Review of Air Quality Assessment Studies and Definitions of Some Research Needs for the Emerging Oil Shale Technology

G. B. Parker

April 1979

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REVIEW OF AIR QUALITY ASSESSMENT STUDIES AND DEFINITIONS OF SOME RESEARCH NEEDS FOR THE EMERGING OIL SHALE TECHNOLOGY

INTRODUCTION

Oil shale is a fine-grained rock that contains organic material called kerogen, which upon heating or retorting yields a synthetic oil and gas. The oil is commonly referred to as shale oil and can be refined into useable liquid fuels similar to oil pumped from oil wells.

The major deposits in the United States are found in the Colorado-Wyoming-Utah area known as the Green River formation, and the Upper Mississippian deposits. Estimates of recoverable oil in the Green River formation range from 0.6 to 1.8 trillion barrels of oil based on shale yielding 15 to 25 gallons of oil/ton of shale⁽¹⁾. The eastern deposits are estimated to yield an equivalent of 3.4 trillion barrels of oil; however, these deposits are of low yield (<15 gal/ton) and gasification is considered to be the most applicable technology for recovery of this energy resource. A map of the Green River formation oil shale region is shown in Figure 1.

FIGURE 1. Distribution of oil shale in the Green River Formation Colorado, Utah, and Wyoming.

SUMMARY

For the United States to achieve energy independence with acceptable environmental modifications, it is essential that all energy resources be used within defined environmental limits. Oil shale is one of the most abundant, but under-developed U.S. energy source. The technology required to begin the demonstration of commercial feasibility is available with only environmental, economic, legislative and policy constraints delaying the construction of prototype processes. The environmental issues have been addressed in several studies by developers, governmental agencies, and independent research organizations. These studies have included the potential impact of an oil shale industry on the air, water, land, plant, human and animal population within the oil shale regions.

This paper reviews the air quality assessment programs that have been conducted by the various private and government sponsored developers who propose to extract energy from the oil shale. These studies have ranged from regional comprehensive baseline and environmental impact studies over several years' period to intermittent localized small scale air quality monitoring programs. A review of the environmental programs, their location, retorting type, and extent of environmental program undertaken is given in the summary following. This will aid in identifying the current trends in industry and government environmental controls needed in the extraction of oil from shale.

<u>Development</u>	<u>Developer</u>	<u>Location</u>	<u>Proposed Retort</u>	<u>Operating Stage</u>	<u>Environmental Program</u>
Federal Lease Tracts					
C-a	Gulf Standard Oil Co.	Colorado	Surface	No Development	Baseline 1976
C-b	Ashland/Occidental Co.	Colorado	Surface	No Development	Baseline 1976
U-a/U-b	Sunco Energy Develop. Co./Phillips/Sohio Petro. Co.	Utah	Surface	No Development	Baseline 1976
Colony Develop. Corp.	Arco/Shell Oil Co.	Colorado	Surface	Pilot Plant	DEIS 1975
Naval Oil Shale Reserve	Develop. Engineering Inc.	Colorado	Surface	Pilot Plant until 1978	EIS 1977
Occidental	Occidental Oil/DOE	Colorado	Modified In-situ	Pilot Stage	Data filed with State of Colorado
Geokinetics	Geokinetics, Inc.	Utah	In-situ	Pilot Stage	Data being taken
Equity-BX	Equity Oil Co./DOE	Colorado	In-situ	Initial drilling & fracturing	Initiated
Talley	Talley Energy Systems/DOE	Wyoming	In-situ	Initial drilling & fracturing	Meteorological data only
Rock Springs	Sandia/LETC	Wyoming	In-situ	Initial drilling & fracturing	None
Superior	Superior Oil Co.	Colorado	Surface/mineral extraction	Pilot Plant	None available
Antrim	Dow Chemical Co./DOE	Michigan	In-situ gassification	Trial Retorting	Initiated

BACKGROUND

The federal government in the 1940's initiated an effort to develop feasible processes for producing a synthetic oil from the shale. The Bureau of Mines (BOM) began development of a gas combustion retort in 1945 at a facility on the Naval Oil Shale Reserve near Rifle, Colorado.

In the 30-plus years following the BOM development, several private and government funded oil shale projects have been conducted. These have been directed mostly toward small pilot plant or semi-work scale above ground retorting of the shale. Only recently have other retorting schemes been advanced beyond a laboratory scale. These methods are the in-situ and modified in-situ retorting.

RETORTING METHODS

Hundreds of U.S. patents have been issued relating to retorting of oil shale; however, no one process has been shown to be best for all purposes. A combination of processes may be best for a commercial shale retorting facility. Retorting processes can be broken down into three categories: 1) above ground, 2) modified in-situ, and 3) true in-situ. Field development of these processes is being done, yet no retorting process has been demonstrated on a commercial scale.

Above Ground

Above ground or surface retorts have been developed to a degree where commercialization is feasible. These surface retorting technologies fall into three classes or modes of operation, shown below.

<u>Class</u>		<u>Examples</u>
I	Externally heated recycle solid retort	TOSCO II
II	Gas combustion retort	Paraho (Direct Mode)
III	Externally heated recycle gas	Union B, Paraho (Indirect Mode)

In each example, the organic matter in the shale is pyrolyzed or decomposed by heat. As kerogen pyrolyzes, it yields oil (in vapor form), gas (high or low Btu depending on amount of air feed) and a residual carbonaceous product which adheres to the retorted shale solids. This residual may or may not be burned in the process.

A Class I type retort is used by the Colony Development Company in a TOSCO II process. This process features the use of a circulating load of heated ceramic balls as a heat-carrying medium for transferring the necessary process heat to finely (<0.5 in.) crushed shale to effect pyrolysis of the kerogen. Pyrolysis occurs in a rotating drum without combustion in the retort. The ceramic balls are separated and reheated in a furnace using product gas.

The TOSCO II retorting technology is well advanced and has been demonstrated at a semi-works scale. The process could be scaled up to operate successfully.

A Class II (GCR) type retort features the continuous pyrolysis of coarsely crushed (<0.25 in.) shale in a vertical kiln utilizing the internal combustion of process-derived fuel with air within a downwind moving bed of shale.

Combustion air plus some recycle process gas are injected into the bed in the combustion zone. Fuel in the recycle gas burns in air to liberate heat. Some residual carbon left on spent shale particles is burned, liberating heat and gaseous products of combustion.

This type retort has been used by the Development Engineering, Inc. Paraho plant at Anvil Points, Colorado. This 450 ton shale/day plant is capable of operating in either a GCR (direct mode) or indirect mode using externally heated recycle gas. Operated in a direct mode, the retort has produced 100,000 bbl of shale oil for the U.S. Navy for refining and military purposes under a DOE contract. After several years of operating in both modes, the indirect mode was determined to be the most efficient for production of oil. Plans are proposed to construct a single full size 13,000 ton/day commercial retort.

A Class III retort is similar to a Class II type except that a separate furnace is used for heating the recycle gas. This gas is then injected, while hot, into the shale in the retort to provide process heat requirements.

The Paraho plant described earlier has been successfully operated using a Class III type technology. Operating experience indicated, however, that the GCR type operation is more feasible for large scale operation of the Paraho retort.

Union Oil Company of California has been operating a Class III type retort since the early 1970's. In the retort, crushed shale 1/8 to 2 in. flows through two fuel chutes to a solids pump. These pumps "push" the shale upward through the retort by a piston action. The shale is met by a stream of externally heated recycle gas flowing downward. The rising oil shale bed is then heated by the gas resulting in evolution of a mixture of shale oil mist and product gas. This mixture is forced downward by the recycle gas and cooled by contact with cold in-coming shale. The oil and gas are withdrawn from the bottom of the retort and a portion of the gas is recycled and heated to provide heat for retorting.

