hazards associated with the use of large (over 600 HP) diesel powered equipment in underground oil shale mines. Presently, the MSHA determines the acceptability of diesel engines operated in coal mines according to Schedule 31. MSHA does not have the capability of testing engines greater than 400 HP, considerably less than needed by an oil shale industry. This project was initiated in anticipation of future oil shale mining needs.

Several potential high powered diesel engines were examined by testing them to Schedule 31. Engines selected include 800 HP, 920 HP, and 1200 HP systems with different combustion cycle fuel injection and produced by different manufacturers. Concurrently, Schedule 31 was evaluated to determine its suitability for testing equipment for use in underground oil shale mines. Southwest Research Institute conducted this study from June 1976 to March 1978. Funding was $153,000.

4.1.6.2 Fire and Explosion Properties of Oil Shale

The objective of this project is to continue oil shale dust explosibility tests to augment current data and to conduct rubble fire tests. The oil shale dust explosion tests will be conducted by PMSRC in a double entry experimental mine to determine the lean limit with respect to oil assay and the lean limit of coarse rich dust. An oil

4.1.6.3 Fire and Explosion Hazards of Oil Shale Mining and Processing

Although considerable pioneering work on oil shale development has been done since the Bureau of Mines first opened its experimental facility at Rifle, Colorado, the potential fire and explosion hazards associated with the mineral remain relatively unknown. There have been a few fire and explosion accidents, but experience in this area is limited. With the expected commercialization of oil shale during the next 25 years, industry needs to identify the potential fire and explosion hazards and determine the production cost impacts of safety regulations.

The objective of this project is to maintain communication with the various large oil shale projects to facilitate sampling and monitoring of dust and gas. There will be a systematic collection and analysis of samples of dust in the wake of blasting to evaluate fuel loading. Explosive and toxic gases from underground and surface retorts continually will be monitored and collected. Spent shale piles will also be monitored to look for possible spontaneous combustion. TOSCO has been working under this contract from June 1977 and will continue until August 1979. Funding for this project has been $242,000. As of 1979, this project was funded under the Metal/Non-Metal Health and Safety Program.

4.1.7 Special Studies

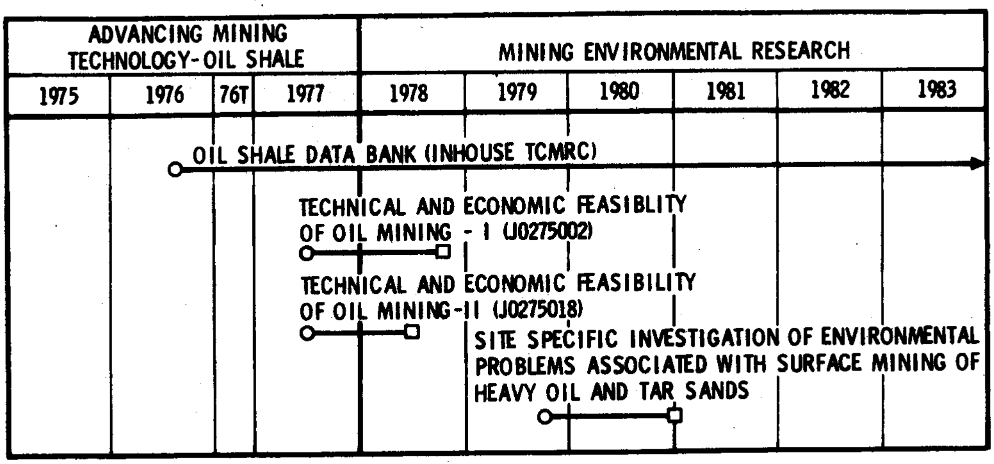
The special studies area comprises projects which (a) may include aspects of some or all of other program areas or (b) do not meet the criteria for inclusion in any of the other areas. The four projects in this component of the program are depicted in Figure 9. The first project involves forming and maintaining an oil shale data bank. The data bank is a bibliographic compilation which identifies areas of research needs and current state of the art technology in oil shale mining. The next two projects study the technical and economic feasibility of oil mining by looking at specific production methods. Under the fourth project, two target oil deposits will be selected for a detailed environmental analysis of surface mining.

4.1.7.1 Oil Shale Data Bank Technology Transfer

The efforts of this project are directed to the establishment of a data bank for oil shale. The need for such a data bank is apparent from the many participants and publications in oil shale research and development. This data bank will store copies of all available literature on oil shale and will present four main categories of output listings (bibliographic, government sponsored research, physical/thermal properties, and patents). The bibliographic listings output will provide the options of a complete alphabetical bibliographic list on oil shale, a listing by subjects pertinent in mining, bibliographic listings with abstracts, and brief commentary. Physical and thermal property information will be extracted from the literature for listing. Government research work plans, contract reviews and patents will be scanned regularly for updating these listings. Property data will also be stored in the data base so that the data can be called out for synthesis and analysis. The staff at Twin Cities Mining Research Center (TCMRC) began work on this data base in January 1976 and are continuing their efforts. This project has cost $225,000 through 1978.

Figure 9.

Special Studies



4.1.7.2 Technical and Economic Feasibility Study of Oil Mining - I

This project and the following project described in Section 4.1.7.3 were designed to reassess the conclusions set out in the Bureau of Mines Bulletin 351 in the light of any changes in technology or circumstances since its publication in 1932. Energy Development Consultants, Inc., looked at two modified in situ methods that can be used to produce previously unrecoverable reserves for two types of petroleum reservoirs. The Drip Drainage method was provided for light conventional crudes while the Flip Flop method was provided for heavy oils. They concluded that these in situ processes are now technically, environmentally and economically viable. The term of this contract was from March 1977 to July 1978. Funding for this project was $123,000.

4.1.7.3 Technical and Economic Feasibility Study of Oil Mining - II

This is a companion study to the one conducted by Energy Development Consultants, Inc. Concurrent with their effort, Golder Associates considered the technical and economic feasibility of extractive or in-seam mining. Five possible underground operations were designed and evaluated, two of them involving direct mining, two employing oil drainage, and the fifth using mining techniques to fracture the rock prior to drainage. Four surface mining operations were also considered. They also concluded that the production of oil by mining methods could become a contributor to the national energy supply. Project initiation was in March 1977 and a final report was submitted in July 1978. Funding was $183,00 for this project.

