Section 17

OIL SHALE: A DEVELOPING INDUSTRY

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Introduction

The United States has been dependent on foreign oil for a long time, a lot longer than most people realize. Only since the Iranian Revolution, when oil imports from that source were curtailed, has Congress and the press given this problem the proper attention. It took the public to get this attention. Congress heard the anger and frustration of the people who waited in the long gasoline lines during the first half of 1979; the farmers, truck drivers, and the construction companies who could not get diesel to run their equipment. Since then the President and Congress have recognized the urgency of developing alternate sources of energy.

Our dependency on foreign oil existed even before the 1973 Arab Oil Embargo. In 1968, the Independent Petroleum Association of America conducted a campaign to acquaint members of Congress that the United States' dependency on foreign oil was reaching a crisis level. That campaign fell on "deaf ears".

In 1968, the USA imported 3.2 million barrels per day, or 23% of the oil supply. In 1979, 8.2 million barrels per day, or 44% of our supply, were imported, and in 1990 it has been estimated 12 million barrels per day, or 60% of our oil supply, will be imported if we do not undertake steps to conserve or replace our oil supply.

In 1979, the Foreign Oil Imports cost approximately $50 billion. Import of foreign oil is the prime reason for the trade deficits, why the world has lost confidence in the dollar, why we are in the throes of inflation, and why we are facing a recession. The prospect of higher OPEC prices and increased costs for foreign oil imports is a major threat to this nation's economy.

The development of an oil shale industry as called for by the President in July of 1979 is one of a number of actions we need to take to protect our economy. Conservation, conversion of oil fired electric generating plants to coal, accelerated domestic oil and gas exploration and a more proactive energy development plan with our neighbors, particularly Mexico, all need our attention and implementation.

The security of our country, our "lifestyle", and our economy is geared to liquid fuels. The U.S. oil shale deposits are important because they should provide a competitively priced, long term, environmentally benign, domestic oil supply.

History

Oil shale has played an illustrious role in providing liquid hydrocarbon since the 14th Century when both the Swiss and Austrian oil shales were retorted to procure "rock oil". England issued patent No. 33 in 1694 for a retorting process to produce "oyle from a kinde of stone". (1)

The oil shale industry in Scotland started in 1859 and flourished for over 100 years.

Since the early 1800's oil shale industries have existed in Scotland, Spain, France, Germany, South Africa, China, and Estonia. The data shown on Figure 1 summarizes these activities.

United States History

The U.S. oil shale industry was an important part of the Nation's energy economy before the first oil well was drilled. At least 50 commercial plants for extraction of fuel oil from eastern oil shales existed prior to 1859. The industry disappeared shortly after commercial petroleum production began.

Between 1915 and 1920, supplies of domestic crude fell below demand, and oil imports increased, especially from new oil fields in Mexico. USGS indicated at that time that the United States had only a 9-year reserve of petroleum in the ground and that the outlook for new discoveries was not good. At about the same time, USGS announced that large fuel resources were contained in the oil shales of the Green River formation. When combined with predictions of forthcoming fuel shortages, the announcement triggered an oil shale boom. Some 30,000 mining claims were filed on Federal lands, and about 200 companies were formed to develop the resource. Retort development programs were initiated at several locations, and at least 25 retorting processes were advanced to the pilot-plant stage. Total shale oil production was negligible, but interest was at an all-time high. The boom ended abruptly with the discovery of large oil fields in eastern Texas. Oil prices dropped to a few cents per barrel, and interest in oil shale development essentially disappeared.

Little R & D was conducted in the United States until World War II. In 1944, out of concern for the hazards of imported energy, Congress passed the Synthetic Liquid Fuels Act, which authorized U.S. Bureau of Mines (USBM) to establish a liquid fuel supply from domestic oil shale. USBM began a comprehensive R & D program that has continued to the present day, although oversight authority was transferred to the Energy Research and Development Administration in 1974 and to its successor, the Department of Energy (DOE) in 1978.

One of USBM's most significant early acts was the establishment of a research facility at Anvil Points on the Naval Oil Shale Reserve near Rifle, Colorado. Between 1944 and 1956, the Anvil Points facility was used for mining studies that led to the application of the room-and-pillar technique of underground mining. The gas combustion retort, the predecessor of modern directly heated retorts was also developing during this period. In 1965, the facility was leased by the Colorado School of Mines Research Foundation, and was the site of a 4-year development program in which the gas combustion retort was evaluated and improved by a consortium of six major oil companies: Mobil, Humble, Continental, Pan American, Phillips, and Sinclair.

In 1973, the facility was leased by Development Engineering, Inc., which operated it for 5 years during which the Paraho retorting process was developed.

Between 1963 and 1968, DOE evolved a leasing proposal that was intended to encourage private development of the Federal oil shale lands in the Green River formation. The program failed to attract private participation. However, it gave rise to current Federal Prototype Oil Shale Leasing Program which was conceived in 1969 and promulgated in 1974 with the sale of leases to four tracts in Colorado and Utah.

In addition to these activities on Federal lands, private companies have also engaged in exploration and R & D programs on their own lands. The companies that have been most heavily involved are Union Oil, Occidental Petroleum, Superior Oil Company, and the Colony Development Operation group which has included Tosco, Atlantic Richfield, Cleveland Cliffs Iron Co., Sohio, and more recently, Exxon. (2)

Green River Formation

"In 1874, workers on the transcontinental rail line found that rocks picked up from the excavations along the Green River in Wyoming ignited when used to protect campfires from the night winds. The March 1874 issue of Scientific American noted that the railroad superintendent:

> ...has caused analyses and experiments to be made with this substance which proves to be a shale rock rich in mineral oils. The oil can be produced in abundant quantities, say 35 gallons to the ton of rock. The oil thus obtained is of excellent quality.

The rocks of interest were pieces of oil shale from the Green River Formation."[3]

Although large amounts of low grade oil shales can be found in a variety of locations within the U.S., the most significant deposits found so far are in three Western States. These deposits, which can be up to 1500 feet thick, are contained within the Green River Formation and underlie about 34,000 square miles of terrain in Colorado, Utah, and Wyoming. This formation is divided into several geologic basinc, with the Piceance Basin (Figure 2) in Colorado being the most important.

Piceance Basin

The oil-in-place in this one formation is almost 1.8 trillion barrels. Assuming a recovery of 40%, recoverable shale oil reserves are therefore about 720 billion barrels. When compared to the U.S. and world proven oil reserves of 28 and 650 billion barrels respectively, our reserves of oil shale clearly give us an opportunity to significantly reduce U.S. dependence on foreign oil supplies for many years to come.

The Piceance Basin covers approximately 630 square miles. The deposit is in a saucer-like shape with the outer edges being higher, thinner and leaner. The center of the basin contains oil shale to a depth of over 1,500 feet with over 1,000 feet of it containing a grade of 25 gallons per ton or greater.

Oil Shale Developers

Developers in the recent time have consisted of the Union Oil Company and Colony Development Company (ARCO and TOSCO) in the Parachute Creek area; Occidental Oil Shale, Inc., in the Roan Creak area in the early 1970's, and in 1977 both of the two Federal Prototype Lease Tracts; the Rio Blanco Oil Shale Company at the C-a Tract and the Cathedral Bluffs Oil Shale Company at the C-b Tract. Recently, Multi-Mineral Corporation leased the Bureau of Mines' ten foot diameter shaft at Horse Draw to enable it to acquire samples of the two sodium minerals, Nahcolite and Dawsonite, that are associated with the oil shale in this region of the Piceance Basin. The activities of Superior Oil located in the northeast section of the Piceance Basin is also planned to include the recovery of these minerals in addition to shale oil. The other major oil companies, Exxon, Mobil, Chevron, Texaco, and Getty, have all substantial holdings in the Piceance Basin; however, 80% of the land in the Piceance Basin is owned by the Federal Government -- some 320,000 acres.(4)

The status today is that both Union and Colony have operated surface retort pilot plants in the range of 1,000 tons a day and have plans to develop a first commercial module that will handle approximately 10,000 tons a day. The two Modified In-Situ processes being utilized are being developed by the Rio Blanco Oil Shale Company at C-a and Occidental Oil Shale, Inc. at Logan Wash and in partnership with Tenneco at the C-b Tract. At C-a, it is presently planned to construct four underground retorts, going from initial size of 30 x 30 x 165 feet high to one close to commercial size of 130 x 130 x 450 feet high. The first Retort (#0) was ignited in October, 1980.

Occidental at its development, the Logan Wash site near DeBeque, has completed the burning of six retorts; the last three being of commercial size, approximately 160 x 160 x 300 feet high.

Occidental Oil Shale, Inc.

Occidental Petroleum Corporation became involved in oil shale in the late 1960's when Dr. Hammer, our Chairman and Chief Executive Officer, became intrigued with the potential that oil shale had to solve the nation's oil import problems. Laboratory scale and pilot plant testing began in Occidental's Laverne Research Laboratories in 1968. Results from this work were encouraging enough to Occidental to proceed with the field evaluation of the Modified In-Situ process.

