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OIL SHALE MINING COST ANALYSIS. VOLUME II. VERTICAL MODIFIED IN SITU RETORTING PROCESS

Final Report

By
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Vayden P. Anderson
Randall D. Metz
Lloyd M. English
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February 1982

Work Performed Under Contract No. AM01-77ET12532

Ketron, Inc.
Wayne, Pennsylvania

U. S. DEPARTMENT OF ENERGY

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OIL SHALE MINING COST ANALYSIS
VOLUME II - VERTICAL MODIFIED IN SITU RETORTING PROCESS

FINAL REPORT

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ABSTRACT

This report documents the results of a study to adapt mining economic models to enable the estimation of mining cost for Vertical Modified In Situ (VMIS) oil shale scenarios. An Oil Shale Mining Economic Model (OSMEM) was developed and executed for mining scenarios representative of commercially feasible VMIS operations.

Four base case VMIS scenarios were evaluated at two sites in the Piceance Creek Basin of Colorado. A VMIS-only and VMIS plus surface retorting recovery scenario were evaluated at each site. Target production was 50 thousand barrels per day for each scenario.

Costs developed for each scenario included all capital and operating expenses associated with mining activities. Parametric and sensitivity analyses were performed to determine the sensitivity of mining cost to changes in capital cost, operating cost, return on investment, and cost escalation. The effects of changes in VMIS retort efficiency and gassy mine conditions were also investigated.

FOREWORD

This report documents KETRON's study efforts and results on U. S. Department of Energy Contract No. ET-77-C-01-8915 (Task Order 14). This is Volume II of a sequence of three reports describing the development and use of a mining economic model for evaluating the production and cost consequences of oil shale mining scenarios. Other reports in this sequence are:

Oil Shale Mining Cost Analysis

Volume I	- Surface Retorting Process
Volume III	- Oil Shale Mining Economic Model (OSMEM) User Documentation

OSMEM was designed to satisfy the requirement for a model that would facilitate estimation of oil shale mining costs. Previous studies developed costs for specific scenarios, but did not provide a facility for readily evaluating the effects of parameter changes and sensitivities.

KETRON's oil shale mining cost analysis efforts were sponsored by the Department of Energy, under the technical direction of Mr. Tim Zeigler and Mr. Charles Hayduk, at the Carbondale Mining Technology Center. Their guidance and assistance are gratefully acknowledged, as are the contributions of numerous other helpful persons in DOE, in other government agencies, and in the private sector.

We wish to acknowledge the technical and management guidance provided by Dr. William J. Douglas and the computer system development efforts of Kathleen Y. Knoebel and Barbara A. Schlack.

We are also grateful to Mrs. Rita Robertson and others for their skillful, persistent, and forebearing preparation of this document.

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EXECUTIVE SUMMARY

Objective

The objective of the study was to adapt previously developed economic mine models to enable the estimation of costs for Vertical Modified In Situ (VMIS) oil shale mining processes.

Scope

The study included:

1. Review of resource data to establish sites representative of commercial development;
2. Review of prior VMIS studies to determine feasible mining techniques;
3. Development of recovery plans applicable to the candidate project sites; and
4. Simulation and financial analysis to determine mining costs.

The primary area of investigation concerned the costs of mining activities associated with oil shale recovery by the VMIS process. For this purpose, an Oil Shale Mining Economic Model (OSMEM) was developed and executed for mining scenarios representative of commercially feasible VMIS operations.

Candidate Sites

Using maps and other resource data, the essential characteristics of oil shale deposits in the Piceance Creek Basin were defined and sites were selected that were representative of a range of factors affecting commercial feasibility. Deposit factors considered most significant to economic feasibility included:

1. Grade
2. Thickness
3. Depth
4. Structure
5. Presence of gases
6. Locations of aquifers
7. Non-uniformity of material properties.

Based on the above factors, two sites in the Green River Formation of the Piceance Creek Basin were selected as locations for VMIS scenarios.

Recovery Methods

Two VMIS scenarios were developed at each of the two Piceance Basin sites. All four of these scenarios were designed to produce an average yield of 50,000 barrels/day. Both scenarios at a given site were based on a common mine plan; however, target production was achieved through:

a) VMIS - only retorting for one scenario

b) VMIS plus surface retorting of mined out shale for the second scenario.

Rectangular mine layouts were employed at each site. Three-entry main entryways bisect each property with parallel boundary airways at the property edges. Intake and exhaust crosscuts connect the main entries and the boundary airways. Retort modules are prepared between each intake-exhaust crosscut pair. Access to the mine is by shaft at each site.

At the first site, six shafts are sunk, main entries are completed across the entire property, and boundary airways are completed halfway before retort module preparation begins. At the second site, retort module preparation begins as soon as the first two pairs of intake/exhaust crosscuts are completed near the center of the property. These pairs connect segments of the main entries and boundary airways, which are developed only far enough to facilitate ventilation at this point. Six shafts are sunk initially to provide intake and exhaust air for this configuration. Development mining and retort preparation proceeds from the center to the edges of the property on each side of the main entry. When the edges are reached, mining proceeds back toward the center on opposite sides of the main entryway.

At the first site, retorts are prepared in module-pairs of six retorts per module. A vertical-slot void configuration involving approximately 20 percent void volume is mined in each retort. After void mining is complete, retorts are rubblized, then hooked-up and operated as module pairs. Work is not permitted adjacent to burning retorts.

Target production for the VMIS-only scenario is achieved when 144 retorts are operating simultaneously. For the VMIS plus surface retorting scenario, target production is attained when 92 retorts are operating simultaneously.

At the second site, retorts are prepared in module-pairs of ten retorts per module. A horizontal, multi-level void configuration involving approximately 30 percent void volume is mined out of each retort. Following rubblization, module-pairs are ignited and operated, when work on adjacent retorts is complete.

Target production, in the VMIS-only scenario, is achieved when 170 retorts are operating simultaneously. For the VMIS plus surface retorting scenario, target production is attained when an average of 83 retorts are operating simultaneously.

Oil Shale Mining Economic Model

KETRON's Oil Shale Mining Economic Model (OSMEM) generates production and financial data that are used to evaluate and compare mining scenarios. The objectives of OSMEM are:

1. To project annual production resulting from user-specified mine designs, production strategies, and equipment parameters;
2. To compute standard financial measures for evaluating alternative strategies;
3. To provide flexibility in analyzing a wide variety of mining scenarios; and
4. To permit sensitivity analysis of technical and financial parameters.

OSMEM is executed in two phases. The first phase simulates mining activities associated with VMIS retort development and the subsequent oil production. This phase generates annual operating outcomes which result from implementing a recovery plan.

The second phase of OSMEM performs financial computations based on outcomes of the production simulation and on financial parameters specified for the scenario. A variety of financial measures are provided in the model outputs, including the initial required selling price (IRSP). This IRSP measure is the price at which all mining related capital and operating costs are recovered, at a specified rate of return on investment. While IRSP includes all mining costs, it does not include costs for operating VMIS retorts or for surface retorting facilities and operation. Therefore, the results herein are interpreted as "the per barrel mining costs associated with the VMIS (or VMIS plus surface) retorting operation."

Economic Analysis

Costs were developed for each scenario to include all capital and operating expenses associated with the mining activities involved in preparing and rubblizing VMIS retorts. Each capital and operating expense was determined from individual cost elements which included:

1. Surface Preparation
2. Surface Facilities
3. Surface Utilities
4. Development Costs
5. Equipment Costs
6. Labor Costs
7. Underground Utilities
8. Operating Supplies
9. Insurance
10. Contingencies
11. Indirect Costs

OSMEM runs were made for each base case scenario, applying the above cost inputs and associated mine plans. The IRSP results for these base case runs are summarized in the following table.

Comparisons of IRSP Between Sites and Between Recovery Methods

Mine Site	Recovery Method		Between-Method Differences (A - B)
	A VMIS Only	B VMIS Plus Surface Retorting	
2	\$15.63 (Plan 1)	\$10.69 (Plan 3)	\$4.94
3	\$16.76 (Plan 2)	\$ 9.94 (Plan 4)	\$6.82
Between-Site Differences (Site 2 - Site 3)	-\$1.13	\$ .75	--

For the base case runs, an analysis was performed to determine the sensitivity of IRSP to changes in capital costs, operating costs, return on investment (ROI), and cost and price escalation rates. Of these parameters, IRSP is most sensitive to ROI; that is, a given percent change in the base ROI value produces the largest change in IRSP of any parameter for which the base value is changed by that same percent.

The base case scenarios were also re-run at a higher VMIS retort recovery efficiency (75 percent) than the base case value (50 percent). IRSP was reduced by 33 percent for the two VMIS-only scenarios at the higher recovery factor. For the VMIS plus surface retorting scenarios, IRSP was reduced an average of 15 percent.

At 75 percent recovery factor, the base case plans produced significantly more than the target value (50,000 barrels/day). Two new scenarios were developed to produce 50,000 barrels/day at 75 percent recovery factor. These scenarios were generated by appropriate decreases in equipment, labor, and operating costs for one VMIS-only plan and one VMIS plus surface retorting plan. The IRSP values for these new scenarios turned out to be essentially the same as their base case counterparts. The failure of expected price reductions to materialize for the higher recovery factor scenarios is attributed to inefficiencies in the base case mining strategies when equipment and labor resources are decreased. Revised strategies that use these resources more efficiently would be required, in order to reduce mining costs and IRSP.

It was determined in a follow-up study (see Appendix A) that gassy conditions can increase oil shale mining costs significantly. For example, increased capital and operating costs and reduced mining rates estimated for gassy operations increased IRSP for VMIS scenarios by as much as 100 percent.

CONCLUSIONS AND RECOMMENDATIONS

The basic study objective -- adapt existing models to enable the estimation of VMIS mining costs -- was achieved. OSMEM was demonstrated to be effective in facilitating evaluation of mining plans, production strategies, and equipment suites. Realistic values were obtained for the mining portion of per-barrel required selling price in the base case VMIS scenarios. And, plausible effects on IRSP were observed when input parameters and assumptions were varied.

Some follow-up analyses and model enhancements are recommended, in order to extend the initial results and capabilities provided by the current effort:

Analyses

- Extend the current results by including processing costs to yield total per-barrel required selling price
- Investigate the effects on IRSP, at various ROI values, of mining strategies that minimize time required to reach full production
- Determine the sensitivity of IRSP to changes in mining advance and production rates used in this study.

Enhancements

- Modify the OSMEM financial sub-model to accommodate debt-financed scenarios. The current version assumes all-equity financing

- Provide a capability to generate equipment and manpower requirements in the model
- Develop a computer-generated mine design capability
- Develop a capability to perform uncertainty analysis.

These recommendations are discussed in more detail in the body of this report.

1.0 INTRODUCTION

1.1 Background

The currently strong interest in oil shale development reflects concern over the nation's ability to develop adequate domestic sources of liquid fuels. This concern is indicative of international conditions which suggest the need to develop capabilities for producing synthetic fuels from domestic resources. The commercial development of the extensive oil shale deposits in the Green River Formation represents one alternative.

Of the methods suggested for recovering oil shale resources, the in situ processes appear particularly attractive because of perceived advantages to conventional recovery techniques requiring surface processing of host rock to extract shale oil. These advantages include potential reductions in the amount of underground mining for shale oil recovery and potential reductions in the environmental consequences resulting from mining and processing. However, technical problems may limit the amount of resource recoverable through true in situ processes, since the development of adequate fracturing, or rubblization, to maintain flame front propagation poses some difficulty. As an alternative to true in situ recovery processes, mining-assisted in situ techniques have been proposed and currently are being researched. The Vertical Modified In Situ (VMIS) recovery process is one such technique.

In order to evaluate alternative oil shale ventures so that resources can be allocated to the more promising methods, consistent economic evaluations are required. This report documents work by KETRON, INC. on U.S. Department of Energy Contract No. ET-77-C-01-8915 (Task Order 14) to adapt mining economic models to the estimation of mining costs for underground oil shale mining. The analytical model developed by KETRON, INC. represents an approach for determining the underground mining costs incurred in developing oil shale resources by the Vertical Modified In Situ method.

1.2 Objective

The objective of the study was to adapt presently available mine models to enable the estimation of costs for Vertical Modified In Situ (VMIS) oil shale mining processes.

1.3 Scope

The study included:

1. Review of resource data to establish sites representative of commercial development through vertical modified in situ processes;
2. Review of prior studies to determine feasible mining strategies for in situ retort development;
3. Development of mine designs applicable to mining-assisted in situ recovery at the candidate mine sites; and

4. Simulation and financial analysis to determine underground mining costs associated with retort development.

The primary area of investigation concerned the costs of mining activities associated with oil shale recovery by the VMIS process. Mining development scenarios were designed for a targeted production level of 50,000 barrels per day. Two strategies were employed in developing mine designs: the first considered that all targeted production was obtained through the in situ process only; the second considered that the targeted production level was obtained through some combination of the VMIS process and surface retorting of mined oil shale.

The results of this study are presented in the following sections. Section 2 discusses the geological resource base of the Green River Formation based on synthesis of existing literature. The rationale for selecting candidate mine sites is presented in Section 3. Section 4 describes the mining scenarios. Underground mining methods are discussed and detailed designs for selected operations are presented. Section 5 contains an overview of the computer model. Section 6 discusses the economic analysis of the mining scenarios. Section 7 summarizes the results of the study and presents conclusions and recommendations. Section 8 lists references cited in the report.

Appendix A presents results showing the impact of gassy mine conditions on base case scenarios analyzed herein and in Volume I of this report.

2.0 GEOLOGY OF OIL SHALE DEPOSITS

The geological setting is a factor for both mine site selection and mining systems design. Discussed below is a compilation of current data related to the salient features of the oil shale deposits in the Western United States. The deposits located in the Piceance Creek Basin of Colorado are of particular interest.

2.1 Green River Formation

Although oil shale deposits underlie much of the United States, the richest and thickest deposits are contained in the Green River Formation in Colorado, Utah and Wyoming.* It is estimated that there are over two trillion barrels of oil in the oil shales of the Green River Formation. The most valuable of these deposits (a trillion or more barrels) lie in Colorado's Piceance Basin. Of those resources, perhaps fifty percent (500 billion barrels) may be economically accessible with current technology. This is equivalent to about 80 years of the United States total current petroleum consumption.

The Green River Formation is composed of five distinct basins: the Green River and Washakie Basins in Wyoming; the Uinta Basin in Utah; and the Sand Wash and Piceance Creek Basins

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* The western oil shales are actually kerogenitic marlstone (largely a carbonate rock), while the eastern shales are true marine shales.

in Colorado. Of these, three are considered to contain oil shale of sufficient grade and quantity for resource recovery -- the Green River, the Uinta, and the Piceance Creek Basins. Both the Green River and Uinta Basins have been mapped and explored geologically to determine recoverable oil shale resources, but it is the Piceance Creek Basin in Colorado that has been explored extensively and represents the more attractive area for potential near-term commercial development. In addition to oil shale, the Piceance Creek Basin contains deposits of dawnsonite, nahcolite, and other saline minerals which, as potentially recoverable by-products of oil shale extraction, enhance the economic attractiveness of resource development.

2.2 Piceance Creek Basin

The geology of the Piceance Creek Basin has been investigated extensively by others, and there are numerous reports available that discuss, in detail, its stratigraphy, physiography, and geologic history (1-3). For this study, the more important criterion is the local structure at specific mine sites that affect mine design. In a larger sense, understanding certain aspects of the Basin's structure and form are necessary to assess the impact of geological conditions in evaluating a site for commercial development.

The Piceance Creek Basin is a large asymmetric structural downwarp located in Garfield, Mesa, and Rio Blanco counties of northwestern Colorado. The low portion of this downwarp is in the north-central portion of the basin, where the beds rise rather steeply (27° maximum) until they outcrop on the northern basin rim. It is generally accepted that the major jointings run northeasterly, as is indicated very clearly by the drainage pattern to the Piceance Creek. The rich oil shale is at its thinnest (approximately 60 feet) at the basin periphery and it thickens towards its maximum (exceeding 2,000 feet) at the north-central low point. Associated groundwater also appears to increase in quantity along this line. The elevated areas of the Roan Plateau are major charging areas for the upper and lower aquifers of the Piceance Creek Basin. The Roan Plateau would provide dry mining conditions; however, mining activities might affect the surface water and groundwater delivered to nearby areas at lower elevations. This possibility must be considered in site selection. Methane gas is concentrated in the deeper oil shale beds (4), and hydrogen sulfide is concentrated in areas which are supplied with freshly oxygenated water. Hydrogen sulfide has occurred in the northwest portion of the basin; however, hydrogen sulfide could exist at any peripheral point or near any major fracture. Substantial quantities of nahcolite and dawsonite are concentrated most heavily in the northern portions of the basin. They may occur both as individual deposits, or intermixed with the oil shale.

The depositional formation containing commercially recoverable oil shale deposits in the Piceance Creek Basin is the Green River Formation. The Green River Formation is overlain by the Uinta Formation, which forms the surface of most of the basin's interior and which is composed essentially of sandstone, siltstone, barren marlstone, and shale. The Green River Formation has three stratigraphic members: the Douglas Creek Member, consisting primarily of sandstone, shale, and limestone; the Garden Gulch Member, composed of laminated shales and marlstone, thin beds of sandstone, and limestone; and, the Parachute Creek Member, which contains most of the oil shale bearing zone (Figure 2-1).

The strata in the Piceance Creek Basin are divided into a number of zones, each having distinguishing characteristics which are useful for correlating stratigraphical sequences at different areas within the basin. The zones generally are grouped as: the Upper Zone; the Mahogany Zone; the Middle Zone; and, the Lower Zone. The Upper Zone contains the Uinta Formation and the Upper Parachute Creek Member, and is composed of both rich and lean oil shale sequences. The Mahogany Zone underlies the Upper Zone and is bound by relatively thin barren horizons known as the A-groove above and the B-groove below the zone (Figure 2-2). Its thickness ranges from less than 100 feet to over 225 feet, and contains shale oil grades generally exceeding 20 gallons per ton (gpt) throughout the basin. The Middle Zone contains the leached zone, which consists of fractured porous oil shale from which saline minerals have been leached out. The Lower Zone consists of rich oil shales containing nahcolite, dawsonite, and other saline minerals.

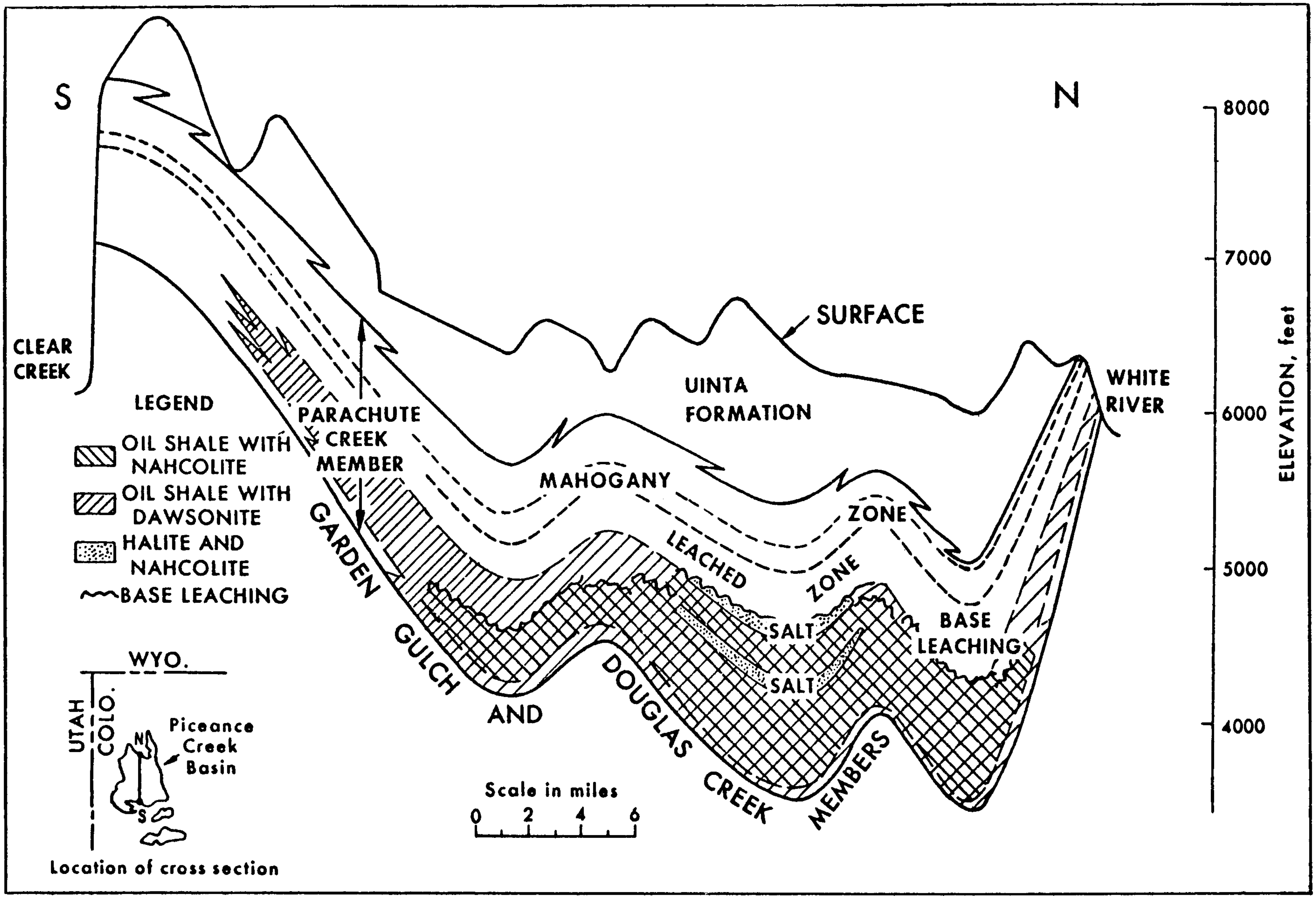

FIGURE 2-1

South-North Diagrammatic Cross-Section of the Green River Formation in Colorado's Piceance Creek Basin. Source: Smith, J.W., et.al., "Colorado's Primary Oil Shale Resource for Vertical, Modified In situ Processes", LERC/RI-78/2 Laramie Energy Research Center, 1978.

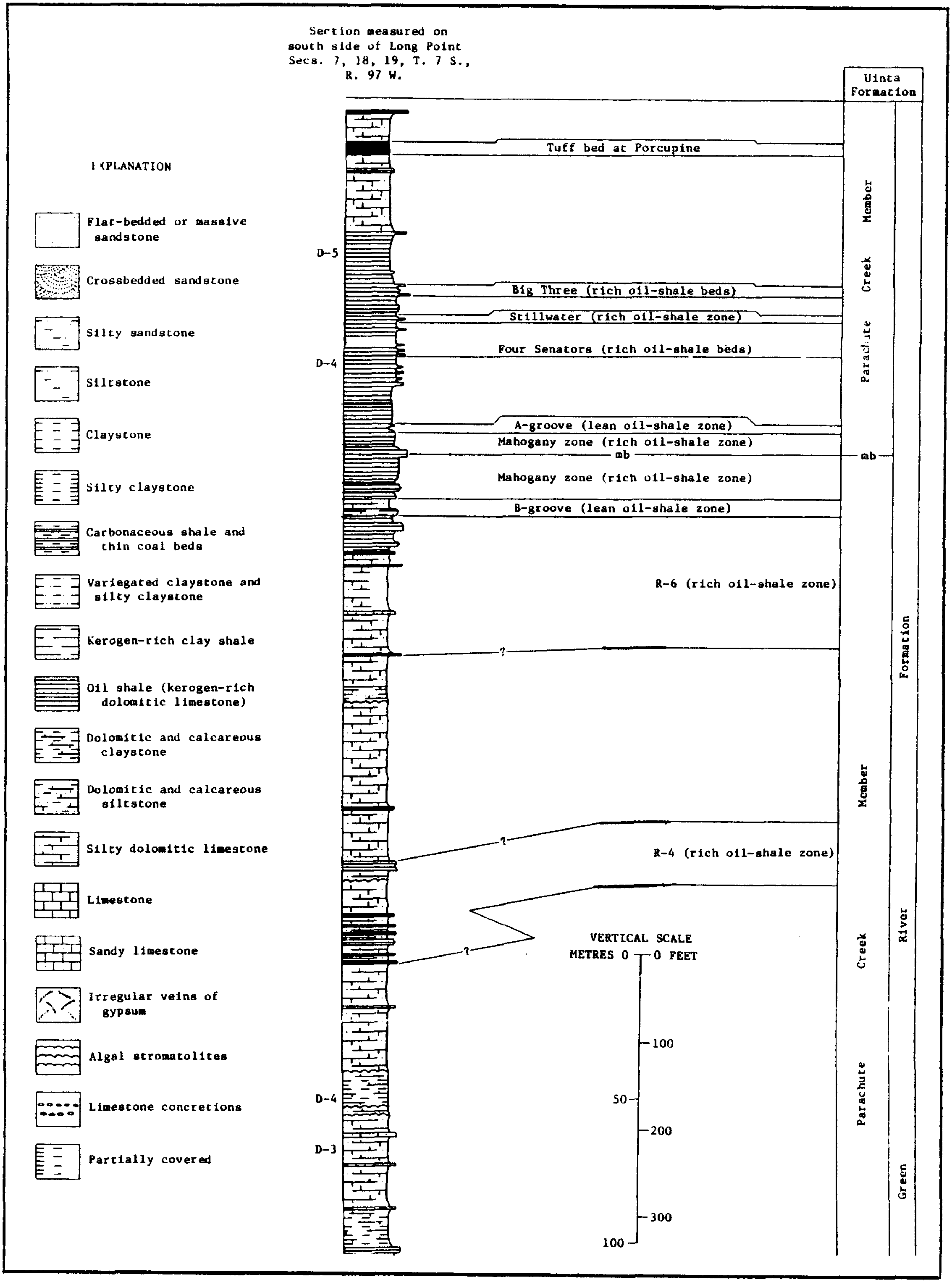

FIGURE 2-2

Typical Core Sample From the Piceance Creek Basin

3.0 SITE SELECTION

3.1 Site Selection Rationale

There are many possible combinations of variables that constitute the mining environment, and it would be unrealistic to account for all of them in selecting candidate sites. A reasonable alternative is to select sites that are representative of values associated with the factors described below in Section 3.2. For this study, scenarios were restricted to sites in the Piceance Creek Basin, since this deposit is the most attractive for near-term commercialization of VMIS recovery technology.

Using maps and other resource data (5-20), the essential characteristics of the Piceance Creek Basin were defined. Some of the more important characteristics are:

1. The thickness of oil shale deposits tends to increase from the periphery of the basin towards a maximum at the structural center (also the low point) of the basin.
2. Average richness of the Mahogany Zone and total in-place reserves increase from the periphery towards a maximum at the structural center of the basin.
3. Overburden thickness follows the same general pattern observed in seam thickness and grade, although to a lesser degree.
4. Groundwater increases in quantity from the southern portion to the northern portion of the Piceance Creek Valley.

5. Methane, of sufficient concentration to impact development methods, occurs in the deep (central) portion of the basin.
6. Hydrogen sulfide may be a problem in areas supplied by fresh water, such as areas near outcrops or areas near faults that may transmit oxygenated surface water to deep areas.

3.2 Factors Affecting Mine Scenario Development

A criterion was established that candidate sites be representative of commercially recoverable deposits. Sites were selected to be representative of a range of factors affecting commercial feasibility. Factors considered most significant to economic feasibility include: grade; thickness; depth; structure; gases; water; and, non-uniformity of material properties. Other factors, such as the potential for accessory mineral recovery, were not considered, although their importance in overall mining economics should not be discounted. Presented below is a brief description of each factor involved in defining scenarios for this study.

3.2.1 Grade

The grade of oil shale generally is regarded as the primary determinant of the economic viability of candidate projects. Variations in mining methods, developments in technology, and changes in the economy determine the appropriate grade of oil shale that can be developed economically.

3.2.2 Thickness

Oil shale thickness varies from a few feet to hundreds of feet, and in some cases, well over a thousand feet. The oil shale thickness will impact site selection, since it affects the design of VMIS retorts.

3.2.3 Depth

Depths to the oil shale zone may range from zero at outcrops to over 3000 feet at some points in the basin. Deposit depth will affect the mine access method and other design factors. Economic and technical considerations caused by extreme depth may reduce the feasibility of resource recovery. For example, research indicates that the compressive strength of oil shale often decreases with increasing depth (21). Since some deep beds will have only half the strength of the overlying material, the need to maintain stable entries may limit the recovery potential.

3.2.4 Structure

Geological features, such as joints, faults, and fractures, will affect the orientation of a mine and other design features, and may possibly limit resource recovery.

3.2.5 Gases

Methane has been encountered in oil shale, and may be present in sufficient quantity to be a mining consideration. For example, the Mine Safety and Health Administration (MSHA) designated Occidental's mine at Lease Tract C_b as gassy. The U.S. Bureau of Mines' (USBM) experimental shaft at AEC/USBM corehole No. 2 encountered heavy concentrations of methane. Also, at the Federal Oil Shale Lease Tract C_a, hydrogen sulfide has been encountered in significant quantity in the groundwater. There is speculation that hydrogen sulfide may be present near the edge of the basin and close to major faults. The gas appears to be the result of microbial activity and may be expected in those areas where fresh, oxygen-bearing water is available to these micro-organisms.

3.2.6 Water

Water must be considered as: a drainage problem in active workings; a needed resource in mining/processing operations; and, a renewable resource that must not be damaged. Each of these factors is highly site-specific and has to be considered on a site-by-site basis.

3.2.7 Non-Uniformity of Material Properties

Many material properties that remain constant in other ores do not remain uniform in oil shale. As previously mentioned (paragraph 3.2.3), compressive strength varies with depth. Compressive strength also varies with grade, and permeability decreases with increasing depth and grade. Laterally, however, the deposits are uniform across the basin as a whole; but, between specific individual mine-sites, this uniformity may not be maintained.

Local variation of material properties may increase the difficulty of developing workable mine designs at specific sites. However, unless material properties vary widely within a mine site, the use of average properties should be sufficient to develop conceptual mine designs.

3.3 Candidate Sites

Site-specific data were organized to delineate resource characteristic variations throughout the basin. Gradual transitions of resource characteristics occur from the periphery of the basin inward towards the structural center. Site selection criteria include the more important characteristics of the Piceance Creek Basin (section 3.1), the factors affecting the mine scenario development (section 3.2), and the following:

1. Proposed sites should be in an area of commercial interest.
2. Proposed sites should account for the changing trend of resource characteristics from the periphery to the structural center.
3. Proposed sites should be near publicly available corehole data to ensure an accurate representation of site characteristics.
4. Unique situations such as steeply pitching beds, which may limit the feasibility of mining-assisted technologies, should be avoided.

Based on the above criteria, two sites in the southern portion of the Piceance Creek Basin were chosen for development of

Vertical Modified In Situ (VMIS) oil shale recovery scenarios. These sites, designated 2 and 3 in Figure 3-1,* are located high on the Roan Plateau, at a point where the drainage basins divide. Dry mining conditions should exist at these points. Additionally, the resource was sufficiently deep, thick, and uniform and the topography was favorable for commercially feasible VMIS recovery operations at each site. Other sites were considered for VMIS scenarios, but were not selected because: a) the resource was too thin and shallow; b) the site involved major faults; and c) the site presented significant mine water problems.

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* Sites 1 and 2 in Figure 3-1 were used as locations of underground mining scenarios in the (Task 13) study described in Volume I of this report.