Union Oil Company proposes to construct and demonstrate a 10,000 ton/day unit. This would be located in the Parachute Creek Valley 2 miles north of Grand Valley, Colorado.

The Superior Oil Company has initiated a program to recover shale oil plus the minerals nahcolite and dawsonite present with the shale located in deep beds. The process combines certain features of a GCR (Paraho Direct Mode) and external heating (Paraho Indirect Mode). A circular grate type retort has been developed in a pilot plant size operation. The operation will include deep mining, crushing of the shale to 3 in. and screening to remove the nahcolite.

The dawsonite shale remaining is fed to a travelling circular grate. Hot recycle gases are drawn downward through the shale producing oil-laden vapors which are removed and shale oil is condensed. The gases are recycled to a cooling zone and drain downward through the spent shale to

reduce the shale temperature. The cooled shale is fed to a leaching plant for recovery of alumina and soda ash from the dawsonite. The spent shale is returned to the underground mine as a wet cake.

If pilot plant results are successful, a 20,000 ton/day full scale commercial module will be constructed⁽²⁾. This module will be built on Superior Oil Co.'s own land in the Piceance Creek Basin in Rio Blanco County, Colorado.

Modified In-Situ Retorting

Modified in-situ retorting of oil shale consists of retorting a rubble column of broken shale formed by expansion of the shale into a previously mined out void volume. Approximately 15-25% of the shale in a given volume is mined either at the upper or lower level of the shale layer. This mined out shale is deposited on the surface.

The mined out area is crushed by blasting. Connections are made to both the top and bottom and retorting is carried out. Retorting is initiated by heating the top of the rubble shale by an external heat source. After several hours the external heat source is turned off and the carbonaceous residue of retorted shale is used as fuel to sustain combustion. The hot gases from the combustion zone move downward to pyrolyze the kerogen in the shale below producing gases, water vapor, and shale oil mist which condenses in the trenches at the bottom of the crushed column. The oil and water are collected in a sump and pumped to storage. Part of the off-gas is recycled to control both the oxygen level in the in-coming air and the retorting temperature.

Occidental Petroleum Company has been involved in modified in-situ retorting operation since the early 1970's. Work has been conducted on the D.A. Shale property at the head of Logan Wash outside of Debuque, Colorado. A commercial size retort was ignited in 1975 and oil was successfully recovered for the shale containing ~15 gal/ton.

A cooperative agreement between DOE-Occidental Petroleum Company and Ashland Oil Company was signed in 1976. Since that time, two modified in-situ retorts have been fired. The latest one, fired in September 1977 has provided oil at near design conditions. These retorts are located on the federal lease tract C-b in Colorado which were originally scheduled for above ground retorting. This land contains a high-grade shale making a commercial venture more practicable.

True In-Situ Retorting

True in-situ retorting involves the in-place heating of an underground shale formation without extensive mining or material removal. The retorting is done under conditions where the flows of heat, vapors and liquids can be controlled resulting in recovery of the gaseous and/or liquid product. The shale must be fractured by hydraulic or explosive methods to create permeability for maintaining combustion. Typical Green River and Devonian shale is hard and nonporous which is generally unsuitable for in-situ retorting. Two major difficulties encountered in the field projects have been the failure to achieve adequate permeability prior to retorting and the failure to achieve adequate control of the flows of heat, vapor and liquid during the retorting process.

Geokinetics, Inc., of Concord, California has been operating an in-situ retort program near the southern rim of Utah's Uinta Basin near Vernal, Utah. In their process, the oil shale bed is fractured by explosives placed in holes drilled from the surface. The shale deposit is located near the surface and void spaces are achieved by uplift of the ground surface. The fire front moves in a horizontal direction and oil is produced both from a condensed mist and a liquid from wells at the downstream end of the retort. Ten retorts have been burned to date and over 5,000 bbl of oil have been produced.

The Bx in-situ oil shale project operated by Equity Oil Company is nearing production in the "leached zone" of Rio Blanco County, Colorado. In this project, retorting is done by injecting superheated steam into

bore holes with oil/water and gas extraction. A field site has been characterized, process wells have been completed, and steam injection is scheduled to start in January 1979.

Talley Energy System, Inc. is exploring true in-situ retorting in a valley near Interstate 90 near Rock Springs, Wyoming. Talley is engaged in a hydraulic fracturing and explosive crushing demonstration. No retorting has been done to date.

Development work in in-situ retorting is also being done at a second site near Rock Springs, Wyoming. Experimental work is being done in drilling wells, horizontal hydraulic fracturing and determination of void volume. Ignition for retorting was attempted but was not sustained. Plans are being formulated for a second ignition.

Three in-situ retorting trials have been completed in deep wells in Devonian Shale at the Dow Oil shale site near Peck, Michigan under a DOE contract. Combustion in the shale zone was initiated by electric heating or propane burner augmented with charcoal. The objectives of this development is to produce only low Btu gas for use in an electrical generating unit.

Another trial is scheduled for 1979 in wells drilled exhibiting the greatest permeability obtained from explosive fracturing. Work is also being done to improve the ignition system and to increase the gas yield through controlled retorting.

ATMOSPHERIC PROCESS EMISSIONS

Interest in commercial extraction of oil from the shale has varied over the years. Presently increasing demand for liquid fuels, decreasing petroleum supplies and increased fuel costs have again focused attention on the development of oil shale resources. Large scale commercial development of the shale region will result in a decline of the general air quality of the region. The following is a general overview of the potential process emission from the described oil shale activities.

General

Emissions will arise from several activities during oil shale processing and any upgrading operations. These emissions include SO_2 , H_2S , NO_x , CO , hydrocarbons, O_3 polycyclic organic matter, particulates and unspecified trace elements. Generally, above ground retorting operations themselves do not involve significant atmospheric emissions; gaseous, liquid, and solid streams leaving the retort can be handled by downstream systems before reaching an atmosphere interface. However, features inherent in the retorting method influence the nature and magnitude of emissions from other sources in the shale oil plant.

A modified in-situ and true in-situ plant would be expected to produce uncontrolled emissions also since large quantities of gas are produced and vented to the atmosphere. A certain amount of mining is required for both types of retorting and the associated mobile equipment emission and dust emission would be similar to those associated with the mining for above ground retorting. If product upgrading is also performed on site, emissions will be associated with such processing.

The major source of SO_2 , H_2S and CO is fuel combustion for process heat. Actual SO_2 emission associated with individual retorting processes will depend on the degree of sulfur removal for in-plant fuels, the extent of on-site shale oil processing, and the degree of control applied to sulfur recovery tail gases. H_2S is emitted in the tail gas of sulfur recovery operations. The largest source of CO is from mobile equipment. The quantity of such emissions is a function of mining method and haul distance rather than retorting process.

Combustion of any hydrocarbon fuel will produce oxides of nitrogen when air containing elemental nitrogen is used as the oxygen supply. The extent of NO_x formation from combustion is related primarily to flow, temperature residence time and air/fuel mixture. The use of fuel oil in mobile equipment and in explosives will result in emission of NO_x and CO along with some hydrocarbons. Hydrocarbons are also vaporized during product storage.

Release of polycyclic organic matter (POM) to the atmosphere can occur in handling and disposing of retorted shale, combustion of shale derived oils containing POM and from flue gases containing retorted shale particles along with retort gas or spent shale coke combustion particles.