A tract of land located on the southwest corner of the Piceance Basin (Figure 2) was acquired. The Piceance Basin is shaped somewhat like a saucer with the formation at the outer rim being higher in elevation, thinner, and also lower in grade. The grade at Logan Wash is about 15 gallons per ton for the full oil shale increment present, which is about 250 feet, versus the 28 gallon per ton for a similar thickness at the C-b Tract, in the middle of the basin. A small mine was started from a portal entrance on the Logan Wash site in 1972. This small mine provided access to the oil shale formation to build the first three research retorts. The Logan Wash property is located about 10 miles from the town of DeBeque, which was the scene of numerous oil shale operations in the early 1920's.

Modified In-Situ Technology

Although the recovery of oil from oil shale appears to be quite simple, effective oil recovery when attempting to process impervious shale deposit several hundred feet thick in place, or in-situ, can only be accomplished if the gas being used to heat the shale can readily pass through the formation. The concept of achieving this is the essence of the Oxy technology. The process basically consists of two steps: 1) forming of the in-situ retort (Figure 3), by removing 15-25% of the oil shale, drilling from the two levels and then blasting the shale into the void created, and 2) retorting the rubblized oil shale in place. Retorting is initiated by heating the rubble pile at the top, using an outside energy source such as shale oil. Once the top is hot, use of the fuel is discontinued and the retorting is conducted by bringing air plus steam into the top of the retort.

An operating retort contains four major zones (Figure 4). Within the first, or preheat zone, the inlet gas is heated by contact with the hot spent shale. The hot gas then reaches a combustion zone in which the oxygen is consumed by burning the residual carbon left on the shale during the thermal decomposition process. Some oil and gas may also be burned. Below the combustion zone is the retorting zone in which the hot combustion gases thermally decompose the organic component of the shale to produce oil and hydrocarbon gas. In the final zone, the combustion and retorting gases are cooled as they flow downward, condensing some water and vaporized oil. Oil and water then flow from the bottom of the retort and collect in a sump located behind a gastight bulkhead at the base of the retort. The operation is continued until all of the shale has been heated and the oil recovered. The burn rate is about one foot per day. After initial oil and water separation takes place, the products are pumped to the surface through separate systems. (5)

The advantages of this concept are many. The process can treat shale zones several hundred feet thick and it can economically handle shale with average grades as low as 20-25 gallons per ton. This results in maximum utilization of the resource. In contrast, surface retorting requires the mining of shales with grades greater than 30 gallons per ton, and the recovery is limited to extraction of about 50% in mine sections which can be no more than 50-60 feet in height. However, it should be recognized that optimal resource recovery will be achieved through a combination of in-situ retorting, and surface retorting of the mined shale.

The off-gas generated from the retort, although low in Btu value, 60-70 Btu's per cubic foot, is sufficient in quantity to provide all of the energy needed to operate a commercial-sized tract, such as Cathedral Bluffs (at C-b Tract). Outside sources of energy will only be needed during the construction and start-up phase, after which the off-gas will provide all of the energy for the operation through its conversion to electricity and/or steam on-site.

MIS Research

Modified In-Situ development went through several stages. The six retorts burned to date have been constructed to research and demonstrate a number of different technical and economical factors (Figure 5). Retorts 1 through 3 were research retorts, with the first one being some 40 times larger than any previous work undertaken in a pilot plant. This retort contained about 4,000 tons of material. This is compared to Retort 6 which contained approximately 360,000 tons of material.

Different methods of forming the retort were studied. Both the blasting into a horizontal room and a vertical slot were evaluated. There are obvious mining economies to constructing a retort utilizing a vertical slot. However, the potential for creating high permeability zones in the vertical direction are greater with this method than with the horizontal free-face blasting method.

Considerable information was learned from the research program encompassing Retorts 1 through 3, the most important being that the mining and blasting results and the oil recovery were encouraging enough to proceed with the development of commercial sized Retorts 4 through 6.

MIS Commercial Development

The preparation of Retort 4, which was 120 x 120 x 290 feet, significantly added to the understanding and know-how concerning scale up of in-situ retorts. For example, valuable experience was gained at ignition and start up of the larger cross section. Also, geological conditions not sensitive to the creation of the smaller research retorts showed up in the rubblization of Retort 4.

The construction of Retorts 5 and 6 were conducted under a cooperative agreement with the Department of Energy. The cost of the program was $29 million and commenced in 1976 and was completed in June, 1979. Two full-scale retorts were developed, one using the vertical slot, the other, Retort 6, the horizontal slot. Retort 6 (Figure 6) was a scale-up of the Retort 3 design, using two intermediate mining levels between the top and floor levels. After an exhaustive series of flow and tracer tests, the Retort 6 was ignited in August of 1978. The start up phase ended 16 days later when a portion of the sill pillar fell into the void between the pillar and the rubble pile and disrupted the operations. The operation continued while remedial action was taken to restore the retort to a normal operation. During the course of the operation, there were 54,000 barrels of shale oil produced. Recovery was somewhat less than had been predicted, and this has been attributed to the problem experienced during start up. The failure of the sill pillar and the ability to control the air distribution to the top of the rubble was lost, and thus some sections of the shale did not effectively retort.

The major conclusions of constructing and operating these three retorts are shown in Figure 7. The more significant ones are: (1) a more uniform void volume distribution can be obtained with the horizontal free phase design resulting in improved retort operability and oil yield; (2) ignition is the most critical step in the retorting process; (3) oil shale can be used to ignite a retort with an energy requirement close to that predicted; and (4) the MIS technology was confirmed in full-scale retorts. (6)

Rock Fragmentation

In addition to the cooperative work undertaken with the DOE, Occidental has and is continuing to fund additional work, particularly in the rock fragmentation area. Construction of a large underground chamber, or retort, containing oil shale particles having fairly uniform size and void volume distribution represents a key element in the Modified In-Situ shale process. The mean shale particle size must be small, on the order of six inches. Producing a small uniform particle size and uniformly distributing the initial void volume throughout the rubble bed in a volume on the order of 300-feet high by 160-feet square when blasting to a limited void volume poses a significant challenge, both technically and operationally.

Retort 6

Retort 6 was rubblized successfully, using newly developed explosive technology and a total explosive weight exceeding 500,000 pounds of ANFO equivalent. The explosive was distributed throughout over six million cubic feet ot total retort volume in 414 blast holes, emanating from three different horizontal mining levels. The blast holes were tied to an extensive millisecond delay. The blasting sequence was designed to control seismic damage to the surrounding mine structure and provide a uniform void volume distribution to the final rubble volume. A high degree of reliability was built in to the overall initiation system to insure a successful detonation.

Prior to Retort 6, an extensive rock fragmentation test program was performed to design and demonstrate the Retort 6 rubbling plan. The program consisted of some fifty underground blasting tests ranging from the ten pounds of explosives to 22,000 pounds, conducted in the Logan Wash Mine. The Retort 6 (Figure 8) design consisted of three vertical spaced apart horizontal void levels. The shale layers between these void levels were blasted vertically into the voids using newly developed horizontal free-face blasting technology which is related to the cratering theory. The void rooms are large and require temporary pillars to insure roof stability within the voids during the mining, drilling, and loading operations. Immediately before the shale layers are blasted, the temporary pillars must be completely removed to give proper free-faces for the horizontal free-face cratering blasts.

In addition to the rock fragmentation tests, a comprehensive series of operational type blasting tests were performed to identify and eliminate any uncertainties associated with such large scale blasting operation. Various operational procedures were practiced full-scale and improved to increase the overall retort blasting liability. This testing included a series of blasting cap tests to establish the delay and scatter that would be present in the Retort 6 blast and account for this scatter in the blasting plan. In addition, a series of full-scale ten inch diameter 200-foot decked holes were loaded and blasted under wet conditions to test the explosive product for Retort 6 under the most severe loading conditions. Reliable loading and priming procedures were established for these holes which improved the overall Retort 6 blasting liability. (7)

DOE Cooperative Agreement - Phase II

Phase II of the DOE Cooperative Agreement was initiated in June of 1979. This program encompasses the construction of two additional full-scale commercial sized retorts, 7 & 8 (Figure 9). The size of these retorts is 165 x 165 x 240-feet high, the full thickness of the oil shale formation. The purpose of this program is to confirm the operation of the full-scale retorts by operating two simultaneously. Another important part of the program is to develop rock mechanics data pertaining to the pillars between the retorts, both those that are acting as structural members and those that are acting as diaphrams between the retorts. Other aspects of this program include the evaluation of new mining equipment, remote sensing equipment, and the slip-stream treatme of the off-gas. These latter tests will be performed in conjunction with EPA and state permit requirements to obtain both verification and development design data for Cathedral Bluffs (C.B.). The light-off of the retorts will occur in October of 1981, with retorting completed in July of 1982. To develop these two retorts, over 6,000 feet of access drift are being driven and some 400,000 tons of muck will be removed to create the void volume and the access drifting. A production of nearly 200,000 barrels of oil is expected from this operation. The cost of the program is about $64 million.