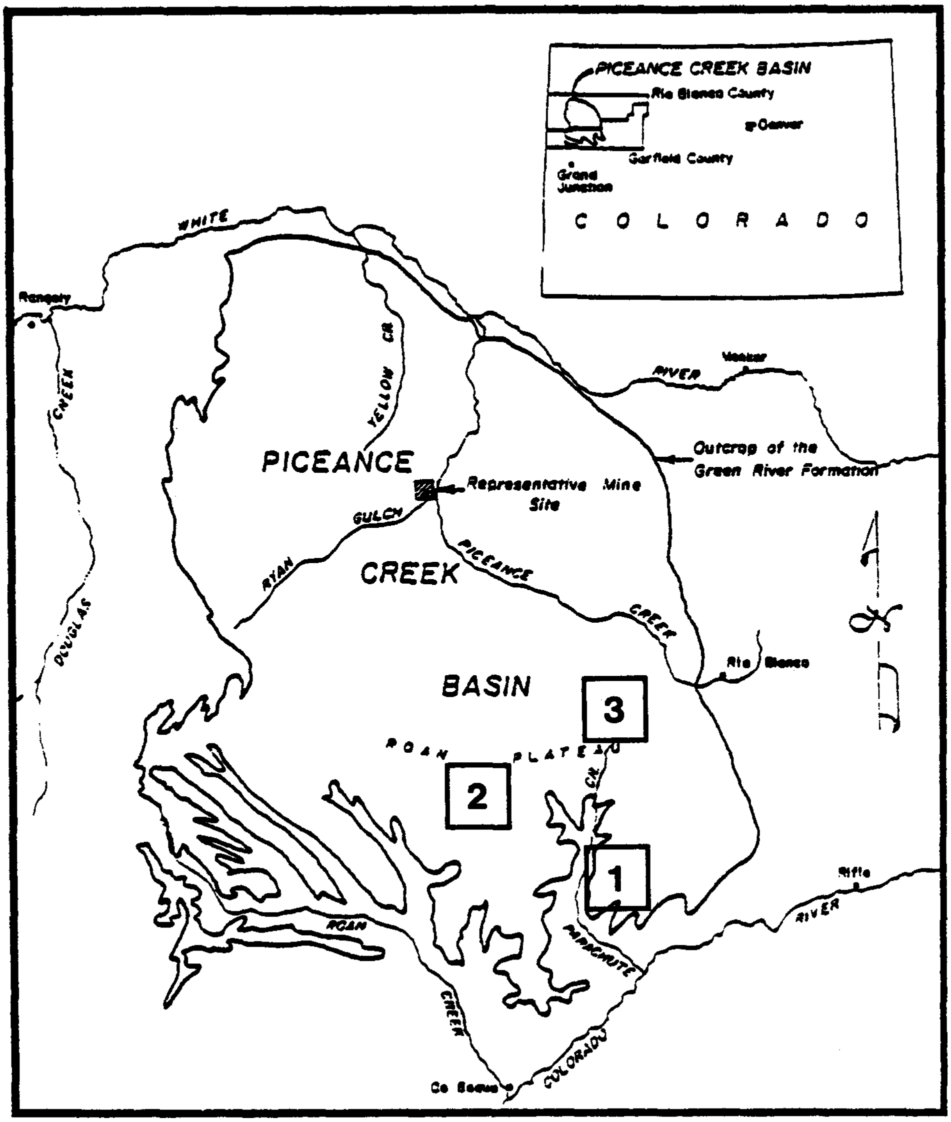

FIGURE 3-1

Piceance Creek Basin, Colorado -- Sites 1, 2 and 3

4.0 VERTICAL MODIFIED IN SITU (VMIS) RECOVERY PLANS

4.1 Description of VMIS Recovery Method

The Vertical Modified In Situ (VMIS) process is one of several recovery methods that involve underground retorting of oil shale. The VMIS method involves mining out shale to provide access to areas where underground retorts are to be created. Each VMIS retort is created by mining out a portion of the oil shale (20-40 percent), then rubblizing the remainder to create a vertical column of shale. This column is burned from the top down, producing liquid and gaseous products which are withdrawn at the bottom. In a commercial-scale operation, producing 50,000 barrels per day, a large number of retorts (100 or more) would be burning simultaneously. Meanwhile, mining would continue concurrently to develop and rubblize additional retorts.* This concept is illustrated in Figure 4-1.

Although it has been suggested that the VMIS concept will reduce mining requirements, a considerable amount of shale has to be mined out for a commercial-scale operation. This quantity is sufficiently large -- 20 to 40 million tons per year, depending on retort characteristics and shale grade -- that surface

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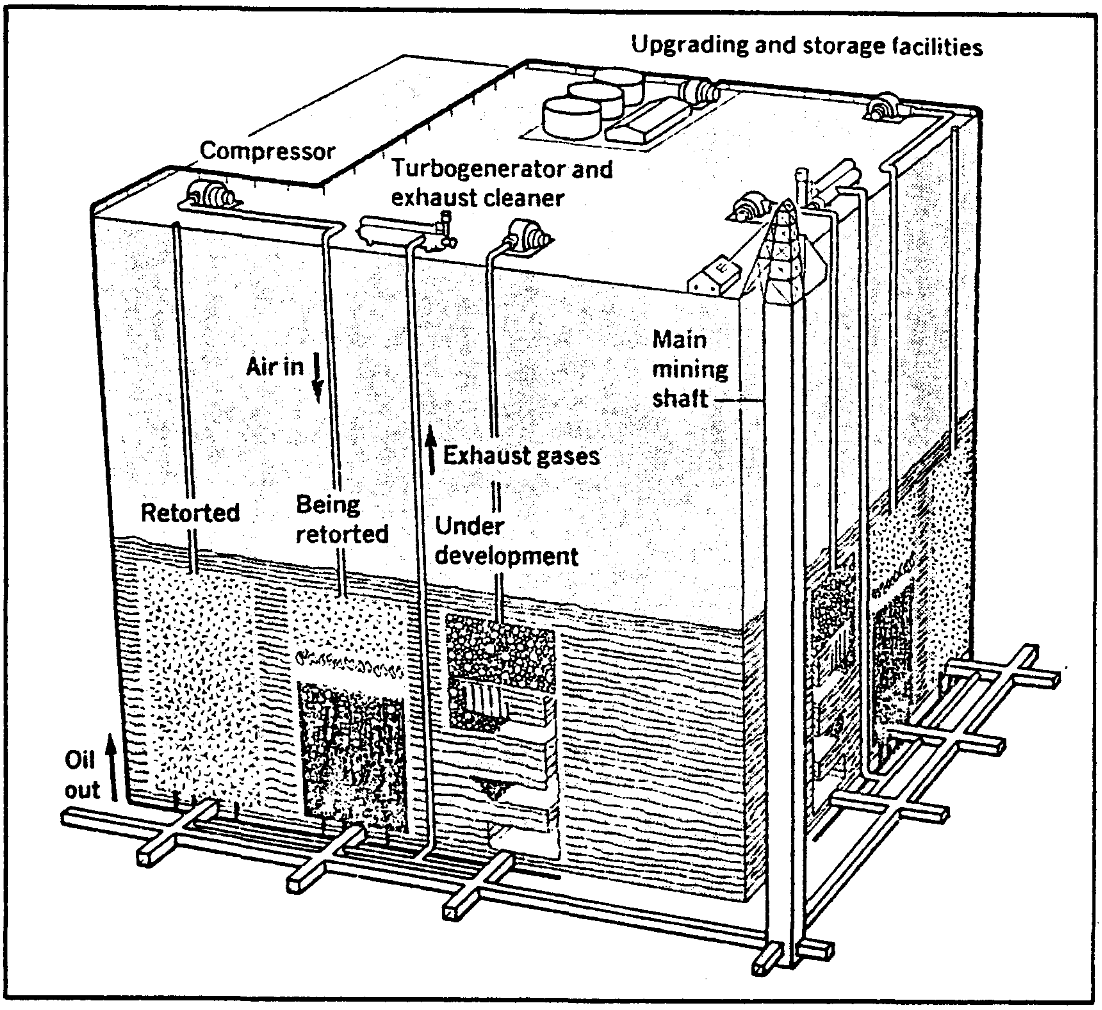
* However, mining operations will not be permitted in areas adjacent to burning retorts.



Source: J. H. Campbell, and J. H. Raley, "Underground Oil Shale Retorting", Lawrence Livermore Laboratory, UCID-18556, February 1980.

FIGURE 4-1
In Situ Oil Shale Rubblization/Recovery Process

retorting of the mined-out shale has to be seriously considered. Thus, VMIS with surface retorting is a potential variation on a basic VMIS scenario.* The parameters that define a VMIS scenario include:

A. Mine Characteristics

- Layout
- Overburden depth
- Mining horizon
- Seam access method
- Number of working levels

B. Mining/Recovery Strategy

- Produce on advance or retreat
- Number of simultaneously burning retorts
- Concurrent surface retorting (or not)
- Number of concurrent production areas
- Number of retorts per module

C. Retort Characteristics

- Cross-sectional area
- Height
- Average grade after rubblization
- Void volume
- Burn rate
- Efficiency

D. Void Configuration

- Horizontal vs. vertical slots
- Number of slots

E. Mining and Haulage Equipment Types

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* In that variation, target oil production is met from both underground and surface retorts; hence, less VMIS production is required to meet a given target amount.

Retort efficiency* is a critical factor to the success of a VMIS operation, since it determines product yield. The efficiency of a VMIS retort depends to a large extent on the outcome of the rubblization step. If reasonably uniform permeability is achieved across and down the rubble pile, efficiencies on the order of 75 percent conceivably could be attained. However, if rubblization produces poor permeability distribution, efficiencies as low as 30 or 40 percent will result. Once the retort has been rubblized, control of its yield is comparatively limited, involving primarily adjustments to inlet gas flow rate and composition. This control aspect of the VMIS recovery process is beyond the scope of this study's recovery plans, as described in Section 4.2 below.

4.2 Scope of the Recovery Plans

The scope of the recovery plans presented in this section reflects the study objective to estimate <u>mining costs</u> for the VMIS recovery process. These plans involve those mining functions and associated costs which are required to:

- access the oil shale mining horizon
- develop entries to access retort areas and provide ventilation and inlet gases

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* Retort efficiency is the percent of oil recovered from the oil in place in the rubblized retort, as measured by Fischer assay.

- develop product removal entries and associated raises
- create retort voids
- haul out the mined shale
- rubblize underground retorts

Process functions which follow rubblization are not included in the recovery plans, nor are their costs. These functions include:

- underground retort hook-up and operation
- post-retorting treatment
- surface retorting of mined-out oil shale*
- raw/spent shale disposal
- product upgrading, storage and shipment
- site reclamation

4.3 Description of the Plans

Four VMIS recovery plans were developed in the Piceance Creek Basin, Colorado. Two plans are located at Site 2 and two plans are located at Site 3 (see Figure 3-1). Plan 1 at Site 2 and Plan 2 at Site 3 each were designed to recover 50,000 barrels of shale oil per day (nominal) by the VMIS process only. Plan 3 at Site 2 and Plan 4 at Site 3 were developed to recover 50,000 barrels of shale oil per day (nominal) from a combination of the in situ process and surface retorting. Thus, lower oil shale

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* For VMIS plus surface retorting scenarios.

mining rates are required for Plan 3 than for Plan 1, and similarly for Plan 4 than for Plan 2.

The mine design layout is the same for Plan 1 and Plan 3 at Site 2, and is described in Section 4.3.1. Likewise, the mine layout is the same for Plan 2 and Plan 4 at Site 3, and is described in Section 4.3.2. A summary of parameters that characterize each of the four recovery plans is presented in Table 4-1.

4.3.1 Plan 1 and Plan 3, Site 2

The property at Site 2 is a square tract (9 sq. mi.) located within the township and range: T4S, R97W, Garfield County, Colorado. Oil recovery in Plan 1 employs the VMIS process only, while Plan 3 includes VMIS recovery and surface retorting of mined-out oil shale. Target production for these recovery plans is 50,000 barrels of shale oil per day (bbl/day).

The shale grade at Site B averages 18.33 gallons per ton (gpt) and is distributed unevenly over the vertical extent of the oil shale deposit, as shown in Figure 4-2. The base of the Mahogany Zone, which contains the highest grade shale, lies at an average depth of 800 feet below the surface.

4.3.1.1 Layout Specifications. Access to the mining area is through five vertical 28-foot diameter shafts and one vertical 32-foot diameter service-production shaft. One shaft is sunk

TABLE 4-1

Summary of VMIS Recovery Plan Parameters

Parameter	Recovery Plan			
	Plan 1	Plan 3	Plan 2	Plan 4
ine Site (See Figure 3-1)	2	2	3	3
verburden Depth (ft.)	400	400	300	300
ract Size (mi.)	3 x 3	3 x 3	3 x 3	3 x 3
verage Grade (gpt)	18.33	18.33	20.75	20.75
arget Production (bbl/day)	50,000	50,000	50,000	50,000
ine Access Method	SHAFT	SHAFT	SHAFT	SHAFT
MIS Retort Height	400	400	500	500
oid Volume (percent)	20	20	30	30
lot Configuration	Vertical	Vertical	Horizontal	Horizontal
imultaneously Burning Retorts	144	92	170	83
nderground Retort Efficiency (%)	50	50	50	50
nderground Retort Production (bbl/day)	49,560	32,270	48,600	23,900
urface Retort Efficiency (%)	-	100	-	100
urface Retort Production (bbl/day)	-	21,990	-	28,700
otal Oil Production (bbl/day)	49,560	54,260	48,600	52,600
il Shale Mined (10^3 tons/yr)	28,247	18,394	43,241	21,203
ine Life (Years)	33	47	36	66

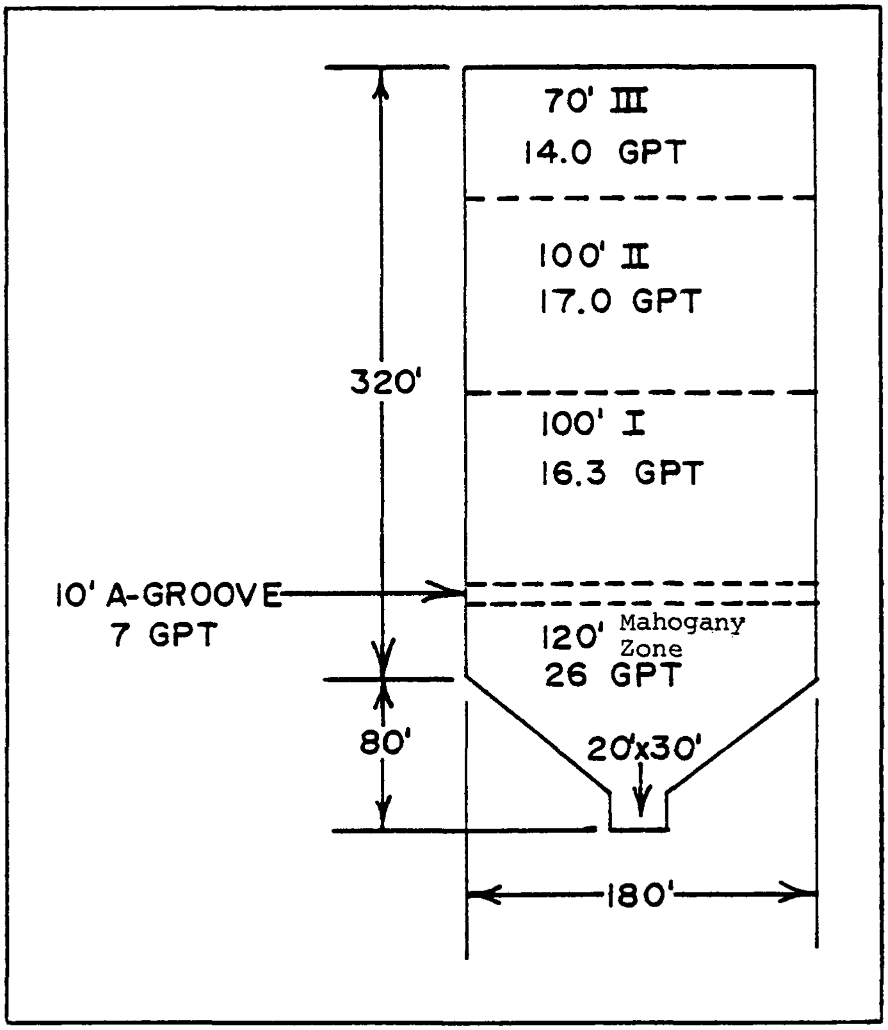

FIGURE 4-2

Oil Shale Grade Distribution over the Mining Horizon.
VMIS Plans 1 and 3, Site 2.

near each side of the property, while two production shafts are driven near the center of the property. Shaft locations and their purposes are shown in the overall mine layout (Figure 4-3), and a more detailed description of each shaft is tabulated in Table 4-2. Figure 4-4 shows a cross-section of the 32-foot diameter service-production shaft located near the center of the property.

Initial mine development occurs on three levels:

1. the haulage/oil collection level at the base of the retorts
2. a sublevel midway up the retort horizon
3. a ventilation level located 60 feet above the retort tops.

Each level requires similar entry configurations up to the development of individual retort modules.

A series of ore passes, raise bored at varying intervals throughout the mine, connects the three development levels. Use of ore chutes allows all mined oil shale to be transported on the haulage level. This feature reduces costs associated with outby haulage equipment. Load-haul-dump vehicles move oil shale from working faces to ore pass locations on the ventilation level and the sublevel. At each location, the shale is broken and fed into the ore pass, from which it emerges on the haulage level into a pre-constructed cavity with a surge capacity of about 50 tons. The oil shale empties out of this cavity onto a

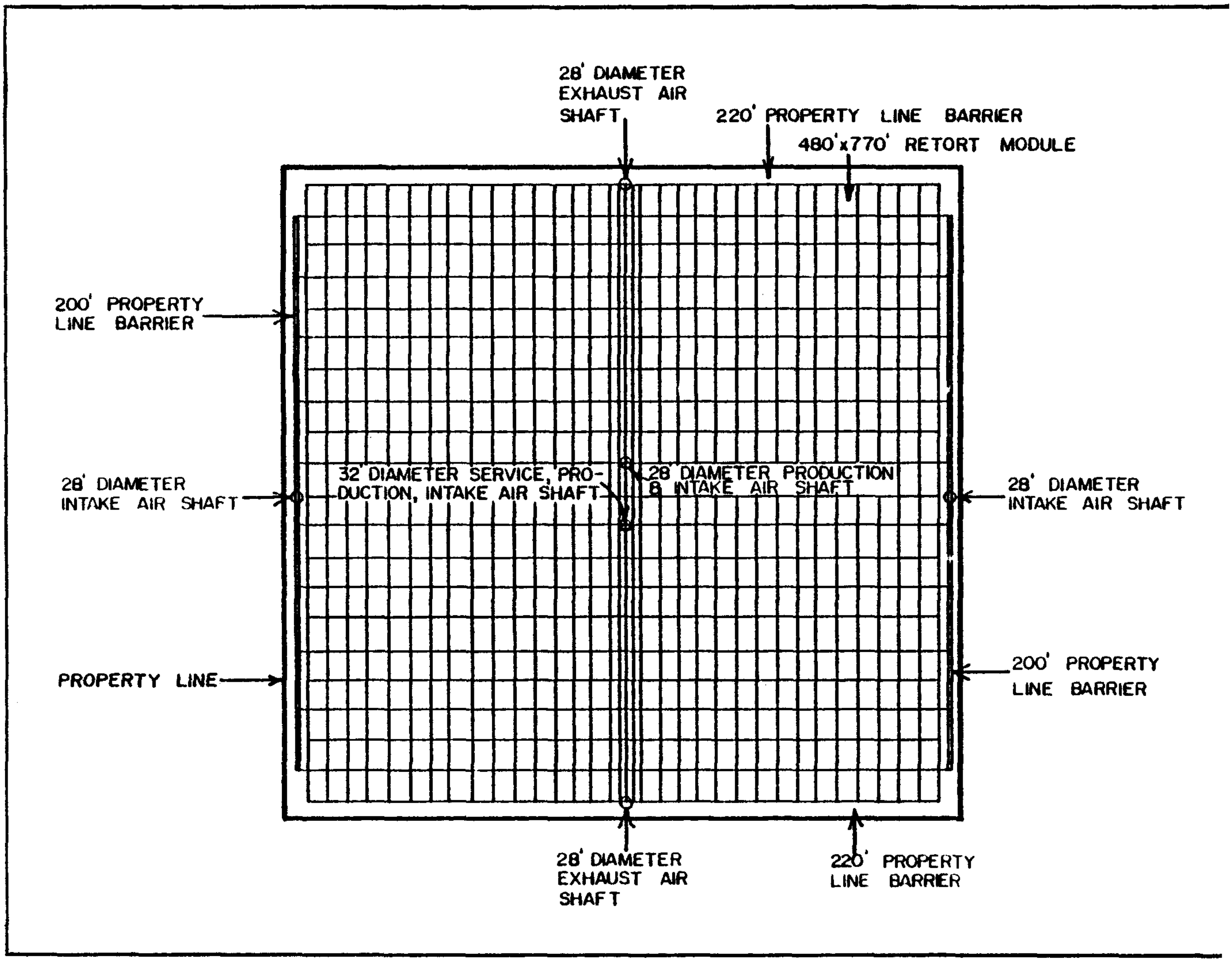

FIGURE 4-3

Plan View of Overall Mine Layouts --
VMIS Recovery Plans 1 and 3, Site 2
(All Three Levels Have the Same Layout Configuration)

TABLE 4-2

Mine Shaft Description

No. Shafts	Inside Diameter (ft)	Description	Purpose	Depth (ft)
1	32	Shaft contains one friction hoist with two 43 ton skips and a headframe. Also there is one double-drum service hoist.	Service, Production, and intake for fresh air.	800
1	28	Shaft contains one friction hoist with two 64-ton hoist skips and headframe	Production, intake for fresh air	800
2	28	Smooth-wall to enhance air movement	Ventilation for the mining and retorting operation.	800
1	28	2-800,000 CFM Axial Vane Exhaust Fans. Contain service lines-including diesel fuel, retort ignition fuel, slick lines, potable water and production-level steam supply lines. Also contains retort off-gas lines, shale oil production lines, and mine water discharge lines.	Exhaust Shaft	800
1	28	2-800,000 CFM Axial Vane Exhaust Fans. Contain service lines-including diesel fuel, retort ignition fuel, slick lines, potable water and production-level steam supply lines. Also contains retort off-gas lines, shale oil production lines, and mine water discharge lines. This shaft also contains an escape elevator.	Exhaust Ventilation/ Escape Shaft	800

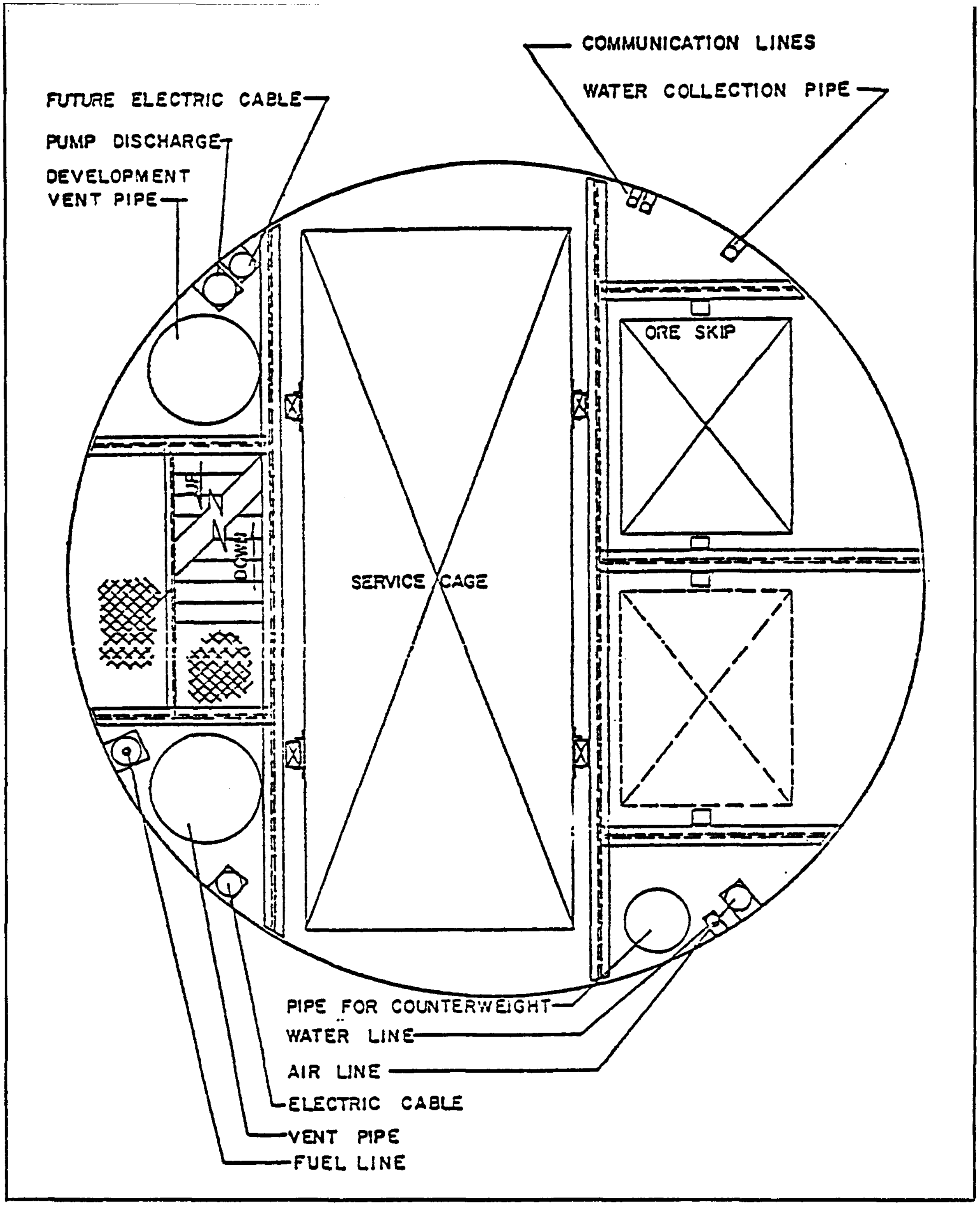

FIGURE 4-4

Combination Service-Production Staff Arrangement
VMIS Plans 1 and 3, Site 2. Raymond, Skelly, and Hoe, 1979.

feeder-breaker that feeds a conveyor belt. Figures 4-5 and 4-6 show the ore pass layout and illustrate the loading function.

Main entries, driven on all three levels, consist of three parallel 20 ft. x 30 ft. entries separated by 75 ft. wide chain pillars with 20 ft. x 30 ft. crosscuts driven on 385 ft. centers (Figure 4-7). The purpose of these entries is to provide a haulage route for oil shale mined out of the retort area, and to provide a ventilation passageway to the exhaust ventilation shaft located at the tail end of the main haulage entries. Retort air intake, natural gas, and steam pipes are constructed in these entries on the ventilation level. Retort off-gases are expelled through piping constructed in the main haulage entries on the oil collection level.

A pair of intake airways is driven parallel to the main entries near two opposite property borders (Figure 4-8). These entries consist of two parallel 20 ft. x 30 ft. entries separated by 75 ft. chain pillars, with 20 ft. x 30 ft. crosscuts driven on 385 ft. centers. These airways direct intake ventilation into the working sections located within the retort module field. Piping for carrying shale oil is constructed in these entries on the oil collection level.