4.1.7.4 Site Specific Investigation of Environmental Problems Associated with Surface Mining of Heavy Oil and Tar Sands

Results from the technical and economic feasibility studies of oil mining indicate that production of many oil deposits is technically and economically viable through the integration of mining and petroleum technology. Several of the more promising systems involve surface mining. The two major obstacles to surface mining are the large capital investment required and the environmental problems which must be overcome. Whereas the magnitude of capital investment required is fairly well quantified, the techniques and associated costs involved in environmental protection are not.

This project plans to design surface mining, benefication, and waste disposal systems for two specific oil/tar sands deposits and quantify the environmental problems which must be overcome in operating these mines and plants. The results will identify the environmental constraints to the surface mining of oil deposits. Since these constraints and their associated costs will have a strong impact on the viability of mining, they will serve as an important decision making tool for organizations contemplating oil mining ventures. The anticipated start date for this project is July 1979 with October 1980 as an end date. 1979 funding is $128,000.

4.1.8 Program Management

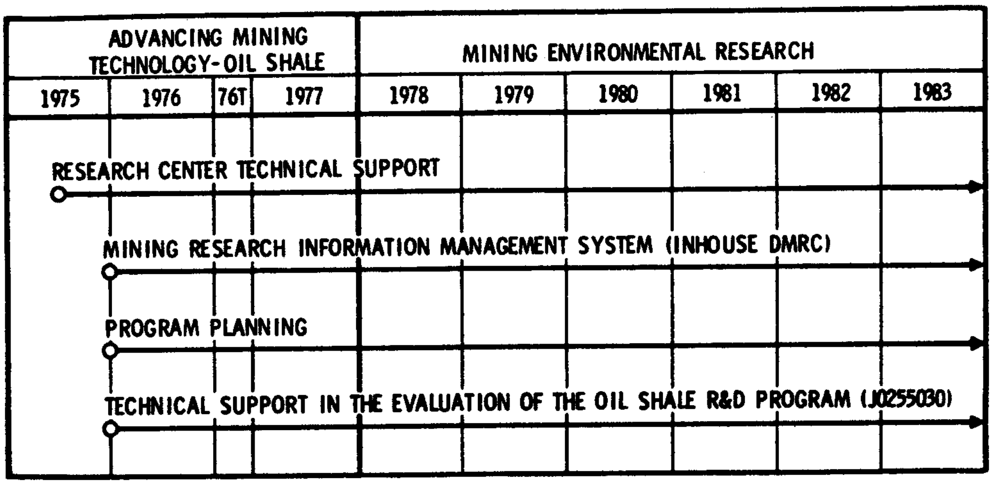
The program management portion of the program supports the technical assistance activities performed by the mining research centers in support of the MER program staff by defining needed research and monitoring contracted research and development projects. It also sponsors program planning, periodic benefit-cost analyses and an information management system. These activities are depicted in Figure 10.

4.1.8.1 Research Center Technical Support

A number of research projects to support the Bureau of Mines oil shale mining environment activities are either under consideration or being conducted under contracts or grants with private industry and educational institutions. This project provides the coordination and control required to manage these projects and to achieve efficiently the goals of the Oil Shale MER Program. Personnel will prepare requests for proposal, evaluate proposals (both solicited and unsolicited), and develop statement of work packages. They will conduct clarification sessions, analyze cost proposals, negotiate terms of contract, and monitor contract performance. They will also assist in technology transfer to industry. The Denver, Pittsburgh, Spokane and Twin Cities Mining Research Centers have been providing the Bureau of Mines Washington office staff with technical support since January 1975. To date, $931,000 has been spent.

Figure 10.

Program Management



4.1.8.2 Mining Research Information Management System (RIMS)

The mining research programs have become so large and diversified and the number of contracts, grants, interagency agreements, cooperative agreements and inhouse projects so numerous that it is extremely difficult to manipulate the large amount of historical and current data without access to a technological advanced information management system. The objective of this project is to provide information, assistance and reports containing useful and timely information to the Washington office. This is accomplished through design and operation of a dynamic information system that has the capability of producing structured and unstructured reports to be used as management tools and for decision making. Funding for this system was divided among research programs from 1976 through 1978. The AMT-OS program portion of the total funding for RIMS was $5,000 in 1976 (including TQ) and $4,000 in 1977. The Oil Shale MER program funding for RIMS was $4,000 in 1978. Beginning in 1979, funding for RIMS was changed, and the Oil Shale MER Program no longer contributes directly to its support.

4.1.8.3 Program Planning

In order to achieve the goals set forth in the Oil Shale MER Program, manpower is needed in planning and directing the to research activities. This project provide technical assistance to the Washington office and the research centers in program preparation, review, evaluation, analysis and coordination. Funding of this project began in July 1975 and $265,000 has been spent through 1978. It is estimated that funding will be $150,000 per year in the future.

4.1.8.4 Technical Support in the Evaluation of the Oil Shale R&D Program

Under the AMT-OS Program, The Aerospace Corporation prepared a report that evaluated the Bureau's Oil Shale Research and Development Program in terms of economic benefits accruing to the nation as a result of a successful program. This evaluation was used extensively for planning the initial Oil Shale MER Program and in preparing the Position Paper on the Bureau's Oil Shale Research Program for the Assistant Secretary—Energy and Minerals in October 1977. A recent contract modification will extend this technical support to the MER program. The contractor will provide program planning assistance, including the preparation of documentation and research schedules supporting the Oil Shale MER program staff in their program management function, and utilize the benefit-cost analysis model developed to explore the benefits which would accrue from the research program. Work under this contract began in June 1975 and is continuing. Funding thus far has been $364,000. In the future, funding will be in the order of $50,000 per year.