The mine utilizes full-scale commercial equipment similar to that which will be used at the C.B. operation. Six yard loaders are used to load twenty-five ton trucks which haul the muck outside of the mine. Twin-boom drill jumbos are utilized at the headings. These units are capable of driving a 14-foot long drill steel in 90 seconds. Bit life is extremely good. Six yard load-haul dump units are also used within the mine and will be used extensively at the Cathedral Bluffs operation.

Currently about 450 people are employed at the Logan Wash site with 300 of those being Oxy hands. Free busing service is provided from both Rifle and Grand Junction to the site. By the end of 1980, Oxy will have expended $100 million for the development of the MIS process, and by the end of Phase II of the Cooperative Agreement in November of 1982 over $125 million will have been expended by Oxy alone, with a total expenditure of $170 million.(8)

Work at Oxy's Research Center in Irvine, California, has played an important part in the development of the MIS process. Work continues, using both bench and pilot facilities to investigate MIS spent shale characteristics, instrumentation, oil-water separation, shale ignition methods, oil upgrading and process modeling. Oxy's development work has led to over 80 U.S. patents being issued, with another 61 under application.

Cathedral Bluffs - Commercial Development

The knowledge gained from the design, construction, and operation of the full-scale retorts at Logan Wash is being used in the design and construction of Cathedral Bluffs. The C-b Tract, which was acquired in 1974 by Arco, Tosco, Shell, and Ashland at a bid price of $118 million, was activated in September, 1977, when the first field work commenced. This was proceeded by a two-year baseline study which was required to evaluate all environmental aspects of the Tract. The activity on the Tract had to be also proceeded with the preparation and submittal to the Area Oil Shale Office of the USGS of a

Detailed Development Plan. This Plan was submitted to the Department of Interior in early 1977 and approved in August, 1977.

The recovery of the shale oil resource in the Tract has undergone a number of changes. The original partners planned to use a room and pillar method to mine the mahogany zone, a 35 gallon per ton zone, taking out about a 60-foot high seam. This rock was to be retorted on the surface. A total recovery of about 400 million barrels from the tract would have been realized. The present partners, Oxy and Tenneco, plan to apply both MIS and surface retorting to the reserve to maximize recovery. With this plan, 1.1 billion barrels will be recovered from a seam 290-feet thick. This is slightly less than a 50% recovery of the shale oil. This is a very high recovery when compared to normal oil field recoveries of 20-30%.

C-b Current Activities

Currently, the Cathedral Bluffs operation is in a shaft-sinking mode. The Production, Service and Ventilation/Escape Shafts are approaching 2/3 of their total depth of 2,000 feet. The Service and Production Shafts were both slip-formed. The Service Shaft headframe, which sits over the 34-foot diameter shaft, is 178-feet high and was slip-formed in about 10 days. The Production headframe, which sits over the 29-foot diameter Production Shaft, was slip-formed in about 26 days.

Mine Development

The overall mine layout showing shaft locations, retort cluster configurations and development drifting is shown in Figure 10. The layout consists of panels of retort clusters arranged to provide an orderly sequence of mining and retorting. Each panel contains 8-10 retort clusters and is surrounded by a set of panel access drifts. A cluster contains six retorts and is the basic building block of the mine layout. The first cluster to be ignited will be a module of three retorts, followed by a cluster of six retorts. There will be 96 retorts burning simultaneously at full production of 54,000 barrels per day. This will require 120 retorts to be developed each year.

The level shown in Figure 11 is the lower void level which will be used as the main muck hauling level. Muck will be hauled by either load-haul-dump units or conveyors to muck raises which will drop the ore to this level. Conveyors will then handle the ore, after it has been crushed to minus 8-inches in feeder breakers, to surge bins located alongside the Production Shaft. The panel drift network will consist of twin drifts connected with cross-cuts at nominal 300-feet. Drifting will be done by conventional drill-blast-muck techniques.

The sequence of development of clusters is governed by muck handling and ventilation considerations, as well as by the constraint that adjacent retorts must be rubblized before ignition of a cluster. The key to rapid retort development is that mining can proceed from both ends of each cluster. This greatly reduces average haul distances in and out of the work area.

A 34-foot diameter lined shaft will exhaust the retort off-gases to surface for processing.

A ventilation level will be required for efficient disposal of exhaust ventilation air from the development workings and for distribution of intake air during initial development. Three additional shafts will be required to meet ventilation requirements under a gassy mine classification. Approximately six million cubic feet per minute of air will be required to be brought underground with a little over one million of that being used in the process.

The floors of the drifts at the main levels will generally be sloped so that mine water will flow by gravity to intermediate sumps at various locations along the drifts. All this mine water will be finally pumped to the mine water settling sumps near the V/E Shaft at the upper and lower levels.

The Production Shaft and headframe arrangement (Figure 12) shows the six levels of the mine along with the exhaust chimney located on the west side of the shaft. Stations at main levels at this shaft and the Service Shaft areas will provide the facilities for mine development and oil shale handling. Designed into each station on the ignition, upper void, intermediate, and lower void levels are warehousing and parking areas; maintenance and repair shops; office; electrical room; blasting agents storage; and a fuel station.

The Production headframe will hold the two 9500 horsepower Koepe hoists at the top of the 313-foot headframe. These hoists will handle 60,000 tons a day, or about 20 million tons per year at full commercial operations. The headframe contains two 800 ton bins to receive the muck from underground. These bins will feed by apron feeder onto conveyors which take the rock to the crushing plant ahead of the surface retorting facilities. Excess or emergency material can be diverted to bins and trucked to the emergency stockpile for storage and further reclaim.

The skip-loading station at the bottom of the Production Shaft is made up of two storage bins. These bins feed the reclaim belt to fill the loading flask. The 51 ton skips are loaded from these measuring flasks, which are controlled both volumetrically, and by weight so that the skip cannot be overloaded or overfilled. Skips are in balance and the cycle time will be 90 seconds for each skip.

The Service Shaft, which is 34-feet in diameter, like the Production Shaft, is being sunk with temporary grade mounted hoists. Both of these shafts are down about 1400-feet. The Service Shaft will be used to movemen and materials to the lower level. Personnel will enter a two level cage through an underground tunnel from the change house. The Service Shaft is an air inlet shaft so that air will be heated during the winter to 35°F to prevent icing in the shaft.

The sinking of these shafts is progressing very well, with an average rate of approximately thirty feet per week for the two large shafts. No grouting for water has been required in the two larger shafts, although grout curtains extending about 100-feet each have been the norm for the V/E Shaft since about a 400-foot elevation. Currently about 1200 gallons per minute are being pumped out of the mine, most of this coming from the station development work. The Shafts are concrete lined. Water rings are used as necessary to collect water coming through the cold joints. In the larger two shafts large scale equipment can be used for handling the muck. All of the muck is loaded into six yard muck buckets, hoisted to surface and hauled by truck to the stockpile.

Surface Facilities

The proposed plot plan (Figure 13) shows the location of the off-gas treatment facilities, as well as the surface retorting facilities for the mined rock. Multiple trains will be used for both the off-gas and surface retorting. Oil and water treatment, along with steam and electrical generation, will also be a part of the surface facilities.

C-b Schedule

The target dates of the schedule for Cathedral Bluffs encompass a thirteen year period, from 1977 to full production in 1990. Initial production is targeted for 1985 for both the MIS and the first module of surface retorting. In 1990, the full production will be approximately 94,000 barrels per day. It is estimated that the cost in 1980 dollars will be over $2 billion to construct this facility.

Environmental

The role of government in the development of oil shale is very large. Figure 14 summarizes the major areas of governmental regulations and their implications. One could justifiably ask, "What areas remain unregulated?" The answer is, obviously, "Very few." Probably the major implication of this over-regulation is that it influences management and design approaches to a project and, as such, has the potential for adding large cost increments. The items of particular importance shown on this figure are monitoring requirements, permit requirements, and wilderness protection. In a way of example, environmental monitoring at C.B. is required primarily by the following regulatory agencies: the C.B. lease is administered by the Oil Shale Supervisory Office of the U.S.G.S of the Department of Interior; The Environmental Protection Agency and both the State of Colorado Air Pollution Control Division and Water Control Division and recently by the Water Court of the State of Colorado. (9)

C.B.'s current monitoring program, both on and off-tract, is depicted in Figure 15. This program covers air, water, biology, noise, ecosystem interrelationships, and is one of the most comprehensive requirements of any industry to date. For example, 60 wells are monitored for water level, a good percentage of which are also monitored for an extensive list of water quality parameters. Precipitation is measured at nine locations and surface water parameters are measured at 17 stream locations. All the major gaseous and particulate constituents required under the Clean Air Act are measured on the 200-foot meteorological towers. Two weather stations provide measurement of near surface winds and temperatures. The acoustical radar provides information on atmospheric stability which influences transport of potential pollutants. Area wide visibility measures have also been made.