Particulate matter and fugitive dust can result from blasting, shale handling and disposal, construction and transporting equipment, fuel combustion and site activity which generates fugitive dust. Generally, processes which require small size shale feed will have more uncontrolled particulate emissions during crushing and raw shale handling operations than a process requiring large feed. Uncontrolled fugitive particulates could constitute a large fraction of a total particulate inventory at a development site. As would be expected, true in-situ retorting would present less of a fugitive dust problem than underground mining or deep surface mining and surface retorting.

Oil shale contains trace amounts of many elements. However, for elements other than Si, Fe, Al, Ca, Mg, Na and K, the concentrations in shale are less than or comparable to that found in sedimentary and igneous rocks⁽³⁾. Conditions during retorting are not severe enough to volatilize most metallic and heavy elements. With the exception of As and Sb, most trace elements remain with the spent shale solids entrained on retort gases. Actual emission of non-volatile trace elements will be in approximate proportion to raw and retorted shale particulate emissions for an oil shale extraction and retorting operation.

Specific Process Generic Emission Inventories

For atmospheric transport modeling purposes, estimates are made of process stream emission and associated operation for several oil shale retorting technologies. Certain features inherent in the retorting method influences the nature and magnitude of emission at the retort and from other sources associated with the shale oil plant. Emission inventories

have been postulated for the TOSCO II, Paraho, and Union B technologies and these have been used as the operation emissions to determine impact of an above ground oil shale retort on the environment.

Each process involves unique features which determine the emission inventories. The TOSCO II process, for example, involves a shale oil upgrading step which will increase the emission of hydrocarbons and POM. The small shale feed to the TOSCO II process will generally involve higher uncontrolled particulate emissions compared with emissions from a Paraho or Union B type process which requires a large feed. A TOSCO II process may also present a larger NO_x emission potential than a GCR plant because of the necessity to burn additional oil for upgrading operations.

Sulfur emissions from process depend on both the fuel mix and degree of sulfur removal from gas and liquid products. Generally, there is less sulfur in a GCR retort than a TOSCO II retort. The sulfur released in a GCR retort will be mainly in the form of H_2S , whereas it will be mostly SO_2 in a TOSCO II process.

In the Superior process, on-site use of low and high Btu gas for process and upgrading purposes will result in emission control requirement similar to those for the Paraho retort. Superior has not developed its process to the point of being able to define such emissions.

A quantitative estimate of emission associated with modified in-situ retorting (Occidental) has not been determined. Emission from mining and blasting and surface mobile equipment will be similar to those from a TOSCO II or GCR type operation, although on a much smaller scale. The same is true for a true in-situ operation. A large amount of low Btu combustion gas will be generated in these types of operations and emissions could be comparable in composition to the stack gas emitted from an oil fired electric power plant⁽²⁾.

REVIEW OF AIR QUALITY ASSESSMENT PROGRAMS

Recognizing that development of an oil shale industry will cause air degradation, the industry and developers have over the past several years conducted air quality monitoring operations. Associated environmental impact studies were required by the federal government on federal lease land and/or by the states in which the developments were taking place.

The remainder of this paper will summarize, review, and evaluate the environmental assessments of the air quality studies completed by developers and organizations. The summary will be broken down according to the type of oil shale retorting processes. A brief description of the specific processes will be given concentrating mainly on the methods and conclusions of environmental impact statements and studies given by the developers. An evaluation of any conclusions about the impact of the proposed oil shale development will be included. The final part of the paper will address the areas of research needed in shale country to better assess the environmental impact on air quality from an oil shale industry.

General

There are approximately 10 sites in oil shale country where there has recently been or is present activity of varying types to extract the shale oil. Site specific information is generally lacking except for federal lease tracts in Colorado (C-a/C-b) and Utah (U-a/U-b), the Colony Development Co. and the Development Engineering Inc. (DEI) operations, both in Colorado. The lease tracts were leased by the Department of Interior to industry after competitive bidding. The lease contained conditions for environmental protection and the leasees have issued final environmental baseline reports. Environmental Impact Statements are completed for the Colony and DEI operations, although data is not as complete as that collected for the lease tracts. Other environmental monitoring studies are underway for oil shale developments but data is not readily available.

A brief discussion is given of existing meteorology and air quality in and around potential developments. This is followed by a discussion of the environmental studies completed or currently underway. Spent shale and solid waste disposal plans are also summarized. A review of the modeling studies which have been undertaken to predict air quality impact in the Green River formation oil shale will complete this section.

Area Meteorology

This area is characterized as having one of the highest frequency of inversions anywhere in the United States. Prevailing winds in the region are south-westerly with surface winds variable being strong spatial, diurnal and seasonal.

Sunshine is prevalent with humidity and precipitation low. Temperature ranges between -40°F to 100°F in the lower region.

The topography of the region has a great influence on local meteorology. The area is rugged terrain which causes turbulence within the planetary boundary layer. Topography influences the mountain-valley system, resulting in differential heating and cooling. Accordingly, mountain-valley breeze systems are observed.

Other types of air flows are found because of the combination of meteorology and topography which can have an effect on air quality in the region. Flows can occur when a plume emitted at the base of a stable layer intercepts a highly unstable lower layer causing rapid mixing to take place. This can produce fumigation which may be intensified by the elevated terrain.

Air Quality

There are very few man-caused emissions in the oil shale areas of Wyoming, Colorado and Utah. This is mainly due to the sparse population of the region. However, measurements taken for baseline studies indicate that levels of ozone and non-methane hydrocarbons sometime exceed the primary National Ambient Air Quality Standards (NAAQS).

A significant amount of haze has been observed in valley regions. Several methods of formation have been proposed to explain its presence. The high levels of non-methane hydrocarbons have been attributed to natural sources such as sagebrush and other vegetation. A more detailed summary of air quality data will be presented in the evaluation of data from the environmental studies.

Federal Lease Tracts

C-a. A baseline study was carried out for the baseline years, February 1976 to January 1977 by the Rio Blanco Oil Shale Project (Gulf Oil Corp. - Standard Oil of Indiana), to satisfy the provisions of the federal oil shale lease agreement⁽³⁾. The oil shale lease is located in north-western Colorado on public land managed by the Bureau of Land Management (BLM), United States Department of Interior (USDOI). Meteorology studies were conducted by EG&G Corp., Waltham, Mass.

Tract C-a is surrounded by high mountains. Light westerly winds prevail and there is a high frequency of clear sunny days with large diurnal temperature changes. There is a high degree of temporal and spatial variability in the area which is expected in the rough terrain.

In this area the dispersion of pollutants is influenced by the presence of frequent atmospheric inversions. Inversion conditions existed for over one-third of the hours during the baseline data years. Inversion will trap airborne pollutants under a lid of air and greatly affect the air quality in the region.

The air quality acquisition system consisted of four monitoring sites with trailer contained air quality instrumentation. The typical air quality parameters were measured (THC, CH₄, SO₂, H₂S, NO_x, CO, O₃, and particulates) along with trace element analysis from a high volume sampler. A summary of the baseline air quality data acquired is given in Table 1.