4.2 ENVIRONMENTAL CONTROL TECHNOLOGY

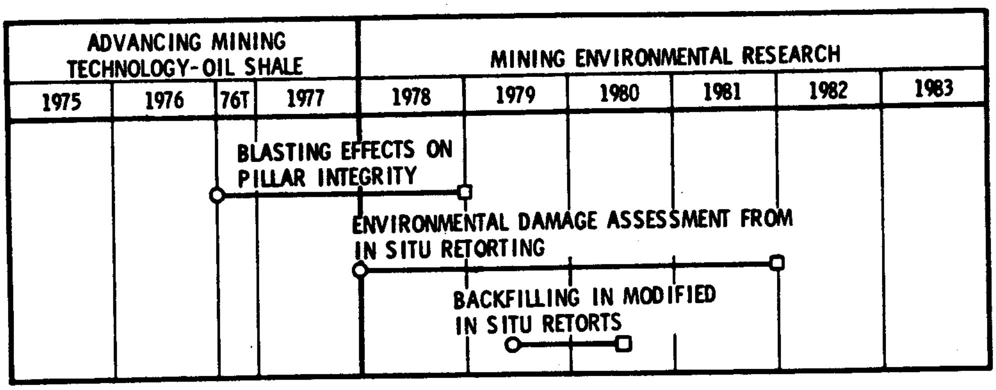
4.2.1 Mine Subsidence

The mine subsidence portion of the program will provide information to maximize the extraction of resources yet maintain the necessary control of earth movements for the safety of the miners, the prevention of costly delays in mining operations due to caveins, and the elimination of surface damage due to subsidence. The knowledge of rock materials and their behavior under force loading and blast effects permits design engineers to define mine structures which allow maximum resource recovery, and to prescribe effective blast rubblization techniques for mine development and resource extraction.

The three projects included in this portion of the program are shown in Figure 11. The first project will quantify the effects of pillar damage caused by large hole blasting. Instrumentation and techniques to assess environmental damage for in situ retorting of oil shale will be developed in the second project, and the last project will look at the use of waste backfilling in modified in situ retorts.

Figure 11.

Mine Subsidence



4.2.1.1 Blasting Effects on Pillar Integrity

An underground oil shale mining operation will involve higher production rates than have been attained in any underground mine in this country. In this size operation it will be essential to use the largest equipment available, consistent with good underground mining practices. The drilling and blasting systems are of particular importance. As drill sizes increase, production increases and costs decrease. However, as a counterbalancing factor, larger blast holes create greater pillar damage, requiring a more conservative mine design and resulting in a lower extraction ratio. Rather than concede to lower extraction ratios, this field research effort will quantify the effects of pillar damage caused by large hole blasting and propose control blasting designs which minimize this damage.

Heading and bench blasting operations in a room and pillar mine configuration were conducted, by use of a range of three blast hole sizes in each type of blasting. The pillar damage created by these tests was assessed. Controlled blasts, using both presplitting and smooth blasting techniques, were conducted to determine their effect at reducing pillar damage. Tradeoffs between the various methods are being determined, and the advisability of using controlled blasting for both underground development and production were assessed. Work on this project began in October 1977 and ended in October 1978. Funding was $175,000.

4.2.1.2 Environmental Damage Assessment for In Situ Retorting of Oil Shale

Most promising of the oil shale recovery techniques from an economic and resource recovery viewpoint, is the method. Since in situ technology is new and still in a state of evolution, little is known about the environmental hazards or consequences associated with the in situ method. An important component of the in situ method is the rubblization process. Poor blast design can create numerous environmental problems such as the venting of gases through fractures, weakening of retort and sill pillars, subsidence, contamination of ground water, disturbance of surface hydrology, and uncontrolled burn-front propagation with associated weakening of support structures.

This project, being conducted by TCMRC, will develop instrumentation and techniques to assess blast damage and characterize rubblization for modified in situ retort structures. Research was started in October 1978 and will continue until October 1981. Funding for 1976 is $120,000.

4.2.1.3 Backfilling in Modified In Situ Retorts

The objective of the backfilling in modified in situ retorts project is the prediction of the effects of slurry injection backfill on the reduction in permeability of in situ oil shale rubble, and the increased stability of in situ retorts. This will lead to the demonstration of actual commercial in situ retort design conditions and residual liquid containment procedures necessary for safe underground operations.

Existing ground subsidence problems will be identified, and large laboratory model tests on shale retorted to various void ratios will be conducted to determine the volume loss and subsidence under varying overburden stresses. Procedures to monitor the subsidence of retorts will then be developed. Next, the post retorting groundwater permeability and leaching conditions in relation to containment of hydrocarbon contaminated seepage will be investigated. The third step will be to determine the effects on stability of slurry grouting spent retort rubble. Laboratory experiments will be conducted to define and optimize grouting characteristics for shale rubble to minimize porosity, to use surface prewetting if needed, and to be effective under the temperature, absorption and other environmental conditions anticipated in shale retorted in situ. The last phase of this project will be to instrument the retort cavities and their rubble, measure subsidence, grouting and permeability performance parameters and to correlate them with earlier predictions. This project is scheduled to begin in January 1979 and to end in March 1980.