In biology, big game, medium size mammals, small mammals, and birds are monitored. Both terrestial and aquatic productivity are measured. Micro-climatic stations measure climatic variables under vegetative canopies. All disturbed areas are subject to revegetation and reclamation over project life, estimated as 60 years.

With regard to permits required prior to construction and operation, 93 permits were obtained for the first six retorts at Logan Wash. For the currently planned Retorts 7 & 8, approximately 13 more will be needed. The more involved permits can take from six months to one year to acquire.

With regard to wilderness areas, two major effects are to be noted: First, the Clean Air Act mandates that all existing wilderness areas over 5,000 acres be classified as Class I, the most stringent clean air category; secondly, two major studies are underway to add millions of acres to the existing wilderness. It should be appreciated that vast percentages of the western states are owned by the federal government: Alaska, 96%; Nevada, 87%; and Colorado, 36%. For both C.B. and Logan Wash, 50 and 100 mile radii include a number of potential wilderness areas. Proximity of their boundaries to oil shale plants has a profound influence on allowable air emissions from these plants. In the sense that these wilderness boundaries, where stringent clean air regulations must be met, are creeping toward fixed oil shale locations, they present moving targets as far as compliance with air pollution laws are concerned.

Water

Water is a key element to the development of a large shale oil industry. Water needs and availability are very much process and site specific. Reports have been recently issued by the State of Colorado that indicate there is approximately 500,000 acre feet of water that could be used for oil shale development. This amount of water does not include the additional potential 25 million acre feet of ground water estimated to be contained in the geological formation of the Piceance Creek Basin. Even though there appears to be sufficient water for a multi-million barrel per day shale oil production rate, it will be vital that action be taken to store water through the construction of new reservoirs and to encourage more efficient use of water in the oil shale industry, as well as in agriculture and other uses. In the case of the C-b Tract, it is estimated that water which underlies the C-b Tract is sufficient for supporting the initial operation of 54,000 barrels per day Modified In-Situ shale operation. It is planned to consume all the processed water. Additional off-site water will be required for the full production of the 94,000 barrels per day. (10)

Socio-Economic

It is estimated that it will require approximately 4,400 people to man this operation with some 3,400 working underground in the areas of mining, construction, and processing. A very critical part of the success of an operation is obtaining and retaining this work force. Close attention has been paid to this aspect of a pioneering industry in a remote area. Recruitment and training task forces have been established and have been operating for the past six months. Training will be a large part of the ongoing operation. It is estimated that80% of the permanent work force will have to be trained. It is also estimated that the project will have a 25% turnover which means that over 1,000 people each year will have to be recruited, relocated, trained, and introduced into the work force. It is vital to the success of this operation that a good living environment is insured for the employees. To date, help has been provided to finance apartments in both Rifle and Meeker. The project has also constructed a 300 pad mobile home park in Rifle. Additional housing programs are underway to meet the project needs.

Free transportation is provided from both Rifle and Grand Junctionfor all of the Oxy employees, as well as those of the contractor. This has been not only a benefit to the employees and in the recruiting effort, but has also had a major impact on reducing pollution and highway deer kill. (The Piceance Basin is the wintering area for the largest mule deer herd in North America.)

The logistics of operating a mine hoisting 60,000 tons a day are obvious; however, one needs to also remember that in additionto the mining activity taking place, there is also major construction and process operating activity going on underground simultaneously. With the 120 retorts being constructed each year, bulkheads and pipelines will need to be built, instrmentation controls installed, as well as product handling equipment installed. There will also be the process operating work force underground required to operate the 96 retorts. One factor that helps to put into perspective the immensity of this mining activity is the amount of explosives that have to be transported underground on a daily basis. Approximately one retort has to be rubblized every three days. This, coupled with the void and access mining, results in the need of approximately 300,000 pounds of explosives per day.

The development of the largest underground mine in the world, hoisting through a single shaft, in a safe, cost effective way, is a real challenge to the mining industry. It presents a unique opportunity to develop people and methods to mine, construct, and process in an underground environment; and more importantly, to be a part of a pioneering industry that is greatly contributing to the economy, defense, and lifestyle of this nation. The development of shale oil is an important step forward towards obtaining our independence from foreign crude oil.

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(3) Ibid, p. 108.

(4) W. F. McDermott, "Oil Shale, The Mining Challenge of the 1980's", 83rd National Western Mining Conference, Colorado Mining Association, Denver, Colorado, February, 1980.

(5) A. Sass, "Status of the Oxy Modified In-Situ Oil Shale Project", Pacific Energy Association Meeting, San Diego, California, October, 1979.

(6) Ibid.

(7) T. E. Ricketts, "Occidental's Retort 6 Rubblizing and Rock Fragmentation Program", 13th Oil Shale Symposium, Colorado School of Mines, Golden, Colorado, April 16-18, 1980.

(8) W. F. McDermott, Department of Energy's 3rd Annual Oil Shale Symposium, Denver, Colorado, January, 1980.

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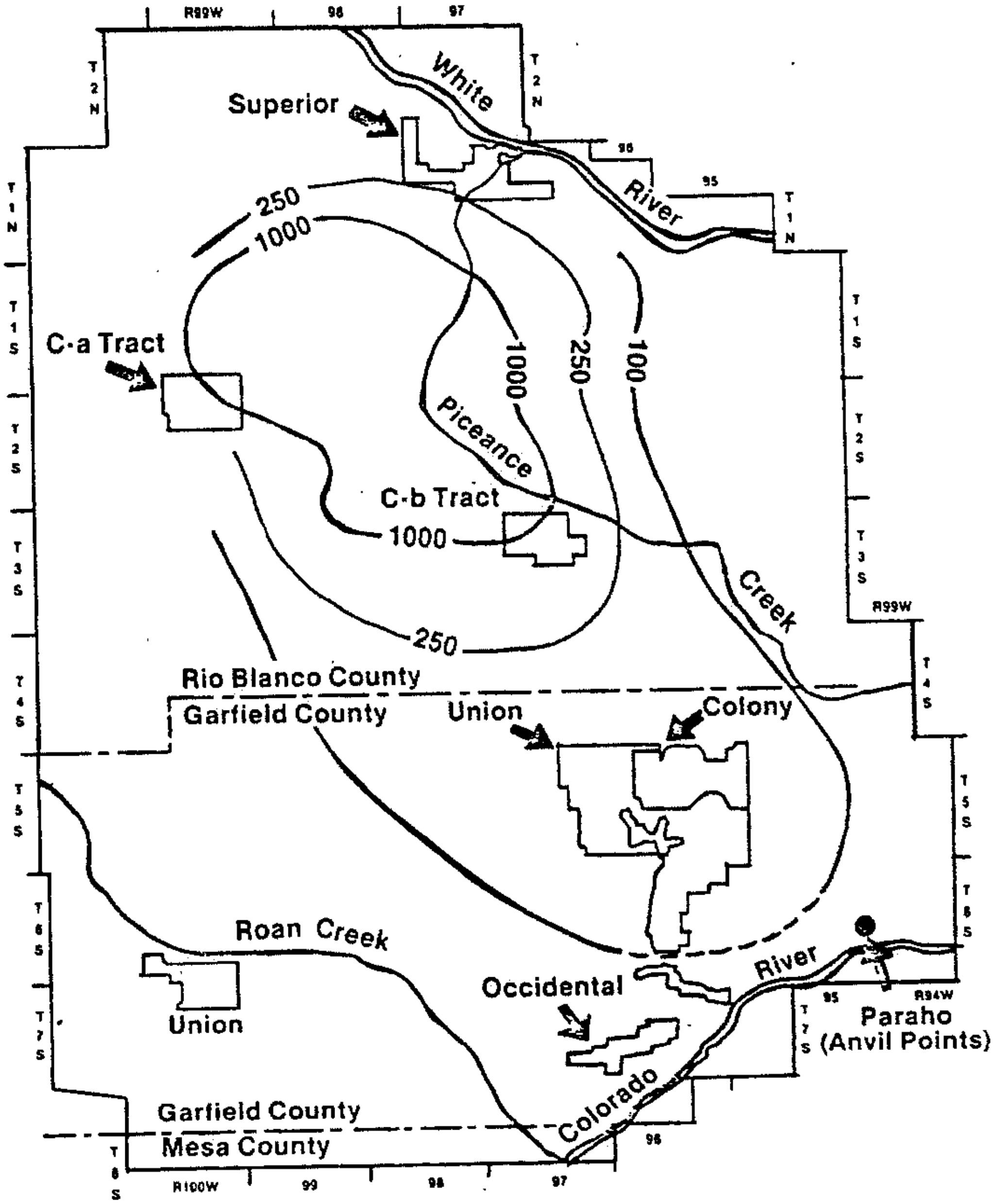
(10) R. J. Fernandes, "Oil Shale", Contractor's Association of West Virginia, 1980.