TABLE 1. Summary of Air Quality Data From Tract C-a Baseline Study

<u>Criteria Pollutant</u>	<u>Tract C-a</u>
Particulate	
Maximum 24 hrs ($\mu\text{g}/\text{m}^3$)	469
Annual Mean ($\mu\text{g}/\text{m}^3$)	18
No. occurrences exceeding NAAQS*	5
SO ₂	
Maximum 3 hrs ($\mu\text{g}/\text{m}^3$)	345
Maximum 24 hrs ($\mu\text{g}/\text{m}^3$)	82
Annual mean ($\mu\text{g}/\text{m}^3$)	11
NO _x	
Annual Mean ($\mu\text{g}/\text{m}^3$)	4
CO	
Maximum 1 hr ($\mu\text{g}/\text{m}^3$)	6,823
Maximum 8 hrs ($\mu\text{g}/\text{m}^3$)	4,824
NMHC**	
Maximum 3 hrs ($\mu\text{g}/\text{m}^3$)	505
No. occurrences exceeding NAAQS*	94
Oxidant	
Maximum 1 hr ($\mu\text{g}/\text{m}^3$)	117
No. occurrences exceeding NAAQS*	5

* National Ambient Air Quality Standards

** Non-methane hydrocarbons

The National Ambient Air Quality Standards (NAAQS), Prevention of Significant Deterioration (PSD), and Colorado Ambient Air Quality Standards are summarized in Table 2. Presently the Colorado oil shale area is designated as Class II under PSD regulations and as Category I under State Ambient Air Quality Standards.

Mean pollutant concentrations measured were low compared to the federal standards. However, particulate, ozone and non-methane hydrocarbons occasionally exceeded the federal standards. A hydrocarbon

TABLE 2. Air Quality Standards

NATIONAL AMBIENT AIR QUALITY STANDARDS (NAAQS)

Emission	Averaging Time	Primary Standards (Human Health) ($\mu\text{g}/\text{m}^3$)	Secondary Standards (Public Welfare) ($\mu\text{g}/\text{m}^3$)
Sulfur Oxides (SO_2)	Annual	80	None
	24-hour ¹	365	None
	3-hour ¹	None	1300
Nitrogen Dioxide (NO_2)	Annual	100	100
Particulates	Annual ²	75	60
	24-hour ¹	260	150
Hydrocarbons (corrected for CH_4)	3-hour ¹ (6 to 9 a.m.)	160	160
Carbon Monoxide	8-hour ¹	10,000	10,000
	1-hour ¹	40,000	40,000
Oxidant (corrected for NO_2 , SO_2)	1-hour ¹	160	160

1. Not to be exceeded more than once per year.

2. Geometric mean of the 24-hour concentrations.

MAXIMUM ALLOWABLE FEDERAL INCREMENTS FOR AREA CLASSES:
PREVENTION OF SIGNIFICANT DETERIORATION REGULATIONS (PSD)

Emission	Averaging	Class I ($\mu\text{g}/\text{m}^3$)	Class II ($\mu\text{g}/\text{m}^3$)	Class III ($\mu\text{g}/\text{m}^3$)
Particulates	Annual ¹	5	10	Same as NAAQS
	24-hour max	10	30	
Sulfur Dioxide	Annual ²	2	15	
	24-hour max	5	100	
	3-hour max	25	700	

1. Geometric mean of the 24-hour concentrations.

2. Arithmetic mean of the 24-hour concentrations.

STATE OF COLORADO AMBIENT AIR QUALITY STANDARDS

Emission	Averaging Time	Maximum Allowable Increments over Baseline ($\mu\text{g}/\text{m}^3$)		Max Allowable Concentra- tions ($\mu\text{g}/\text{m}^3$)
		Category I	Category II	Category III
SO_2	Annual	3	15	60
	24-hour max	15	100	260 ¹
	3-hour max	75	700	1300 ²

Maximum allowable ambient air concentrations in non-designated areas

Particulates	Annual ²	45
	24-hour max ¹	150

1. Not to be exceeded more than once in a 12-month period.

2. Arithmetic mean of the 24-hour concentrations.

concentration above the standard was measured 94 times. The only apparent source of the hydrocarbons seems to be natural. Vegetation has been suspected as well as volatilization of compounds from surface shale.

The ambient air concentrations of the other pollutants all average near or below the reliable threshold of detection of the measuring instruments. Since there are no local sources of SO_2 , NO_x , or CO, these pollutants must be of natural origin or transported into the region by continental air mass movement.

A modeling effort was undertaken to assess the impact on air quality of a full scale oil shale operation. The EPA Valley model (C8M3D) was used for simulating air quality with modification as necessary for making 3 hr and 24 hr predictions⁽⁴⁾. Emission for two phases of operation were considered. Phase I was a 10,000 ton/day TOSCO II type above ground retort with open pit mining.

This capacity would be increased to 108,000 ton/day in the Phase II operation. The process would also include coking and hydrotreating to upgrade the shale oil prior to transporting. Estimated emission for Phases I and II are given in Table 3.

TABLE 3. Estimated Air Pollution Emissions Used in Modeling Study

<u>Tract C-a</u>	<u>Oil Production bbl/day</u>	<u>Emissions kg/day</u>			
		<u>SO_2</u>	<u>NO_x</u>	<u>THC</u>	<u>PM</u>
Phase I	6,000	12	146	51	67
Phase II	55,600	120	451	64	260

Modeling results indicate that Phase I operation will meet the NAAQS and Colorado State standards for all criteria pollutants except non-methane hydrocarbons. Phase II operation would have a similar impact on NAAQS except that short term State Ambient standards would be violated unless the area was classified as Category II or stronger emission controls were instituted, especially on the upgrading operations.

C-b. An environmental baseline program was conducted on the C-b federal lease tract in Piceance Basin, north of Rifle, Colorado, from November 1974 through October 1976⁽⁵⁾. This was performed for Ashland Oil and Occidental Oil Shale, Inc. by Quality Development Associates, Inc.

A meteorological program was conducted utilizing a 200 ft instrument tower, 3 mechanical weather stations, and other data taken from measuring instruments. Wind fields, temperature fields, upper air studies, and other meteorology were recorded.

Ambient air quality was monitored in accordance with the lease agreement and to satisfy federal and State of Colorado regulations. Five instrumented air quality trailers were used during the baseline period to monitor conventional gaseous pollutants and suspended particulates. The standards that were applicable to tract C-a were also applicable to tract C-b and are summarized in Table 2.

The topography of tract C-b is similar to tract C-a, and therefore the meteorology is similar. In general, wind fields were found to be driven primarily by differential heating of the area topography and as such are local, diurnally variable and complex. The tract encompasses an area of the Piceance Creek valley which has a marked channeling effect on the wind. The wind flows primarily from the west and the structure is determined by terrace influence. Surface inversions are common as noted in discussion of tract C-b.

Sulfur dioxide, hydrogen sulfide and suspended particulates were monitored at all five stations. In addition, ozone, NO_x , methane, total hydrocarbons and carbon monoxide were monitored at two of the stations. A summary of the air quality data is presented in Table 4.

Generally, measured concentrations of gaseous pollutants and particulates were below federal standards. It was concluded that the particulate concentrations correlated best with wind speed, solar radiation and precipitation indicating that the nature of particulate loading is primarily natural fugitive dust possibly from nearby agricultural activities. Cumulative particulate mass concentration in the respirable range were log-normally distributed with particle size.