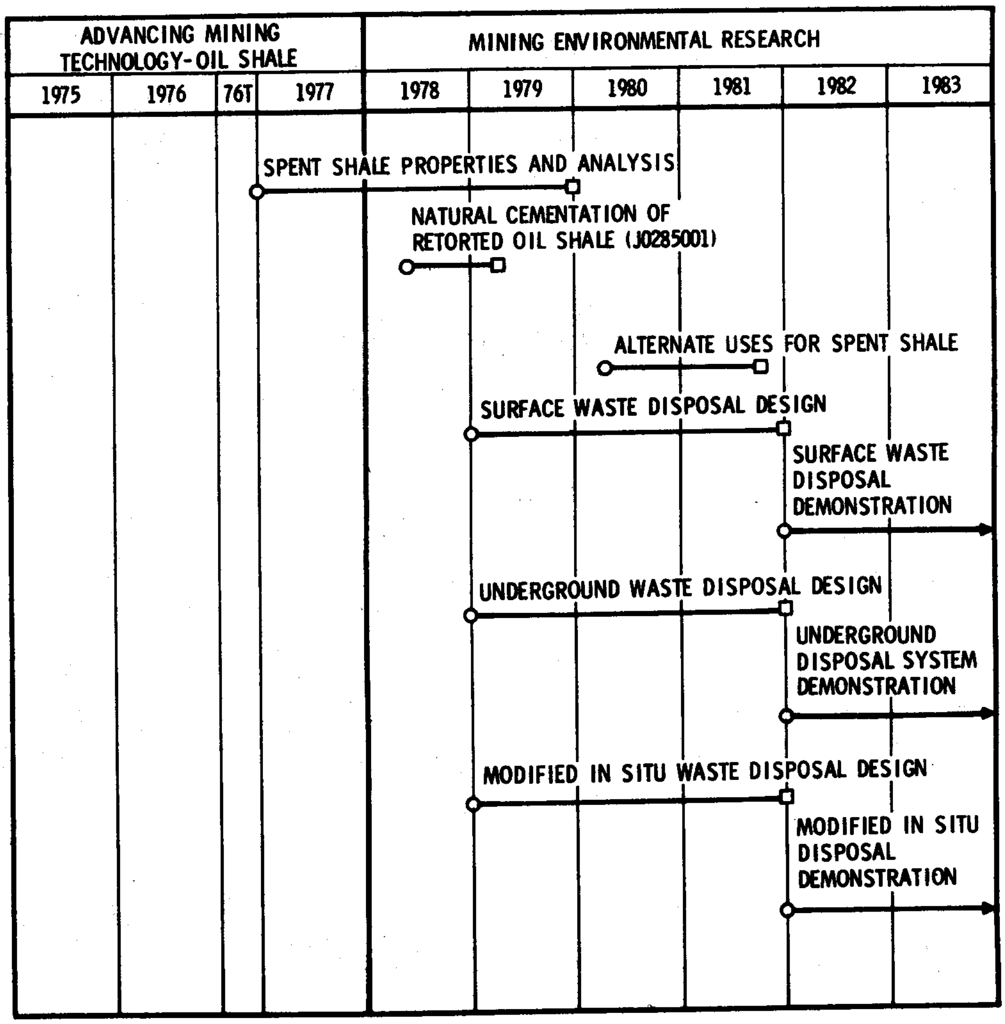
4.2.2 Mining Waste Management

It appears probable that aboveground retorting methods will be used for many of the commercial oil shale operations regardless of the mining methods employed for shale extraction. When raw shale is crushed prior to retorting, the volume per unit mass is doubled. About 40 percent of this volume is then lost in retorting, leaving spent shale which occupies a 20 percent greater volume than the raw shale in place. The ultimate proportion of the spent shale volume that must be placed in some disposal area depends upon the extent to which byproducts are extracted from waste material and whether mine backfilling techniques are employed.

The projects in this portion of the program will lead to the disposal of spent shale in an environmentally safe manner. They are illustrated in Figure 12. The spent shale properties and analysis project will acquire physical property data pertaining to oil shale waste material and its disposal. The following two projects will investigate the cementing action of retorted shale and possible uses of material with these properties. Specific designs and demonstrations for surface, underground, and modified in situ waste disposals are covered in the last six projects.

Figure 12.

Mining Waste Management



4.2.2.1 Spent Shale Properties and Analysis

Current oil shale waste technology is inadequate to design structurally and environmentally safe disposal systems. Since the Waterways Experiment Station, U.S. Army Corps of Engineers, has the equipment, experience and reputation to perform material property testing and analytical modeling of oil shale waste disposal, an interagency working fund agreement was made for them to perform these activities. Specifically, this project will involve laboratory testing of raw shale and spent shale from the Paraho and TOSCO II processes to develop additional data necessary for the design of waste disposal systems. The initial laboratory tests will be directed to obtain material parameters, including density, gradation, permeability, shear strength and compression strength. This study will also entail the analytical modeling of various waste disposal systems to determine (a) the structural stability and leaching potential of surface embankments, and (b) the supportability of underground backfills. A literature search will be performed, and a summary will be prepared of all physical property data pertaining to oil shale waste material and its disposal. Work on this project began in September 1976, and it is expected to be completed in October 1979. The Bureau of Mines has expended $323,000 toward the funding of this project.

4.2.2.2 Natural Cementation of Retorted Oil Shale

Previous Bureau of Mines efforts have indicated that if compacted retorted shale is cured, before strength testing, considerable strength gain can be obtained from a natural cementing action. High strength retorted shale by natural cementing could substantially reduce costs of surface and underground disposal by reducing or eliminating mechanical compaction effort. This project plans to look into this cementing action with more detail. The objectives are to determine (a) the lowest retorting temperature and residence time required to produce retorted shale with natural cementing properties and (b) the possible variations in shale oil yield and quality which may result from producing these properties.

The retorting testing program will retort two grades of oil shale in the laboratory at various temperatures and residence times. Both direct and indirect heating modes will be tested. The retorted shale will then be tested in unconfined compression for strength gain due to natural cementation. Upon the indication of improved strengths, chemical and physical tests (x-ray diffraction, thin sections, etc.) will be conducted to determine the nature of any cementing constituents. The Colorado School of Mines Research Institute began work on this project in February 1978 with completion in December 1978. Funding for this project was $146,000.

4.2.2.3 Alternate Uses for Spent Shale

After the natural cementing properties of retorted oil shale are determined, alternate uses for the spent shale will be investigated. The final goal will be to create an enlarged market for spent shale derived materials. Spent shale could be used as fill material, gravel for highways, and in earth dam construction. These alternate uses will reduce the need for surface disposal of spent shale, alleviating the waste disposal problems. This project is scheduled to begin in January 1980 and end in July 1981.

4.2.2.4 Surface Waste Disposal Design

Surface waste disposal design is the first of two linked projects which will consider various aspects of surface disposal design and culminate in a full scale demonstration. The objective of this research effort is the selection of feasible sites and the preparation of preliminary layouts of surface disposal facilities which demonstrate the theory and techniques developed under previous inhouse and contracted research efforts.