Parallel intake and exhaust crosscuts are driven on all three levels to connect the main entries with the intake entry pair driven up the sides of the property. These entries are 20 feet high and 30 feet wide and are separated by a distance of

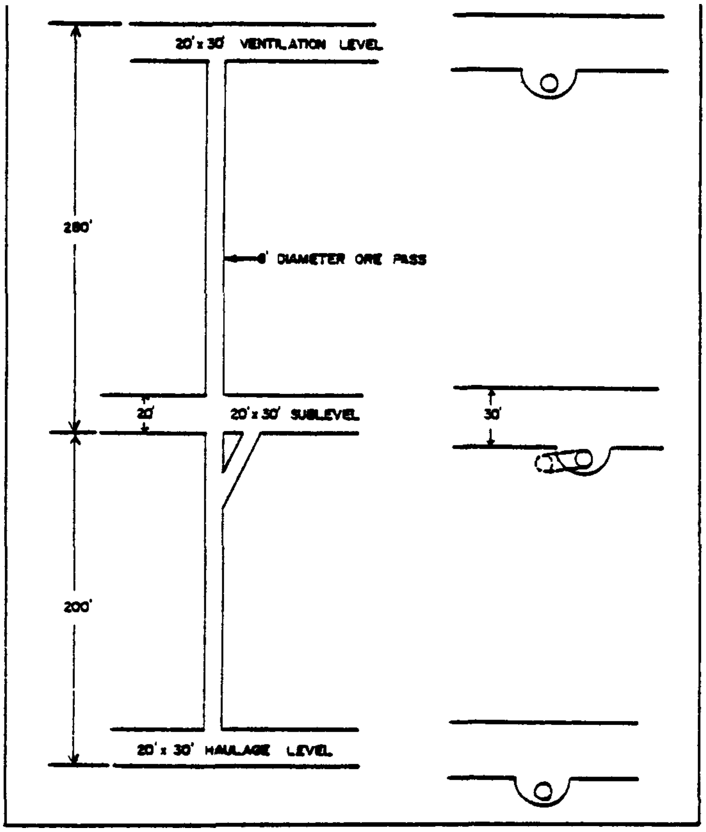

FIGURE 4-5

Layout of Ore Pass. VMIS Plans 1 and 3, Site 2

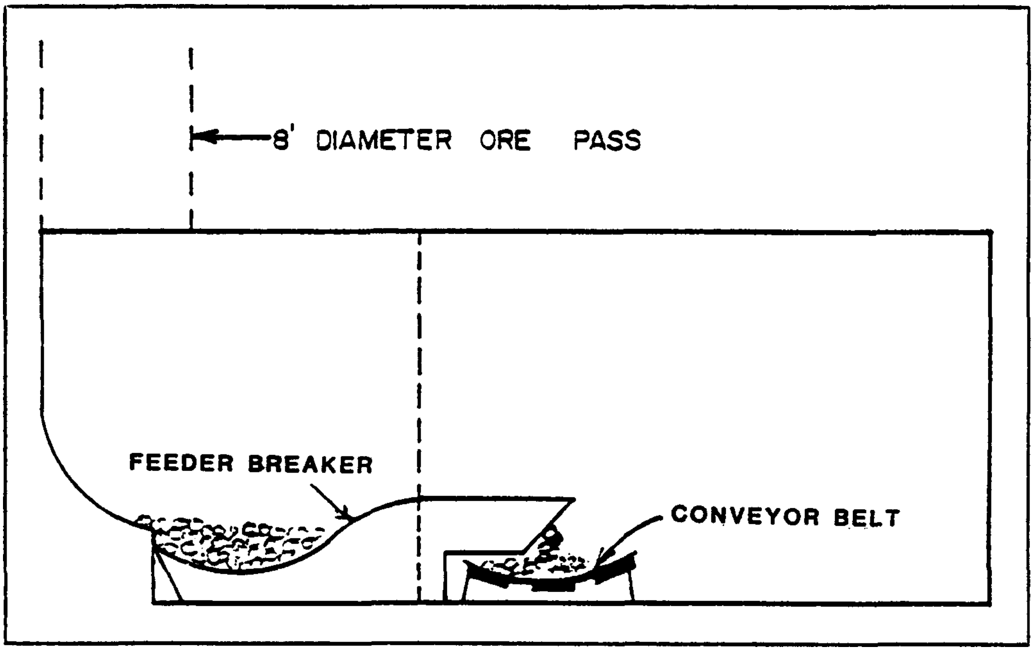

FIGURE 4-6

Conveyor Belt Loading Station Located Under Ore Pass
VMIS Plans 1 and 3, Site 2

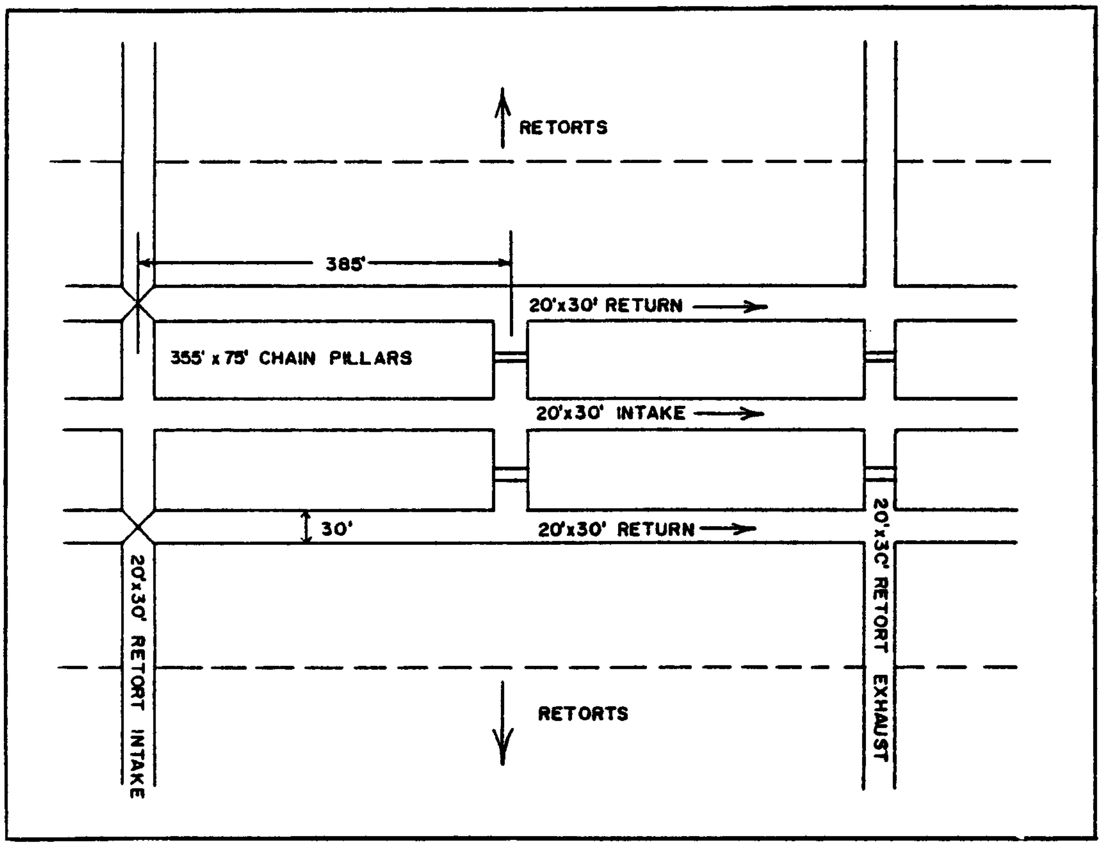

FIGURE 4-7

Main Entry Configuration. VMIS Plans 1 and 3, Site 2

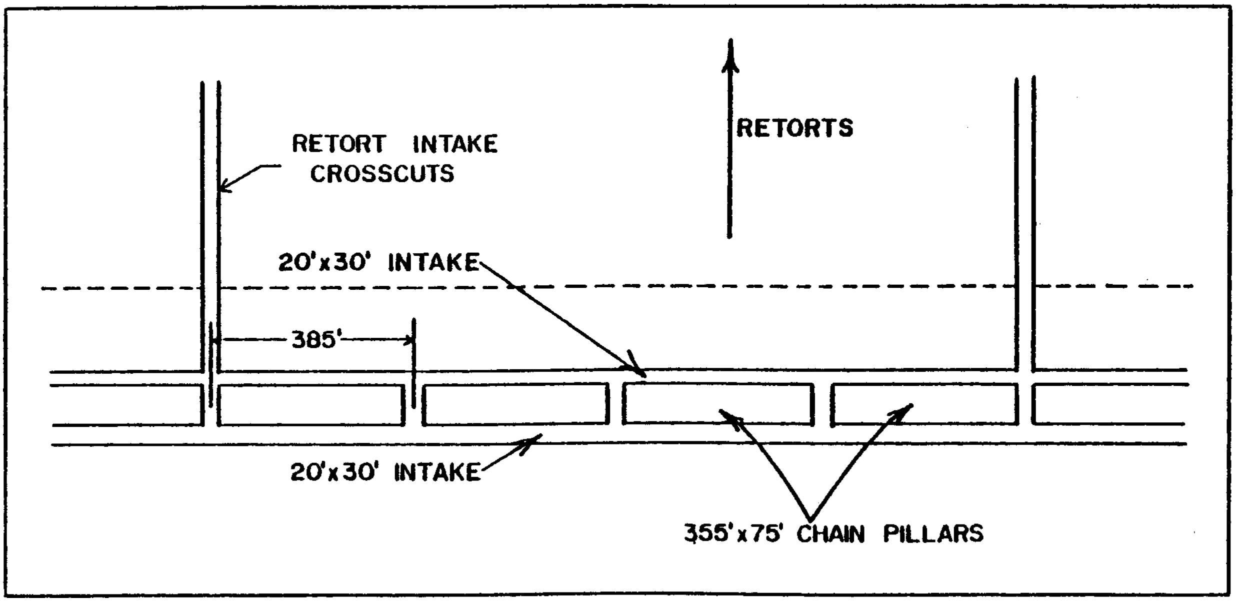

FIGURE 4-8

Property Boundary Intake Airway Configuration,
VMIS Plans 1 and 3, Site 2

770 feet. The entries provide direct access for air and piping to reach the retort modules, which are developed between the crosscuts. Figure 4-9 shows the locations of main entries, intake entry pairs, and intake and exhaust crosscuts as they occur on all three levels of the mine.

Retort module development layout specifications are based on: the need to access piping for ventilating and draining the individual retorts; the method of mining the voids for individual retorts; and, the method of drilling and rubblizing the retort. Haulage level retort module development (Figure 4-10) consists of a simple network of 20 ft. x 30 ft. entries connecting intake and exhaust crosscuts. Sumps are constructed at the bottoms of these entries within individual retorts where shale oil is collected and piped out of the module. Sublevel retort module development (Figure 4-11) consists of a more complicated series of 20 ft. x 30 ft. entries that provide access for the mining of voids and for drilling in preparation for the rubblization of each retort. Ventilation level retort module development (Figure 4-12) consists of driving a series of 20 ft. x 30 ft. and 15 ft. x 15 ft. entries to provide access for drilling blasting holes and rubblizing individual retorts.

4.3.1.2 Mine Operation. Mine operation proceeds with the initial development of retort module accessways that include main entry development, dual entry intake airways driven up the sides, and the development of intake and exhaust crosscuts used to access

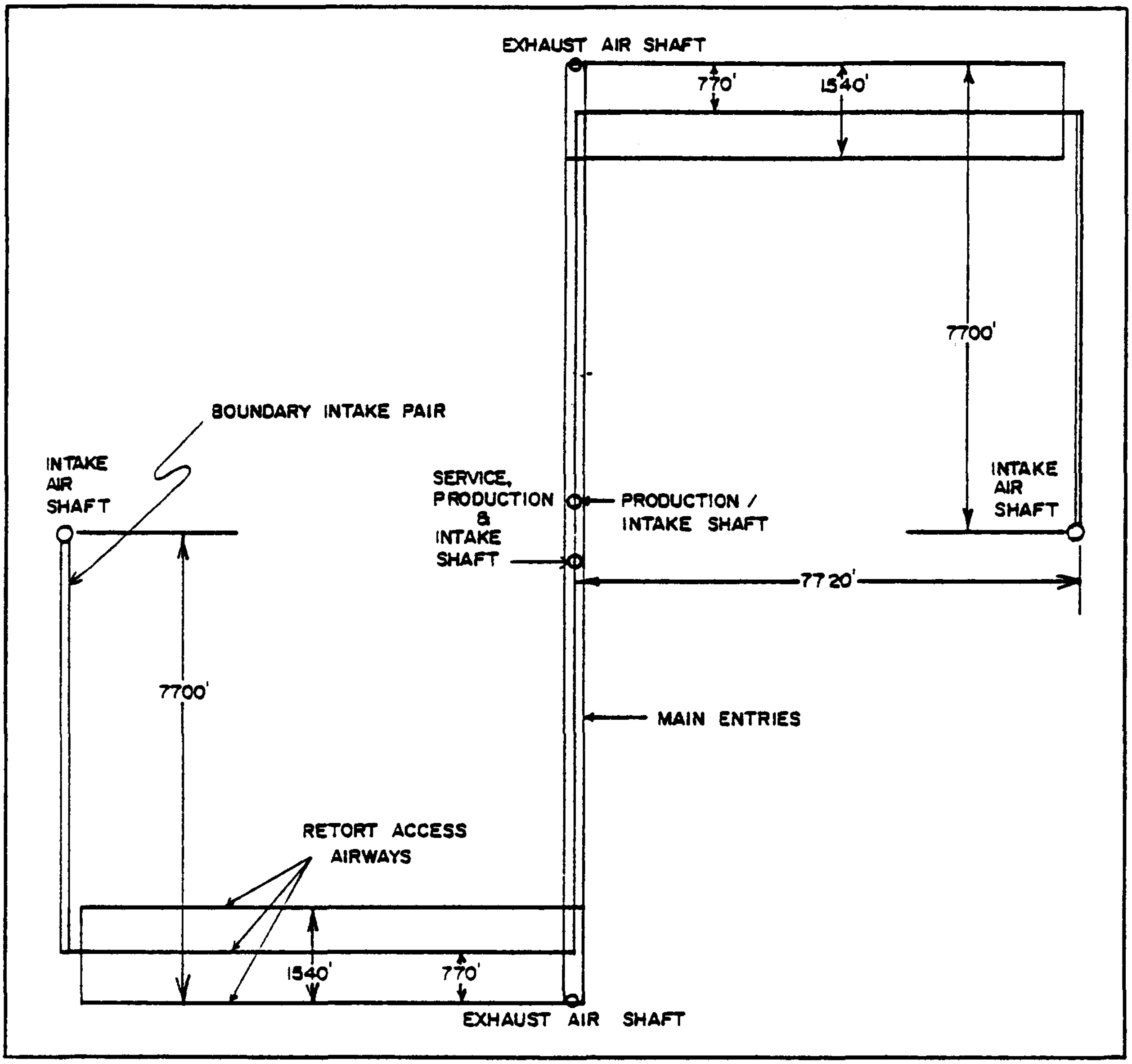

FIGURE 4-9

Plan View of Initial Development Required Before Retort Module Preparation Can Be Started. VMIS Plans 1 and 3, Site 2

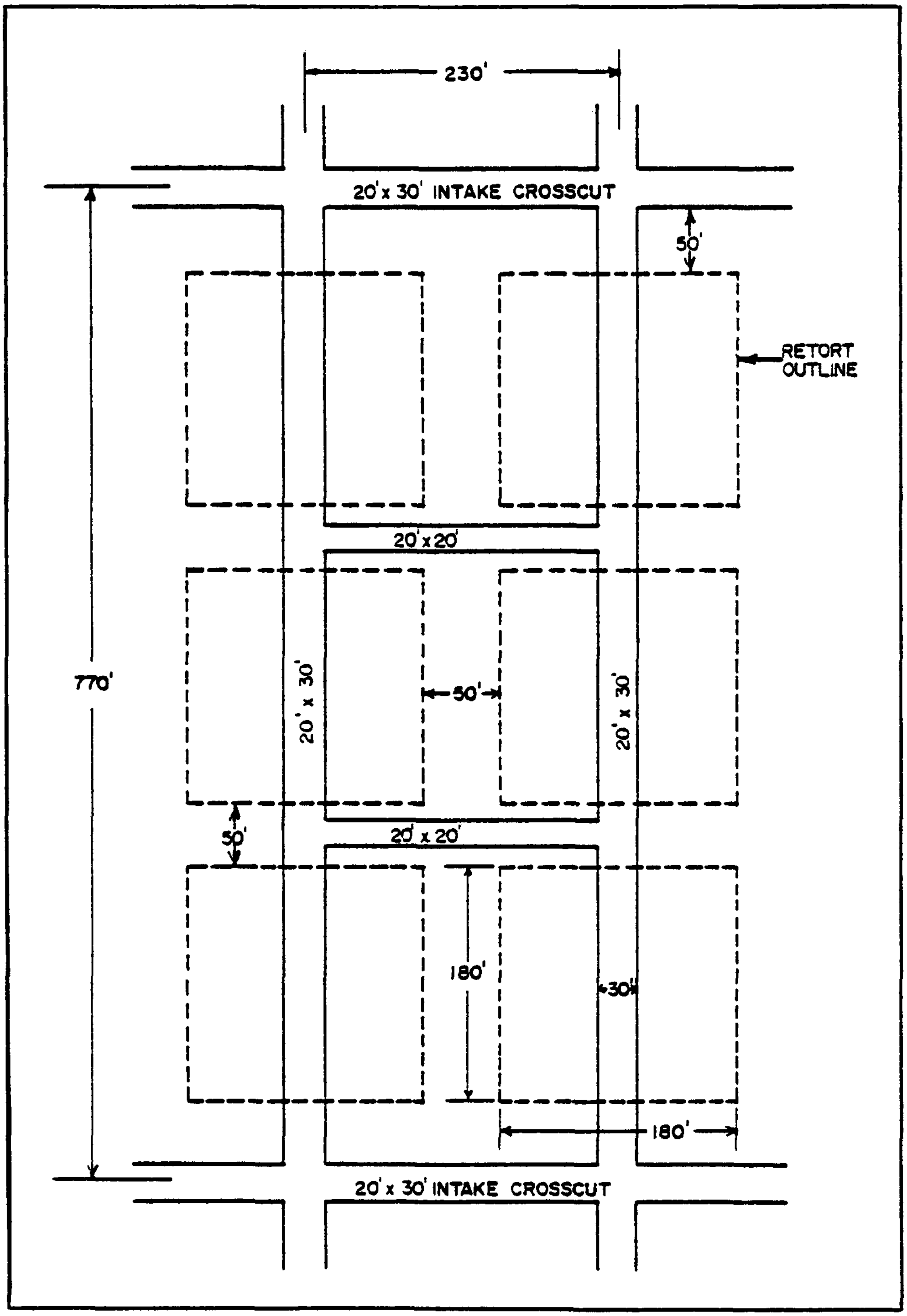

FIGURE 4-10

Haulage Level Retort Module Development Configuration
VMIS Plans 1 and 3, Site 2

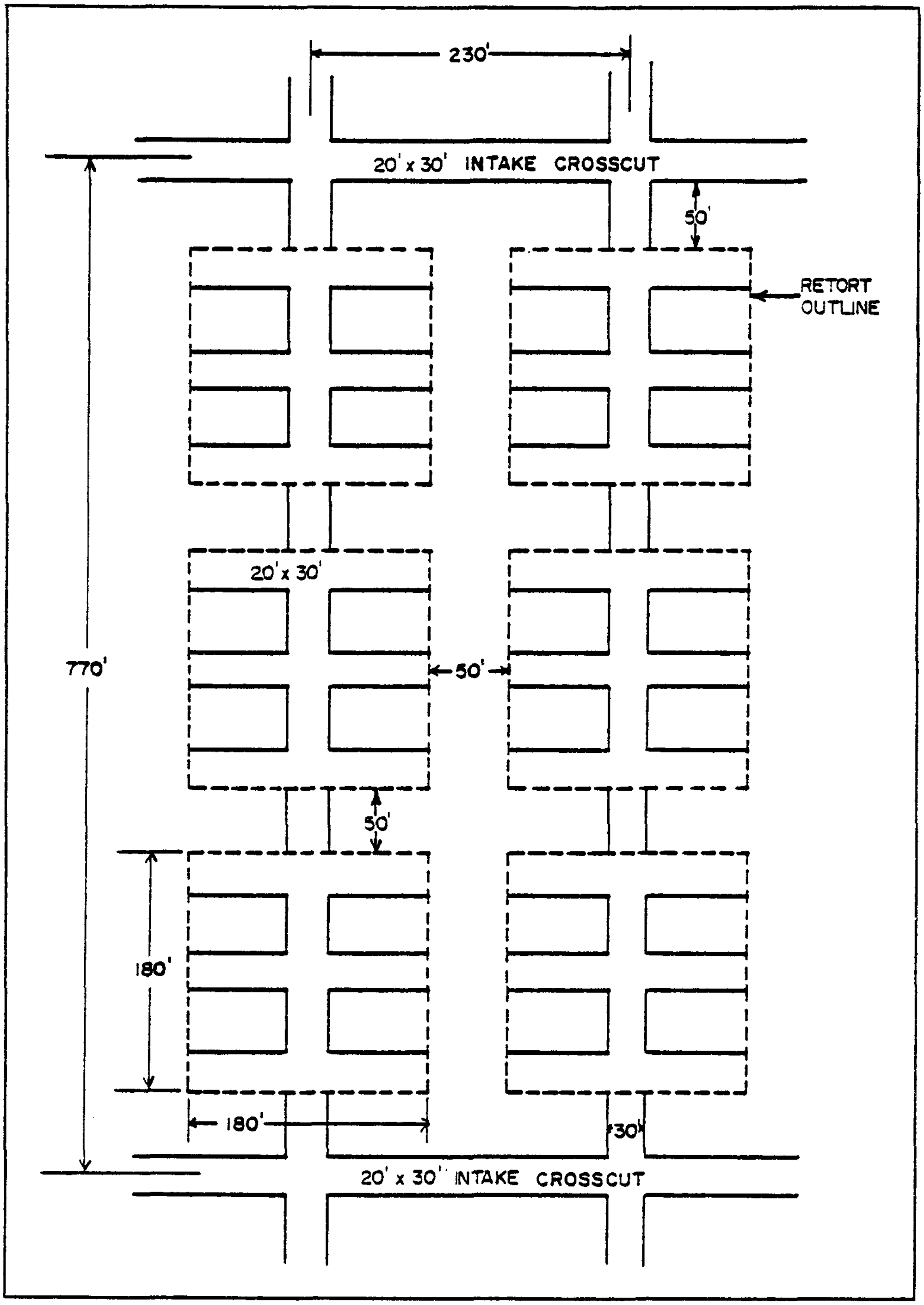

FIGURE 4-11

Sublevel Retort Module Development Configuration
VMIS Plans 1 and 3, Site 2

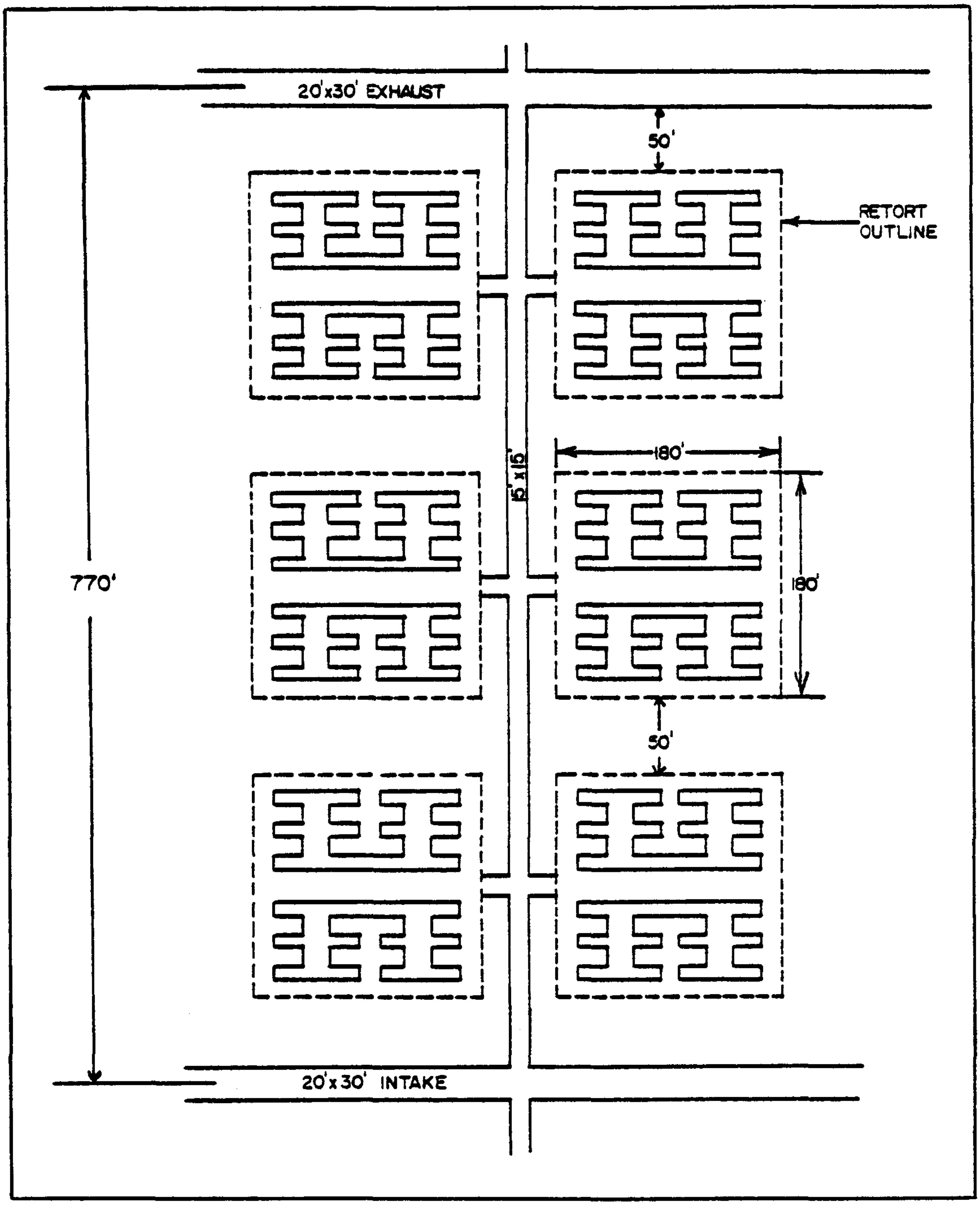

FIGURE 4-12

Ventilation Level Retort Module Development Configuration
VMIS Plans 1 and 3, Site 2

retort module pairs. This initial development pattern is identical on all three levels.

After the shafts are driven to a depth of approximately 800 feet, development of the main entries along double-entry intake passageways may proceed. The main entries are initiated by crews starting at the base of the production shafts located at the center of the property and at the base of the exhaust ventilation shafts. From these three points of origin, a triple entry main haulageway is driven to a point of intersection. Upon completion, the main entries will completely bisect the property and connect all four shafts. Concurrent development will occur in double-entry intake airways that originate at the prescribed level of the two intake shafts. Initially, the intake airways are driven in opposite directions toward opposite corners of the property. After both the mains and the intake airways are completed, a single intake and two exhaust crosscuts are driven in each half of the mine. Figure 4-9 shows the layout of the mine after the initial development is completed and prior to retort module preparation.

Retorts are prepared in modules of six individual (180' x 180' x 400') rubblized shale columns located between intake and exhaust airways. Preparation involves: 1) retort development, 2) void mining, and 3) rubblization. Retort modules must be prepared at an average rate of one every 17 days for Plan 1 and one every 25 days for Plan 3. These rates are attained by developing simultaneously in both halves of the mine. In each half, a module pair is developed simultaneously on both sides of an intake airway. In this manner, four modules are prepared every 68 days (on the average) for Plan 1 or every 100 days for Plan 3.

Retort module development involves driving a series of entries to prepare a module of six retorts for void mining and pre-rubblization drilling. Configurations of the retort module development entries on each of the three levels are shown in Figures 4-10, 4-11, and 4-12. Mining crews and equipment are distributed as needed among the three levels to assure synchronous operation during the development phase.

Upon completion of development work for a module pair, a 30 foot wide vertical slot is mined through the entire width (180') and height (400') of each individual retort (see Figure 4-13). This slot creates a void of approximately 20 percent* of the total volume of the retort, into which the rubblized oil shale can expand. Mining of the vertical slot is accomplished by an overhand stoping method in which dual-boom jumbos drill blastholes into the top of the haulage level and sublevel entries. The oil shale is blasted and mucked-out using 9 cubic yard load-haul-dump units. Each round takes a 30-foot cut, and cuts are taken until the entire 180-foot width of the retort slot is mined. Due to limitations on the effective drill length of jumbos, additional blast holes must be drilled down from both the sublevel

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* Previously mined areas on the sublevel and haulage level are included in the 20 percent void volume.

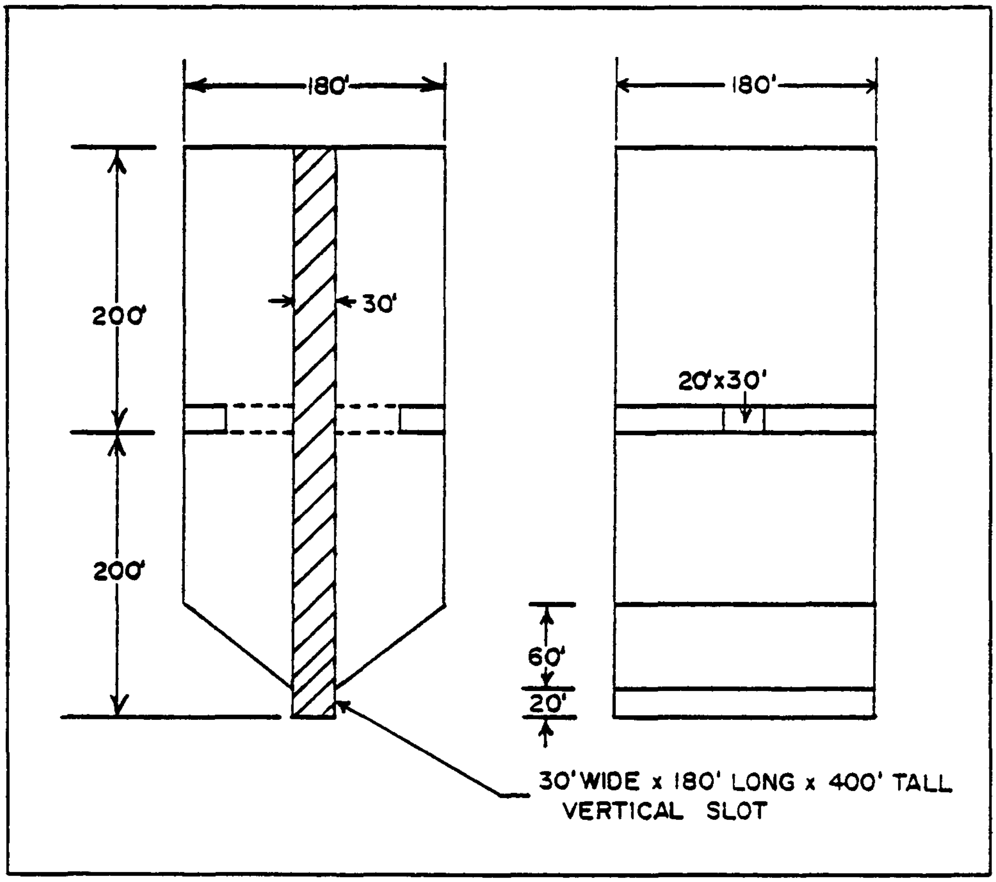

FIGURE 4-13

Vertical Modified In Situ Retort Configuration
VMIS Plans 1 and 3, Site 2

and ventilation level. Figures 4-14, 4-15a, 4-15b and 4-16a show the typical drill pattern for mining a vertical slot.

After the expansion void is mined, the retort is drilled in preparation for rubblization. Drilling is done from the ventilation level with down-hole pneumatic hammer percussive drills. Ninety-eight 10-inch diameter holes are drilled, following the pattern shown in Figure 4-16b. Many of the holes are drilled from the ventilation level through the entire 400-foot height of the retort. Those holes that intersect a mined area at the sublevel are discontinued and restarted from the sublevel. An additional ninety-four 2-1/2 inch diameter relief holes are drilled around the perimeter of each retort to assure that pillars left between the retorts are not weakened by the rubblization blast. The amount of explosives required is determined from a rubblization powder factor of 1.4, using a high density ammonium nitrate and fuel oil (ANFO) mixture.*

After a module pair has been rubblized, the piping required for retort operation and product removal is installed. When hook-up is complete and the next adjacent module pair has been prepared, retorts are ignited. For safety reasons, work is not permitted adjacent to burning retorts.

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* Powder factor is the ratio of pounds of ANFO used to tons of material blasted.