TABLE 4. Summary of Air Quality Data From Tract C-b Baseline Study

<u>Criteria Pollutant</u>		<u>Tract C-b</u>
Particulate		
Maximum 24 hrs	($\mu\text{g}/\text{m}^3$)	178
Annual Mean	($\mu\text{g}/\text{m}^3$)	11
No. occurrences exceeding NAAQS*		4
SO ₂		
Maximum 3 hrs	($\mu\text{g}/\text{m}^3$)	88
Maximum 24 hrs	($\mu\text{g}/\text{m}^3$)	112
Annual Mean	($\mu\text{g}/\text{m}^3$)	1
NO _x		
Annual Mean	($\mu\text{g}/\text{m}^3$)	21
CO		
Maximum 1 hr	($\mu\text{g}/\text{m}^3$)	4,651
Maximum 8 hrs	($\mu\text{g}/\text{m}^3$)	4,502
NMHC**		
Maximum 3 hrs	($\mu\text{g}/\text{m}^3$)	2,597
No. occurrences exceeding NAAQS*		262
Oxidant		
Maximum 1 hr	($\mu\text{g}/\text{m}^3$)	160

* National Ambient Air Quality Standards

** Non-methane hydrocarbons

Non-methane hydrocarbon numbers were obtained from total hydrocarbon less methane and are considered relatively inaccurate. However, there were many incidences of very high concentrations above the NAAQS. These mainly occurred in the summer and are hypothesized as being caused by terpenes from sagebrush.

During the program, ozone levels were observed to reach the NAAQS standard. It is concluded that the high readings could be attributed to either long distance transport from urban sources outside the shale region (Los Angeles or Salt Lake City), or from stratospheric injection of ozone associated with passages of storm fronts.

For both SO₂ and H₂S, the analyzer frequently measured zero pollutant concentrations. The levels evidently are near the minimum detectable levels of the instruments most of the time.

A Gaussian plume model was used to estimate concentrations of SO₂, NO_x, THC and PM. Average meteorology was used and the Briggs method was used for treating plume rise.

The developers of tract C-b propose to use the TOSCO II technology for retorting the shale which is similar to the retort operation proposed at tract C-a. The emission inventory assumed for this process is given in Table 5.

TABLE 5. Estimated Air Pollution Emissions Used in Modeling Study

<u>Oil Production</u> <u>bb1/day</u>	<u>Emissions kg/day</u>			
	<u>SO₂</u>	<u>NO_x</u>	<u>THC</u>	<u>PM</u>
45,000	121-160	741-859	119-142	352-439

It was concluded that the best estimated use of the model shows that compliance with federal and state standards could be achieved. The EPA reviewed the modeling effort and concluded that there were areas of deficiency⁽⁴⁾. These included too few details with respect to air pollutant emissions, inadequate modeling exercise, and neglect of fugitive emissions. The EPA ran their C7M3D model on the data and concluded that all federal and state air quality standards would be violated. Further work in emission control evaluation and worst case modeling was scheduled to be done by the developers of tract C-b.

U-a/U-b. The White River Oil Shale project plans to develop tracts U-a/U-b in Uinta County, Utah probably using primarily Paraho type technology. A final environmental baseline report was issued covering monitoring from October 1974 through January 1977. The Air Resources section of the report

was done by Aero-Vironment, Inc. who evaluated existing air quality and meteorological conditions on the tracts and within a 1.6 km perimeter around the tracts.

A network of 12 fixed meteorology stations were installed for monitoring wind speed, direction and temperature and to measure H_2S , SO_2 , and TSP. Three stations were used for measuring additional parameters: relative humidity dew point turbulence, upper air speed and direction, pressure, radiation, lapse rate, hydrocarbons, NO_x , CO , O_3 , haze, trace metals and visual range.

The weather on the tracts is determined by the latitude, elevation and location with respect to the average storm tracks over the inter-mountain region. Clear skies prevail most of the year with fairly wide range of temperature. Wind speeds associated with high pressure areas are light to moderate. Exceptionally high winds are encountered with passing fronts and low pressure disturbances which occurred mostly in spring. Surface based or elevated inversions are not common in winter.

Air quality data is representative of naturally occurring background environment because of the lack of significant anthropogenic sources of air contaminants in the area. All pollutants measured were present at measurable quantities in the beginning of the monitoring program when well drilling and setup activities were carried out. As activity diminished, most of the concentrations dropped to the threshold limit values of the instruments. Pollutants that still showed variation were ozone and non-methane hydrocarbons. A summary of the air quality data is given in Table 6.

Readings for NMHC exceeded the NAAQS on several occasions during the 2 year monitoring period. State standards were not violated since there are no Utah State Standards for air pollutants other than particulate matter. Two explanations were given for exceeding the NAAQS. First, the precision of the measuring instrument was questioned, and second, there could be naturally occurring hydrocarbon sources in the area such as sagebrush and other vegetation.

Table 6. Summary of Air Quality Data From Tracts U-a/U-b Baseline Study

<u>Criteria Pollutant</u>		<u>Tracts U-a/U-b</u>
Particulate		
Maximum 24 hrs	($\mu\text{g}/\text{m}^3$)	127
Annual Mean	($\mu\text{g}/\text{m}^3$)	22
SO ₂		
Maximum 3 hrs	($\mu\text{g}/\text{m}^3$)	40
Maximum 24 hrs	($\mu\text{g}/\text{m}^3$)	25
Annual Mean	($\mu\text{g}/\text{m}^3$)	10
NO _x		
Annual Mean	($\mu\text{g}/\text{m}^3$)	10
CO		
Maximum 1 hr	($\mu\text{g}/\text{m}^3$)	5,200
Maximum 8 hrs	($\mu\text{g}/\text{m}^3$)	3,900
NMHC**		
Maximum 3 hrs	($\mu\text{g}/\text{m}^3$)	1,970
No. occurrences exceeding NAAQS*		138
Oxidant		
Maximum 1 hr	($\mu\text{g}/\text{m}^3$)	190
No. occurrences exceeding NAAQS*		42

* National Ambient Air Quality Standards

** Non-methane hydrocarbons

Ozone readings exceeded the NAAQS during the first year but not during the second. Highest readings occurred during the summer months and lowest during the fall. It was assumed that the high readings were either from naturally occurring ozone associated with the formation in the troposphere or generated from sources outside the area and brought in by prevailing winds. All other pollutants were well below the NAAQS as expected in a remote area.

Two models were used for simulating air quality at tracts U-a and U-b during oil shale operations. Short term (<24 hrs) concentrations were simulated with EPA's PTMTP model while long-term predictions were made with EPA's C9M3D terrain model.

The project plans to develop a Paraho type technology and emissions were estimated based on a Paraho retort. Fines are to be handled via a TOSCO II technology in later phases of tract development. Table 7 presents an emission inventory for phase II, III and IV of operation.

TABLE 7. Estimated Air Pollution Emissions Used in Modeling Study

<u>Tract U-a/U-b</u>	<u>Oil Production bbl/day</u>	<u>Emissions kg/day</u>			
		<u>SO₂</u>	<u>NO_x</u>	<u>THC</u>	<u>PM</u>
Phase II	10,000	3.8	49	0.4	31
Phase III	50,000	67	621	25	205
Phase IV	100,000	134	1242	50	410

Total NO_x emissions are comparable for similar sized operations at Tracts C-a and C-b; however SO₂, THC and PM will differ somewhat. This is caused by the inclusion of mining, mobile equipment, and fugitive dust, a combination of direct and indirect mode Paraho retorting and TOSCO II retorting, hydro treating of crude shale oil, and the use of fuel oil in utility boilers.

For Phase III development, the model results indicated that all short term (<24 hours) NAAQS would be met with the exception of THC and PM. The THC emissions include those from fines type preheaters which may emit as much as 80% methane in the THC emission. Therefore, NMHC may be as low as 11.8 µg/m³, well below the short-term NAAQS. Additional control devices will be necessary to meet the PM short-term standards. Modeling results predicted, however, that the long-term NAAQS would be met for all criteria pollutants.