THE ROCK THAT BURNS

When?	Where?	What?
14th Century	Austria, Switzerland	Ointment (called Icthyol)
1694	England	Patent No. 33 issued for "Oyle"
1800 - 1859	Atlantic Seaboard U.S.	Fuel Oil
1859 - 1962	Scotland	Crude Oil
1874	Green River, Wyoming	Railroad workers discover campfire rocks burned.

Figure 1

Selected Tracts in the Piceance Basin



Contours Show Thickness (Feet) of 25 gpt Oil Shale

Figure 2

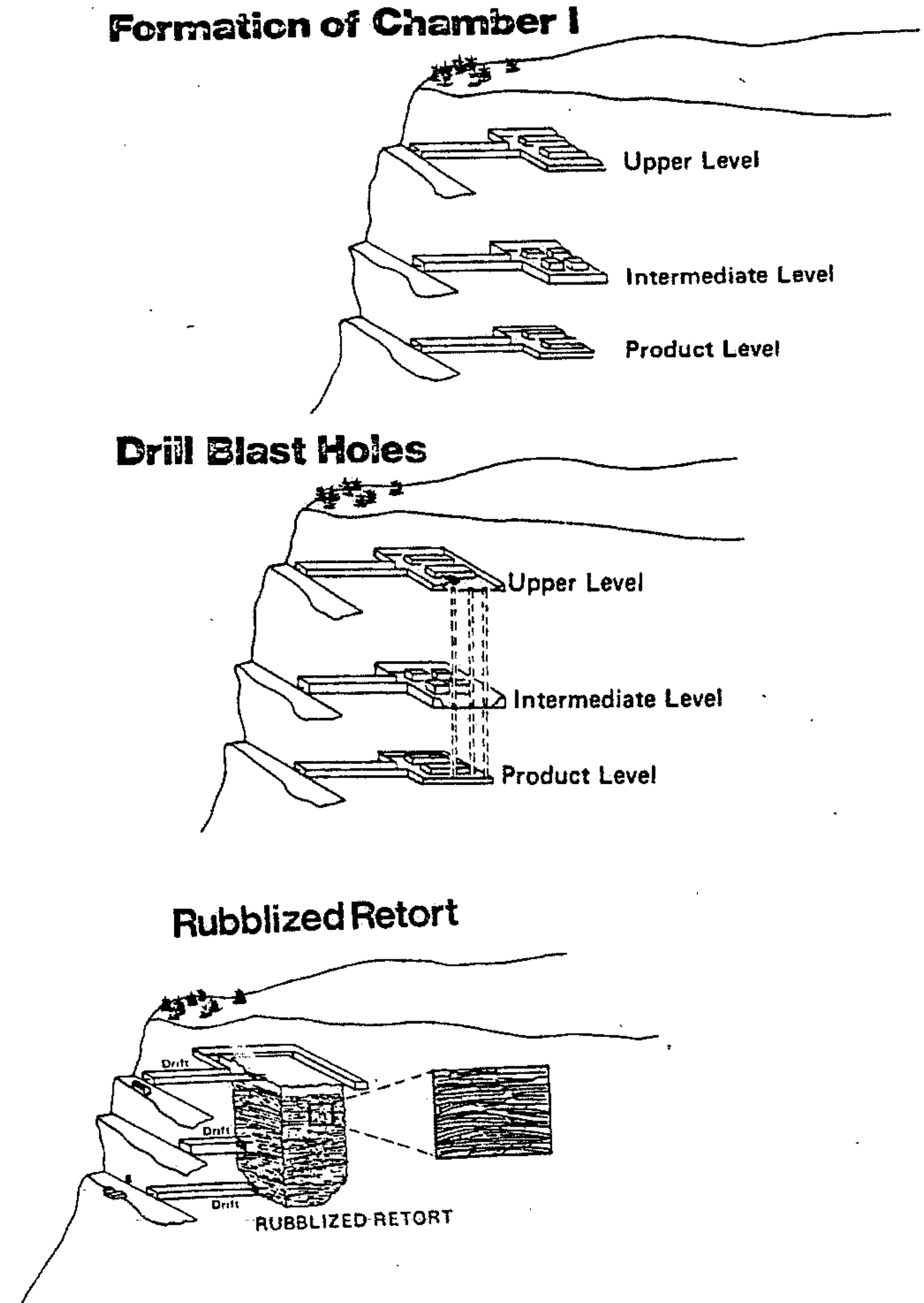

Formation of Chamber I
Upper Level
Intermediate Level
Product Level
Drill Blast Holes
Upper Level
Intermediate Level
Product Level
Rubblized Retort
Drift
Drift
Drift
RUBBLIZED RETORT

Figure 3

Occidental Process

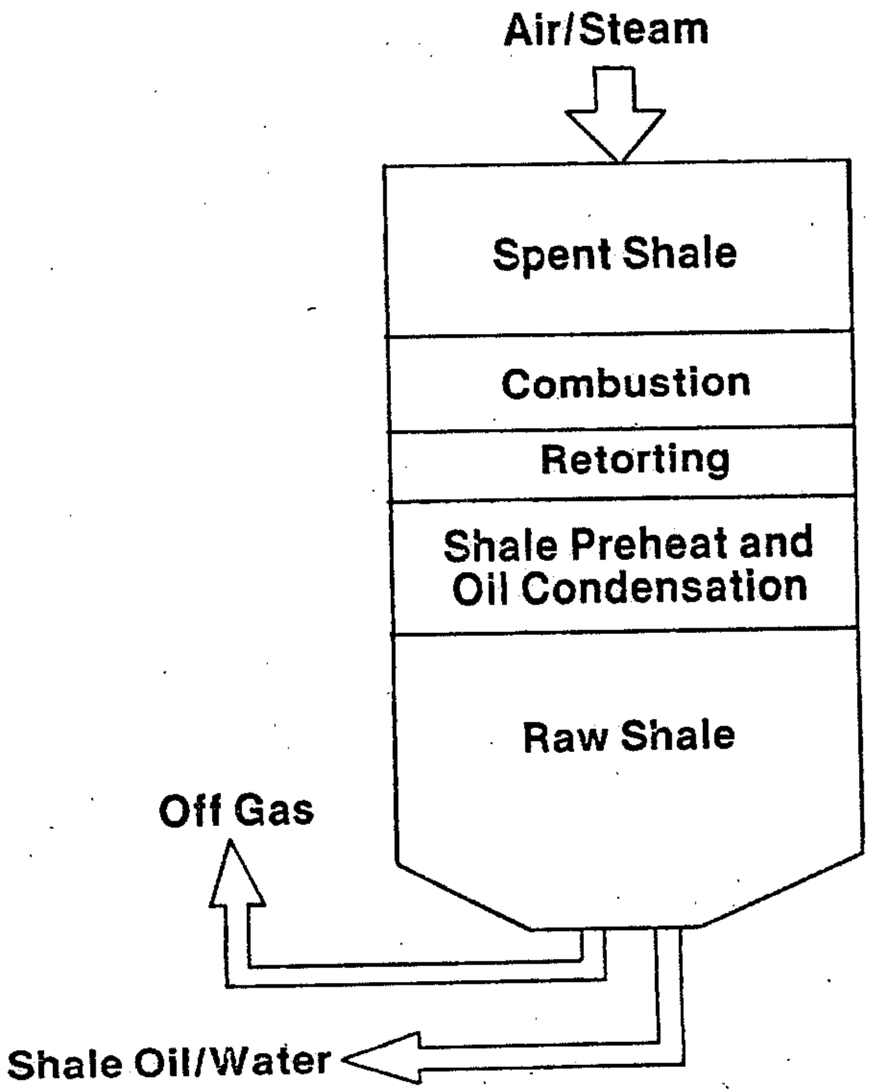
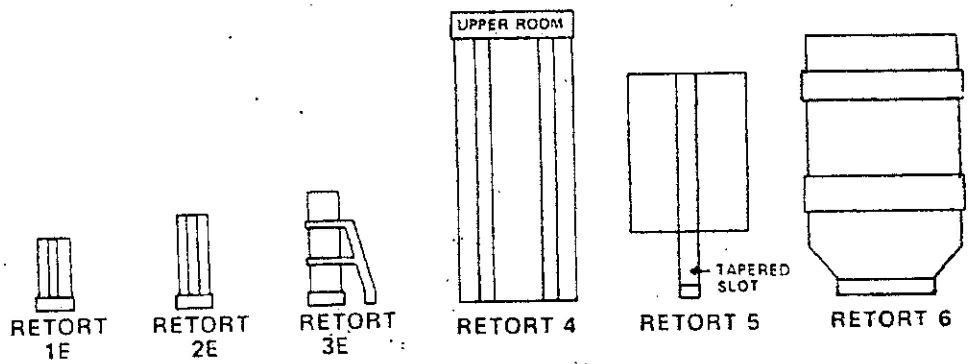