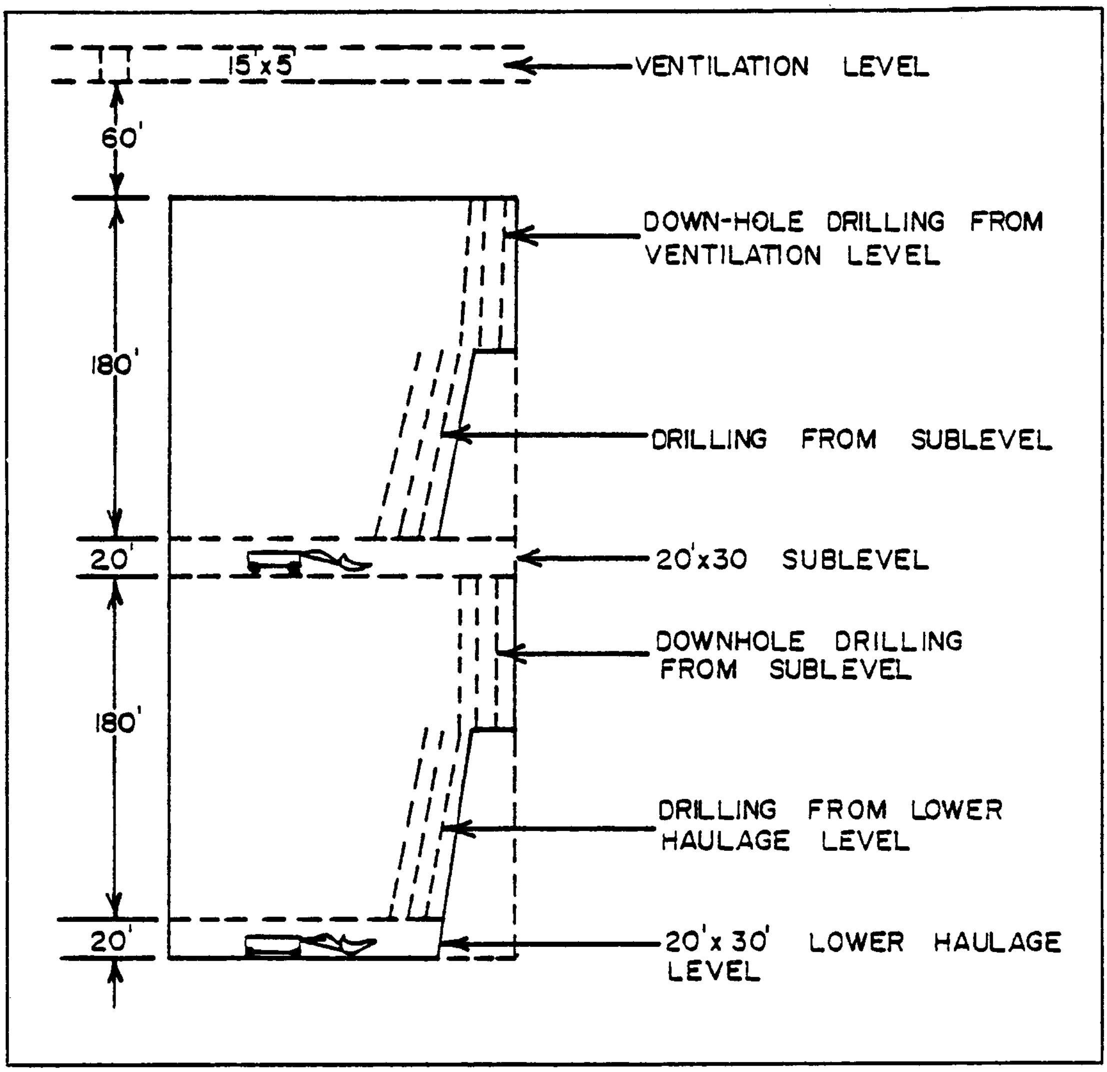

FIGURE 4-14

Drilling Required to Create Vertical Slot Retort Void
VMIS Plans 1 and 3, Site 2

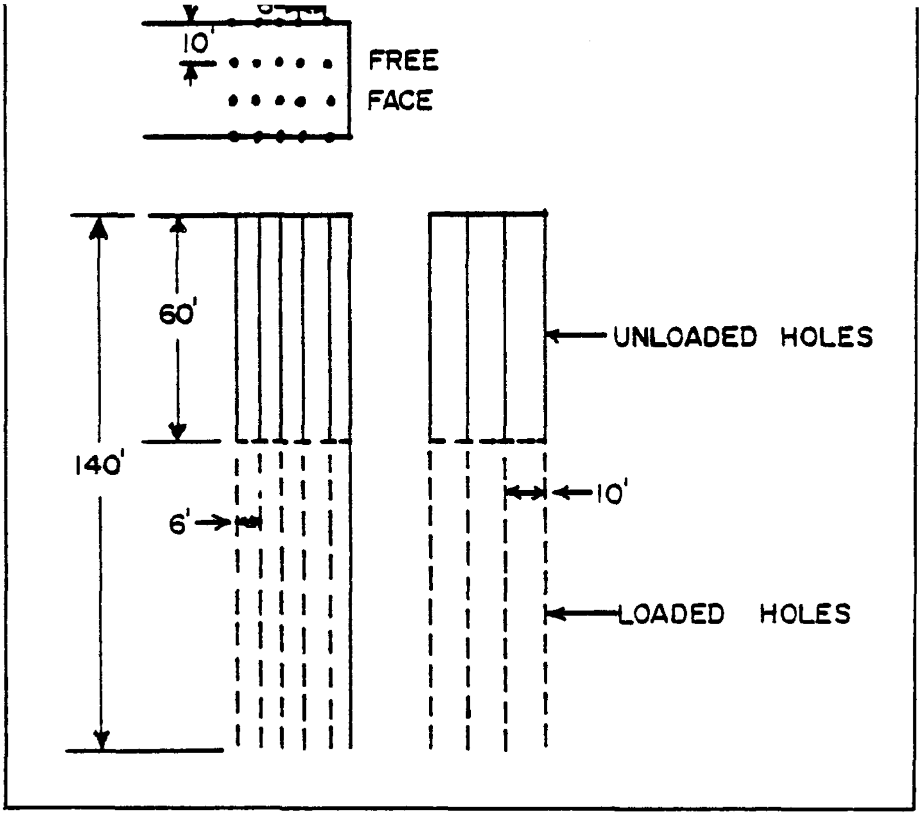

FIGURE 4-15a
Downhole Drilling Pattern from Ventilation Level

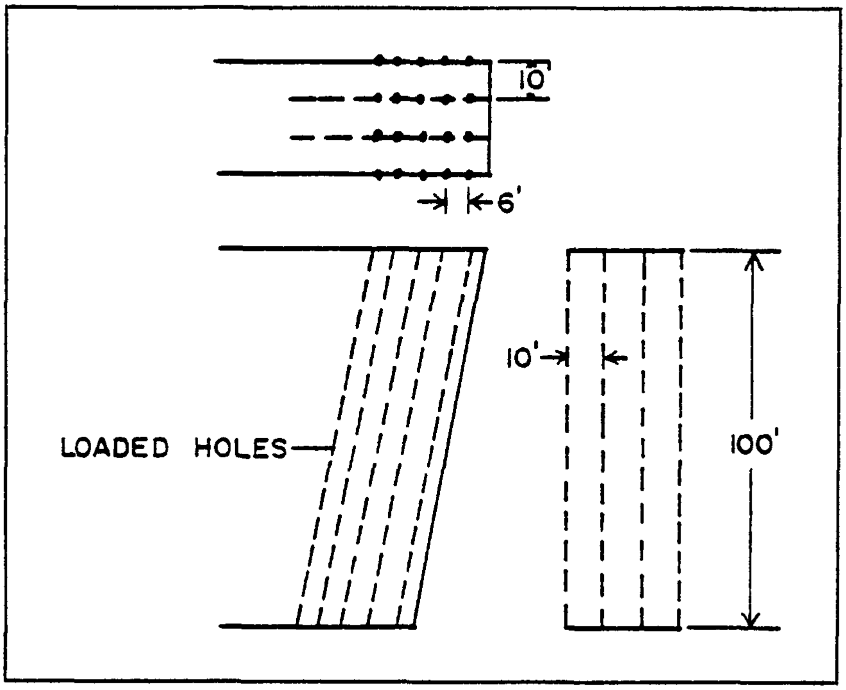

FIGURE 4-15b
Drilling Pattern from Haulage Level and Sublevel

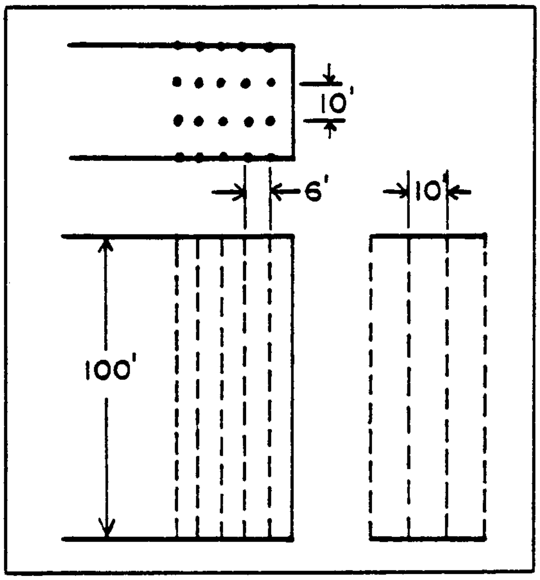

FIGURE 4-16a

Downhole Drilling Pattern from Sublevel

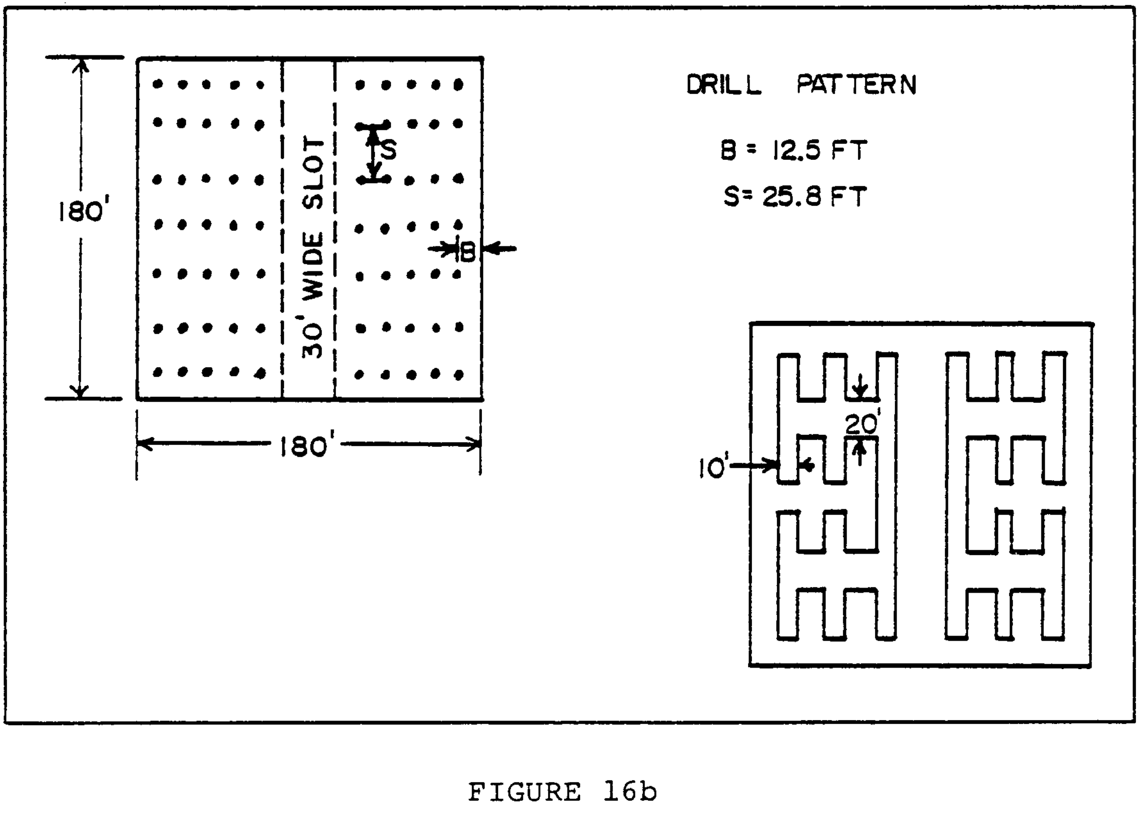

FIGURE 16b

Ventilation Level Retort Rubblization Drill Hole Configuration

Steady-state or full production is attained when N retorts are burning simultaneously, where N depends on shale grade, recovery efficiency, burn rate, retort cross-section area, and void ratio -- in addition to target production. Recovery efficiency is assumed to be 50 percent and burn rate is assumed to be one foot per day for in situ retorts. Surface retorts are assumed to have 100 percent recovery efficiency. Target production is 50,000 barrels per day.

Full production in Plan 1 (VMIS only) is approximately 49,560 bbl/day, which is attained when 144 retorts are producing simultaneously. The mine life expectancy for Plan 1 is estimated to be 33 years.

In Plan 3, full production from the VMIS retorting is approximately 32,270 barrels per day, which is achieved when 92 retorts are producing simultaneously. An additional 21,990 barrels of shale oil are surface retorted daily from the 50,400 tons/day of mined-out shale. Thus, full production for VMIS plus surface retorting in Plan 3 is approximately 54,260 barrels per day. The life expectancy of the mine for Plan 3 is estimated to be 47 years.

4.3.2 Plan 2 and Plan 4, Site 3

The property at Site 3 is a square tract (9 sq mi) located within the township and range: T4S, R95W, Garfield County, CO. Oil recovery in Plan 2 employs the VMIS process only, while Plan 4 includes VMIS and surface retorting of oil shale extracted as a result of the mining operations. Target production for these recovery plans is 50,000 barrels per day (bbl/day).

The shale grade at Site 3 averages 20.75 gallons per ton (gpt), and is distributed unevenly about the vertical extent of the VMIS retorts, as shown in Figure 4-17. The base of the Mahogany Zone, which contains the highest grade shale, lies at an average depth of 800 feet below the surface.

4.3.2.1 Layout Specifications. Access to the mining area is through five vertical 28-foot diameter shafts and one vertical 32-foot diameter production-service shaft located at the center of the property. One 28-foot exhaust shaft is sunk near each of two opposite property borders. The 32-foot combined production-service shaft, the 28-foot production/intake shaft, and two 28-foot intake ventilation shafts are sunk near the center of the property. Shaft locations and their purposes are shown in the overall mine layout (Figure 4-18); a more detailed description of each shaft is presented in Table 4-2. Figure 4-4 shows a cross-section of the combination production-service shaft located at the center of the property.

Initial mine development occurs on four levels:

1) the haulage/oil collection level at the base of the Mahogany Zone
2) a sublevel which is driven 180 feet above the haulage level

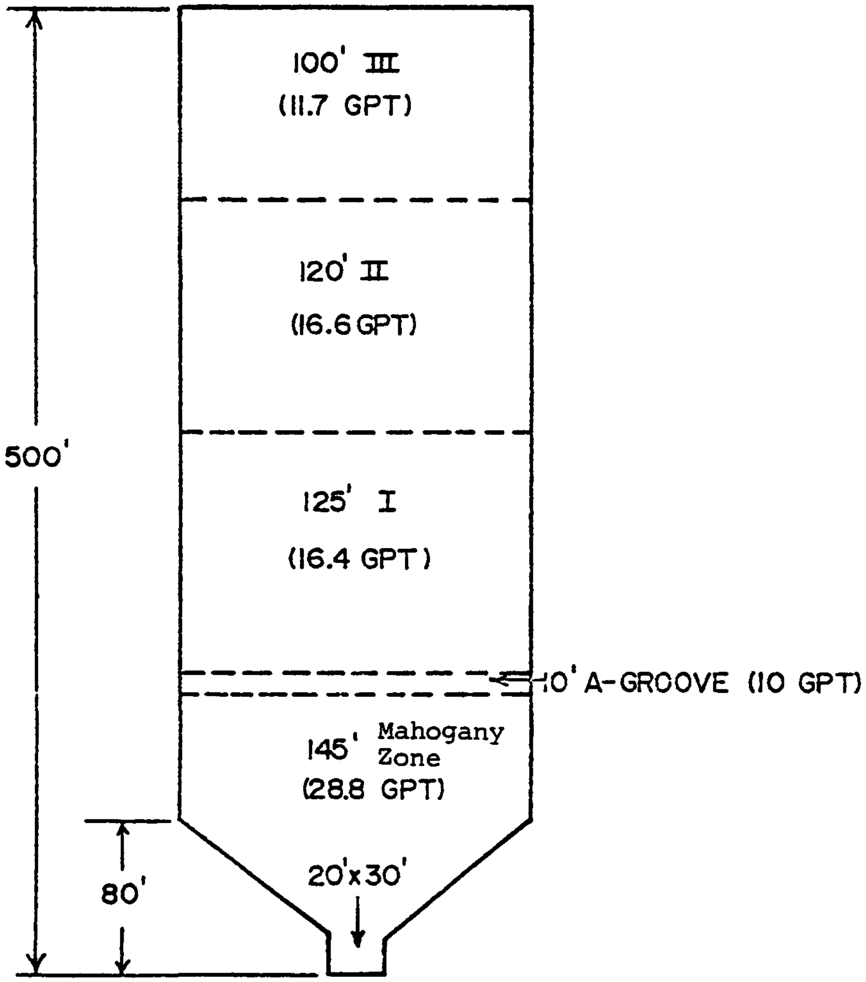

FIGURE 4-17

Oil Shale Grade Distribution over the VMIS Retorts
Plans 2 and 4, Site 3

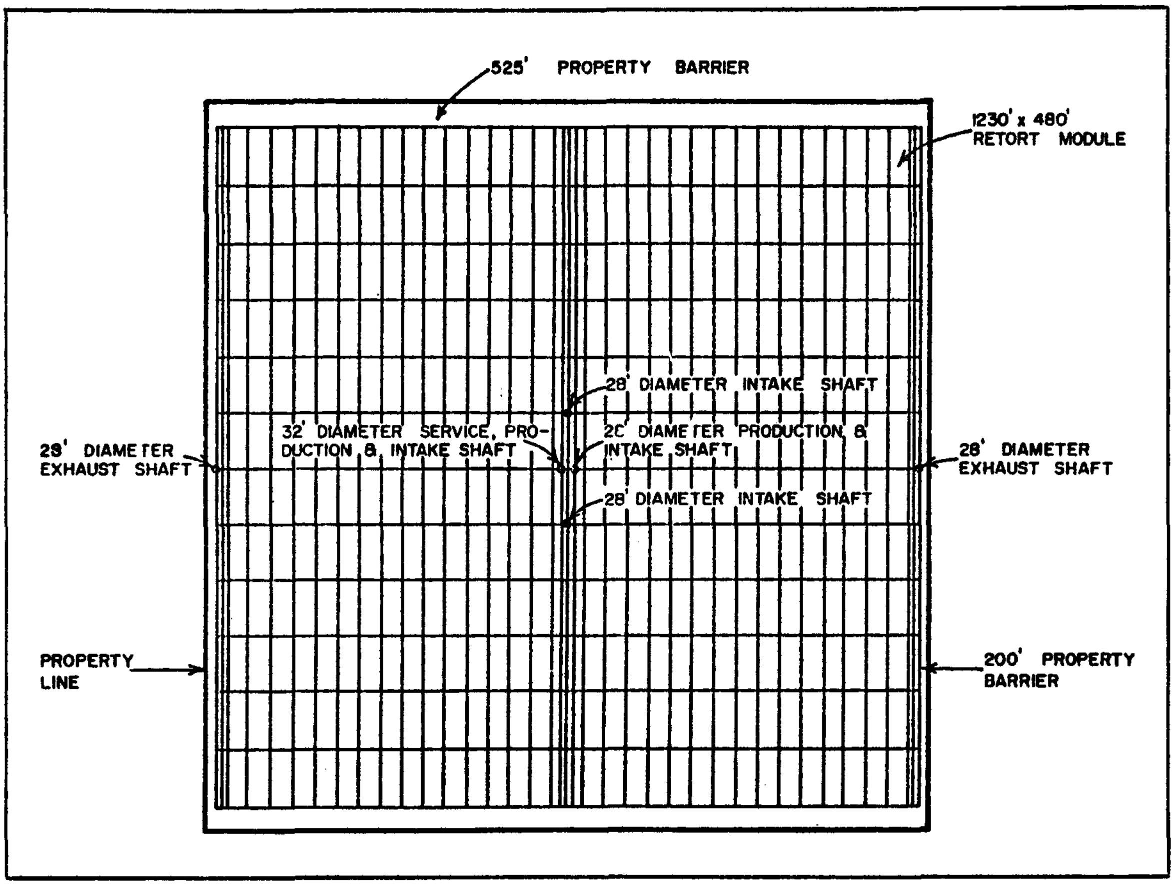

FIGURE 4-18

Plan View of Basic Mine Plan. VMIS Plans 2 and 4, Site 3

3) a second sublevel which is developed 200 feet above the first sublevel

4) a ventilaton level which is 180 feet above the bottom of the second sublevel.

Each level requires similar entry configurations up to the development of individual retort modules. The layout of these levels and associated ore passes is shown in Figure 4-19.

A series of ore passes, raise bored at varying intervals throughout the mine, connects the four development levels. Using these ore chutes permits all mined oil shale to be transported on the haulage level. This feature reduces costs associated with outby haulage equipment. Load-haul-dump vehicles move oil shale from working faces to ore pass locations on the ventilaion level and each of the two sublevels. At each location, the shale is broken and fed into the ore pass, from which it emerges on the haulage level into a cavity with a surge capacity of about 50 tons. The oil shale empties out of this cavity onto a pan feeder-breaker that feeds a conveyor belt. Figure 4-20 illustrates loading from the surge cavity to the conveyor.

Main entries, driven on all four levels, consist of three parallel 20 ft. x 30 ft. entries separated by 75 ft. wide chain pillars, with 20 ft. x 30 ft. crosscuts driven on 307.5 ft. centers (Figure 4-21). The purpose of these entries is to provide a haulage route for oil shale mined out of the retort areas and to

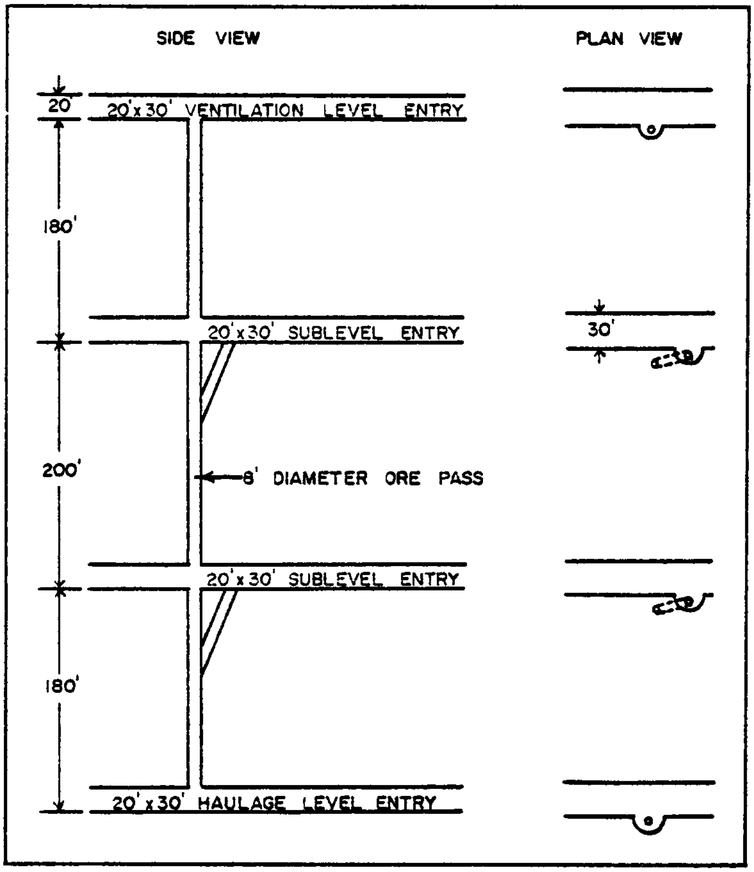

FIGURE 4-19

Development Levels and Ore Pass Configuration.
VMIS Plans 2 and 4, Site 3

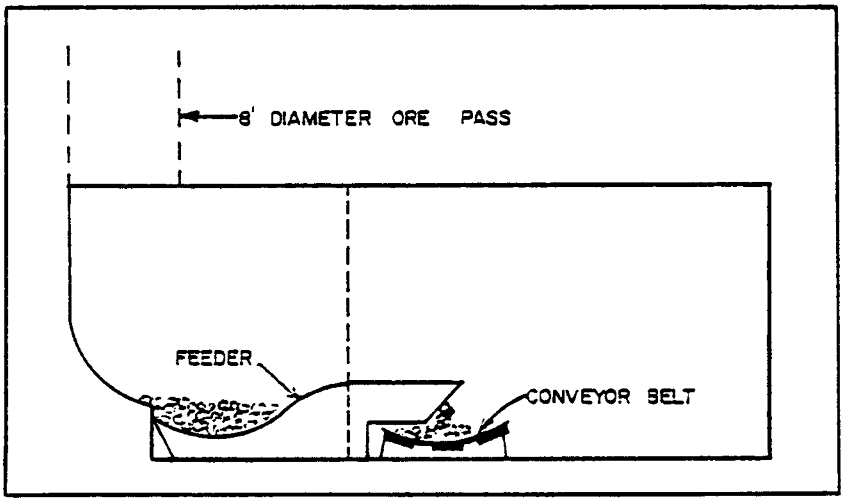

FIGURE 4-20

Conveyor Belt Loading Station Located under Ore Pass
VMIS Plans 2 and 4, Site 3

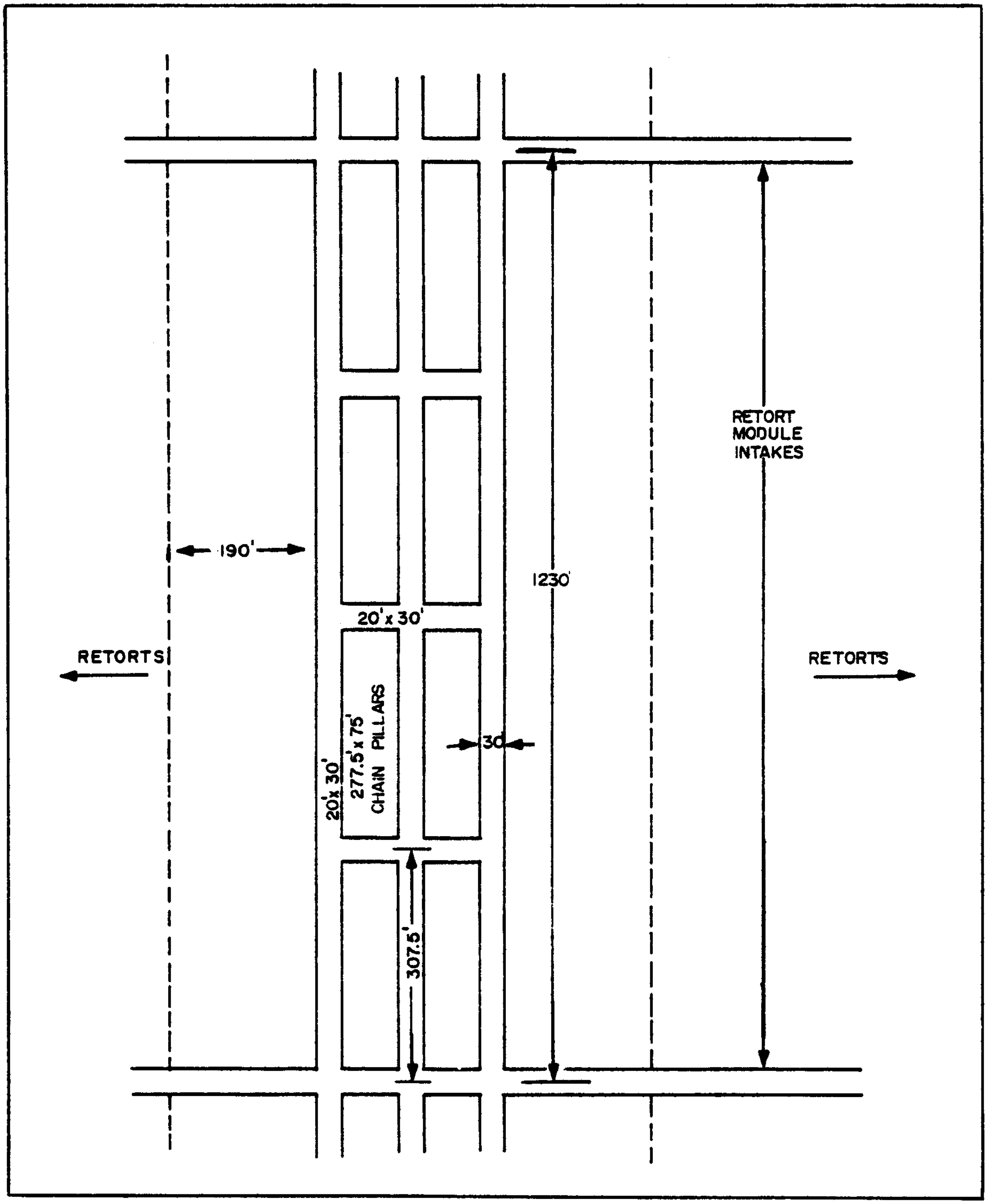

FIGURE 4-21

Main Entry Configuration. VMIS Plans 2 and 4, Site 3 provide a route for intake ventilation to reach crews working in these retort fields.

A pair of exhaust airways is driven parallel to the main entries near two opposite property borders. These boundary exhaust airways consist of two parallel 20 ft. x 30 ft. entries separated by 75 ft. wide chain pillars, with 20 ft. x 30 ft. crosscuts driven on 277.5 ft. centers. The configuration of these boundary airways is illustrated in Figure 4-22. These entries provide a route for exhaust air to escape through the exhaust ventilation shafts which bisect each exhaust entry pair. Retort air intake, natural gas, and steam pipes are constructed in these entries on the ventilation level. Product removal piping is constructed in these entries on the haulage level. Shale oil is pumped to the surface through these pipes, by way of the exhaust ventilation shafts.

Parallel intake crosscuts are driven on all four levels to connect the main entries with the boundary exhaust pairs driven up the sides of the property. These intake entries are 20 feet high and 30 feet wide and are separated by a distance of 1,230 feet. The entries provide direct access for air and piping to reach the retort modules which are developed between crosscuts. Figure 4-23 shows the locations of main entries, boundary exhaust pairs, and intake air crosscuts as they occur on all four levels of the mine.