Colony Development Operation

An environmental impact assessment was submitted by Colony Development Operation in 1975 for construction and operation of a TOSCO II type retort⁽⁷⁾. A semi-works retort has been built and operated in the Roan Plateau-Parachute Creek, Colorado River Valley region near Debuque, Colorado.

No comprehensive climatological study has been conducted for the development nor are extensive meteorology data available for the area. Climate is similar to that of the federal lease tracts C-a and C-b which are 60 miles north of the Colony property. The Colorado River is the dominant natural feature within the area of proposed development. The complex itself was proposed to be located in the upper canyon of Parachute Creek and on the adjacent Roan Plateau. Grand Valley, 15 miles down the canyon is the nearest town. As is typical in this area, frequent inversion conditions exist in the valleys.

Air quality near Colony's proposed plant, mine and tailings disposal area has been monitored and has produced the following incomplete baseline concentration data on air pollutants:

SO ₂ -- "nil"	NO _x -- 10 µg/m ²
PM -- 20 µg/m ³	

Studies have also been conducted which indicate that natural hydrocarbon concentrations due to vegetation transpiration reached "high levels" during the growing season.

Three air quality impact studies of retort operations were conducted. Battelle, Pacific Northwest Laboratories did a tracer and modeling study of the Parachute Creek valley and Roan Plateau using a Gaussian plume model⁽⁷⁾. Colony Development operators did a study of the Parachute Creek valley using the same model methods with revised emissions. These studies attempted to predict the impacts of plant operations on air quality above the Roan Plateau and in the Parachute Creek and Colorado River Valleys.

The emission inventories used for modeling were confined to concentrations which would be produced by a TOSCO II type retort. The inventories included emissions from disposal of the shale residue which ranges in the size from clay to fine sand⁽⁸⁾. This residue has a high carbon content and has little structural stability. It is land-filled in a canyon area nearby the retort and is being studied for possible revegetation. The finished pipeline for oil transport and power corridor were excluded.

Table 8 is a summary of emission inventories for the modeling studies. The Colony study used revised emissions greater than those used in the Battelle study based on additional work in identifying process parameters and associated upgrading emission values.

TABLE 8. Estimated Air Pollution Emissions Used in Modeling Studies for the Colony Development Operation

<u>Study</u>	<u>Oil Production bbl/day</u>	<u>Emissions kg/hr</u>			
		<u>SO₂</u>	<u>NO_x</u>	<u>THC</u>	<u>PM</u>
Battelle	50,000				
Roan Plateau		62	132	21	62
Parachute		Case A 109	281	--	131
Creek		Case B 38	192	--	131
Colony Development Corporation	50,000	Normal 128	819	147	374
		Peak 144	792	138	382

In the Battelle studies of the Parachute Creek Valley, field experiments were conducted to analyze the transport and diffusion of airborne pollutant emission. The analyses were supported by experimental field investigations using tracer material and meteorological data from a 200 ft instrumented tower on the Roan Plateau plus two other smaller towers in the valley. Results indicated that a likely potential existed for introducing ambient air concentrations of contaminants that would exceed the current NAAQS and State Air Quality Standards for SO₂ for both Case A and Case B emission inventories. As a result of this study, it was decided to relocate the plant on the Roan Plateau and do a detailed air quality study at this location.

The Roan Plateau study consisted of installation and operation of a tower mounted meteorological data acquisition system, performance of limited field experiments to measure surface concentrations arising from tracer releases under documented meteorological conditions and investigation of the validity of various assumptions commonly made in diffusion modeling. Predictions of pollutant distribution over an extended period were made through diffusion analysis of the tower data.

The Battelle investigation and modeling effort at Roan Plateau indicated that airborne gaseous effluents emitted from an oil shale processing plant located at the proposed site are unlikely to cause concentrations which exceed the NAAQS. Particulates may, however, exceed the allowable state and federal limits for 24 hours averaging time; however, the annual average would not be exceeded beyond the plant boundaries.

The model took a very conservative approach, assuming that there is no deposition of pollutants during their transport from the source. This assumption may have been unrealistic for particulate matter which may have appreciable fall velocity for the larger sizes. Therefore, the short term particulate standards may not be exceeded. This can only be shown through additional research in actual measurements of an operating oil shale retort.

The Colony Development Operation study used the same modeling methods as the Battelle study but with updated emission estimates as given in Table 8. The results of the study predicted that annual mean concentrations due to plant emissions would not exceed Colorado's ambient air quality standards. The State short term (24 hrs) standards may, however, be exceeded. Additional control may be required for all process and fugitive emissions.

Naval Oil Shale Reserve Operations

In 1944, the U.S. Department of Navy made available to the U.S. Bureau of Mines (BOM) a plant site and oil shale deposit on the Naval Oil Shale Reserve near Rifle, Colorado. The BOM constructed a mining, retorting and refining facility at this site and research and development activities were conducted until 1955. The operations were reactivated in 1964 when they were leased to the Colorado School of Mines for research funded by a consortium of six petroleum companies.

In 1972 the facility was leased to Development Engineering, Inc., a subsidiary of Paraho Development Corporation. Paraho pilot and semi-works retorts were installed and operations started in 1974. The mission of the operation was to produce 100,000 bbls of shale oil for the U.S. Navy to use as military fuel⁽⁸⁾. This mission was completed in September 1978 and the plant is currently inactive. By statute, Anvil Points can only be used for research, development, testing, evaluation and demonstration work.

The operation is located in the Piceance Creek Basin which has a pronounced dry continental climate characterized by large diurnal and seasonal temperature changes. This area is surrounded by very high mountainous terrain which has an effect on pressure systems and wind patterns. In winter there is a tendency for persistent high pressure cells to form; during the summer the weather is dominated by the large area of low pressure associated with the hot continental effect.

There are no records of wind direction and velocity within the reserve area nor are long term wind records available for the weather stations at either Grand Junction or Rifle, Colorado. However, inferences of wind patterns have been made from vegetation and terrain observations and theoretical meteorological analysis. Strongest winds normally occur in winter and early spring with more pronounced valley concentration on south facing slopes. On north facing slopes, maximum valley winds are strongest along steep slopes facing the direct solar radiation. Mean fair weather winds will rarely exceed 24 mph.

Significant amounts of haze have been observed in the Colorado River Valley and Parachute Creek Valley. Available data is not sufficient to determine whether this haze is attributed to smog or a combination of suspended particulates and local humidity. Dust generated by traffic on unpaved roads is the most noticeable air pollution.

Although Development Engineering, Inc. has not conducted a comprehensive air quality monitoring study, two other groups have made estimates of local air quality. The Colony Development Operation, which is approximately 10 miles from the Anvil Points site and located adjacent to the Naval Oil

Shale reserve, has collected limited data in the Parachute Creek and Roan Plateau area. This was detailed in the previous section of this paper. Engineering Science, Inc. made an air quality assessment for the whole of the Roan Plateau.

In the baseline study conducted in 1973, Engineering Science assumed no existing sources of air pollution in the basin⁽⁹⁾. Natural background pollution levels were therefore assumed to be zero for all gaseous air contaminants. In the case of particulates, predicted concentrations of suspended particulate matter were made for five stations near Piceance Creek Basin. These are given in Table 9. The background levels were assumed to be best represented by the Rio Blanco Station located on the eastern edge of the Basin. The other stations are farther removed from the Basin and reflect the impact of "local" pollution source of suspended particulates.