Figure 4



RETORT	1E	2E	3E	4	5	6
DIMENSIONS	31'x31'x72'	32'x32'x94'	32'x32'x113'	120'x120'x298'	118'x118'x217'	162'x162'x270'
OIL REC'V.	1,250 bls.	1,424 bls.	1,616 bls.	27,500 bls.	11,300 bls.	48,000 bls.
YEAR PROC.	1973	1974	1975	1975	1977	1978

Figure 5

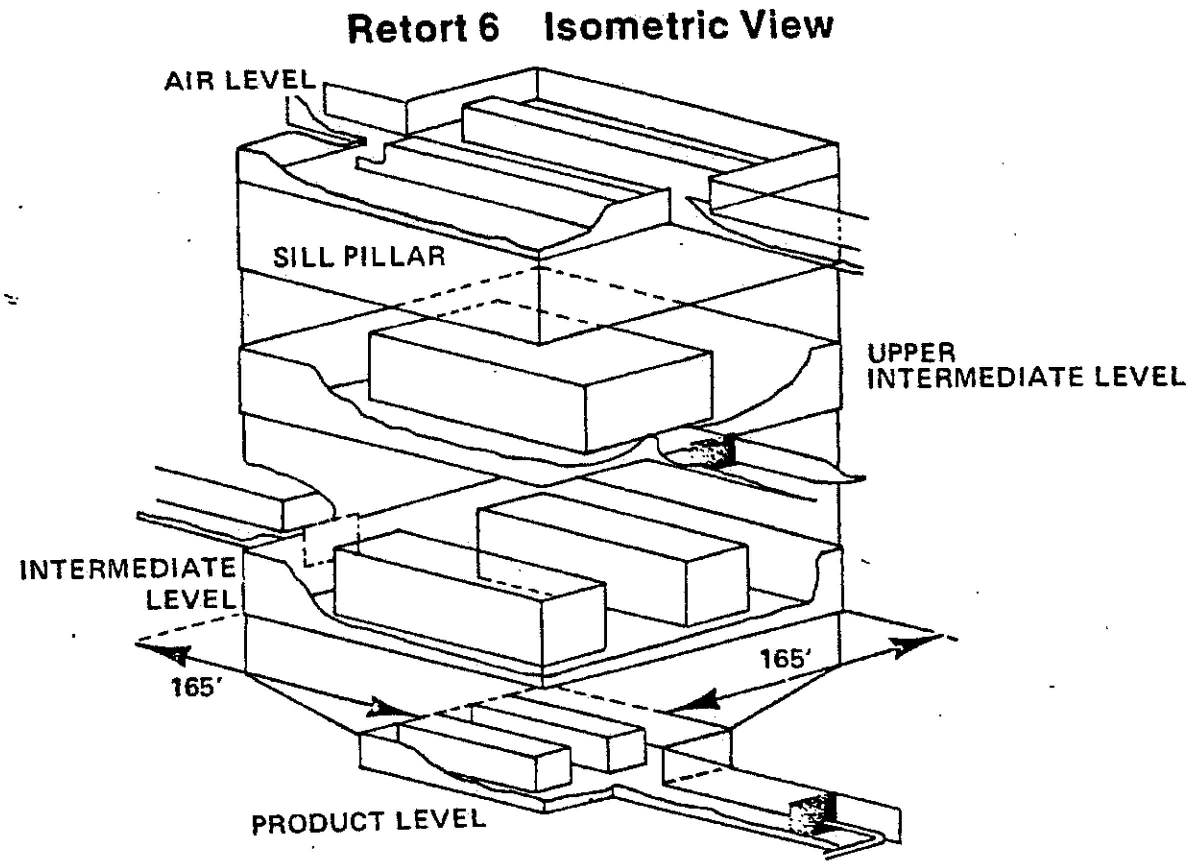
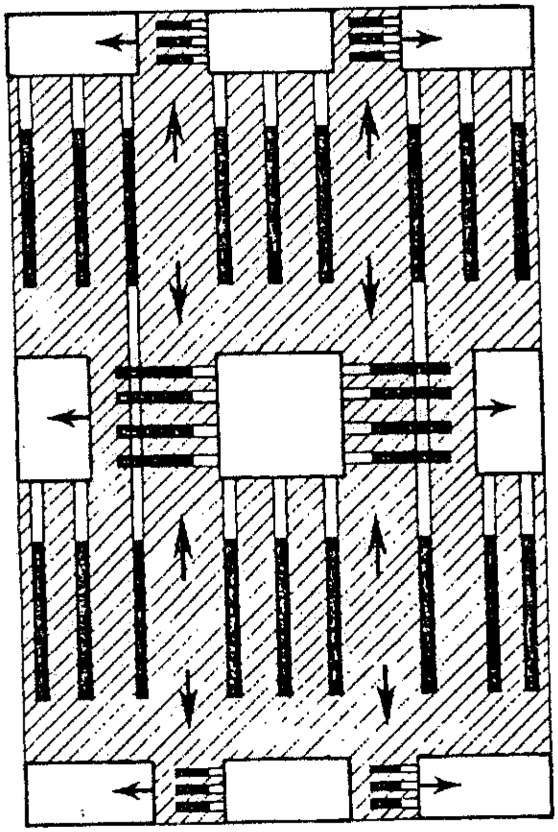

Retort 6 Isometric View
AIR LEVEL
SILL PILLAR
UPPER
INTERMEDIATE LEVEL
INTERMEDIATE
LEVEL
165'
165'
PRODUCT LEVEL

Figure 6

RETORTS 4, 5 & 6
Major Items Learned

- Ignition step critical.
- Off-gas data - not sole predictor.
- Less seismic damage - HFFR.
- Off-gas can be burned.
- Shale oil ignites retort.
- Mis technology confirmed.
- HFFR Rubble Pile more uniform than VFFR.
- More uniform void distribution results in improved operability and oil yield.
- Bottom design significant.
- Vertical slot-inadequate radial distribution of void.