The immediate goal of the project is to establish the feasibility of alternative disposal sites by conducting geologic, hydrologic, and engineering studies in the general area of consideration. The economic feasibility of alternative waste disposal concepts will be considered with respect to (a) specifications of equipment and operational requirements for handling and placing the wastes, (b) type of disposal site and its structural design, (c) water control facilities, runoff and stream diversion or bypass, (d) environmental factors such as leaching, erosion, air pollution, and (e) reclamation. The total environmental impact will also be considered. Preliminary layouts will then be prepared for the best disposal plan to be demonstrated at the most practical site. The design will be predicated on the use of Paraho spent shale because of availability of physical property data and the high probability of its future utilization by industry. Funding is expected to be $500,000. The period began in October 1978 and will continue until October 1981.

4.2.2.5 Surface Waste Disposal Demonstration

The surface waste disposal demonstration project will construct a surface waste impoundment and demonstrate its structural soundness and environmental acceptability. The spent shale used in the demonstration should be available from a commercial retort. The impoundment will be fully instrumented and continually monitored to provide data on structural stability, water percolation through the structure, and pollutants within the downstream from the structure. This structure will conform to the land geology and vegetation on and around the structure will be closely studied. All results will be documented and reported to the oil shale industry.

4.2.2.6 Underground Disposal System Design

The intent of the underground system design project is to develop detailed designs to integrate the underground disposal concepts selected in the "Underground Disposal of Spent Shale from the Paraho Process" (Section 4.1.4.1) into a full scale demonstration site. Initially, a preliminary design concept will be developed based upon known physical and chemical properties of spent shale. This concept will include methods of transportation, stowage and cooling. Developmental tests will then be performed to assure the adequacy of the design concept. Following these tests, final detailed design drawings will be prepared for all required conveyors, bins, pumps, pipes, pipe-shale interfaces, nozzles, etc. Final fabrication and utilization cost estimates will be prepared concurrently with the detailed designing efforts. The term of this contract is from 1978 to 1981, and the estimated cost is $500,000.

4.2.2.7 Underground Disposal System Demonstration

The objective of this project is the demonstration of a complete backfilling operation. Based on final design drawings produced in the previous study, a demonstration facility will be constructed. This demonstration will provide actual labor, cost and time data. The effects of backfilling on the mine environment will be assessed with particular emphasis on temperature, noise, dust and liberated gases and the ability to reduce roof falls. The area environment and stability will be studied, including the effects of surface subsidence and changes in groundwater hydrology, and estimates of additional land available for other uses resulting from decreased surface waste disposal requirements will be developed. A successful backfilling operation has not yet been accomplished in the oil shale industry. The actual demonstration of such a facility could encourage private enterprise to attempt such operations and, consequently, help exploit the oil shale resource while operating within the constraints of environmental legislation. This project is scheduled to begin in 1981 and is anticipated to extend beyond the 1987 time period.

4.2.2.8 Modified In Situ Waste Disposal Design

The objectives of this project are to develop and design an underground waste disposal system for rubblized in situ oil shale retort mining methods. Work will be done with the following goals in mind: (a) reduce or eliminate waste being placed on the surface, (b) increase mine stabilization and improve resource recovery, (c) sealing of retorts and old workings to reduce or eliminate vapor explosion potential in in situ retort mines, and (d) proper sealing of the retorts to effect control of air when processing pillar material.

There will be an inspection, field sampling and testing of in situ retort rubble after processing. Field tests will determine in situ density, void ratios and size distributions. In addition, deep testing for densities through the retort will be performed with nuclear density probes in a cased drill hole. This hole could also be used to assess differential consolidation of the rubble in the lower parts of the retort with a variety of test methods. This project is scheduled to begin in October 1978 with completion in October 1981.

4.2.2.9 Modified In Situ Waste Disposal Demonstration

The modified in situ waste disposal demonstration project will attempt to inject a slurry into the coarse rubble in the in situ retort with oil shale waste material removed from the mine and retorted on the surface. Initially, a model simulation experiment would be conducted on oil shale waste materials to determine the feasibility of the filling system and an estimate of the engineering requirements needed for a full scale experiment in a mine retort. Sampling and testing of the stabilized rubble in the model experiment will include determination of consolidation, shear strength and modulus values. At the completion of the model experiment and a favorable analysis of the data, a field experiment will be designed to fill an actual retort. This will require construction of a sizing and batch slurry plant, fill transport system, and a fully instrumented retort containing piezometers, density meters, water level stand pipes and flow control meters. This project should begin in October 1981 or after the modified in situ waste disposal design.

4.2.2.10 Organic Residues from In Situ Oil Shale Retorting

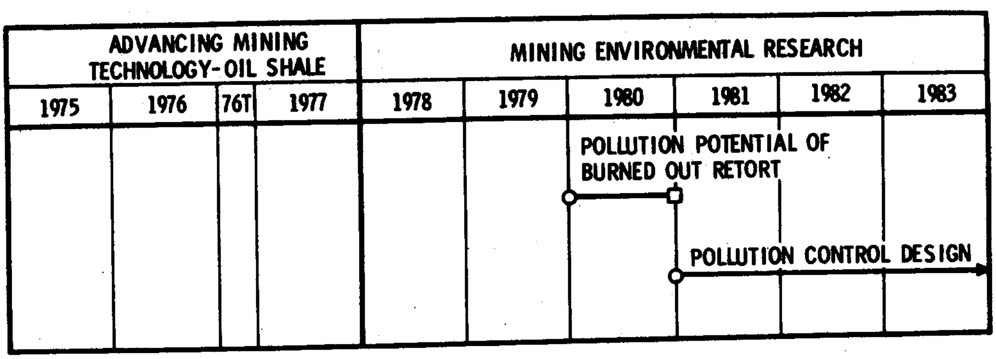
Retorting oil shale by in situ methods may cause health and environmental problems because of percolating ground water into and out of the in situ retorts. During in situ retorting all of the oil shale may not be completely pyrolyzed. Because of this, residue organic carbon and perhaps even organic carbonates will remain after the burn is completed. Percolation of ground water through the spent shale may cause large scale mobilization of these residues, resulting in the environmental degradation in the quality of the water. This project plans to investigate the role of trace organic matter in spent shale from in situ operations and determine its influence on ground water quality and on the mobilization of inorganic trace elements when subjected to water inflow. The proposed start date of the year long project is September 1979 and funding is expected to be $100,000.