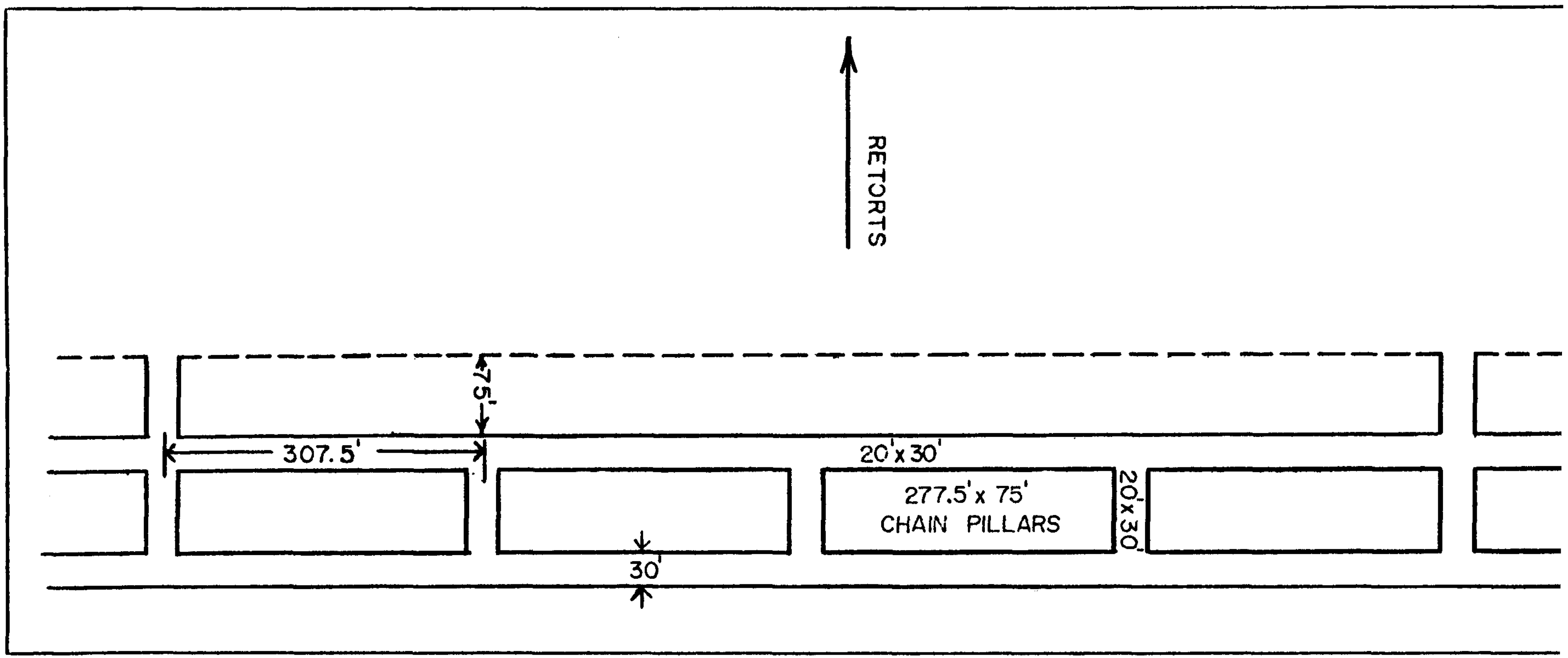

FIGURE 4-22

Boundary Exhaust Airway Configuration. VMIS Plans 2 and 4, Site 3

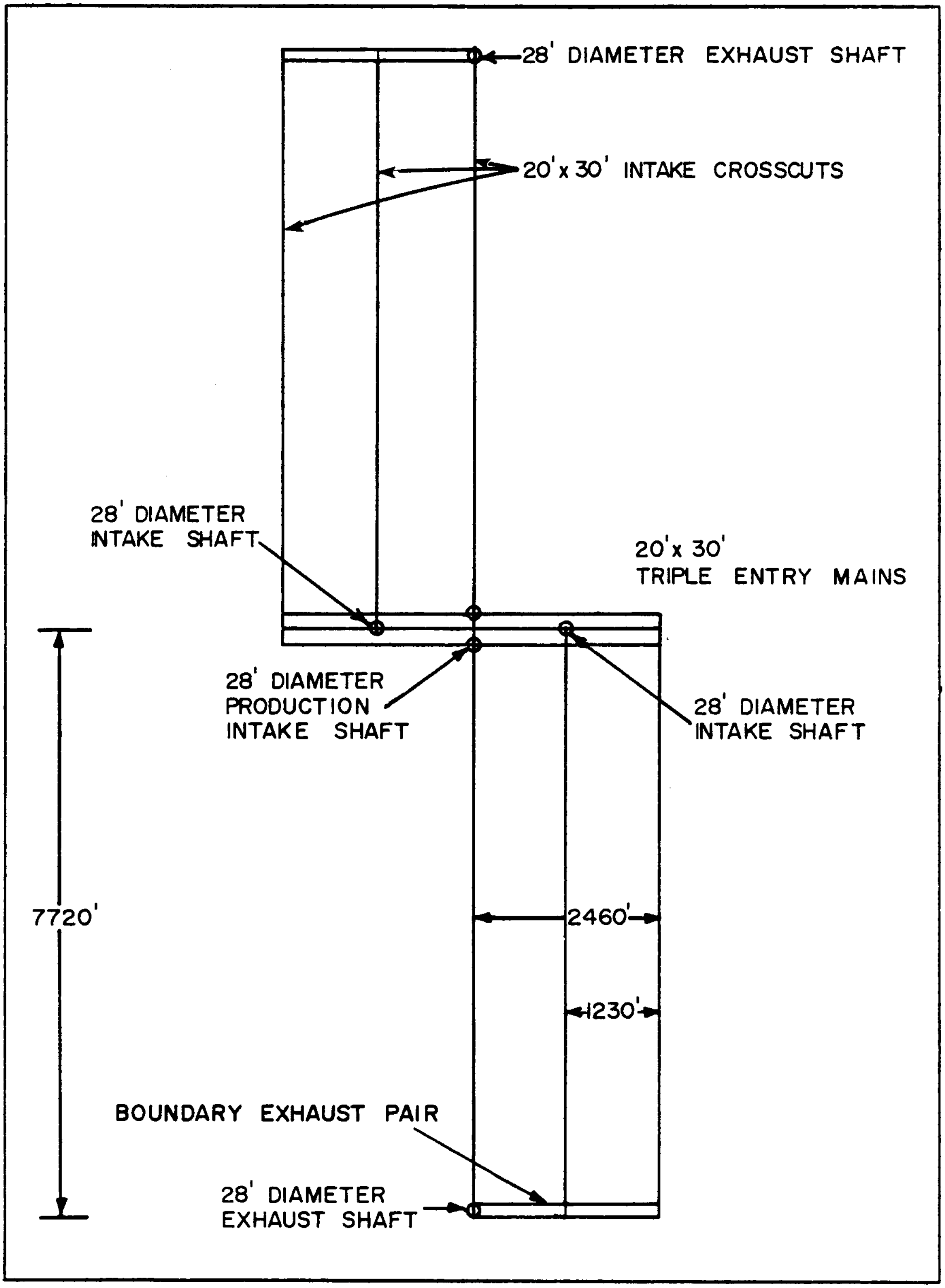

FIGURE 4-23

Preproduction Development Configuration
VMIS Plans 2 and 4, Site 3

Retort module development layout specifications are based on: the need to access piping for ventilation and draining the individual retorts; the method of mining the voids for individual retorts; and, the method of drilling and rubblizing the retort. Haulage level retort module development (Figure 4-24) consists of a simple network of 20 ft. x 30 ft. and 15 ft. x 15 ft. entries that connect intake crosscuts. Sumps are constructed at the base of entries that are positioned directly under individual retorts. Shale oil is collected and piped out of these pumps into the intake crosscut, and ultimately out of the mine. Sublevel retort module development is similar on both sublevels. It consists of performing room and pillar operations within each retort, in which a series of 45 ft. x 40 ft. entries is driven as shown in Figure 4-25. A series of 20 ft. x 30 ft. entries connects the retorts and also links the retorts to the intake crosscuts. Ventilation level retort module development (Figure 4-26) is a simple series of 20 ft. x 30 ft. and 15 ft. x 15 ft. entries which provide access to the retorts for ignition and intake ventilation.

4.3.2.2 Mine Operation. After the shafts are driven to a depth of approximately 800 feet, mining operations proceed with the initial development of retort module accessways that include: main entries, boundary exhaust pairs, and intake air crosscuts. This initial development pattern is identical on all four levels. After the main entries and boundary exhaust pairs are developed to a certain extent, the initial intake ventilation crosscuts

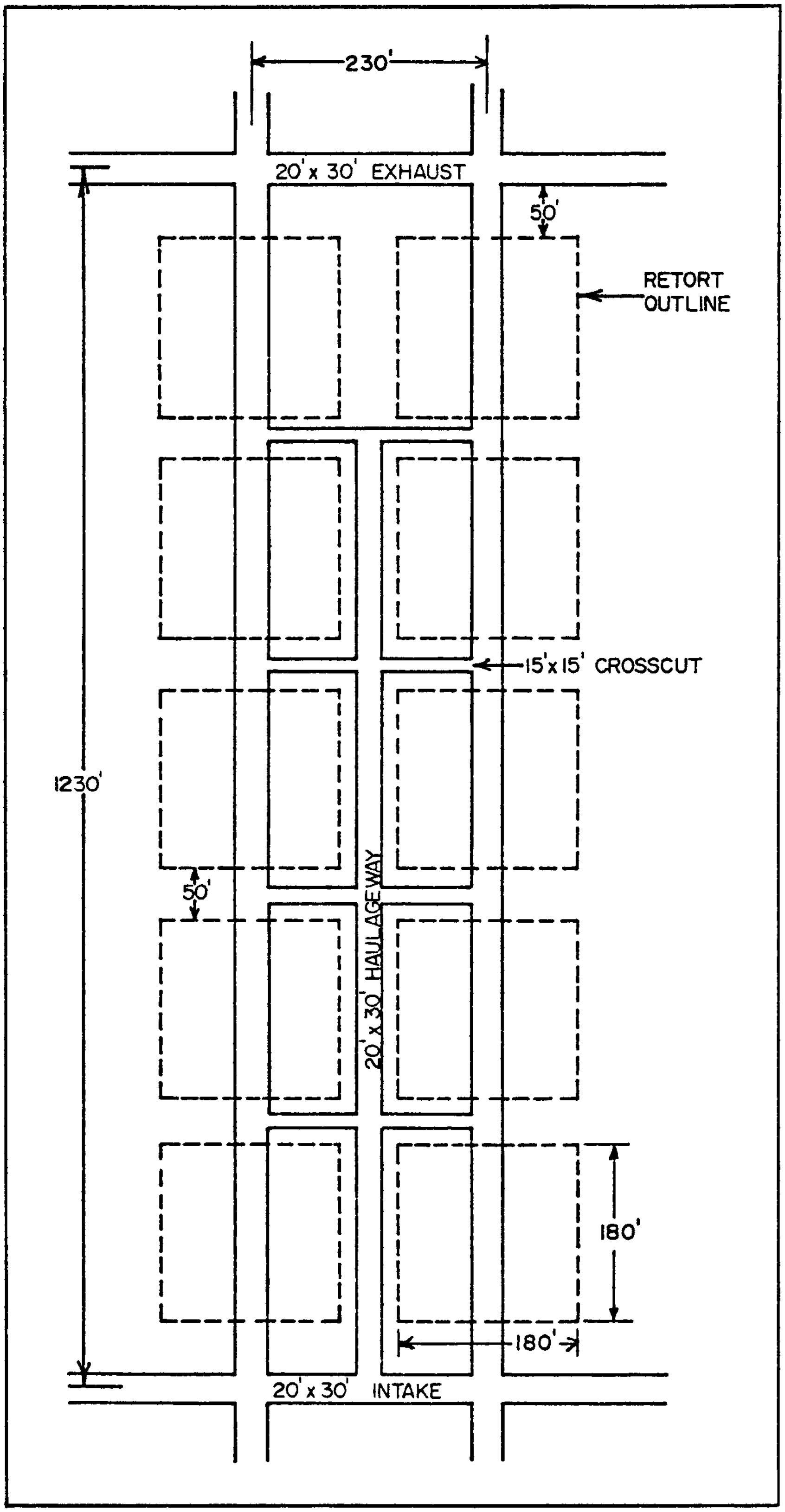

FIGURE 4-24

Haulage Level Retort Module Development Configuration
VMIS Plans 2 and 4, Site 3

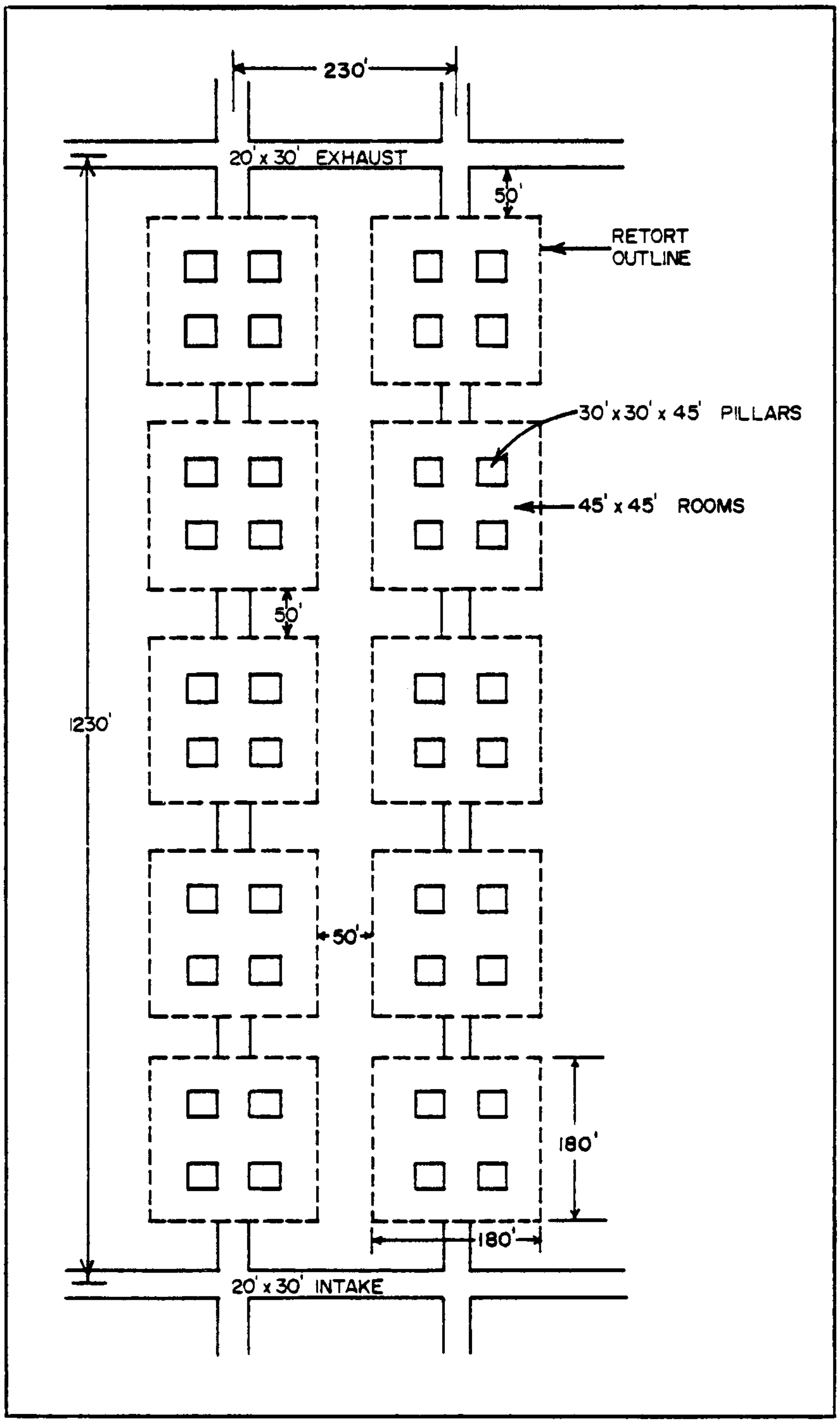

FIGURE 4-25

Sublevel Retort Module Development Configuration
VMIS Plans 2 and 4, Site 3

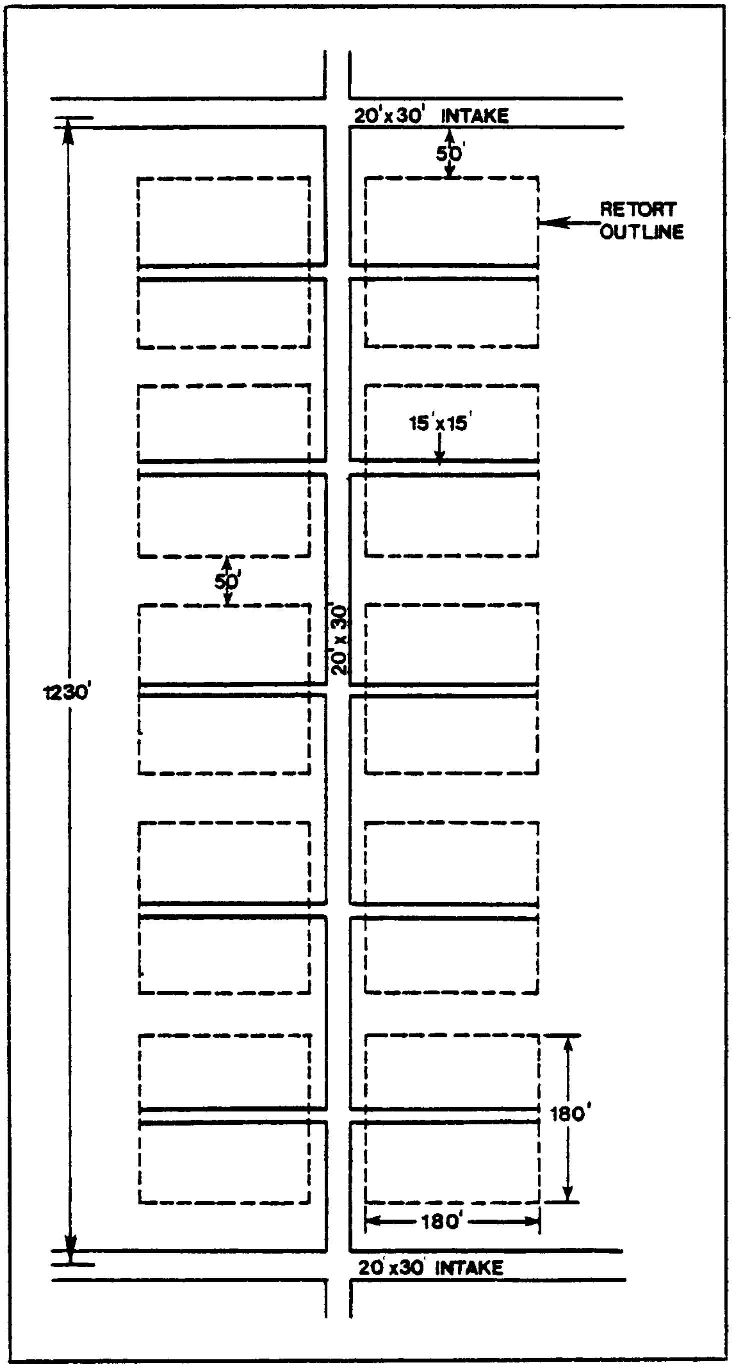

FIGURE 4-26

Ventilation Level Retort Module Development Configuration
VMIS Plans 2 and 4, Site 3

are driven. This initial development (Figure 4-23) must be completed before further development continues in a half advance-half retreat manner in both halves of the mine.

Preparation of retort modules begins when the initial development described above is completed. Retort modules in Plans 2 and 4 consist of ten individual (180' x 180' x 500') rubblized shale columns located between airway crosscut pairs. Preparation involves: 1) retort development, 2) void mining, and 3) rubblization. Retort modules must be prepared at an average rate of one every 29 days for Plan 2 and one every 60 days for Plan 4. These rates are attained by mining simultaneously in both halves of the mine. In each half, a module is prepared simultaneously on both sides of an intake crosscut. In this manner, two pairs or four modules are prepared every 118 days (on the average) for Plan 2, or every 240 days for Plan 4.

Retort module development involves driving a series of entries to prepare a module of ten retorts for void mining and pre-rubblization drilling. Configurations of the retort module development on each of the four levels are shown in Figures 4-24, 4-25, and 4-26. Mining crews and equipment are distributed as needed among the four levels to assure synchronous operation during the development phase.

Upon completion of the development work for a module pair, individual retorts are accessible for void mining operations. In Plans 2 and 4, room and pillar mining on each sublevel, along with mining on the haulage level, creates voids in each retort (see Figure 4-27). The sum of these voids amounts to approximately 30 percent of the total retort volume.

Void mining on each of the two sublevels involves a standard room and pillar mining technique in which the rooms are 40 feet wide and 45 feet high. Four square pillars, each 30 feet on a side, are left standing within each retort on each sublevel. Rooms are mined using dual-boom jumbos to drill a preset pattern of 15 ft. deep holes. The holes are loaded with explosives, the cut is blasted, and the fragmented oil shale is mucked-out using 11 cubic yard load-haul-dump units. These load-haul-dump units transport the oil shale to ore chutes located in the intake airways. From these points the shale is transported out of the mine as previously described in Section 4.3.2.1.

Void mining on the haulage level involves fan drilling with dual-boom jumbo drills into the roof of a 20 ft. x 30 ft. entry located at the base of each retort. A representative drill pattern is shown in Figure 4-28, where a 30-foot cut is taken. When the oil shale is blasted, it falls to the entry on the haulage level, where it is mucked-out with 15 cubic yard load-haul-dump units. The load-haul-dump units transport the oil shale to a haulage entry conveyor belt located within the module, from which point it is transported to an intake crosscut and deposited onto a larger belt conveyor. This conveyor transports the shale to skips in a production shaft, where it is hoisted to the surface. Equipment and man-

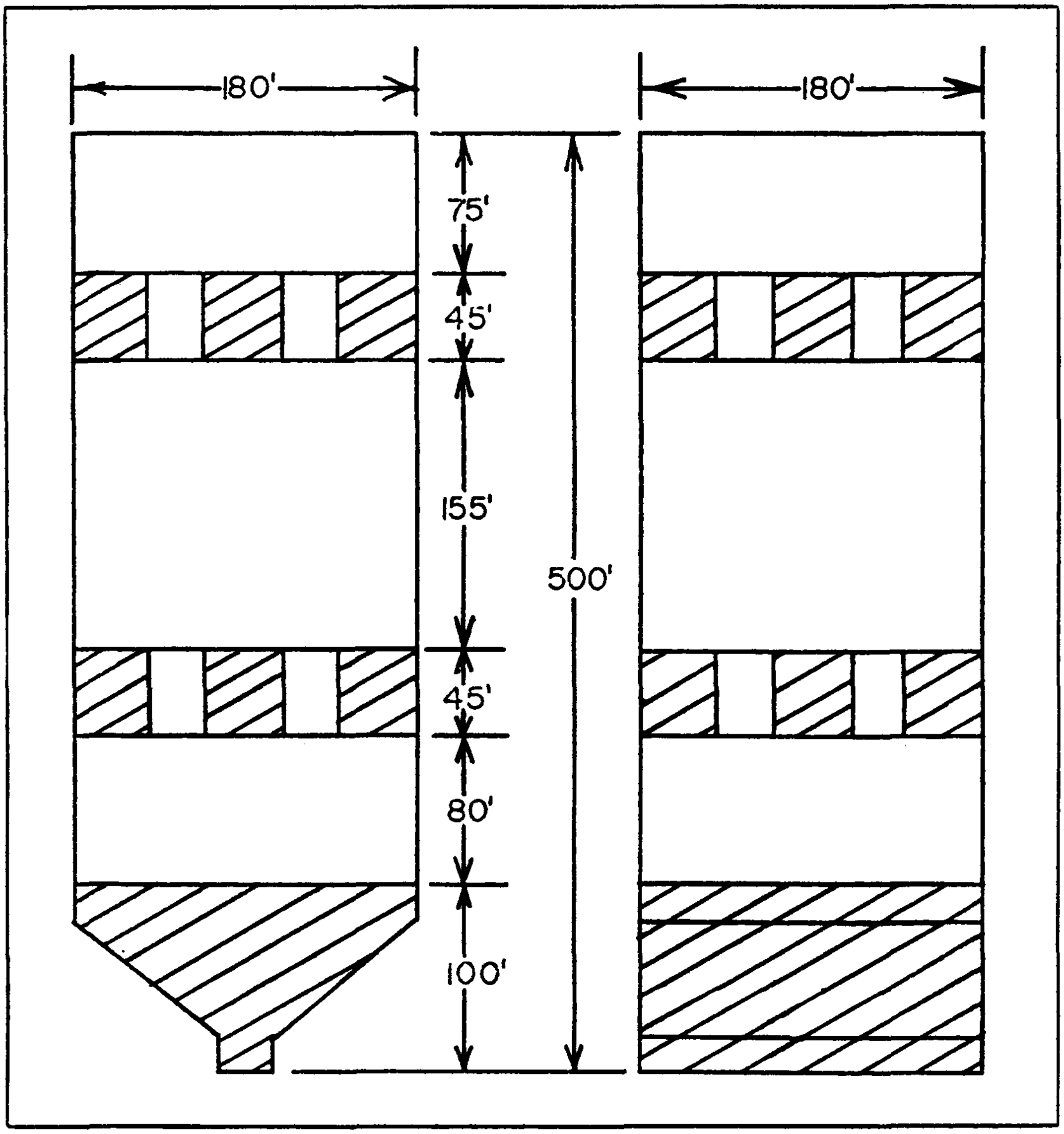

FIGURE 4-27

Front and Side Views of a Retort Showing Expansion Void Locations. VMIS Plans 2 and 4, Site 3

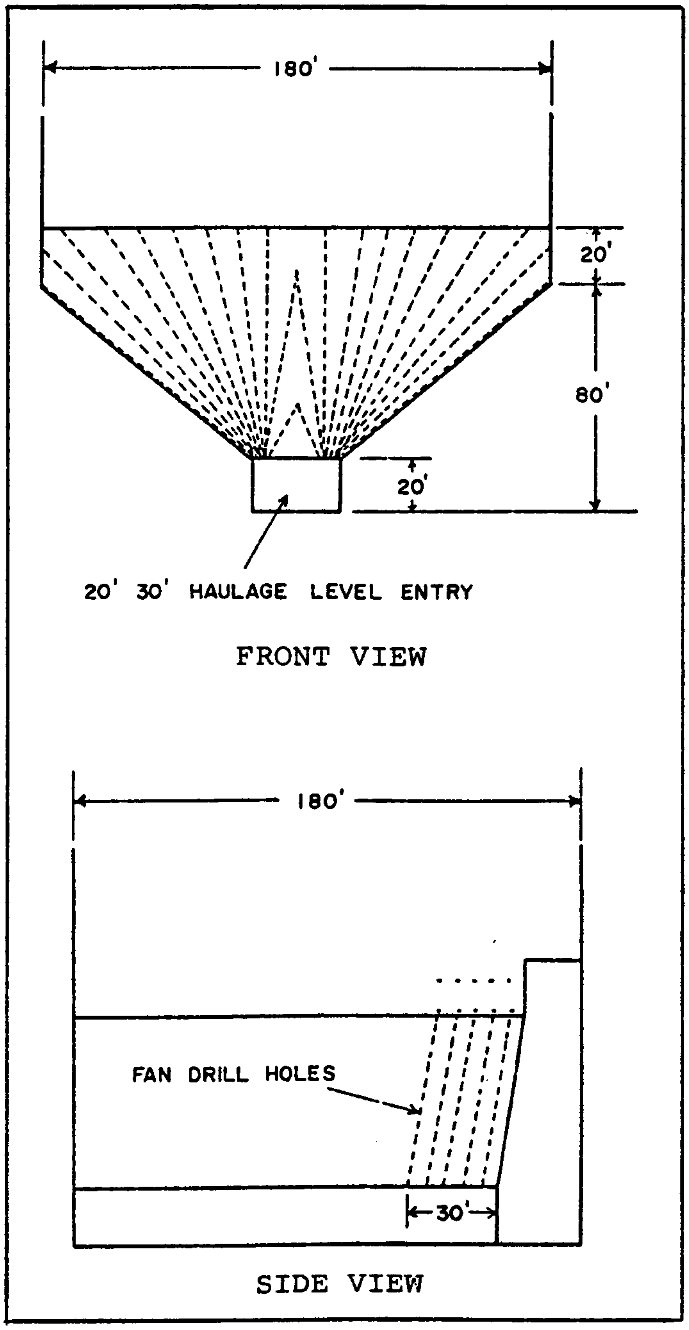

FIGURE 4-28

Representative Drill Pattern for Void Mining on the Haulage Level. VMIS Plans 2 and 4, Site 3 power are adjusted so that retort module development and void mining proceed as synchronous operations which support the 50,000 bbl/day target production level.

When the expansion voids have been mined, each retort is drilled and prepared for rubblization. Drilling is performed using dual-boom jumbo drills on both sublevels. Three-inch diameter holes are drilled into the tops, sides, and bottoms of the rooms in a pattern similar to that shown in Figure 4-29. The number of drill holes and amount of explosives required are determined from a rubblization powder factor of 1.4, using a high density ammonium nitrate and fuel oil (ANFO) mixture.

After a module pair has been rubblized, the piping required for retort operation is installed. When hook-up is complete and the next adjacent module pair has been prepared, retorts are ignited.

Full production levels attained by Plans 2 and 4 vary slightly from nominal target production (50,000 bbl/day), and reflect the number of simultaneously burning retorts, average shale grade, retort cross-section area, void ratio, burn rate, and recovery efficiency. Average shale grade after void mining and rubblization is approximately 17 gals/ton.* Burn rate is one foot per day and recovery efficiency is assumed to be 50 percent for VMIS retorts and 100 percent for surface retorts.

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* This is slightly less than the average pre-mining grade because the void areas tended to fall in richer areas of the retort horizon. Average grade of mined shale is slightly less than 21 gals/ton. This situation penalizes VMIS-only yields, but improves VMIS plus surface retorting yields.

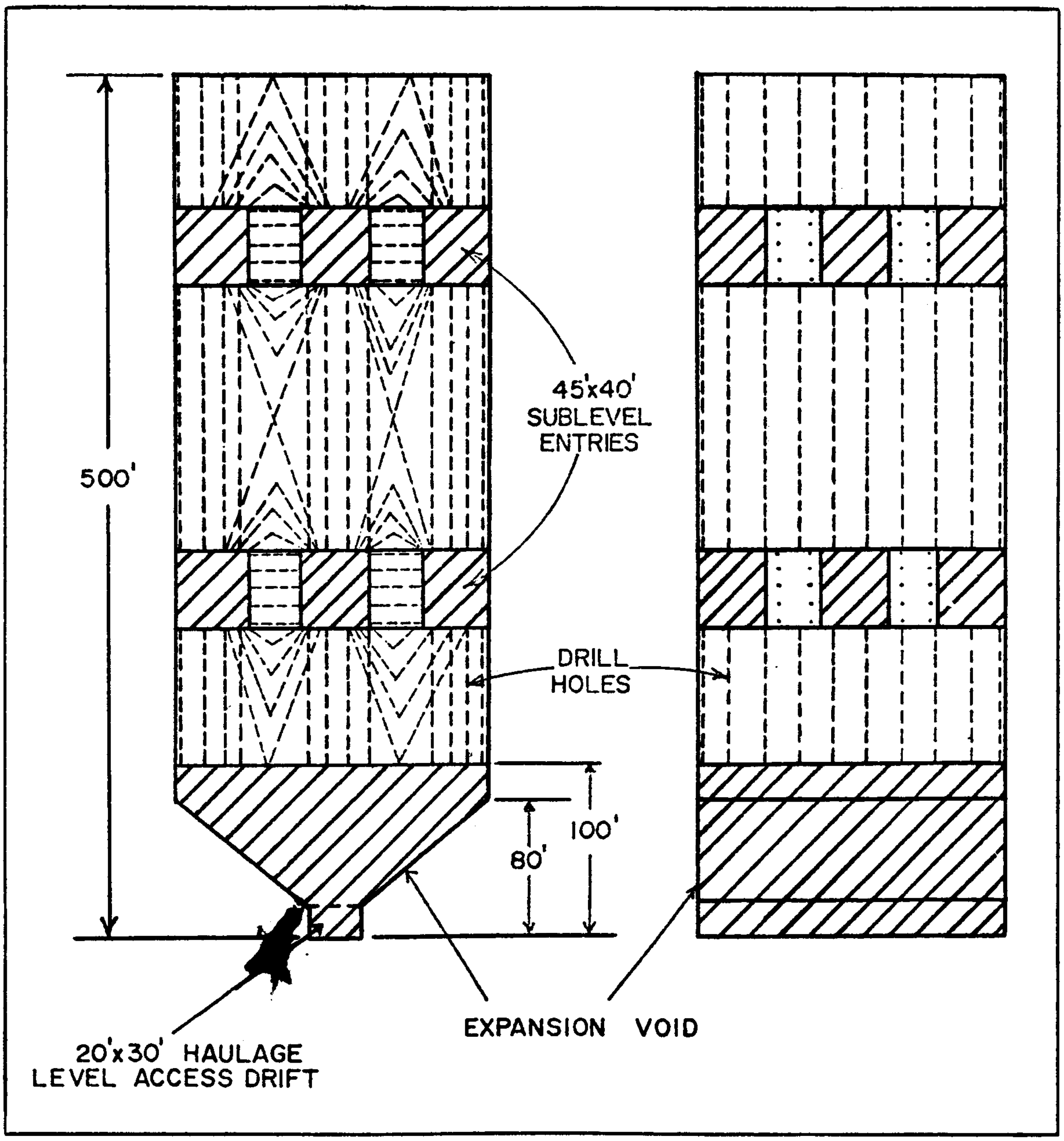

FIGURE 4-29

Representative Fan Drilling Pattern for Retort Rubblization
VMIS Plans 2 and 4, Site 3

Full production in Plan 2 is approximately 48,600 bbl/day, which is achieved when 170 retorts are producing simultaneously. The mine life expectancy for Plan 2 is estimated to be 36 years.

In Plan 4, total production is approximately 23,900 bbl/day from the VMIS operation. This level is achieved when 83 retorts (on the average) are producing simultaneously. An additional 28,700 barrels of shale oil per day is surface retorted from the mined out shale; therefore, the total production in Plan 4 is 52,600 barrels per day when full production is reached. The mine life expectancy for Plan 4 is estimated to be 66 years.