Figure 7



Three-Level Rubbilization Design

Figure 8

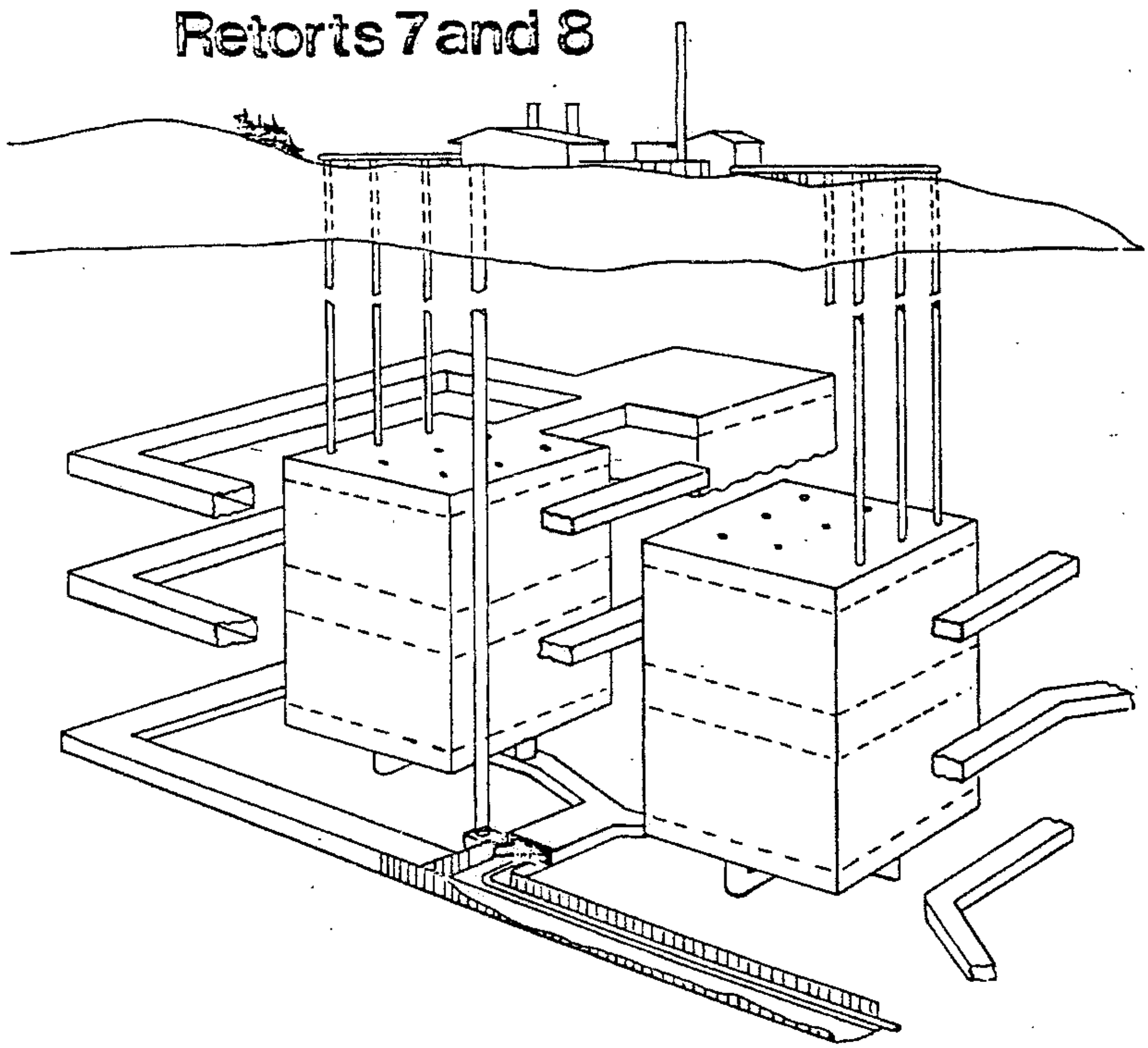


Figure 9

C-b Initial Production

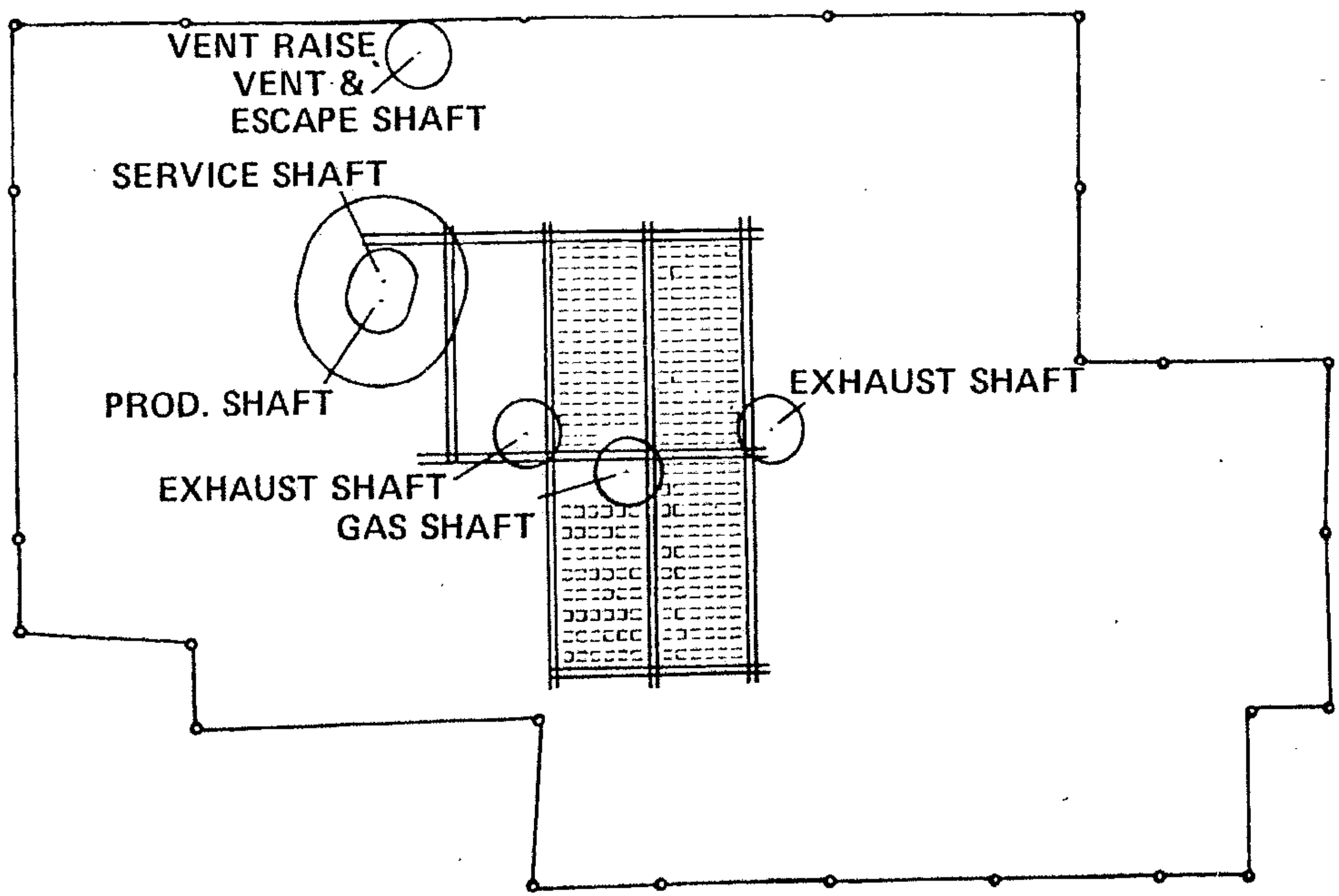
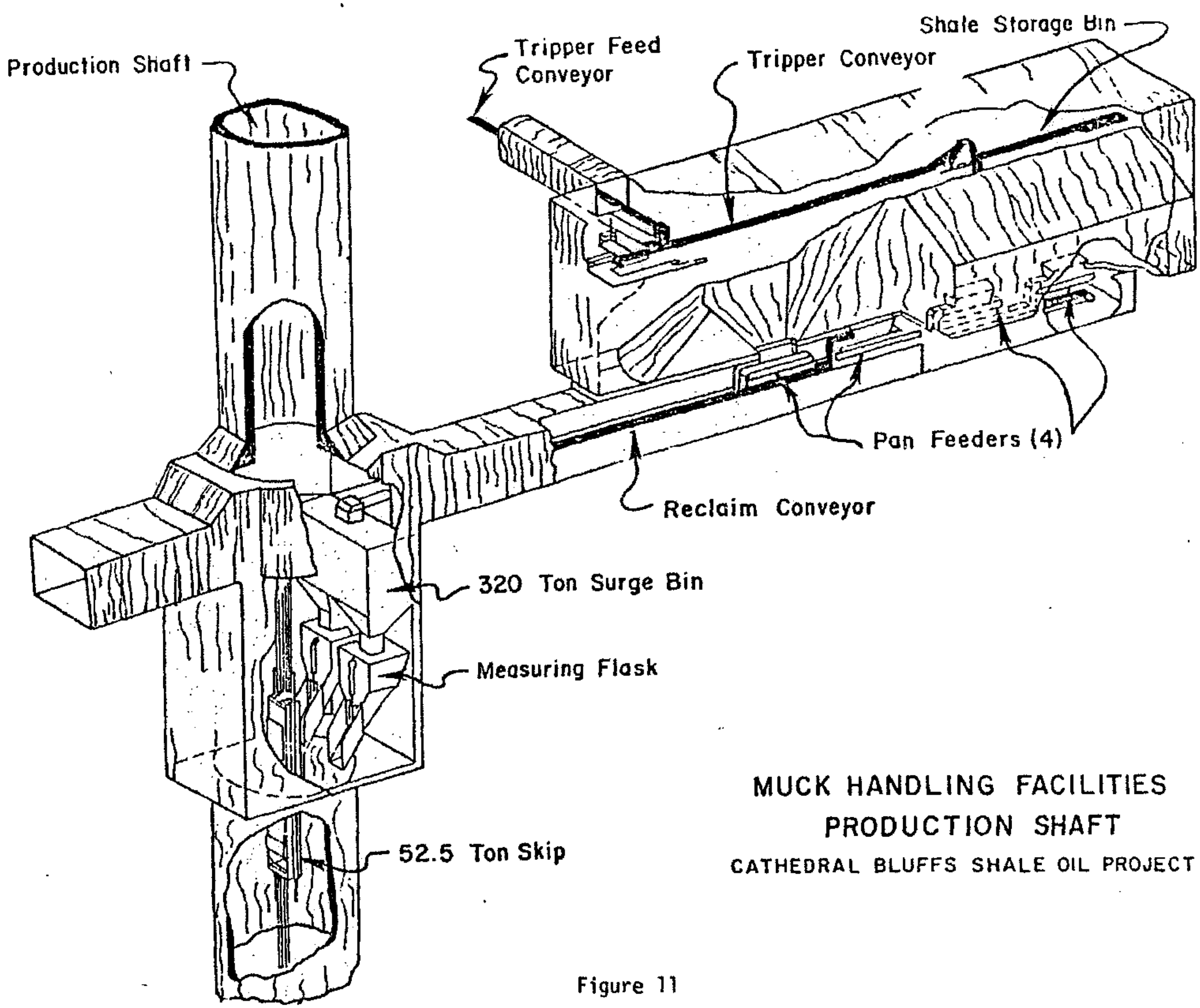