4.2.3 Water Management

The water management element of the program will provide information needed to develop pollution control technology. Projects in this element are shown in Figure 13. The pollution potential of burned out retort will be investigated in the first project, while the second project will develop techniques to control groundwater contamination.

Figure 13.

Water Management



4.2.3.1 Pollution Potential of Burned Out Retort

This project investigates the effect of circulating groundwater through burned out retort. The specific problems concerned with effluents loaded with acids, alkalis, dissolved solids, heavy metals, radioactive ions and suspended solids will be addressed. In addition, laboratory and field investigations will be conducted to determine the mechanisms by which these pollutants enter the groundwater. Initiation for this year long project is scheduled beginning in 1979 at a cost of $100,000.

4.2.3.2 Pollution Control Design

The objective of this project is to develop and demonstrate procedures and systems for pollution abatement. Methods of constructing burned out retort compoundments and heap leaching areas to prevent groundwater contamination will be devised once the pollution potential has been established by the previous project. Efforts will begin on this work in 1980 and will be funded at $100,000 per year until completed.

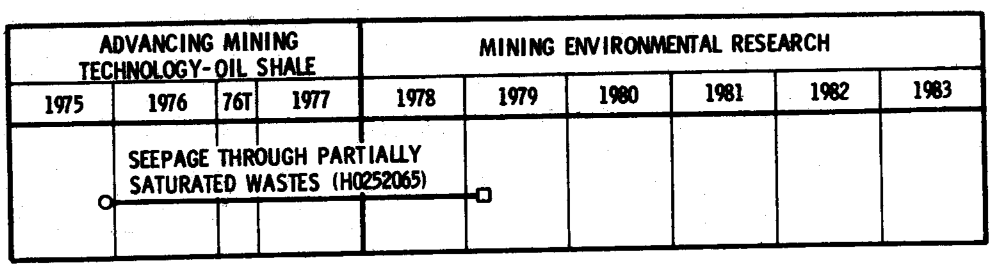
4.3 MINED LAND RECLAMATION TECHNOLOGY

4.3.1 Mining Waste Management

The overall goal of this program is to provide systems and techniques by which the mining cycle can be completed, and the mined area left in a stable state and a configuration that optimizes its potential for future utilization. The project, shown in Figure 14, will identify the environmental problems with the overburden. It will study the manner in which rainwater enters the shale waste and flows toward the water table to determine the stability of the waste deposits and the amount of leachate contaminating the groundwater system.

Figure 14.

Mining Waste Management



4.3.1.1 Seepage Through Partially Saturated Shale Waste

The seepage through partially saturated shale waste project will develop and demonstrate a computer program for analyzing unsaturated flow from rainwater through shale wastes. An important consideration in the environmental assessment of surface disposal facilities is the effect of water infiltration caused by rainfall or discharge from processing plants. The manner in which this water enters the shale waste and flows toward the water table determines the stability of the waste deposits and the amount of leachate contaminating the groundwater system. This project will provide a tool with which seepage patterns in shale waste deposits can be determined. Existing computer programs for seepage analysis assume that flow is fully saturated; however, due to the nature of materials contained in spent shales, such flow conditions are unlikely to exist. Although various analytical techniques are available, they are incapable of handling the complex boundary conditions encountered. Thus, the capability provided by the unsaturated flow program will contribute substantially to the development of enhanced waste disposal designs for controlling effluent leaching and subsequent groundwater contamination. These computer program development efforts will be tied to field verification tests. The University of Idaho began work on this project in June 1975 and completed the effort in November 1978. Funding was $73,000.

APPENDIX A

FEDERAL WATER AND AIR QUALITY REGULATIONS AFFECTING CONDUCT OF MINING OPERATIONS

Water

- Rivers and Harbor Acts of 1886 and 1889
  First legislation governing Federal waters.

- Federal Water Pollution Control Act of 1948
  Structured to enhance the quality and value of our water resources. Established a national policy for the prevention, control and abatement of water pollution.

- Water Pollution Control Act Amendments of 1956

- The Water Quality Improvement Act of 1970

- Federal Water Pollution Control Act of 1972 (PL 92-500)
  Mandated that by July 1977, industries use the "best practicable control technology currently available," and by July 1983 the "best available treatment economically achievable" to eliminate pollution.

- Safe Drinking Water Act of 1974 (PL 93-523)
  Protects the quality of aquifers which are existing or are potential sources of drinking water for public systems.

- National Interim Primary Drinking Water Regulations

- Toxic Substances Control Act of 1976

- Resource Conservation and Recovery Act of 1976 (PL 94-580)
  Provides for a permit system that regulates treatment, storage, and disposal of hazardous waste.

Air

- Air Pollution Act of 1955
  Initiated concern for air quality and the adverse effects of industrial activities.

- Motor Vehicle Pollution Act of 1965

- Air Quality Act of 1967

- Clean Air Act of 1970
  Instituted a new system of national uniform air quality standards based on geographic regions.

- Noise Control Act of 1972 (PL 92-574)
  Established a noise abatement and control program.

APPENDIX B

SUMMARY OF OIL SHALE ENVIRONMENTAL RESEARCH PROJECTS BY AGENCY

The environmental concerns addressed in the research is indexed to the following numerical code:

1. Natural Environment
   - 1.1 Water Availability and Quality
   - 1.2 Air Quality
   - 1.3 Wildlife and Grazing
   - 1.4 Rehabilitation of Disturbed Areas
   - 1.5 Historic Sites and Antiquities
2. Living and Working Environment
   - 2.1 Health Hazards
   - 2.2 Mine Safety
   - 2.3 Socioeconomic Impacts
3. Waste Management
   - 3.1 Surface Disposal of Spent Shale
   - 3.2 Underground Disposal of Spent Shale
   - 3.3 Water Management