Since the study by Engineering Science, the data from lease tract C-b was released indicating that most gaseous and particulate pollutants are indeed relatively low on an annual basis. However, relatively high concentrations of HC and ozone can also exist as recorded in the baseline study reviewed earlier in this paper for tract C-b. Therefore, no real conclusion can be drawn about the air quality at Anvil Points since no complete baseline data have been taken. The inference is that air quality may be "similar" to that found at lease tract C-b some 25 miles to the northwest of the Anvil Points plant.

A ten meter tower was proposed for installation under the project authorization to obtain ambient air quality data for SO₂, H₂S, CO, THC, ozone, NO_x and particulates and to monitor meteorological data for wind speed, direction and temperature. Two week upper air studies were also proposed. No data have been received to date on this study.

Because of the lack of funds for an early detailed meteorology study at Anvil Points plant, no analysis of air quality degradation has been completed. However, estimation of the potential effect on air quality has been made and Engineering Science, Inc. has done some modeling of air pollution levels in the nearby Piceance Creek Basin.

TABLE 9. Suspended Particulate Ambient Air Quality Near the Piceance Creek Basin

<u>Station</u>	<u>Concentration $\mu\text{g}/\text{m}^3$</u>	
	<u>1973</u> <u>AGM</u> ^(a)	<u>1974</u> <u>AAM</u> ^(b)
Grand Valley	39	37
Meeker	56	45
Rangely	31	32
Rio Blanco ^(c)	14	7
Craig	67	98

- a. Annual geometric mean.
b. Ordinarily reported as AGM, this is the annual arithmetic mean for two quarters of 1974.
c. Rio Blanco is the closest station to the Piceance Basin. It is located on the extreme eastern boundary.

Several major sources of pollution have been identified and estimations at Anvil Points for a Paraho type retort have been made for emissions including fugitive dust created during mining, hauling and disposal of the shale. The spent shale contains less than 3% carbon and is relatively coarse ⁽⁸⁾. It will be disposed of by landfilling in canyon areas, with revegetation a likely option to reduce resuspension and erosion of the surface. Total controlled and uncontrolled emissions are estimated in Table 10.

TABLE 10. Estimated Air Pollution Emission Inventory for Paraho Operations

<u>Oil Production bbl/day</u>	<u>Emissions kg/hr</u>			
	<u>SO₂</u>	<u>NO_x</u>	<u>THC</u>	<u>PM</u>
11,500				
Uncontrolled	3.8	43	1.6	543
Controlled	3.8	43	0.4	14

Development Engineers, Inc. has estimated that the Paraho operation of a single 11,500 bbl/day retort will result in minimal degradation of regional and local air quality. All state and federal ambient air quality standards are estimated to be met with adequate control technology applied to the plant.

A modeling study of air pollution on the Piceance Creek Basin was done by Engineering Science, Inc. under contract to the Federal Energy Administration⁽⁴⁾. Three separate models, all Gaussian in nature, were used in determining ground level concentrations: up valley model (APAX), Gradient Wind model (APSIM) and a fumigation model. The APAX model was used to calculate short term concentrations extended to 1 hr average. The APSIM model was used to simulate annual averages by incorporating the wind flow pattern and a stability frequency distribution function. The fumigation model assumed that the plume would move down the valley at night and would be contained in a stable layer above the valley floor. Thus, with solar heating in the morning, the ground-based inversion would be eroded upward to the plume layer.

Emission data was defined for a TOSCO II type process which included upgrading rather than a Paraho process, which has no onsite upgrading facilities. The emission data is given in Table 11.

TABLE 11. Estimated Air Pollution Emission Inventory for ESI Study

<u>Study</u>	<u>Oil Production bbl/day</u>	<u>Emissions kg/hr</u>			
		<u>SO₂</u>	<u>NO_x</u>	<u>THC</u>	<u>PM</u>
Piceance Creek Basin (EIS for FEA)	50,000	604	604	144	336

The study evaluated the primary pollutants. It found that under development which could produce up to 1.7×10^6 bbl/day in 1980-1990, NAAQS for SO₂, NO_x and particulates would be met. However, the production would be limited to a maximum of 50,000 bbl/day under the Colorado Class II incremental limit for SO₂ unless better emission controls were implemented.

Occidental (Modified In-Situ)

Occidental has been operating a modified in-situ operation for several years near Debuque, Colorado. Occidental has a cooperative agreement with DOE to retort shale underground.

A modified in-situ operation without surface retorting would release fewer uncontrolled emissions than a surface retort. Since in-situ retorting is operated in a gas combustion mode, large quantities of low BTU gas is produced. Table 12 summarizes probable atmospheric emissions from a 100,000 bbl/day in-situ retorting operation⁽¹⁰⁾.

TABLE 12. Estimated Air Pollution Emissions Inventory for Occidental Oil Company Modified In-Situ Operations

	Oil Production bbl/day	Emissions kg/hr			
		SO ₂	NO _x	THC	PM
Modified In-Situ					
Uncontrolled	100,000	4942	768	453	263

Work on a full scale in-situ retort shifted to lease tract C-b. Currently underway is construction of support facilities, shaft sinking and development of ancillary mine and retort test area. The retort facility is scheduled to begin operation in 1981 to confirm procedures for commercial operations. A 200 ft tower at the site gathers meteorological data at three levels. Sampling of 25 different pollutants and high volume sampling of particulates is also being done. Occidental has filed certain emissions data with the State of Colorado but the data are not currently public information.

Geokinetics, Inc.

Geokinetics, Inc. has been operating a true in-situ retort on state owned land in eastern Utah, 25 miles southwest of lease tract U-a. Geokinetics, Inc. has established their own onsite analytical laboratories and have instituted a baseline monitoring program. This program was initiated before blasting operations began and will continue during development operations. No data are available from this operation.

Equity-Bx

Equity Oil Co. is operating a program in cooperation with DOE at a site in Colorado 10 miles northeast of federal lease tract C-a. An environmental research plan has been established with installation of instruments for two weather stations and airborne gas analysis. Data are now being collected and monitoring will be done for a year past program completion.

Talley Energy Systems-Rock Springs

The Talley Energy Systems, Inc. true in-situ oil shale project is currently underway in Wyoming shale country with experimentation in hydraulic fracturing and rubbing. The operation has one meteorological tower set up downwind for meteorological data. No known atmospheric pollution baseline data are or have been taken. Retorting of the shale has not been initiated.

Sandia Laboratories-Rock Springs

A true in-situ field operation is being conducted by Sandia Laboratories at a site near Rock Springs, Wyoming. According to the Environmental Development Plan, Oil Shale FY 1977 from U.S. ERDA, a baseline environmental monitoring program was to be initiated in FY 1976 and completed in FY 1977⁽¹¹⁾. No data have been found nor is it known if a study was ever initiated or completed.

EVALUATION OF ENVIRONMENTAL PROGRAMS

The following section will evaluate the environmental assessment programs conducted by the various oil shale developers. This evaluation will be useful in determining the direction of research needed to fill the gaps in the assessment programs and to answer questions about the environmental impact of oil shale operations.

Assessment of Baseline Studies

Comprehensive baseline studies have not been completed for all potential retorting operations. This is a necessary exercise to assess

the impact of the operations on existing air quality. Some studies have been and are currently being done while operations are proceeding. It is difficult to predict background levels of contaminants if additional contaminants from site operations are contributing to the natural background, even if this operation is only roadbuilding. At least a year of site-specific information needs to be collected regarding background levels of pollutants to adequately assess the undisturbed air quality.