Figure 10



MUCK HANDLING FACILITIES
PRODUCTION SHAFT
CATHEDRAL BLUFFS SHALE OIL PROJECT

Figure 11

Production Shaft VERTICAL CROSS-SECTION

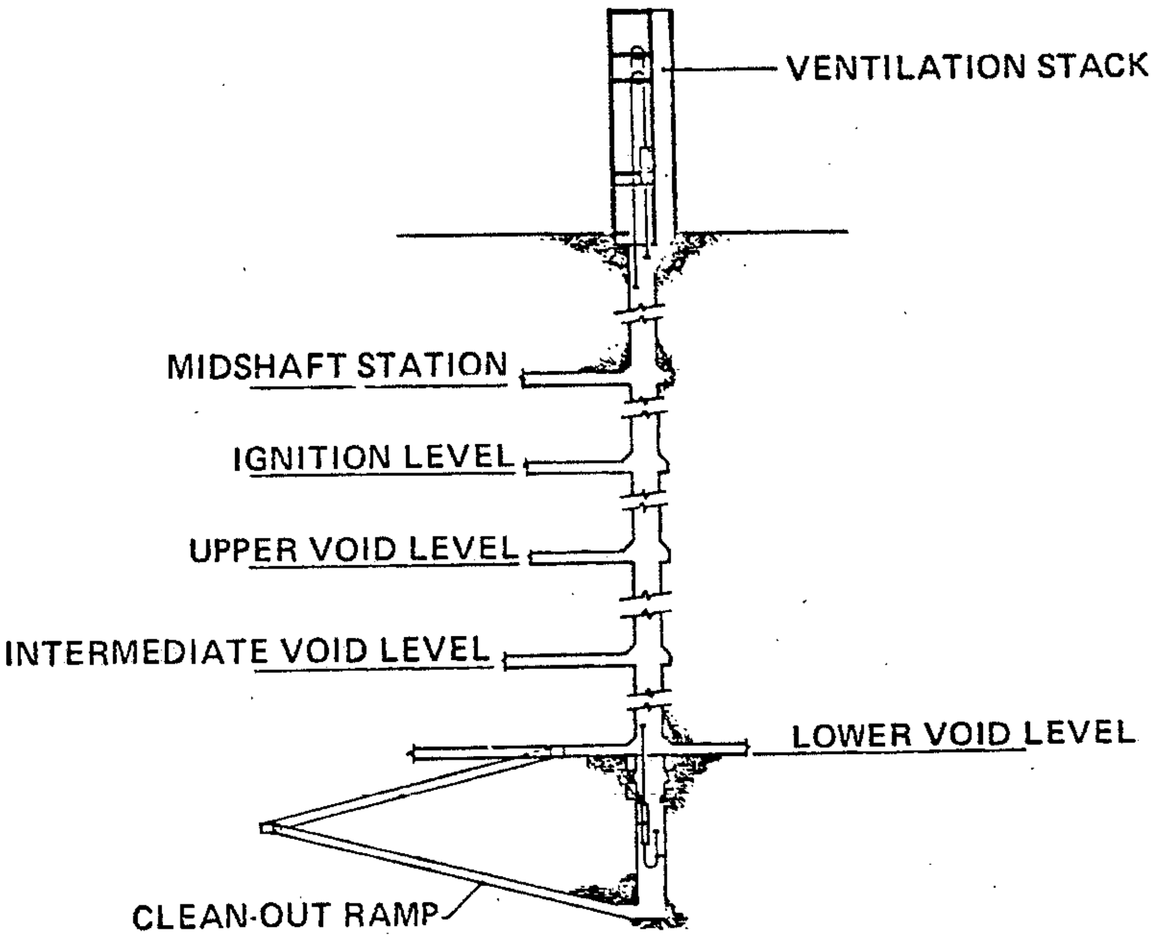


Figure 12

Site Plan

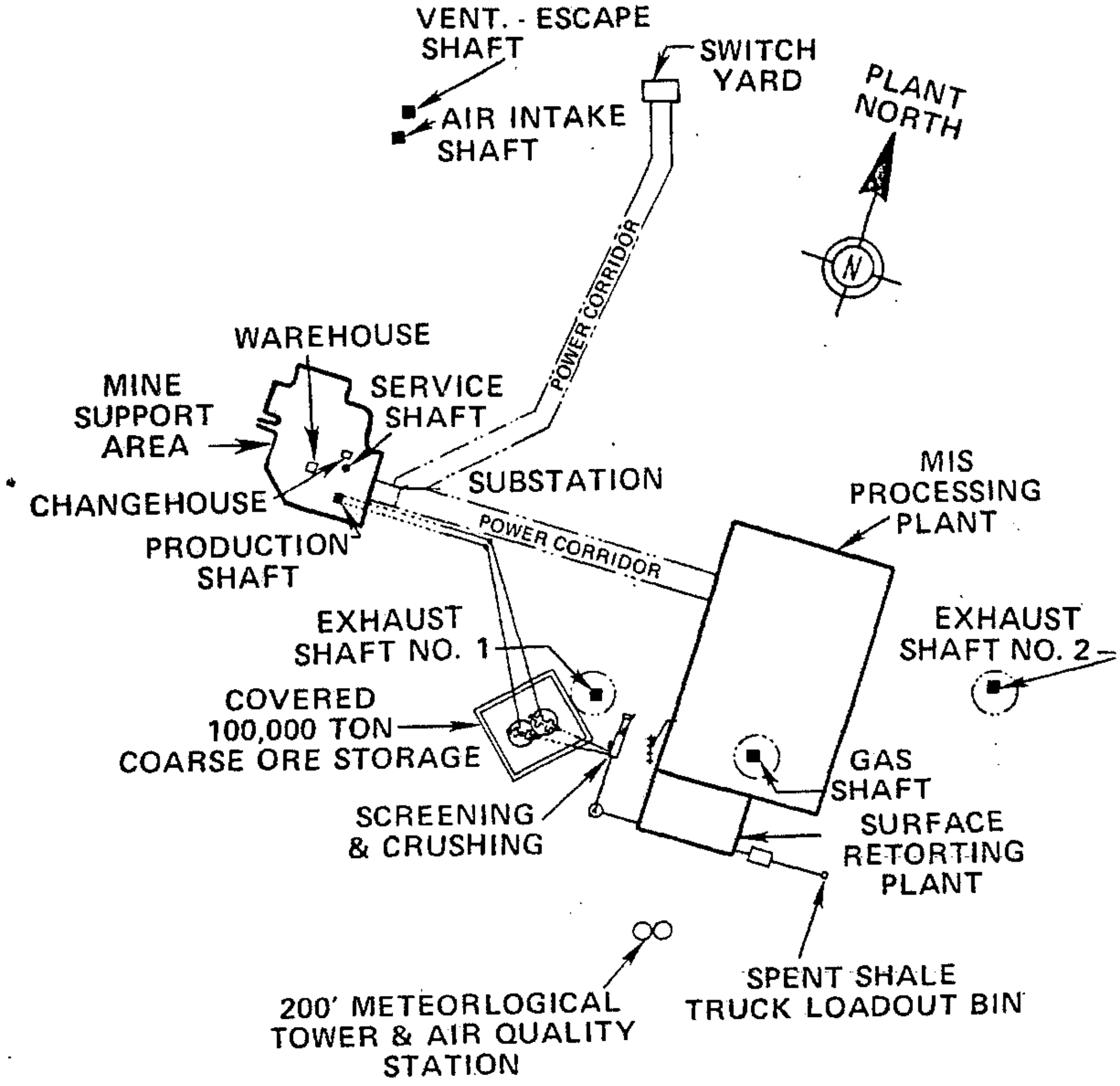


Figure 13

GOVERNMENTAL REGULATIONS AND THEIR IMPLICATIONS

Regulated Areas:

Air Quality
Water Quality Rights
Hazardous and Toxic Chemicals
Solid Waste
Buildings
Land—Reclamation,
Revegetation & Rights-of-Way
Subsurface Disposal
Wilderness Protection
Noise
Occupational Safety and Health

Implications:

Management and Design Approach and Economics Affected
Availability of Fuel Sources
Require Permits —Plans for Compliance Before Construction
May Require Monitoring Measurements
Time Delays
Public Involvement
Uncertainties and Moving Targets
Potential for Litigation

Figure 14

CB MONITORING PROGRAM

Air

2 Air Quality Trailers
1 200′ Meteorological Tower
2 Weather Stations

Noise

1 Road Traffic
1 Tract Construction

Biology

Big Game-Deer and Elk
Medium Sized Mammals-
Coyotes and Rabbits

Small Mammals

Birds and Raptors
Aquatic Ecology
Terrestrial Vegetation
and Productivity
Micro-Climate
Reclamation

Water Wells

CB	Observation	20
	Alluvial	13
Non CB		27
Total		60

Precipitation

CB	2
Non CB	7
Total	9

Stream Gauging Stations

CB	13
Non CB	4
Total	17

Springs and Seeps

CB	9
Non CB	10
Total	19

Figure 15