	Concerns Addresses
1. American Petroleum Institute	
Environmental Impact of Emissions and Effluents from Shale Oil Processes	1
Acute and Subacute Toxicity and Mutagenic Potential of Shale Oil Products	2.1
Acute Toxicity Tests of Oil Shale and its Process Products	2.1
Analytical Support for Program on Toxicity for Shale Oil Products	2.1
Carcinogenic Potential of Shale Oil Products	2.1
Chronic Inhalation Toxicity of Shale Oil Process Products	2.1
Comprehensive Analysis of Oil Shale Samples	2.1
Hazards of Major Shale Oil Processes and Their Control	2.1

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Medical Surveillance Procedures for Shale Oil Operations	2.1
Mutagenic Potential of Oil Shale	2.1
Sensitization Potential of Shale Oil Products	2.1
Teratogenic Potential of Oil Shale Materials in Rats and Monkeys	2.1

2. Council on Environmental Quality

Socio-Economic Impacts of Western Energy Resource Development	2.3

3. Environmental Protection Agency

Energy-Related Water Monitoring Data Integration	1.1
Environmental Assessment of Oil Shale Processes	1.1
Groundwater Research Monitoring of Energy-Related Developments	1.1
Impacts of Oil Shale Development on Colorado Resources	1.1
Identification of Components of Energy-Related Wastes and Effluents	1.1
The Mineralogy of Overburden as Related to Groundwater Chemical Changes in Strip Mining of Coal, In Situ Coal Gasification, and Oil Shale Retorting	1.1
Monitoring the Impact of Western Coal Strip Mining and Oil Shale Extraction on Groundwater Quality	1.1
Nonpoint Source Surface Water Monitoring Technology for Oil Shale Development	1.1
Water-Quality Hydrology of Surface-Watersheds	1.1
Water Quality Hydrology Affected by Oil Shale Development	1.1
Sampling and Analysis of the Paraho Surface Retort	1.1,1.2
Western Energy-Related Overhead Monitoring and Technique Development (WEROM)	1.1,1.2,1.4
Evaluation & Development of an Environmentally Acceptable Shale Oil Industry	1.1,1.2,1.4,2.3
Impacts of Synthetic Liquid Fuel Development	1.1,1.2,1.4,2.3
Air, Water, and Multi-Route Exposures and Their Effects: Pollutants Associated with Energy Development	1.1,1.2,2.1

Environmental Impact of Oil Shale Development	1.1,1.2,2.1
Potential Radioactive Pollutants Resulting from the Expanded Program, Quality Assurance Aspects	1.1,1.2,2.1
Effects of Aqueous Effluents from In Situ Fuel Processing on Aquatic Systems	1.1,1.3
Air Pollution Emissions from Oil Shale Conversion Facilities	1.2
Air Quality and Surface Wind Monitoring in Colorado	1.2
Development of a Two Frequency Downlooking Airborne LIDAR System	1.2
Energy-Related Western/Southwestern Regional Air Monitoring	1.2
Evaluate the Impact on Ambient Air Quality of an Oil Shale Industry	1.2
Investigation and Feasibility Study of Methods for the Identification and Measurement of Inorganic Compounds Emitted as Particulates from Sources Using or Processing Fossil Fuels	1.2
Oil Shale Area Meteorological Data Analysis	1.2
Perform a Literature Survey on Present Emissions from Various Stationary Sources and to Conduct Smog Chamber Studies of Emissions Found	1.2
Quality Assurance in Support of Energy-Related Air Monitoring in the Western United States	1.2
Upper Air Meteorological Data Collection	1.2
Fugitive Dust from Oil Shale Extraction	1.2, 2.1
Toxic Effects on the Aquatic Biota from Coal and Oil Shale Development	1.3
Vegetative Stabilization of Paraho Spent Oil Shale	1.4
Vegetative Stabilization of (TOSCO and USBM) Spent Oil Shales	1.4
Determination of the Effects of Materials from Alternate Energy Sources on Upper Respiratory Tract Clearance Mechanism	2.1
Determination of the Influence of Mineral Cofactors in Conjunction with Carcinogens from Energy-Related Materials	2.1
Technology Assessment of Western Energy Resource Development	2.3

4. Federal Energy Administration

Energy Alternatives - A Comparative Analysis	1.1,1.2,2.3
A Western Regional Energy Development Study	1.1,1.2,2.3
Macro Economic Impact of Coal and Oil Shale Development in the Intermountain West	2.3

5. National Aeronautics and Space Administration

Western Energy-Related Overhead Monitoring and Technique Development	1.1,1.2,1.4

6. National Science Foundation

Characterization of Contaminants in Oil Shale Residuals and the Potential for their Management to Meet Environmental Quality Standards	1.1,1.2
Botanical Baseline Studies on Federal Lease Oil Shale Lands in Utah	1.3,1.4

7. United States Department of Agriculture

Microbial Ecology of Water in Various States of Pollution	1.1
The Political Economy of Water Resources	1.1
Surface Effects and Mining Program (SEAM)	1.1,1.3,1.4
Erosion Effects and Pollutant Movements from Coal and Oil Shale Strip-Mining Deposition	1.1,1.4
Water Harvesting Parameters on Saline Media	1.1,1.4
Economics of Coal and Oil Shale Development on Environmental Quality in Rural Areas	1.1,2.3
Upper Colorado Environmental Plant Center, Meeker, Colorado	1.3,1.4
Activities Associated with Energy Resources Extraction	1.4
Selection of Superior Tree Ecotype - Mycorrohizal Fungi Associations for Mineland Revegetation	1.4
Technologies for Controlling Adverse Effects Disturbed in the Development of Oil Shale and Coal	1.4
Integrated Assessment: Socio-Economic Consequences of Coal and Oil Shale Development	2.3

8. United States Department of Commerce

Quality Assurance and Instrumentation in Air and Water Pollution from Mining	1.1,1.2,2.1