5.0 DESCRIPTION OF THE MODEL

The objective of the study was to develop a model to enable the estimation of mining costs associated with Vertical Modified In Situ (VMIS) strategies for developing oil shale resources. The Oil Shale Mining Economic Model (OSMEM), developed by KETRON, addresses this objective. It consists of a sequence of computer programs which provide production and financial data necessary for evaluating the consequence of specific mine designs and production strategies. The objectives of OSMEM are:

1. To project annual production resulting from user-specified recovery designs, production strategies, and equipment parameters;
2. To compute standard financial measures for evaluating alternative strategies;
3. To provide flexibility in analyzing a wide variety of mining scenarios; and
4. To permit sensitivity analysis of technical and financial parameters.

For purposes of this study, VMIS mining was assumed to encompass all activities from deposit access through rubblization of in situ retorts. OSMEM simulates these mining operations and accounts for mining capital and operating costs; it also accounts for pre-mining costs. Pre-mining and mining activities are identified in Figure 5-1 and enclosed within dashed lines. Referring to that figure, pre-mining is seen to include:

- resource acquisition
- exploration, environmental and permitting activities

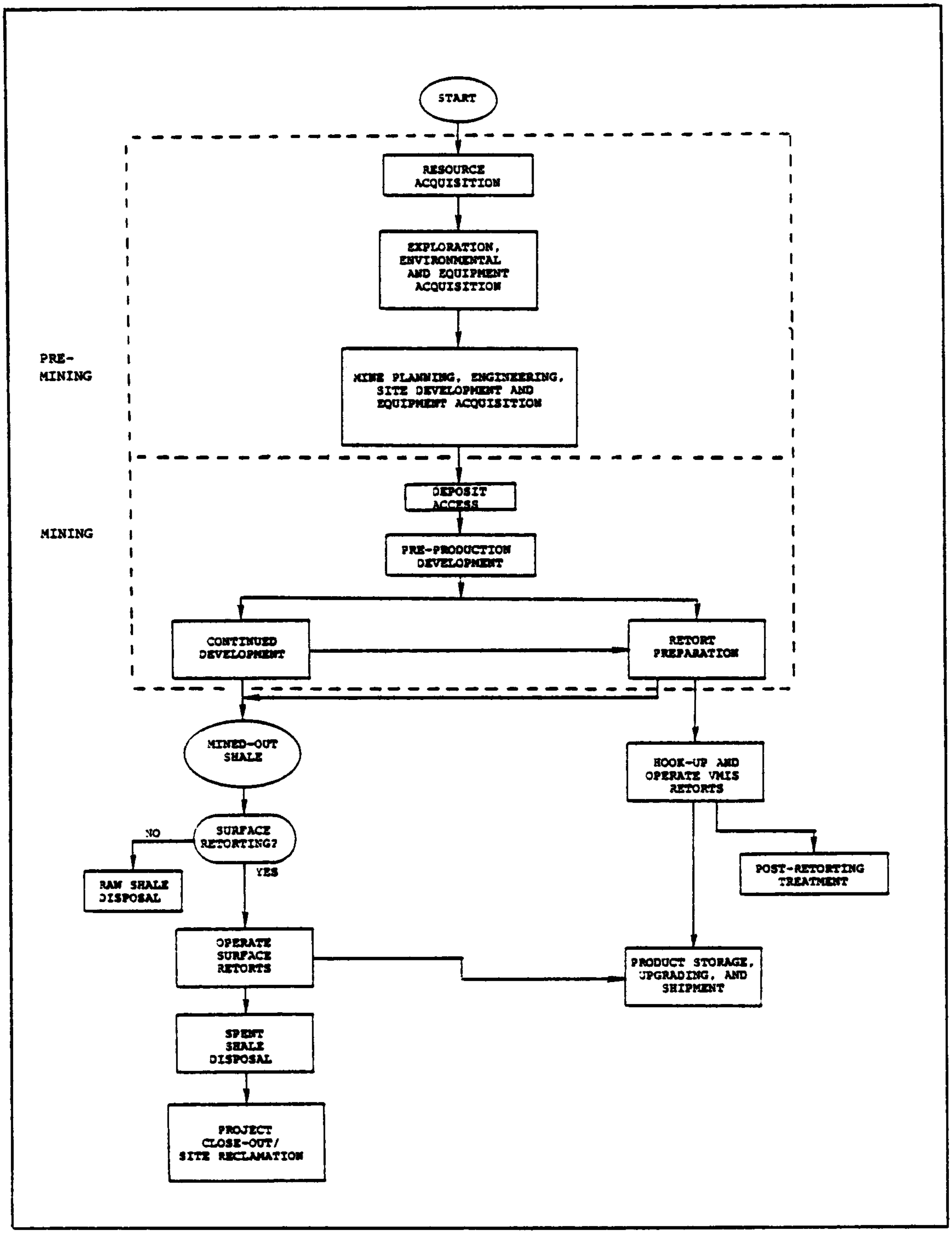

FIGURE 5-1

Scope of OSMEM with Respect to VMIS Scenarios

- mine planning, engineering, site development (including surface facility construction), and equipment acquisition

Mining operations include:

- pre-production development
- retort preparation (including retort module access and development void mining, and rublization)
- continuing mine development concurrent with retort preparation

Activities which appear outside the dashed-line enclosures in Figure 5-1 are not simulated in OSMEM; however, their associated capital and operating costs can be included in the economic analysis. These activities include:

- VMIS retort hook-up and operation
- post-retorting treatment
- surface retorting of mined-out shale (where used)
- product storage, upgrading, and shipment
- raw/spent shale disposal
- project close-out and site reclamation

OSMEM is executed in two phases. The first phase simulates mining activities associated with VMIS retort development, and the subsequent oil production. This phase provides annual operating outcomes (retorts prepared, shale mined, barrels produced, etc.) that result from implementing a scenario recovery plan. Yearly production and advance may be simulated for a period up to one hundred years.

The second phase of OSMEM performs financial computations based on outcomes from the production simulation and previously specified financial parameters. This phase determines cash flow and computes the mining portion of product selling price that is required to recover capital costs and operating expenses, at a desired rate of return on investment. Financial analysis may be performed for a period up to thirty-five years. Estimates of financial scenarios beyond this point are not considered meaningful, due to the uncertainty associated with financial parameter values in the remote future.

Discussed in the following sections is an overview of the computer model. A more detailed discussion of the model, its structure and input requirements, is presented in a companion document: "Oil Shale Mining Economic Model User Documentation (Volume III)."

5.1 OSMEM Production Sub-System

The production sub-system defines a set of interconnected "elements" representing unique operating segments of the mine. Examples of mine elements include: shaft, main entry, submain, intake/exhaust airway, retort development, retort void, and rubblization. Elements are differentiated further by design parameters and by equipment selections. A mine element type is defined uniquely by the following set of parameters:

1. element configuration and dimensions
2. advance rate
3. production rate
4. equipment requirements
5. operating costs

For simulation purposes, a mine design is reduced to a set of segments, many of which may be the same mine element type. It is the interrelationship between segments which defines the allowable sequence of operations and determines the manner in which mining proceeds.

5.1.1 Input

The simulation process requires the specification of a mine design. Although this design need not be detailed in nature, the mine layout, entry configuration and geometric dimensions must be realistically estimated. The design is translated to a single line diagram which represents the order in which each element is executed. Through consistent changes in the mine design, by reformulating the order in which elements are executed, the impact of variations in development and production strategies can be evaluated.

The line diagram subsequently is reduced to a strategy tree structure to facilitate input to the computer. Each unique mine segment appearing in the strategy tree is characterized by: 1) its position in the tree, 2) its element type, and 3) its length.

5.1.2 Processing

Once the mine element parameters have been defined, the mine strategy tree is processed by executing individual segments in sequential order. The criteria to be met prior to segment execution are:

1. All predecessor segments have been executed.
2. All equipment required for the segment is available.

If either of these criteria is not met, a segment is queued, to be serviced when the appropriate deficiency has been satisfied.

Segment completion time is computed based on: 1) start time, 2) advance rate, and 3) segment length. Production is accrued by element type, based on segments processed during each time period.

5.1.3 Output

The production sub-system provides annual output reports which include:

1. The barrels produced, tons mined, feet advanced, and shifts required for each segment type -- for each year and cumulatively over all years.
2. The number of initial equipment requests and initial denials,* by equipment type, and the sum over all equipment types for the year.

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* A "denial" occurs when equipment needed by a segment is not available in the equipment pool.

3. The barrels produced from surface retorting, if included in the scenario.

In addition to these reports, the production sub-system generates a file of data elements subsequently used by the financial sub-system in developing economic performance measures.

5.2 OSMEM Financial Sub-System

The financial analysis sub-system accepts inputs generated by the production sub-system and provides various economic measures of project performance. The financial sub-system computes discounted cash flow return on investment based on cost and revenue streams from three sources:

1. User input
2. Production sub-system
3. Program default values

The financial analysis conforms to the guidelines published by The Engineering Societies Commission on Energy, Inc. (ESCOE). The guidelines are defined in "Guidelines for Economic Evaluation of Coal Conversion Processes" (22).

5.2.1 Input

The structure of the financial sub-system permits a degree of flexibility in specifying parameters associated with mining operations. Financial input parameters used by the program include: fixed and variable cost data, such as capital and operating expense for each element type; pre-mining expenditure data, such as mineral right and development costs; and, supplementary cost data, such as royalties, escalation rates, and discount rate (minimum acceptable rate of return on investment). Additional input parameters allow for decisions concerning depreciation method, equipment purchases, and equipment retirement.

The financial sub-system also has the following characteristics:

1. Development and mineral rights costs occur in year 0.
2. Development costs are treated as expenses in the years in which they are incurred.
3. Initial mining capital expenditures are assumed to occur in year 0.
4. Severance tax is computed when applicable.
5. County-level taxes are not included.

5.2.2 Processing

In the financial sub-model, simulation-generated annual production and cost streams are merged with other financial parameters to compute economic performance measures.

First, revenue streams are determined. These data are used to calculate annual profit. Second, the yearly cash flow is computed by adding back annual non-cash expense to annual net profit. Then, the net present value of the investment is determined from the present value of yearly cash flow and present value of capital expenditures. Finally, a break-even calculation is performed to determine the initial required selling price* (IRSP), in dollars per barrel. This measure is a key result of interest in that it represents the price required to recover all mining costs, at a specified rate of return on investment (ROI). In addition to mining costs, the price of a barrel of shale oil produced by VMIS methods will reflect the costs associated with in situ retort hook-up and operation, post-retorting treatments, environmental considerations, and other cost-generating items.

5.2.3 Output

Using the information obtained from the production simulation, the financial sub-system computes the costs and revenue streams associated with the recovery plan and operation strategy. From these data, various financial indicators are computed and output in the several reports described below.

5.2.3.1 Capital Costs

The Capital Cost Report shows capital expenditures per year, by capital item, for up to thirty-five years. Capital items include mineral rights costs, development costs, and capital equipment costs. The Capital Cost Report also includes the present value (year 0) of all capital expenditures discounted at the minimum acceptable return on investment.

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* The initial required selling price represents the first year selling price required to recover all costs of production, at a specified rate of return. Selling price is escalated in subsequent years at the user-specified escalation rate.

5.2.3.2 Production and Revenue

Production and revenue outputs include:

1. Annual production for each mine element and total production for the mine.
2. Annual royalties for each year of production, as a percentage of sales.
3. Annual net revenues, calculated as gross revenues minus royalties.
4. The present value (year 0) of all gross revenues, royalties and net revenue, discounted at the specified return on investment.

5.2.3.3 Cash Operating Costs

The Cash Operating Cost Report includes the cash operating costs per mine element per year. Typical cash operating costs include direct labor, operating supplies, and maintenance supplies. This report also includes the present value of all cash operating expenses, discounted at the minimum acceptable return on investment.

5.2.3.4 Non-Cash Operating Expenses

Non-cash operating expenses consist of depletion, depreciation, and allocated costs. Such costs represent the usage over time of capital items; they are used in the calculation of income taxes. The model reports the yearly totals of all non-cash operating expenses and the present value of all non-cash operating expenses, discounted at the minimum return on investment.

5.2.3.5 Net Profit

Annual net profit is calculated as in a standard corporate income statement. The sum of all operating expenses, i.e., cash and non-cash, and any tax losses carried forward, are subtracted from taxable income. The non-cash operating costs are "expensed"; i.e., equipment is depreciated, and development expenses are used to offset taxable income (and to generate tax losses carried forward). Taxes are charged to the taxable income and a net profit per year is reported.

5.2.3.6 Cash Flow

The yearly cash flow is calculated by adding back the yearly non-cash expenses (i.e., depreciation, depletion and allocated development expense) to the yearly net profit. The program performs this calculation for each year of the mine's life and then determines the present value discounted at the minimum return on investment.

5.2.3.7 Summary Statistics

The results of the financial computations are tabulated. The required selling price is output and the progam calculates the net present value of the investment. This is computed by subtracting the present value of capital expenditures from the present value of yearly cash flow. The program calculates a payback period for all initial capital investments and determines the effective tax rate over the 35 year period (or the mine life, if less than 35 years).

6.0 ECONOMIC ANALYSIS

OSMEM was utilized to analyze the four base case mining scenarios described in Section 4. This section provides cost input details for these runs and presents results of base case, parametric, and sensitivity analyses.

6.1 Cost Estimates

Costs developed for each scenario include all capital and operating expenses associated with the mining required to gain access to and rubblize the VMIS retorts. Cost of surface support facilities and pre-mining activities are included. The analysis does not include costs associated with the VMIS retorting process, nor does it include costs associated with the surface retorting process included in Plans 3 and 4. Therefore, the results should be interpreted as "the per barrel mining costs associated with a VMIS (only) or a VMIS and surface retorting operation".

Capital and operating expenses are determined from individual cost elements which include:

1. Surface Preparation
2. Surface Facilities
3. Surface Utilities
4. Development Costs
5. Equipment Costs
6. Labor Costs
7. Underground Utilities
8. Operating Supplies
9. Insurance
10. Contingencies
11. Indirect Costs

Capital and operating cost summaries for each recovery plan are presented in Tables 6-1 through 6-4. These costs were compiled from various sources, as described in the remainder of this section.

Depletion allowance, depreciation, and taxes are handled internally by OSMEM; these cost items are also described in this section.

6.1.1 Capital Cost

Capital cost elements include pre-mining preparation and development, surface facilities and utilities, equipment, contingencies and indirect costs, as described below.

1. Surface Mine Support Facilities. Includes the cost of the Surface Maintenance Shop, Warehouse, Dispensary, Changehouse, Administrative Offices, Mine Offices, Gatehouses, and Explosive Storage.
2. Surface Fuel/Service Station. The cost of the facility at which surface equipment and tank trucks are fueled and lubricated.
3. Surface Utilities. Includes the cost of electric power, communications, fire protection, and sewage disposal facilities.
4. Surface Sitework. Includes the cost of sitework, roads, parking, drainage and fencing.
5. Surface Water Facility. Includes the cost of minewater storage and treatment.
6. Preliminary Site Development. Includes the cost of design engineering, exploration, environmental studies, and other preproduction mining development.

TABLE 6-1

Cost Summary -- Plan 1

Capital Costs	(In Thousand Dollars)
Surface Mine Support Facilities	20,981
Surface Fuel/Service Station	558
Surface Utilities	44,027
Surface Sitework	8,351
Surface Water Facility	10,061
Preliminary Site Development	28,500
Headframes (3)	29,814
Shafts (6)	34,248
Contingency (9%)	15,889
Equipment Cost	83,331
Indirect Cost (6%)	11,546
	287,306
Annual Operating Costs	
Supervisory Labor	4,703
Underground Labor	21,630
Underground Support Labor	7,980
Surface Labor	1,365
Utilities	8,886
Operating Supplies	
- Fuel and Lubrication	8,281
- Explosives	13,461
- Material	3,915
- Contingency (9%)	2,309
Indirect Cost	3,125
Insurance	702
	76,357

TABLE 6-2

Cost Summary -- Plan 2

Capital Costs	(In Thousand Dollars)
Surface Mine Support Facilities	20,981
Surface Fuel/Service Station	558
Surface Utilities	44,027
Surface Sitework	8,351
Surface Water Facility	10,061
Preliminary Site Development	28,500
Headframes (3)	29,814
Shafts (6)	34,248
Contingency (9%)	15,889
Equipment Cost	92,912
Indirect Cost (6%)	11,546
	296,887
Annual Operating Costs	
Supervisory Labor	4,800
Underground Labor	21,840
Underground Support Labor	8,190
Surface Labor	1,365
Utilities	8,772
Operating Supplies	
- Fuel and Lubrication	12,258
- Explosives	15,582
- Material	5,944
- Contingency (9%)	3,040
Indirect Cost	3,636
Insurance	787
	86,214

TABLE 6-3

Cost Summary -- Plan 3

Capital Costs	(In Thousand Dollars
Surface Mine Support Facilities	20,981
Surface Fuel/Service Station	558
Surface Utilities	44,027
Surface Sitework	8,351
Surface Water Facility	10,061
Preliminary Site Development	28,500
Headframes (3)	29,814
Shafts (6)	34,248
Contingency (9%)	15,889
Equipment Cost	76,073
Indirect Cost (6%)	11,546
	280,048
Annual Operating Costs	
Supervisory Labor	4,703
Underground Labor	17,220
Underground Support Labor	7,980
Surface Labor	1,365
Utilities	8,704
Operating Supplies	
- Fuel and Lubrication	6,884
- Explosives	9,102
- Material	2,722
- Contingency (9%)	1,684
Indirect Cost	2,512
Insurance	587
	63,463

TABLE 6-4

Cost Summary -- Plàn 4

Capital Costs	(In Thousand Dollars)
Surface Mine Support Facilities	20,981
Surface Fuel/Service Station	558
Surface Utilities	44,027
Surface Sitework	8,351
Surface Water Facility	10,061
Preliminary Site Development	28,500
Headframes (3)	29,814
Shafts (6)	34,248
Contingency (9%)	15,889
Equipment Cost	82,792
Indirect Cost (6%)	11,546
	286,767
Annual Operating Costs	
Supervisory Labor	4,800
Underground Labor	15,750
Underground Support Labor	7,980
Surface Labor	1,365
Utilities	8,673
Operating Supplies	
- Fuel and Lubrication	8,902
- Explosives	7,890
- Material	3,148
- Contingency (9%)	1,795
Indirect Cost	2,525
Insurance	585
	63,413

Costs for these items were estimated from existing studies (23-26) or from in-house data.

Mining equipment includes the cost of all underground equipment required for mining operations and their direct support. A summary of required equipment for each scenario is presented in Table 6-5. Equipment was selected for each mining scenario on the basis of a seven-day, three-shift operation. Sufficient spares of critical equipment types were specified to account for equipment failures. Equipment costs for most major items are based on vendor quotes. Items for which vendor quotes were unavailable were estimated from reference (24). All costs are in 1980 dollars.

Contingencies were determined as nine percent of the total capital expenses, excluding mining equipment. Indirect costs were estimated as six percent of the total capital investment.

Project financing was assumed to be 100 percent equity for each scenario; therefore, no interest costs were incurred.

6.1.2 Operating Cost

Operating cost elements include: supervisory labor; underground labor, surface labor; utilities; operating supplies; indirect costs; and insurance.

The supervision and labor force were determined from the production and equipment requirements specified for each mining scenario. Manpower requirements were based on a continuous seven-day, three shift operating schedule. Additional underground

TABLE 6-5

Required Equipment and Unit Costs

Equipment	Unit Cost (in thousands of dollars)	Quantity			
		Plan 1	Plan 2	Plan 3	Plan 4
Face Drill Jumbo	510	28	50	23	40
Fan Drill Jumbo	510	10	--	10	--
LHD - 9 Cubic Yard	186	54	28	40	28
LHD - 11 Cubic Yard	210	--	36	--	19
LHD - 15 Cubic Yard	250	--	10	--	5
Bench Drill	150	30	--	18	--
ANFO Loading Truck	30	18	18	18	18
Central Compressor	450	1	1	1	1
Portable Compressor	30	26	--	16	--
Scaling Machine	140	12	14	12	14
Water Truck	58	3	4	3	4
Raise Borer and Tools	1475	2	2	2	2
Hydraulic Rock Breaker	60	18	27	18	27
Rock Bolter	160	12	16	12	16
Ventilation Fan - 800 K cfm	292	4	4	4	4
Auxilliary Fan - 30 K cfm	12	32	36	32	36
Lubrication/Fuel Truck	50	12	16	12	16
Portal Bus	33	24	30	24	24
Maintenance Vehicle	24	6	8	6	8
Electrical Vehicle	24	6	8	6	8
Fork Lift	40	2	2	2	2
Supervisors Vehicle	8	15	20	15	20
Road Maintenance Vehicle	30	3	4	3	4
Rescue/Fire Vehicle	50	6	8	6	8
Conveyor - 60 in.	0.30/ft.	9 mi.	9 mi.	9 mi.	9 mi.
Conveyor - 36 in.	0.25/ft.	6 mi.	6 mi.	6 mi.	6 mi.
Apron Feeder	110	10	10	10	10
Feeder/Breaker	205	12	10	12	10
Track, Light	40.83/mi.	70 mi.	88 mi.	70 mi.	88 mi.
Locomotive	100	12	16	12	16
Supply Car	9	15	20	15	20
Underground Maintenance Shop	3400	1	1	1	1
Surge Bin	200	2	2	2	2
Electrical Cable	.025/ft.	17 mi.	21 mi.	17 mi.	21 mi.
Ambulance - Surface	40	1	1	1	1

workers were added to the requirements to allow for vacation time, sick leave, and absenteeism. Supervision and labor wage rates were estimated from reference (24) and from information concerning average salaries in the Denver area. Underground and surface labor wage rates were estimated at $25,000 per year, including fringe benefits. An additional five percent of the total payroll was added to account for overtime payments. Fringe benefits of thirty-five percent were added to total supervisory labor costs. All wage rates were adjusted to 1980 using an annual escalation rate of ten percent. Manpower requirements and annual wage rates for each mine scenario are tabulated in Tables 6-6 through 6-8.

Material costs, utilities, fuel and lubrication costs were estimated from reference (22) and adjusted to 1980 dollars. Explosive costs were estimated using a bulk rate vendor quote; a powder factor of 1.4 was assumed.

Contingencies were computed as nine percent of operating supply costs (fuel and lubrication, explosives, materials). Indirect costs were estimated from the sum of all labor costs, exclusive of fringe benefits, and operating supply costs. Insurance was computed as one percent of the direct costs (utility, labor, operating supplies).

6.1.3 Depreciation and Depletion

Annual depreciation costs are calculated by OSMEM using either the straight-line (SL) method or the sum-of-the-year digits (SYD) methods. Surface facilities were depreciated using

TABLE 6-6

Supervisory Labor Requirements

Job Classification	Annual Salary	Quantity			
		Plan 1	Plan 2	Plan 3	Plan 4
General Superintendent	$55,000	1	1	1	1
Mine Superintendent	49,500	1	1	1	1
Assistant Mine Superintendent	38,500	1	1	1	1
General Mine Foreman	31,000	1	1	1	1
Shift Foreman	27,500	4	4	1	1
Section Foreman	27,500	56	56	56	56
Maintenance Superintendent	44,000	1	1	1	1
Chief Mechanical Foreman	33,000	1	1	1	1
Shift Mechanical Foreman	31,000	4	4	4	1
Chief Electrical Foreman	33,000	1	1	1	1
Shift Electrical Foreman	31,000	4	4	4	4
Belt Crew Supervisor	27,500	2	2	2	2
Chief Mining Engineer	42,000	1	1	1	1
Senior Mining Engineer	33,000	1	1	1	1
Development Engineer	31,000	1	1	1	1
Ventilation Engineer	31,000	1	1	1	1
Production Engineer	31,000	1	1	1	1
Mine Geologist	31,000	1	1	1	1
Chief Surveyor	27,500	1	1	1	1
Surveyor	18,000	12	12	16	16
Draftsman	15,500	2	2	2	2
Safety Director	28,500	1	1	1	1
Safety Inspector	24,000	8	8	8	8
Nurse	18,000	1	1	1	1
First-Aid Attendant	15,500	4	4	4	4
Purchasing Supervisor	23,000 (1)	1	1	1	1
Purchasing Agent	16,500 (1)	2	2	2	2
Chief Accountant	20,000 (1)	1	1	1	1
Accountant	18,000	1	1	1	1
Bookkeeper	15,000 (1)	4	4	4	4
Personnel Administrator	23,000	1	1	1	1
Labor Relations	23,000	1	1	1	1
Warehouse Supervisor	23,000 (1)	1	1	1	1
Warehouseman	15,000 (1)	8	8	8	8
Executive Secretary	15,000 (2)	1	1	1	1
Secretary	12,500 (2)	4	4	4	4
Receptionist	12,500 (2)	1	1	1	1
Watchman	13,000 (1)	4	4	4	4

The above salaries are based on R. M. Parsons Co. except as noted:

(1) Cameron Engineers data x 1.64
(2) Denver Area 1979 salary base x 1.10

Underground Labor Requirements

Job Classification	Annual Wages	Quantity			
		Plan 1	Plan 2	Plan 3	Pla 4
Direct Segment Labor					
Drill Jumbo Operator	$25,000 per year including fringe benefits. Rates are based on R. M. Parsons Company Report adjusted by 10% to 1980 levels	102	154	88	110
Drill Jumbo Helper		102	154	88	110
Bench Drill Operator		104	---	64	---
Bench Drill Helper		104	---	64	---
LHD Operator		164	204	120	104
Bolter		50	64	42	64
Bolter Helper		50	64	42	64
Powderman		74	96	74	74
Powderman Helper		74	96	74	74
Direct Segment Helper Subtotal		824	832	656	600
Support Labor					
Conveyor Beltman		40	40	40	40
Raise Borer		32	32	32	32
Pumper		8	8	8	8
Ventilation Man		8	8	8	8
Mechanic		48	48	48	48
Mechanic Helper		48	48	48	48
Electrician		16	16	16	16
Electrician Helper		16	16	16	16
Welder		8	8	8	8
Machinist		8	8	8	8
Machinist Helper		8	8	8	8
Supplyman		24	24	24	24
Laborer		40	40	40	40
Support Labor Subtotal		304	312	304	304
Total Underground Labor		1,128	1,144	960	904

TABLE 6-8

Surface Labor Requirements

Job Classification	Annual Wages	Quantity			
		Plan 1	Plan 2	Plan 3	Pla 4
Hoistman	$25,000 per year including fringe benefits. Rates are based on R. M. Parsons Company Report adjusted by 10% to 1980 levels	12	12	12	12
Mechanic		4	4	4	4
Mechanic Helper		4	4	4	4
Electrician		4	4	4	4
Supplyman		8	8	8	8
Lampman		8	8	8	8
Janitor		8	8	8	8
Surface Labor Totals		4	4	4	4
		53	53	53	53

the straight-line method. Equipment was depreciated using the sum-of-the-year digits method.

Surface facilities were depreciated over the life of the mine, assuming zero salvage value. Equipment types were aggregated into three groups: 1) equipment to be depreciated over the life of the mine; 2) equipment depreciated over an eight-year life and replaced at the end of this period; and 3) equipment depreciated over a sixteen-year life, and then replaced. Zero salvage value was assumed in all cases.

Once production begins, certain costs can be recovered through depletion allowance. Depletion may be taken as either a cost depletion or a percent depletion; each is computed by OSMEM. For a given year, the method resulting in the larger deduction is used. A depletion allowance of fifteen percent was used in the economic analysis.

6.1.4 Taxes

Federal income tax, state income tax, and state severance tax are computed by OSMEM based on applicable tax schedules. Royalties, rents, bonus bid payments, county taxes, and inspection fees were not included in the analysis.

6.2 Results of Economic Analysis

An analysis of each recovery plan described in Section 4.0 was performed to demonstrate the utility of OSMEM. The cost data presented in 6.1 were input to the financial sub-model for the economic analyses of these plans.

6.2.1 Base Case Results

Table 6-9 summarizes the baseline parameter values and key results associated with each base recovery plan. The start-up production histories for these plans are tabulated in Table 6-10 and plotted in Figure 6-1.