The most complete baseline studies are those completed for the federal lease tracts C-a/C-b and U-a/U-b. These studies were completed more than two years ago using instrumentation and techniques that were the current state-of-the-art. In all tract studies, measured concentrations of the gaseous pollutants SO_2 and H_2S were zero or near the detection limit of the instrument. The measurements of non-methane hydrocarbons were of little value due to the uncertainty of the analysis⁽⁵⁾. Recent developments in instrumentation for portable continuous gaseous pollutant analyses have been made which would give more useful readings for H_2S and SO_2 at lower detection limits. The same is true for non-methane hydrocarbon analysis.

Most of these pollutant measurements at the lease tracts were taken from sampling ports no more than 10 to 12 ft above the ground. A truly representative sample needs to be taken at higher elevations also (20 to 30 ft) either by a "snorkle" or from a tower. A concentration differential could then be established and correlated with wind speed and direction at those elevations.

Some instruments and associated data reduction equipment described were run by 110v sources. The power for these instruments would have to come from diesel or similar generators because of the remote location. The generators can contribute to local pollution, giving false readings of natural background levels. Use of portable battery operated instrumentation is recommended.

Criticism of the air quality baseline and meteorology program has been expressed by others⁽¹²⁾. The criticism centers around the methodology

and data collection procedures used in response to the required monitoring program. The programs instituted on the federal oil shale lease tracts did not answer the question, "What will be the environmental impact if the extensive oil shale resources of Colorado, Utah and Wyoming are developed?" There was a lack of integration of the data to assess the environmental effects of an oil shale industry over the entire three-state region. There was little coordination of efforts among the leaseholders with a non-uniform data acquisition system. In other words, and this author agrees, the data acquired over the monitoring period have no realistic and practical use unless it is reworked.

The meteorological data for the lease tracts taken for use in modeling were not sufficient. No upper air studies were conducted with the only data acquired from two levels at a single site on each tract. The study for the Colony Development Corp. had demonstrated difficulty in describing transport and diffusion over complex terrain even when upper air studies were conducted.

Assessment of Models and Modeling Studies

All oil shale programs reviewed that involve modeling efforts to predict air quality and environmental impact utilize the basic Gaussian equations in one form or another. The modeling ranges from simple applications estimating ground level pollutant concentrations using meteorological data collected at a site not necessarily at the same geographic location at the plant site, to complex studies simulating long and short term concentrations using data from tracer studies to predict influences of area topography and local meteorological data collected onsite. There are, however, limitations in these modeling studies which include using strictly a Gaussian approach, non-site-specific meteorology and inaccurate representative plant emission inventory data.

Gaussian models will overestimate ambient concentrations under calm conditions and at long distances from the source as well as underestimating ambient concentrations near surface levels. Reasons for this behavior will not be detailed in this paper. But more importantly, the Gaussian model

(or any model) is difficult to apply with any accuracy in complex terrain such as that found in oil shale regions. Complex terrain can contribute to high ground level concentrations. It physically alters air trajectory and it increases the turbulence levels.

The only viable method of treating the enhanced turbulence has been direct observation from tracer studies. This was done in the Battelle modeling study for Colony Development Operation. Even with observation, there are shortcomings to using the model in complex terrain. Predictions can still be off by an order of magnitude or more. It is recognized that the best meteorological talents are at present unable to supply realistic regional scale predictions of air pollutant concentrations for sources in complex terrain.

In a model application for the Naval Oil Shale Reserve, little local upper air data was collected for use in the model. Other model applications for the region used upper air data collected at Salt Lake City, Utah or Grand Junction, Colorado and were applied to the Uinta and Piceance Creek Basins, respectively. This is a questionable use of data even for upper air measurements. Site-specific measurements must be taken. This must include measurements of at least average wind speed and direction as a function of time at several locations.

Atmospheric modeling is also limited in its ability to handle particulate and secondary pollutants. Atmospheric formation of such substances depends on sunlight as well as precursor concentrations. Most models are useful only to the extent that emission data are accurate and representative. The Colony study is a good example of this since emission data were revised from the early modeling studies in 1972⁽⁷⁾. The impact on predicted ambient air concentrations is noticeable. Differing assumptions regarding emission factors (and controls), resources covered, normal versus transient operations, associated operations (upgrading, construction, mining, etc) can lead to dramatically different predicted pollutant concentrations.

RESEARCH NEEDS AND REQUIREMENTS

The last section of this paper will deal with the areas of research that are required to fill the technology gaps identified in the evaluation of the environmental programs. The required research will be primarily in the characterization, measurement, transport and monitoring atmospheric pollutants, and the physical and chemical processes, and effects of these pollutants in the environment. The following research areas should be considered for each new individual oil shale development and be integrated into a program for the entire region.

Characterization and Measurement

A systematic study is required to characterize the particulates, gases and vapors in air and deposited in water and on surfaces. Methods need to be developed to sample and analyze pollutants using the most sensitive portable instrumentation. This type of study should be done prior to site operations and after processing of the shale is initiated. The following subtasks are part of this effort.

1. A systematic study should include a complete meteorological network to enable pollutant concentrations to be correlated with at least wind speed and direction and time. Pollutants should be analyzed by portable instrumentation placed at ground level and higher, 20 to 30 ft. A high degree of quality assurance is necessary to assure a collection of representative samples.
2. Research is required to characterize the particles resuspended in air during unit operations. This study will include onsite collection of representative samples over a several year period during plant operation. There is a potential for release of hazardous trace materials such as polynuclear aromatic organic matter and trace metals. These trace metals have not been fully characterized and there is a concern over unregulated trace materials. These need to be established to assess the health and ecological effects and identify control requirements.
3. Research is also required to characterize gases and vapors in air and deposited in water and on surfaces for each unit operation for shale

retorting. This will involve development of sampling techniques and onsite collection of data over a several year period. The identity and chemical properties of these gases and vapors must be known to assess the health and ecological effects and to identify control requirements.

Transport and Deposition

The physical transport and deposition of particulates, gases, and vapors need to be assessed. The research will address the applicability of existing information of transport phenomena to the oil shale development programs and the need to provide additional information and develop improved predictive techniques for monitoring (especially) on a regional basis. Close cooperation with other research efforts, notably those addressing characterization of pollutants and ecology effects, will be required.

The program will develop and validate procedures necessary to predict the atmospheric transport of gases and particulate pollutants to be released by shale oil production. This will include field experiments, such as tracer studies, to assess the dispersion, deposition and resuspension applicable to complex terrain, physical and chemical transformation and interactions of pollutants during transport.

Field tracer studies can be useful in determining not only transport and diffusion patterns on a local scale, but also aid in the development of a regional scale network of sampling stations to best assess the fate and concentration of atmospheric pollutants. Tracer studies, along with upper air studies, are necessary for accurate modeling in complex terrain. As noted earlier, most developers of oil shale used conventional approaches to modeling and found them inadequate.

The information developed in this effort can be used to estimate the air quality expected in the different regions likely to be developed, evaluate the need for pollution control under different levels of development or different combinations of technologies and determine suitable monitoring programs. This work should be initiated immediately to provide information for control technology before widespread development of the shale region.

Summary

All of the above research work should be put together in an integrated program involving a coordinated effort between scientists and engineers qualified to perform work in the various tasks. The research will be done over a period of several years including the period prior to development of an area to establish baseline data, the period during site preparation and construction, and the period after shale oil production is initiated. This research will provide answers for the regulation agencies, the public and the operators concerned with the total environmental impact of an oil shale industry.

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