9. United States Department of Defense

Descriptive Toxicology of JP-5 Fuel Derived from Shale Oil	2.1

10. United States Department of Energy

Instrumentation and Methods for Characterizing Aqueous Effluents from Oil Shale	1.1
Laboratory Determination of Leaching Rates from Oil Shale Retorted Under Simulated In Situ Retorting	1.1
Role of Spent Shale in Oil Shale Processing and the Management of Environmental Residues	1.1
Removal of Ammonia and Alkalinity from Oil Shale Retort Water	1.1
Water Conservation with In Situ Oil Shale Development	1.1
Oil Shale and Tar Sand Effluent Characterization	1.1,1.2
Rock Springs Site 9 In Situ Environmental Studies	1.1,1.2
150-Ton Retort Simulated Power Plant Burn	1.1,1.2
Environmental Aspects of In Situ Oil Shale Processing	1.1,1.2,2.3
Terrain Influences on Low-Level Meteorological Transport	1.2
Analysis of Air Quality and Meteorological Baseline Data from Federally Leased Oil Shale Tracts in Colorado and Utah	1.2
Rehabilitation Potential and Practices of Colorado Oil Shale Lands	1.4
Analysis of the Effects of Energy-Related Materials to Karotype Stability in Mammalian Cells	2.1
Development of Cytochemical Markers for Cell Transformation and Carcinogenesis	2.1
Development of Permanent Epithelial Cell Lines	2.1
Development of an In Vitro Assay for Co-Carcinogenesis of Coal/Oil Shale Derivatives	2.1
Detection of Early Changes in Lung Cell Cytology by Flow Systems Analysis Techniques	2.1
Effects of Agents Associated with Coal and Oil Shale Extraction, Conversion, or Utilization on Cell Cycle Kinetics and on Chromatin/Chromosome Structure	2.1
Effect of Alternate Energy Source Material on Whole Animal Carcinogenesis by Percutaneous Application of Extracts and Fractions to Mice	2.1
Effects of Potentially Hazardous Agents Associated with Coal and Oil Shale Technologies	2.1
Establishment of a Chemical Repository for Alternate Energy Source Material for Toxicity Testing	2.1

Evaluation of the Mechanisms of Energy-Related Toxic Agents on the Mammalian Hematopoietic System	2.1
In Vivo Screening for Gene Mutation in Mouse Germ and Somatic Cells	2.1
Late Effects of Oil Shale Pollution	2.1
Morphological Variants in Damaged Sperm	2.1
PRF-Screen for Hazardous Chemicals: Rapid Detection of Health Hazards	2.1
Quantitative Mutagenesis Testing in Mammalian Cellular Systems	2.1
Somatic Cell Genetics	2.1
Toxicity of Oil Shale Products, Including Metabolism and Carcinogenicity	2.1
Development of a Chemical, Stability, and Transport Model of Oil Shale Process Wastes in Soil	3
Oil Shale Processing and Management of Environmental Residues	3
Leaching Rates from Retorted Oil Shale	3.1,3.2
Role of Spent Shale in Oil Shale Processing and the Management of Environmental Residues	3.1,3.2
Assessment of Environmental Control Technology for Waste Waters in In Situ Oil Shale Retorting	3.3

11. United States Department of Health, Education and Welfare

Control Technology for Mine Reclamation (Resource Extraction)	1.4
Compilation and Tabular Abstracting of Literature on Mutagenic Effects of Energy Related Pollutants	2.1
Enumeration of Energy Occupational Health Problems	2.1
The Interaction of Chemical Agents Present in Oil Shale with Biological Systems	2.1
Oil Shale-Potential Health Problems (Human)	2.1
Mortality, Morbidity and Industrial Hygiene Study of Oil Shale Workers	2.1,2.2

12. United States Department of the Interior

Aquifer Testing, Piceance Creek Basin, Northwestern Colorado	1.1
Collection of Geochemical Data in the Piceance Creek Structural Basin of Colorado	1.1
Controls and Devices for Measurement of Sediment Laden Flows	1.1
Core Drilling for Pilot Demonstration Oil Shale Mine	1.1

Identification of Presumptive Carcinogenic Compounds Released to Water Supplies by Oil Shale	1.1,2.1
In Situ Combustion of Fossil Fuels	1.2
Mitigation Goals for Oil Shale	1.3
Trace Substances in Wildlife Food Chains	1.3
Backfilling in Modified In Situ Retorts	1.4
Effects of In Situ Retorting on Oil Shale Pillars	1.4
Detailed Geologic Surface Mapping	1.4
Laboratory Determination of Static Design Parameters	1.4
Northwest Colorado Oil Shale Environmental Geology	1.4
Pillar Effects - Large Hole Blasting	1.4
Physical Properties for Mine Design	1.4
Redistribution of Accessory Elements and Compounds Associated with Mineral Resource Exploitation	1.4
Stress Research Applied to Mine Design	1.4
Stress-Strain-Time Relations	1.4
Surface Geology and Fracture Analysis	1.4
Surveying Services for USBM Tract	1.4
Test Site Archaeological Survey	1.5
Fire and Explosion Hazards of Oil Shale Mining and Processing	2.2
Fire and Explosion Properties of Oil Shale	2.2
Large Diesel Testing for Oil Shale	2.2
Oil Shale Dust Explosibility	2.2
Surface Waste Disposal Design	3.1
Surface Waste Disposal Demonstration	3.1
Alternate Uses for Spent Shale	3.1,3.2
Design of Oil Shale Waste Disposal Systems	3.1,3.2
Natural Cementation of Retorted Oil Shale	3.1,3.2
Retorted Shale Handling and Disposal	3.1,3.2
Spent Shale Properties and Analysis	3.1,3.2
Testing and Analysis of Retorted Oil Shale Specimens	3.1,3.2
Modified In Situ Waste Disposal Design	3.2
Modified In Situ Waste Disposal Demonstration	3.2
Underground Disposal of Spent Shale from the Paraho Process	3.2
Underground Disposal System Design	3.2
Underground Disposal System Demonstration	3.2
Pollution Control Design	3.3
Pollution Potential of Burned Out Retort	3.3
Seepage Through Partially Saturated Shale Waste	3.3
Water Management Control Procedures	3.3
Water Management in Oil Shale Mining	3.3
Water Management System Design	3.3

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4. Environmental Protection Agency, "EPA Program Status Report: Oil Shale," EPA-600/7-78-020, February 1978.

5. Environmental Protection Agency, "Oil Shale Research Overview," EPA-908/4-77-007.