TABLE 6-9
Summary of Baseline Values

Parameter	Recovery Plan			
	Plan 1 VMIS Only	Plan 2 VMIS Only	Plan 3 VMIS + Surface Retorting	Plan 4 VMIS + Surface Retorting
Mine Site	2	3	2	3
Shale Grade (Gal. per ton)	18.33	20.75	18.33	20.75
Void Volume (percent)	20	30	20	30
Capital Investment*				
- Equipment Cost	$ 83,331	$ 92,912	$ 76,073	$ 82,792
- Development Expense	140,361	140,361	140,361	140,361
- Surface Facilities	63,614	63,614	63,614	63,614
Total	$287,306	$296,887	$280,048	$286,767
Annual Operating Cost*	$ 76,357	$ 86,214	$ 63,463	$ 63,413
Annual Escalation Rate	7%	7%	7%	7%
Rate of Return of Investment (ROI)	25%	25%	25%	25%
Full Production Averages				
- VMIS (bbl/day)	49,560	48,600	32,270	23,900
- Surface (bbl/day)	--	--	21,990	28,700
Total Production (bbl/day)	49,560	48,600	54,260	52,600
Per Barrel Operating Cost	$ 4.22	$ 4.86	$ 3.20	$ 3.30
Required Selling Price($/bbl)**	$15.63	$16.76	$10.69	$ 9.94

* Cost in thousands of 1980 dollars

** Mining portion of required selling price -- initial year price

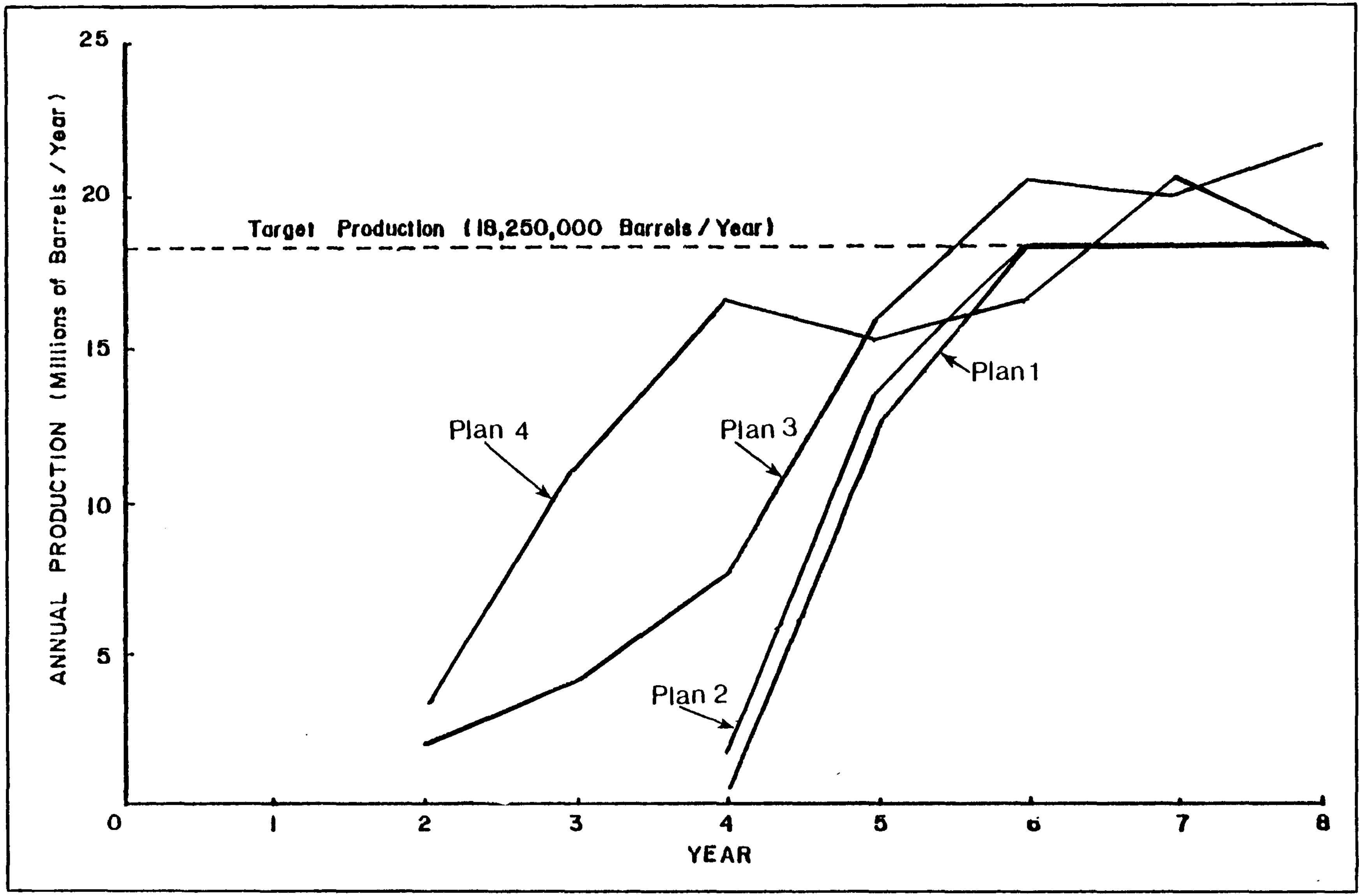

FIGURE 6-1

Annual Production Levels Prior to Full Production

TABLE 6-10

Annual Production Summary First Nine Years

(Millions of Barrels)

Recovery Plan	Year after Start of Mining								
	1	2	3	4	5	6	7	8	9
Plan 1 - No Surface Retorting	-	-	-	.5	12.3	18.2	18.2	18.2	18.2
Plan 2 - No Surface Retorting	-	-	-	1.7	13.6	18.2	18.2	18.2	18.2
Plan 3 - With Surface Retorting	-	2.2	4.1	7.7	15.9	20.4	19.8	21.6	20.1
Plan 4 - With Surface Retorting	-	3.3	11.0	16.6	15.2	16.6	20.7	18.0	20.6

Table 6-11 presents pair-wise comparisons of initial required selling price (IRSP) for the following recovery plan pairs:

- Plan 1 v. Plan 2 -
  VMIS-only production at two different sites
- Plan 3 v. Plan 4 -
  VMIS + surface production at two different sites
- Plan 1 v. Plan 3 and Plan 2 v. Plan 4
  VMIS + surface production at the same site

TABLE 6-11

Comparisons of IRSP Between Sites and Between Recovery Methods

Mine Site	Recovery Method A VMIS Only	 B VMIS Plus Surface Retorting	Between-Method Differences (A - B)
2	$15.63 (Plan 1)	$10.69 (Plan 3)	$4.94
3	$16.76 (Plan 2)	$ 9.94 (Plan 4)	$6.82
Between-site Differences (Site 2 - Site 3)	-$ 1.13	$ .75	--

The between-site differences in IRSP are comparatively small ($1.13 and $0.75), reflecting essentially the capital and operating cost differences between plans. Between-method IRSP differences are larger ($4.94 and $6.82), and not totally explained by capital and operating cost differences. Production history differences appear to contribute significantly to the between-method IRSP differences. Oil production begins earlier in the plans where mined-out shale is surface retorted than in the VMIS-only plans. This early production generates revenues which, in these recovery plans, are not offset by corresponding capital and operating costs for surface retorting facilities. Thus, the mining portion of IRSP is substantially lower for VMIS with surface retorting than for corresponding VMIS-only plans.

6.2.2 Sensitivity Analysis

An analysis was performed to determine the sensitivity of mining costs to changes in capital costs, operating costs, return on investment, and annual escalation rates. For each recovery plan these parameters were varied, one at a time, by selected percent changes relative to their base case values. Table 6-12 indicates the parameters varied, their percentage changes, and the resulting IRSP for each plan. These results are displayed graphically in Figures 6-2 through 6-5, which show the sensitivity of the required selling price to various percent changes in the base case parameter values for each plan.

Initial required selling price is most sensitive to return on investment. When the base ROI was increased by 20% (to 30% ROI) the required selling prices increased by 34%, 43%, 28% and 31% for Plans 1 through 4, respectively. When the base ROI was reduced by 40% (to 15% ROI) the required selling prices went down by 44%, 52%, 41% and 44% for Plans 1 through 4, respectively. Figure 6-6 shows IRSP in dollars per barrel as a function of ROI, for each plan. The zero percent ROI results are of interest, as they represent cases where capital and operating costs are recovered, but no return on investment is earned.

Capital and operating cost changes did not cause equivalent percent changes in the inital required selling price. Increases of capital costs by 50% increased IRSP by 31%, 32%, 36% and 39%

TABLE 6-12

Sensitivity Analysis
Initial Required Selling Price for Parameter Variations

				Initial Required Selling Price ($/bbl)*			
Parameter	Case	% Change	Value	Plan 1	Plan 2	Plan 3	Plan 4
Return on Investment	None	-100	0%	5.18	5.38	3.97	3.98
	Low	- 40	15%	8.66	9.34	6.27	6.18
	Base	0	25%	15.63	16.76	10.69	9.94
	High	+ 20	30%	20.89	22.19	13.73	12.44
Capital Investment	Low	- 25	See Table 6-9	13.20	14.30	9.15	8.75
	Base	0		15.63	16.76	10.69	9.94
	High	+ 50		20.50	21.71	14.53	13.64
Annual Operating Cost	Low	- 25	See Table 6-9	14.18	15.00	9.80	9.11
	Base	0		15.63	16.76	10.69	9.94
	High	+ 50		18.43	20.14	12.49	11.59
Inflation - Costs Only	Base	0	7%	15.63	16.76	10.69	9.94
	High	+100	14%	20.82	22.47	14.15	13.12
Escalation - Prices & Costs	None	-100	0%	23.84	25.22	15.21	13.45
	Base	0	7%	15.63	16.76	10.69	9.94
	High	+ 50	10.5%	12.80	13.79	9.00	8.56

* Mining portion only

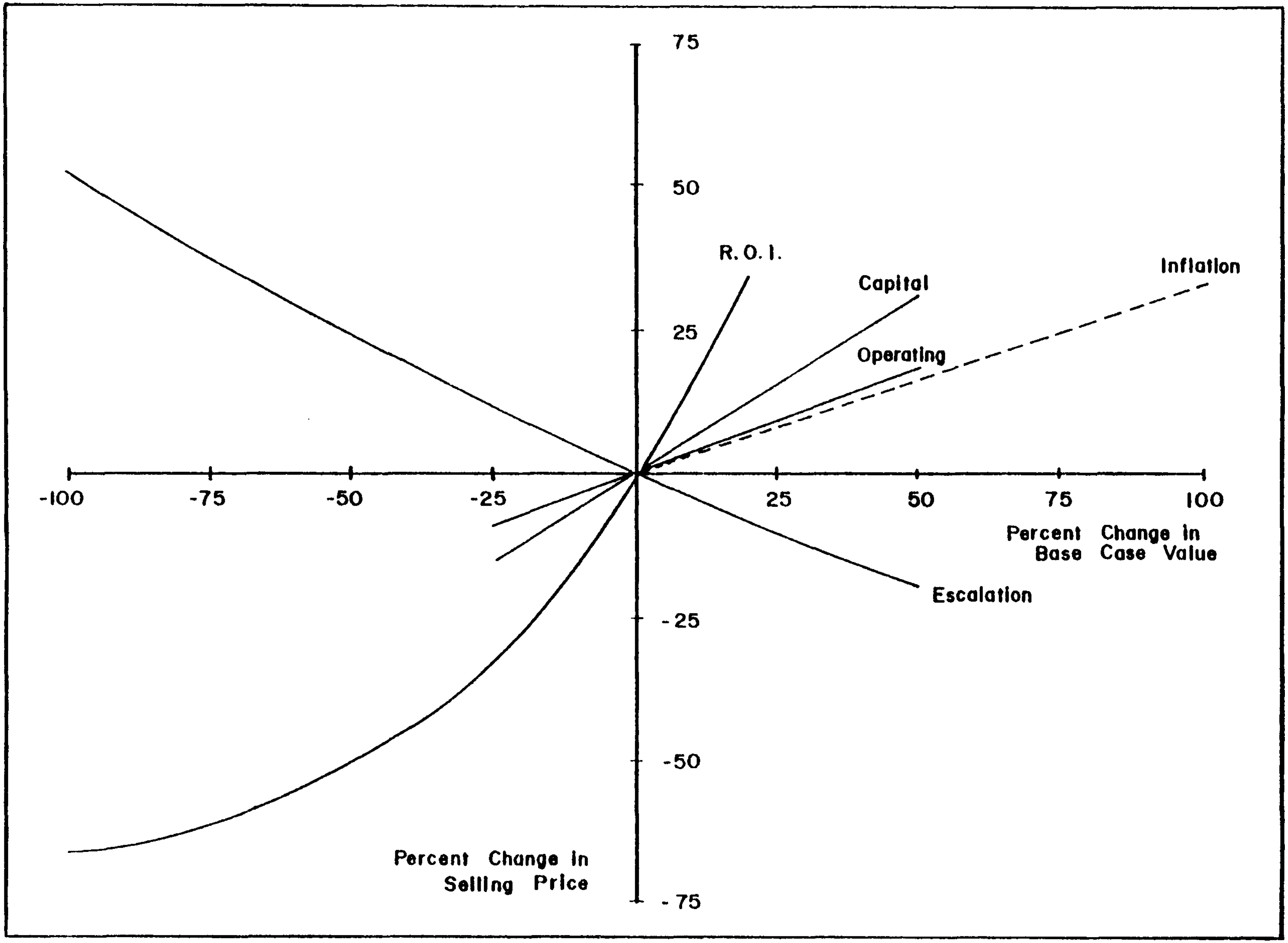

FIGURE 6-2

Required Selling Price Sensitivity, Plan 1

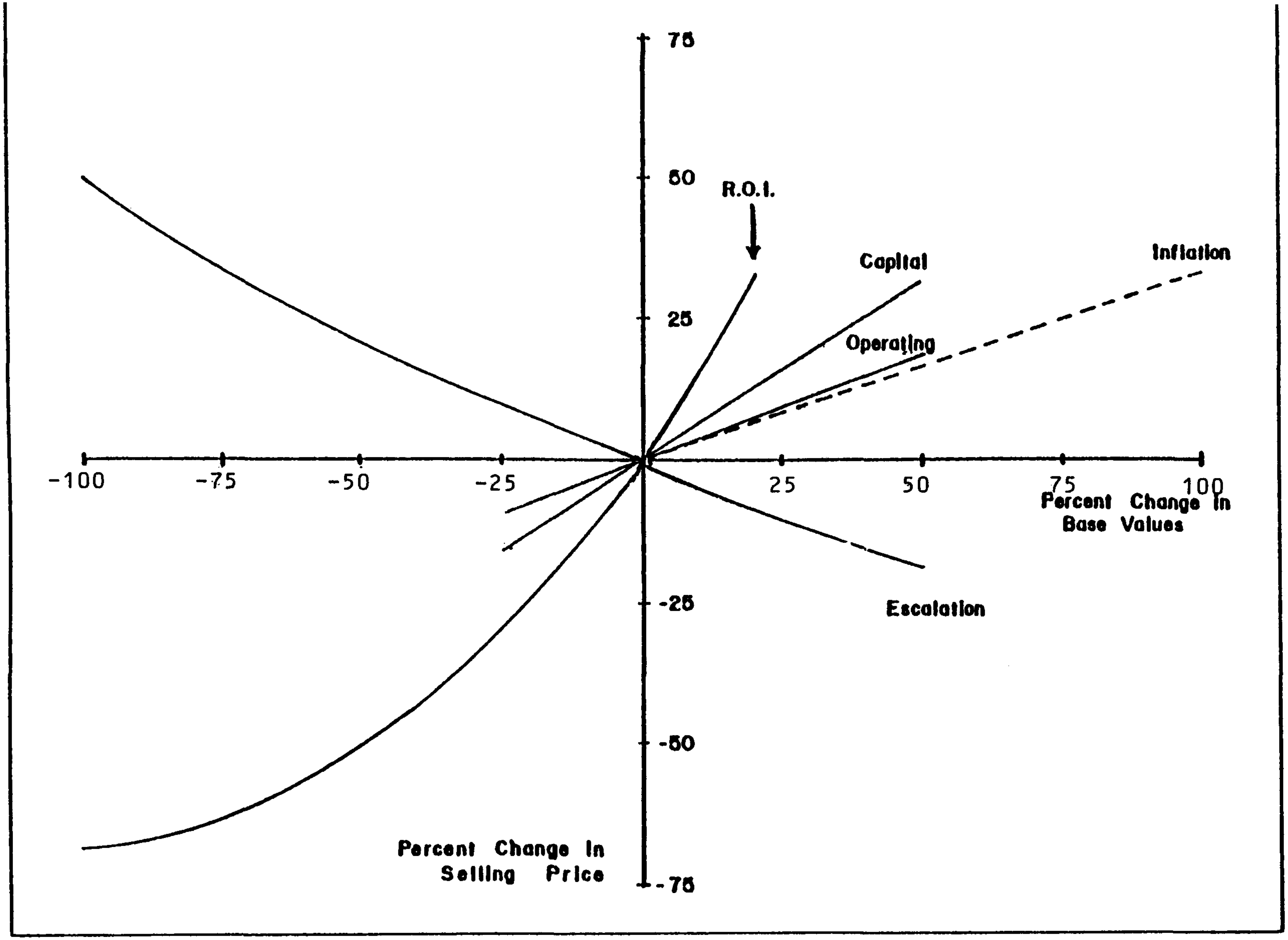

FIGURE 6-3

Required Selling Price Sensitivity, Plan 2

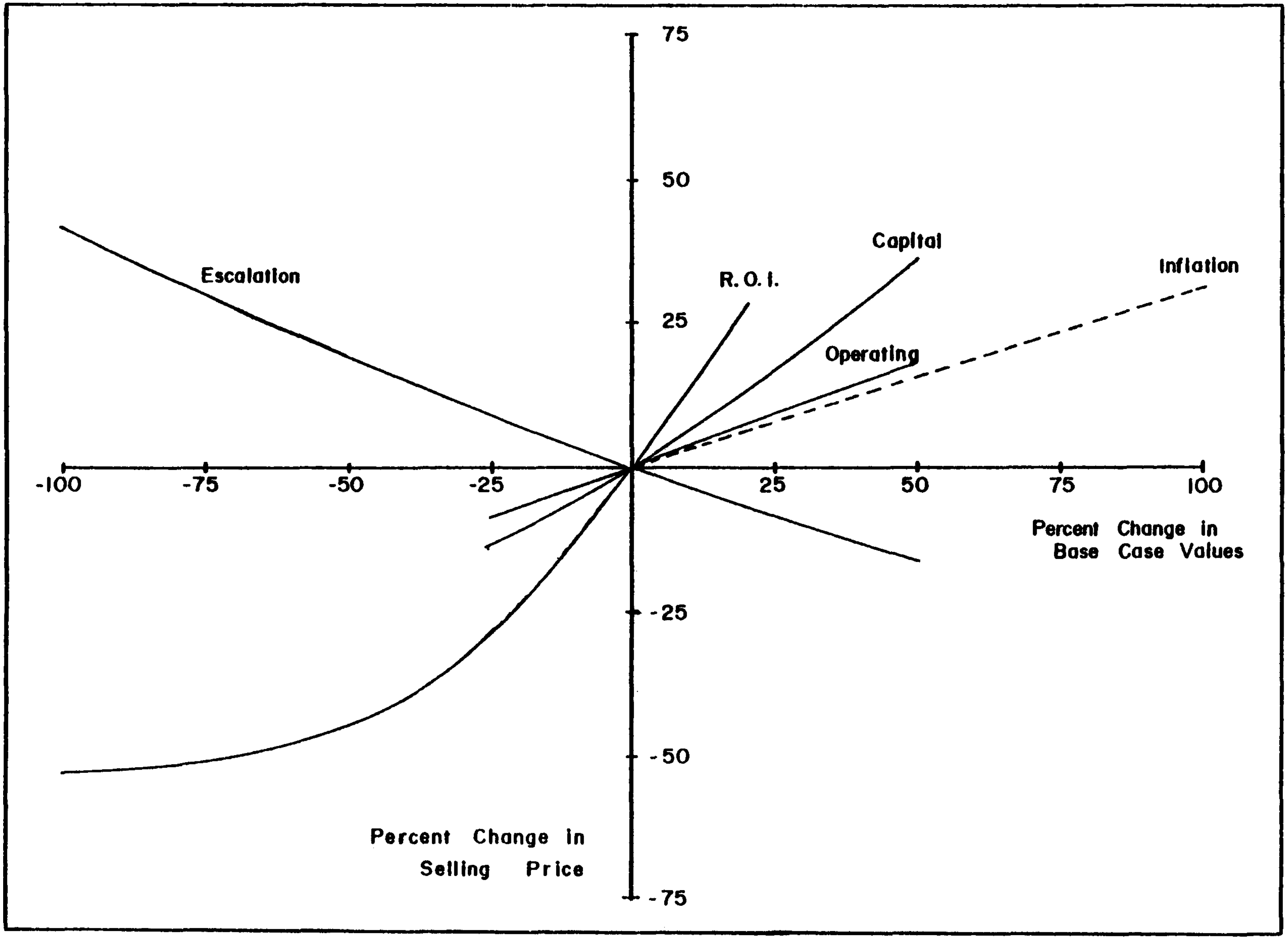
75
50
25
-25
-50
-75
-100
-75
-50
-25
25
50
75
100
Escalation
R. O. I.
Capital
Inflation
Operating
Percent Change in Base Case Values
Percent Change in Selling Price

FIGURE 6-4

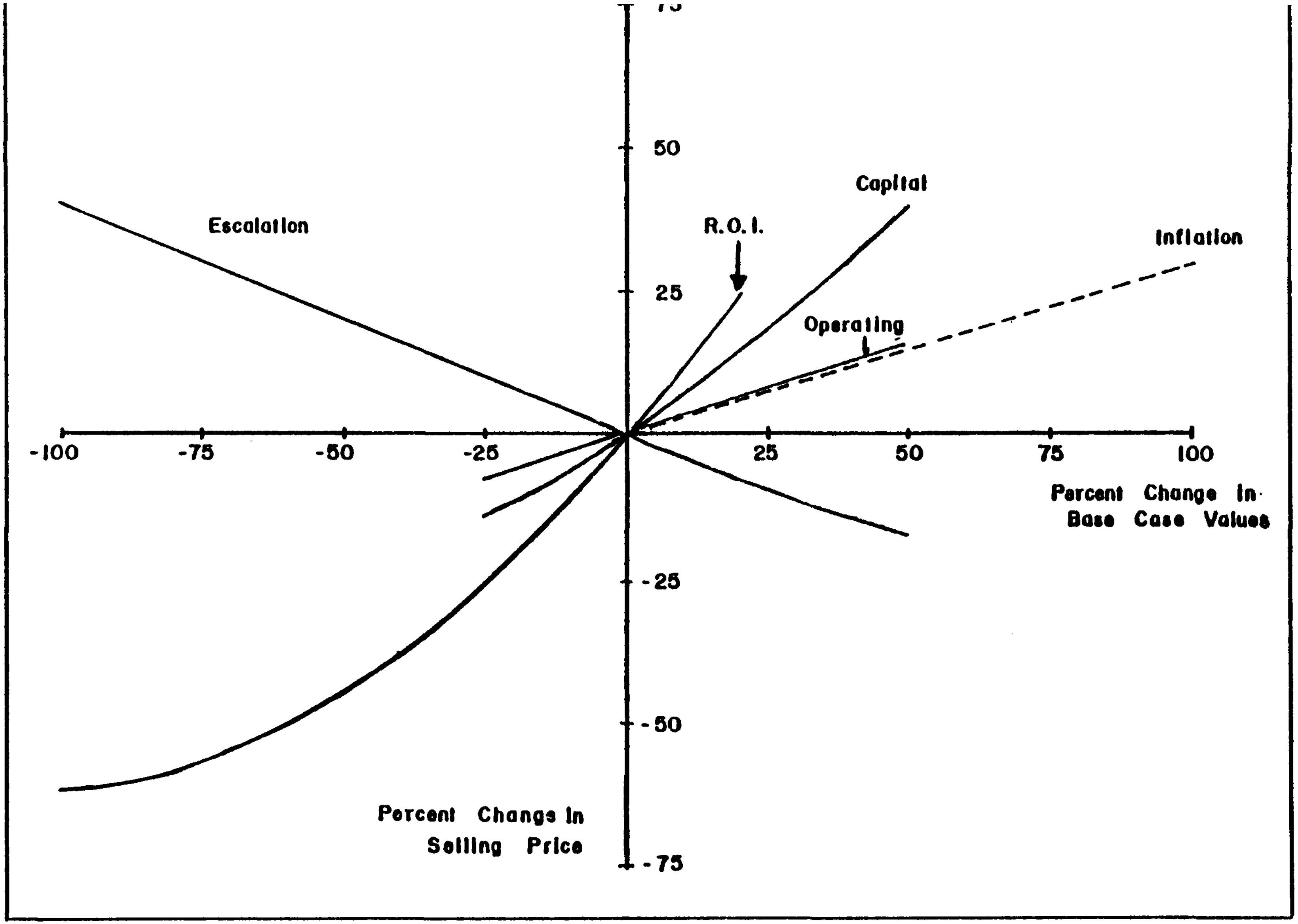

FIGURE 6-5

Required Selling Price Sensitivity, Plan 4

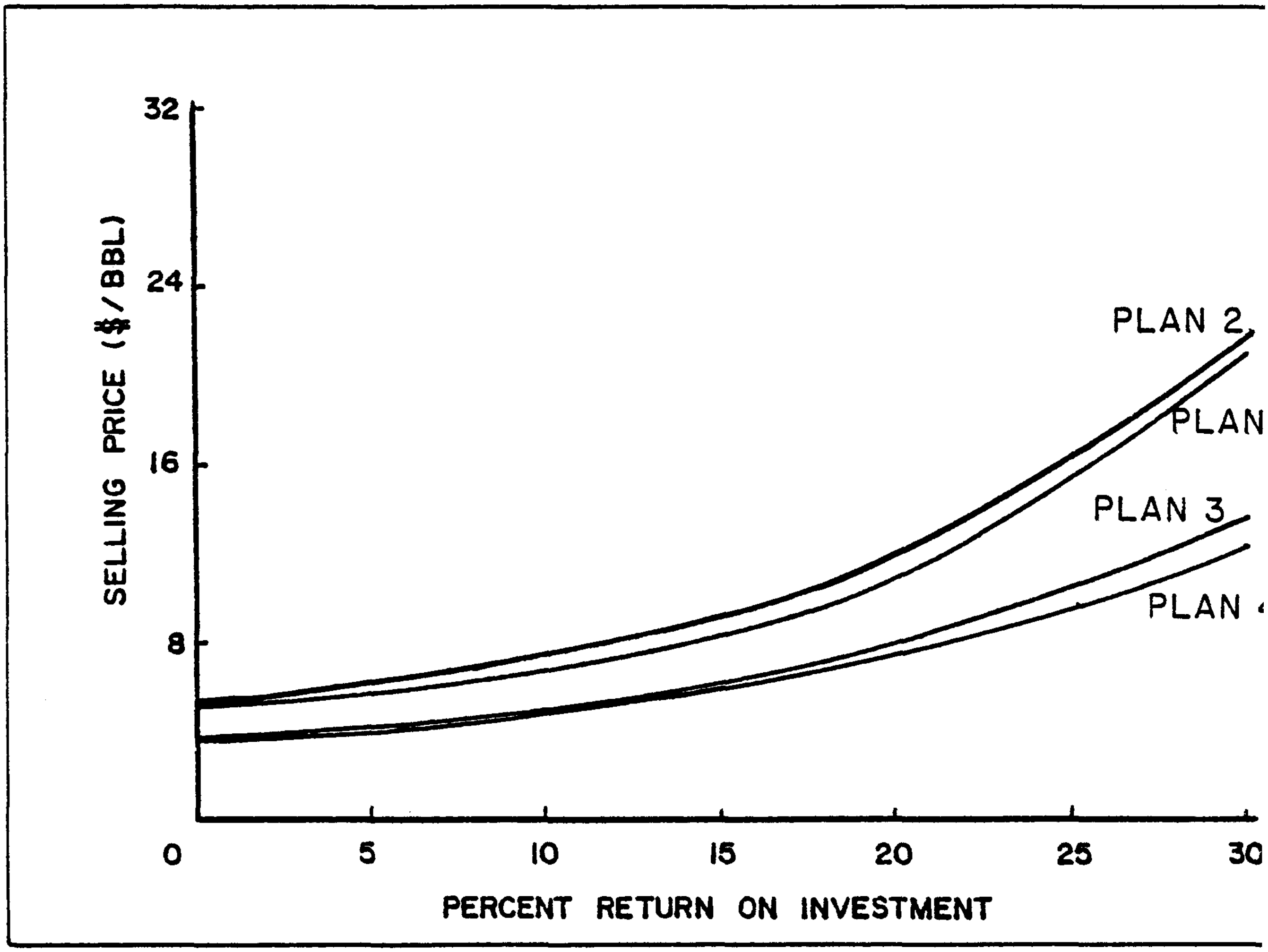

FIGURE 6-6
The Effect of Return Investment on the Required Selling Price

for Plans 1 through 4. Increases of operating costs by 50% increased IRSP by 18%, 18%, 17% and 15% for Plans 1 through 4, respectively.

When the selling price is allowed to escalate annually at the same rate as capital and operating costs escalate, IRSP changes are inversely proportional to changes in the escalation rate. For example, when the base case escalation rate (7%) was increased by 50% (to 10.5%), IRSP was reduced by 18%, 23%, 16% and 17% for Plans 1 through 4, respectively. This effect occurs because annual increases in selling price have a greater positive effect on ROI than the negative effects caused by the same percentage increases in capital and operating costs.

When costs are allowed to increase faster than the selling price, the effect is to raise the initial required selling price. Thus, when the escalation factor for costs was increased 100% (to 14%), while the selling price escalation was held at 7%, IRSP increased by 33%, 35%, 32% and 31% for Plans 1 through 4, respectively.

6.2.3 Increased VMIS Recovery Factor -- Base Cases

The four base case VMIS recovery plans were designed to produce 50,000 barrels per day (nominal) of shale oil, when the VMIS retort recovery efficiency factor is 50 percent. Additional OSMEM runs were made to determine the IRSP for each base plan when the VMIS recovery factor was increased to 75 percent.

Table 6-13 shows the new IRSPs and the changes caused by increasing the VMIS recovery factor to 75 percent. IRSP was reduced by 33%, 33%, 18% and 12% with respect to base case values, for Plans 1 through 4, respectively. Plans 3 and 4 (VMIS plus surface retorting) exhibit a smaller reduction in IRSP than Plans 1 and 2 (VMIS only), because the increased retort efficiency applies only to the underground portion of total production.

TABLE 6-13

Effect of Increased VMIS Recovery Factor
in Base Case Plans on IRSP
(dollars per barrel)

VMIS Recovery Factor	Recovery Plan			
	Plan 1	Plan 2	Plan 3	Plan 4
50% (Base Cases)	15.63	16.76	10.69	9.94
75%	10.52	11.27	8.73	8.72
Differences (relative to base cases)	-5.11 -(33%)	-5.49 -(33%)	-1.96 -(18%)	-1.22 -(12%)

The decrease in IRSP seen in Table 6-13 is explained as follows. When the VMIS recovery factor was increased to 75%, the resulting shale oil production increased to 74.3, 72.9, 70.4, and 64.6 Kbbl/d for Plans 1 through 4, respectively. Since mining operations and costs remained the same, while production increased, a smaller unit selling price was required to generate the specified rate of return on investment.

6.2.4 Increased VMIS Recovery Factor -- New Plans

Increasing the base case VMIS recovery factor from 50% to 75% caused production to exceed the original target value (50,000 barrels per day). Plans 5 and 6 were developed in order to determine the effects on IRSP of attaining this target production at a 75 percent VMIS recovery factor. Plans 5 and 6 are scaled-down operations corresponding to base case Plans 1 and 3; they require fewer VMIS retorts to be burning (producing) simultaneously, than Plans 1 and 3. Since the retort development rate is reduced, capital equipment, labor, and operating costs were somewhat decreased for Plans 5 and 6; however, they still require very large amounts of up-front capital for surface facilities and general mine development. Total capital costs decreased only 1.5 to 2 percent. Also, operating costs decreased only 10 to 12 percent. Retention of the original Plan 1 and Plan 3 mining strategy, involving simultaneous operations in two halves of the mine, precluded larger reductions in capital equipment and labor for Plans 5 and 6.

Table 6-14 shows capital and operating costs for Plans 5 and 6, as well as for Plans 1 and 3, and the resulting IRSPs. These results are somewhat surprising, in that increasing the VMIS recovery factor from 50 to 75 percent did not decrease IRSP; in fact, IRSP actually increased slightly. Differences in start-up production histories between Plans 1 and 5 and between Plans 3 and 6 appear to account for this outcome. Lags in production and associated revenues for the higher recovery factor plans apparently offset their slightly lower capital and operating costs. In each case, production starts earlier for the base case plan. For instance, Plan 1 begins production 146 days before Plan 5 and reaches full production 113 days earlier than Plan 5. Similar production history differences occur between Plans 3 and 6.

TABLE 6-14

Comparisons Between Low and High VMIS Recovery Factor Plans

	Plan 1 VMIS (50%)	Plan 5 VMIS (75%)	Plan 3 VMIS (50%) + Surface Retorting	Plan 6 VMIS (75%) + Surface Retorting
Capital Costs ($000)	287,306	282,348	280,048	276,206
Annual Operating Costs ($000)	76,357	67,436	63,463	56,855
Daily Production (Barrels)	49,560	49,530	54,260	53,090
Discount Rate	25%	25%	25%	25%
Required "Selling Price" ($/bbl)	15.63	16.00	10.69	11.01

These production history differences derive from the fact that retort development occurs at a slower rate in the higher VMIS recovery efficiency plans.* Plan 1 (50% VMIS recovery) requires 144 retorts burning simultaneously at full production and a development rate of 0.36 retorts per day to maintain full production. Plan 5 (75% VMIS recovery) requires 96 retorts burning simultaneously at full production and a development rate of 0.24 retorts per day. The initial five-year time history of concurrently burning retorts for Plans 1 and 5 is shown in Figure 6-7.

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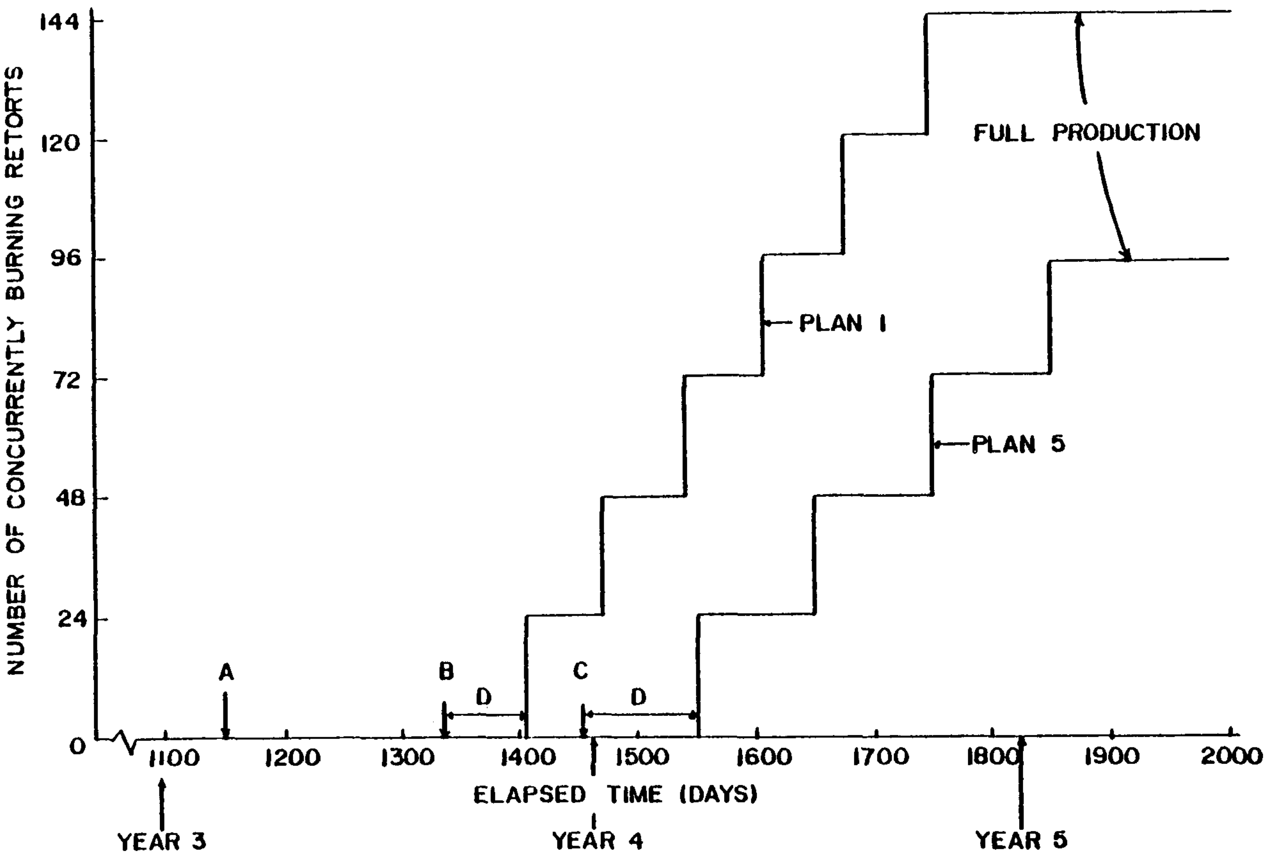
* Retort dimensions and burn rates are the same in each plan.



Notes:

A. Pre-production development complete, begin retort prior to module development, Plans 1 and 5.
B. First module pairs are rubblized, Plan 1.
C. First module pairs are rubblized, Plan 5.
D. Time required between completion of development and retort ignition.

FIGURE 6-7

Time Histories of Concurrently Burning Retorts, Plans 1 and 5

Plans 5 and 6 are probably not the most efficient strategies for producing 50,000 barrels per day at a 75 percent VMIS recovery factor. In particular, operating simultaneously in both halves of the mine (as in base case Plans 1 and 3) may preclude additional equipment and labor cost savings that could be realized by concentrating resources in one-half of the mine, when recovery efficiency is 75 percent. Pre-production development time might also be shortened by concentrating mining resources in that case.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The objective of this study, "Adapt existing models to enable the estimation of mining costs for the Vertical Modified In Situ (VMIS) process", was achieved by the development of OSMEM. This model represents an initial effort to merge mining simulation and financial models and evaluate the production and cost consequences of VMIS plans.

OSMEM is effective in facilitating the evaluation of mining plans, production strategies, and equipment suites. After a conceptual plan has been prepared and input to OSMEM (requiring a week or so of mining engineering effort), variations of the plan can be defined rather quickly to the model.

The impacts of financial parameter variations can be evaluated readily with OSMEM. Input changes representing different financial conditions can be made in a matter of minutes. Extensive outputs in the form of production histories, financial performance measures, and back-up data are provided to facilitate analysis of OSMEM results. Outcomes of the recovery plans evaluated in this study suggest that OSMEM properly estimates the mining costs associated with the VMIS process. Although not definitive, these results are considered representative of commercially feasible VMIS operations in Colorado's Piceance Creek Basin. Some preliminary observations based on these results are presented below:

1. The rate of return required on a mining investment is an important factor in determining IRSP. The selling price is very sensitive to this parameter, particularly at values of ROI above 15 percent. At these higher values, dollar differences in IRSP among different plans are more pronounced. Conversely, at lower ROI values, the IRSP dollar differences are smaller. At zero ROI, IRSP reflects only capital and operating cost recovery. In this case, there is no discounting of operating cost and revenue streams; therefore, the effects of any between-plan differences in timing of these streams are minimized.

2. The oil production time history is also an important determinant of IRSP. Earlier production generates earlier revenues and decreases the IRSP, for a given ROI. This effect is more pronounced at higher values of ROI, due to the impact of discounting which was discussed above.

3. The mining portion of IRSP is less for VMIS with surface retorting than for the corresponding VMIS-only recovery plan. Mining capital and operating costs are less for the VMIS with surface retorting plans, and revenues begin sooner, due to surface production. However, additional factors such as surface processing, environmental, and reclamation costs must be considered in order to determine the net benefits of VMIS with surface retorting.

4. An increased VMIS retort recovery efficiency decreases the <u>mining</u> portion of IRSP for a given plan. More oil revenue is produced from the same number of retorts, at the same mining costs. The decrease in IRSP is less when surface retorting accompanies VMIS, because early revenues from surface-produced oil are a significant factor in determining IRSP for these plans.

5. The mining portion of IRSP may not decrease when a VMIS recovery plan is scaled-down to produce 50,000 bbl/day due to an increased VMIS retort recovery factor. A simple scale-down may result in an inefficient mining plan, in which modest equipment and labor cost reductions are offset by decreases in early production revenues. Mining strategy may have to be revised in order to effect additional equipment and labor savings and increase equipment and labor utilization.

7.2 Recommendations

The VMIS results generated for this study have indicated some areas where systematic investigations and follow-up analyses are warranted. Also, using the model has indicated some areas where refinements to OSMEM will improve its utility. Recommendations pursuant to these points are presented below.

7.2.1 Follow-up Analyses

- Generate total per barrel costs for the recovery plans developed for this study. This can be done by incorporating capital and operating costs associated with VMIS and surface retorting (where included), raw and/or spent shale disposal, and other environmental costs. OSMEM can accommodate these additional input costs.
- Investigate the effects on IRSP of production history changes at various ROI levels. In particular, mining strategies that minimize the time required to reach full production should be investigated.
- Determine the sensitivity of IRSP to changes in the advance and production rates used in this study. The base case values were based on hard-rock mining experience; rates for oil shale mining may differ from other hard rock mining.

7.2.2 Model Enhancements

- Modify the OSMEM financial sub-model to accommodate non-zero debt/equity ratio scenarios. This capability is needed in order to represent commercial oil shale projects that involve some debt financing. The current version handles only all-equity financing cases.
- Provide the capability to have the model generate equipment and manpower requirements. In the current version of OSMEM, equipment and associated labor requirements are estimated in connection with the

mine planning process and input to the model. This preliminary effort could be reduced by having the model determine numbers of user-specified equipment types and manpower needed to meet the target production rate. Time-phasing of capital equipment purchases would also be handled by the model.

- Develop a computer-generated mine design capability. OSMEM is driven by the tree processor, which computes production history and associated operating costs, based on a mine design and a strategy for developing the property. The procedure involved in transferring the mine design to inputs for the model involves a number of steps, many of which are amenable to automation. By automating some, if not all, of the process by which the tree structure is defined, much of the burden for generating input data can be lessened and the risk of generating input errors can be reduced. Ultimately, it may be possible to generate a mine design from a few key parameters, such as geological conditions, areal extent, and mining method. This capability would facilitate the evaluation of different mining scenarios.

- Develop a capability to perform uncertainty analysis. The computer program could be enhanced to provide an optional capability to determine the effects of uncertainties associated with input cost. The approach would involve a Monte Carlo simulation based on known or assumed distributions of individual cost elements. The results would provide the user with a mining cost probability distribution; i.e., the probability that mining cost per barrel will be less than or equal to any specified amount. Likewise, mining equipment availability data could be introduced to consider the economic effects of equipment reliability and repair time characteristics.

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APPENDIX

The Impact of Gassy Conditions On Oil Shale Mining Costs

A.1 INTRODUCTION

This appendix presents an account of work performed under DOE/PETC Purchase Order No. DE-AP22-81PC10242, dated February 2, 1981. The purpose of this study was, "to analyze the cost of all underground oil shale development and extraction of ore by mining or extraction of crude by a modified in situ process under gassy conditions -- to be compared with results of DOE Contract ET-77-C-01-8915, Task Orders 13 and 14."

The Task Order 13 results are documented in, "Oil Shale Mining Cost Analysis: Volume I - Surface Retorting Process. Task Order 14 results appear in the main body of this (Volume II) document.

The results presented in this Appendix show the changes, relative to Task Orders 13 and 14 base case scenario results, caused by capital and operating cost changes and production delays associated with gassy mining conditions.

A.2 STUDY METHODOLOGY

The study involved the following three tasks:

1) identification of affected mining operations and costs
2) discussions with knowledgeable sources to assess quantitative impacts
3) determination of effects on mining portion of required selling price.

These tasks are described in the following paragraphs.

A.2.1 Affected Mining Operations and Costs

A gassy classification produces a number of potentially adverse impacts on mine production and/or costs. The following discussion identifies some of the major impacts/problem areas and their implications.

Equipment must be permissible. A gassy classification requires that permissible face equipment be used; however, permissible equipment (i.e., front-end loaders and off-highway haulage trucks) does not currently exist in the large sizes required by the oil shale industry. If this equipment is still not available when full-scale operations begin, the industry will be forced to use smaller equipment. Mine production may suffer as a result.

Development of large-scale permissible equipment is constrained due to the present inability to test the larger engines for permissibility. Additionally, many design problems still exist in the area of meeting explosion-proof requirements. It is expected that permissible equipment items will be more expensive than their non-permissible counterparts.

A more extensive ventilation system may be required. The large cross sections anticipated in underground oil shale mines (especially room-and-pillar) will require large volumes of air to obtain effective velocities. Directing the airflow via stoppings or brattices may be difficult and inefficient due to the entry sizes. An auxiliary ventilation system may be needed at the face to properly dilute explosive gases, the liberation rate of which has been measured at up to 125 ft^3 gas/ton oil shale.

These increased ventilation requirements and their attendant difficulties will increase capital and operating costs. Manpower costs may also increase, if additional personnel are required in order to maintain auxiliary ventilation systems apace with the high production rates.

Permissible explosives will be required. Permissible explosives are less powerful per unit cost than conventional explosives. For a given size cut, greater quantities of permissible explosives are needed for proper fragmentation. This translates into increased drilling costs, either for larger holes or more holes per round. The increased drilling time may slow down the overall production rate. Greater explosives quantities will also increase the already complex supply problem, and as such will increase mine supply costs.

"Frequent" gas checks will be required. Current regulations require methane checks at each working place before equipment is energized, before equipment enters the face area, and at 20 minute intervals while operating within a cut. These gas checks will be time consuming in high entries, as they must be made 12 inches from the roof, and production may be adversely affected.

One solution to this problem is to install a continuous monitoring system similar to those employed in gassy Louisiana salt mines. This option would eliminate production stoppages at the expense of increased equipment costs. It is possible that continuous monitoring systems may be required by MSHA.

All mining methods will be affected. Gassy mine regulations are applicable to all proposed underground oil shale mining methods; however, the above discussion considered primarily their impacts on conventional room-and-pillar methods. Other candidate oil shale mining methods may also have difficulty complying with certain ventilation and methane testing regulations. In particular, chamber and pillar and stoping methods tend to leave unsupported voids in which explosive gasses can accumulate. Diluting these gasses to acceptable levels may not be possible.

A.2.2 Discussions With Knowledgeable Sources

The prospective impacts identified in A.2.1 were discussed with various government and industry personnel who are involved in oil shale mining. Their comments concerning the validity and estimated magnitudes of these impacts were solicited.

Permissible Equipment. Varying opinions were stated by the respondents as to the state of permissible equipment, ranging from "unavailable in the forseeable future" to "no problem, we'll have them when the industry needs them". No information pertaining to equipment cost was obtained; the manufacturers are treating all cost data as highly proprietary.

Respondents were unanimous in their view on permissible equipment productivity; namely, there should be no appreciable change in machine performance and production levels should not be expected to decrease. This presumes, however, that an additional maintenance effort is made to keep permissible equipment reliability comparable to that of non-permissible equipment. The permissible equipment will be more complex in nature and, therefore, should be considered to be inherently less reliable. An increased maintenance cost will be required to maintain the desired level of availability such that production is not adversely affected.

Ventilation. The majority of the respondents agreed that some type of auxiliary face ventilation system will be necessary, although one person said this was more to carry off diesel fumes than methane gas. In all likelihood, this system will consist of an auxiliary fan and ventilation tubing. Installation and advancement of this tubing will be difficult, time consuming and expensive. Maintenance and advancement of the tubing is anticipated to be a significant problem when one considers that the tubing will most likely be blown down by the blast from shooting the cut. Continual replacement of damaged tubing may involve considerable delay and expense.

Another possible consequence of a gassy classification is that greater quantities of air may be required. This results in more expensive mine fans and increased power costs. It is difficult to quantify these effects at this time, since no data exists describing the necessary air quantities required by gassy oil shale mines.

Permissible Explosives. According to some of the respondents, blasting will be done off-shift, as is the practice in Louisiana salt mines. This will eliminate the problems caused by blasting fumes, and production can commence immediately upon arrival of the following shift. On-shift blasting would probably stop all section activities until the smoke and fumes are removed from the work area.

Increased costs are expected with permissible explosives utilization, both from the increased quantity requirements and the corresponding supply problems. The respondents could not quote an expected increase amount because of the many uncertainties and variables associated with blasting practices.

Expected Production Constraints. None of the respondents volunteered an absolute figure on overall production decreases, but some of them were willing to discuss possible reasons for the decrease. For example, a potentially major constraint could arise if an auxiliary face ventilation system is used. Production machines will be forced to wait while a ventilation crew advances or repairs the system. The low air velocities may not be able to handle the dust generated by the loading function, and delays will occur while watering down the muck pile or waiting for the dust to clear. These are just two examples; other operating constraints may or may not arise. In total, the various constraints could substantially increase the time required to load each cut.

Maintaining the large production levels associated with commercial-scale oil shale mines requires the front-end loaders to be working almost constantly throughout each shift. Thus, the loading function will be extremely sensitive to any delays. Introduction of even minor constraints in the face area will thus reduce section production and advance rates.

A.2.3 Required Selling Price Effects

The Oil Shale Mining Economic Model (OSMEM) was exercised to determine the effects on the mining portion of required selling price due to gassy conditions. OSMEM runs were made for the following conditions:

- Each base case scenario from Tasks 13 and 14 (total of 8) was rerun at reduced advance and production rates.
- The base case room-and-pillar mine from Task 13 and a base case VMIS scenario (Plan 1) from Task 14 were rerun with increased capital and operating costs that might be anticipated if gassy conditions exist -- in addition to reduced advance and production rates.

A.2.3.1 Advance/Production Rate Reductions

Quantitative estimates of the prospective impact of gassy conditions on mining advance and production rates were not obtainable from the study sources. Lacking these estimates, the effects of a ten (10) percent and a thirty (30) percent reduction in mining rates were simulated. The thirty percent reduction reflects our professional judgment concerning possible worst case impacts of gassy conditions. The ten percent reduction represents a more optimistic case in which these impacts are minimal.

Each base case scenario from Task 13 and Task 14 was rerun twice -- once at each reduced mining rate -- to determine the effects on required selling price of these reductions.

A.2.3.2 Capital and Operating Cost Increases

Estimates of capital and operating cost element increases due to gassy conditions also reflect our best professional judgment, since these data were not provided by study sources.

Listed below are cost elements which were assumed to change and amounts or percentages by which they will change over base case values.

A. Capital Cost Elements

o Permissible equipment	+ 20 percent
o Ventilation equipment	+$1.25 million (non-VMIS) +$1.5 million (VMIS)
o Additional safety devices	+$1.0 milion

B. Operating Cost Elements

o Underground labor	+ 20 percent
o Permissible explosives	
- cost per ton	+ 20 percent
- additional quantity	+ 30 percent
o Replacement of line brattice and/or vent tubing destroyed by blasting	+$0.5 million/year

A.3 RESULTS

A.3.1 Reduced Mining Rates

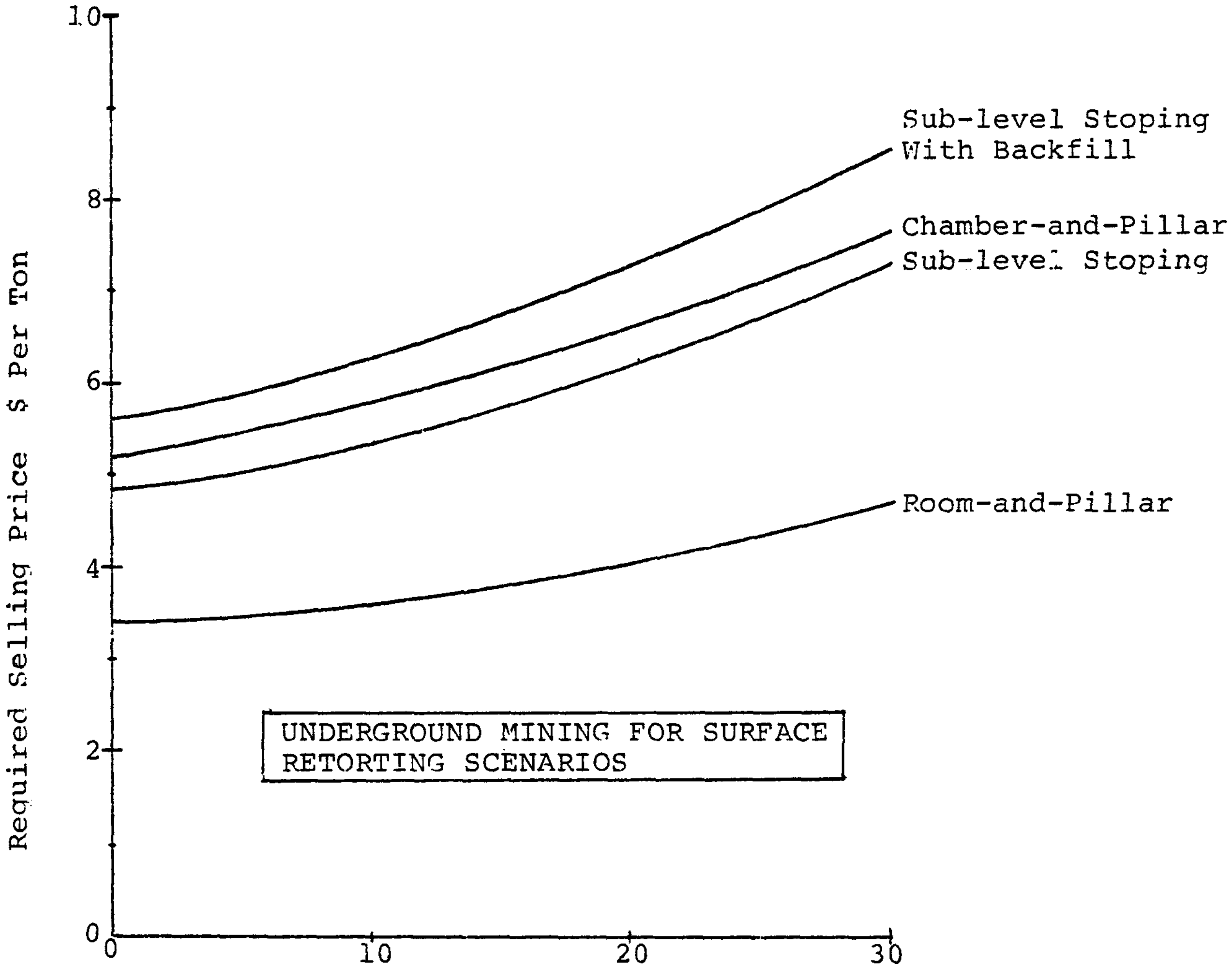
Table A-1 shows the mining portion of required selling price for each of the Task 13 (underground mining for surface retorting) base case scenarios and for the reduced values of advance and production rates. Reducing these mining rates by 10 percent increased required selling prices by 10 to 12 percent for these scenarios. Reducing the mining rates by 30 percent increased selling price by 42 to 52 percent. These results are presented in graphical form in Figure A-1.

TABLE A-1

Effects of Production and Advance Rate Reductions
(Underground Mining for Surface Retorting Scenarios)

	Required Selling Price ($ Per Ton)			
Production and Advance Rates	Room-and-Pillar	Chamber and Pillar	Sublevel Stoping	Sublevel Stoping with Backfill
Base Case	3.48	5.20	4.84	5.62
10% Reduction	3.84	5.83	5.42	6.32
30% Reduction	4.93	7.70	7.30	8.54

Table A-2 shows production impacts of gassy conditions for the VMIS (Task 14) scenarios. The effects on required selling price are more pronounced for these scenarios than for the



Percent Reduction in Base Production Rate

FIGURE A-1

Effects on Required Selling Price
of Mining Production Rate Impacts
Due to Gassy Conditions

underground mining for surface retorting scenarios. Reducing mining rates by 10 percent increased selling price by 13 to 18 percent for the VMIS scenarios. Reducing mining rates by 30 percent increased selling price by 58 to 82 percent. These results are presented in graphical form in Figure A-2.

TABLE A-2

Effects of Production and Advance Rate Reductions
(Vertical Modified In Situ Scenarios)

Production and Advance Rates	Required Selling Price ($ Per Barrel)			
	Plan 1 VMIS Only	Plan 2 VMIS Only	Plan 3 VMIS Plus Surface	Plan 4 VMIS Plus Surface
Base Case	$15.63	16.76	10.69	9.94
10% Reduction	18.46	19.49	12.29	11.26
30% Reduction	28.50	29.67	17.85	15.68

A.3.2 Capital and Operating Cost Increases

Table A-3 presents the effects of increased capital and operating costs due to gassy conditions for the room-and-pillar scenario and one VMIS scenario. The mining portion of required selling price is shown in this table for the base case production and advance rates and for reduced values of these rates.

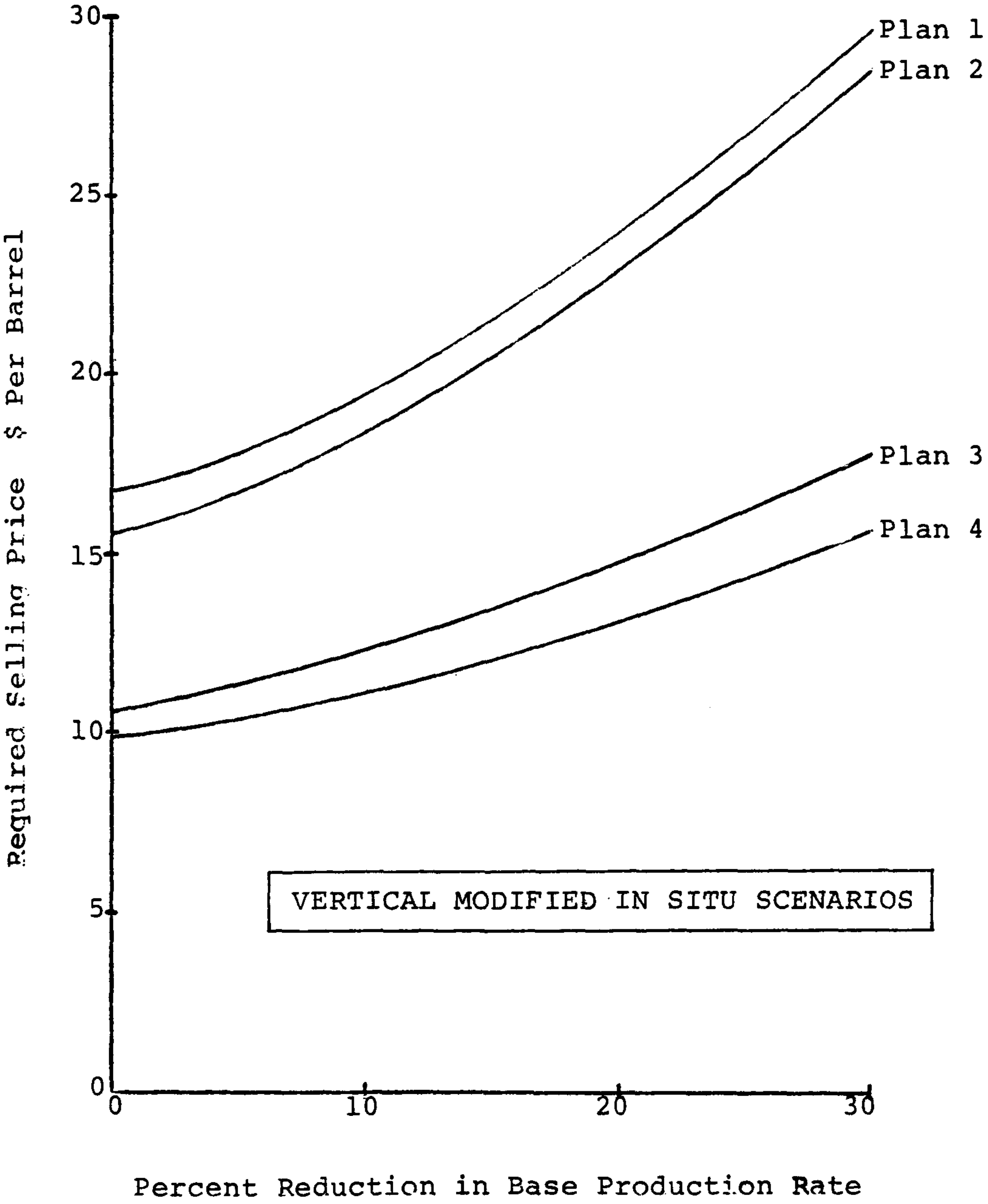


FIGURE A-2

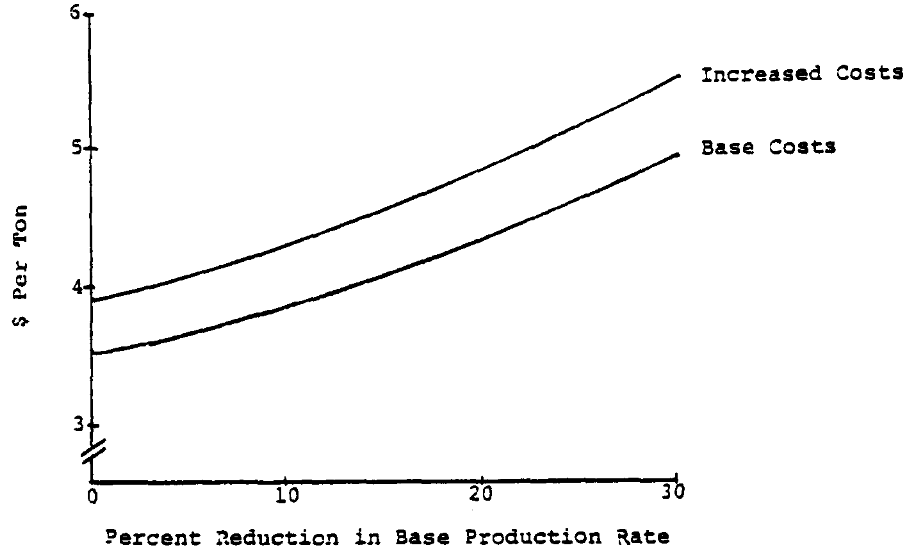
Effects on Required Selling Price
on Mining Production Rate Impacts
Due to Gassy Conditions

The capital and operating cost increases listed in A.2.3.2 resulted in a 12 percent increase in required selling price for the room-and-pillar scenario, at each production rate. The VMIS scenario exhibited a 15 percent increase in selling price at each production rate, for the same (A.2.3.2) capital and operating cost increases. Figure A-3 presents graphical representations of these results.

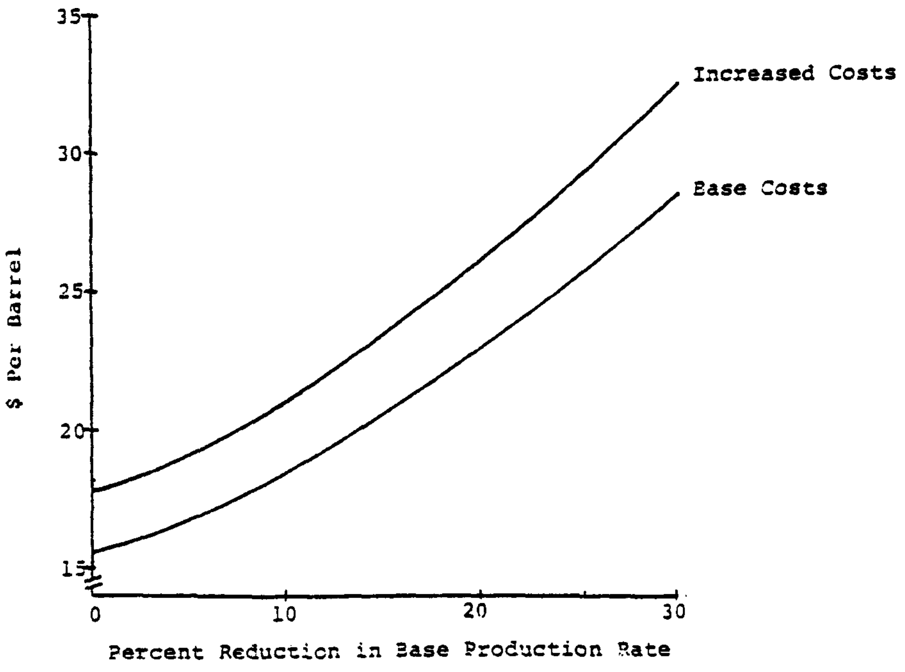
TABLE A-3

Effects of Increased Capital and Operating Costs and Mining Rates on Required Selling Price

Production and Advance Rates	Room-and-Pillar Scenario ($ per ton)		VMIS Scenario ($ per barrel)	
	Base Costs	Increased Costs	Base Costs	Increased Costs
Base	$3.48	$3.90	$15.83	$17.91
90% Base	3.84	4.30	18.46	21.14
70% Base	4.93	5.53	28.50	32.65



A. Room-and-Pillar Scenario



B. VMIS Scenario

FIGURE A-3

Effects of Increased Capital and Operating Costs and Increased Mining Rates Due to Gassy Conditions

A.4 DISCUSSION OF RESULTS

Knowledgeable sources agree that gassy conditions in oil shale mines will impact mining rates and capital and operating costs. However, little or no information is currently available to permit quantifying these impacts.

The results of this study indicate that gassy conditions could cause signficant increases in the mining portion of required selling price, compared to non-gassy conditions. For example, increases of 25 to 35 percent were observed when mining rates were reduced 10 percent and capital and operating costs increased as shown in A.2.3.2. Much greater increases (60 to 100 percent) were observed when mining rates were reduced 30 percent.

Since the present results are based on impacts that are judgmental, the realism of these inputs should be established at an early date. The magnitude of the price effects derived from these inputs is sufficiently great to warrant a more extensive investigation than this preliminary study permitted.

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