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MOBIL RESEARCH AND DEVELOPMENT CORPORATION

RESEARCH DEPARTMENT

TECHNICAL MEMORANDUM NO. 67-28

BASES FOR ECONOMIC EVALUATION OF A MINING-CRUSHING-RETORTING COMPLEX USED FOR OIL SHALE PROCESSING

ANVIL POINTS OIL SHALE RESEARCH CENTER

Rifle, Colorado

October 9, 1967

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C. to WRB-JCK

The primary object of the Anvil Points Oil Shale Research Center TECHNICAL MEMORANDUM is to advise authorized personnel employed by the Participating Parties[1] that various activities are in progress or that certain significant data have been obtained within the Research Center.

These TECHNICAL MEMORANDA have been prepared to provide rapid, on-the-spot reporting of research currently in progress at Anvil Points. The conclusions drawn by project personnel are tentative and may be subject to change as work progresses. The TECHNICAL MEMORANDA have <u>not</u> been edited in detail.

[1] Mobil Research and Development Corporation, Project Manager

Continental Oil Company
Humble Oil and Refining Company
Pan American Petroleum Corporation
Phillips Petroleum Company
Sinclair Research, Inc.

BASES FOR ECONOMIC EVALUATION OF A MINING-CRUSHING-RETORTING COMPLEX USED FOR OIL SHALE PROCESSING

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BASES FOR ECONOMIC EVALUATION OF A MINING-CRUSHING-RETORTING COMPLEX USED FOR OIL SHALE PROCESSING

I. INTRODUCTION

This memorandum is intended to provide the economic ground rules for updating three economic studies that have dealt with the economics of operation of the component plants of a mining-crushing-retorting oil shale processing complex. These revised studies are to reflect our Stage II experience in each of these areas.

In the previous economic evaluations some inconsistencies in bases did exist and further, some omission and duplication of facilities inadvertently occurred. (The earlier studies are listed in the references at the end of this memorandum.) To minimize this duplication, a study intended to estimate the cost of a common set of off-site features for the entire complex is also presented in this memorandum.

These new economic studies are intended to describe the "state of the art" as it is at the end of Stage II. Some facts needed to fully evaluate this state of the art are not available. A serious effort will be made to indicate the assumptions which are needed to tie together the assorted bits of information now available on oil shale processing.

These economic studies represent a hypothetical situation which is limited by the constraints of the multicompany contract under which the research program has been carried out. Refining facilities are excluded for this reason. The use of proprietary information from any of the participating parties has been minimized so that these studies may serve as base points from which individual companies may proceed with their own more detailed economic evaluations.

II. SUMMARY

A description of the economic bases and the methods of estimation of investment and operating costs of a mining-crushing-retorting complex capable of producing 50,000 barrels per calendar day of crude shale oil has been prepared. These bases and methods will be used in updating earlier economic studies of mining, crushing and retorting in the light of the Stage II experience.

Table 1 summarizes changes in the economic bases from earlier studies. Equipment and labor costs are to be based on 1966 levels. No escalation of these costs will be considered so that the cost escalation policy of each participating party may be easily factored into more detailed economic evaluations.

An additional feature of this memorandum is an estimate of the off-site facilities, plant overhead and administrative expense needed to support such a complex.

TABLE 1

CHANGE IN BASES FROM PREVIOUS STUDIES

	Investment Estimates
Direct Cost	
Off-Sites	Previously these were included partially in mining, crushing and retorting costs. In this memo, they are separately estimated and they will be excluded from mining, crushing and retorting costs.
Colorado Sales and Use Tax	Not considered previously. Estimated as $.03/$ uninstalled equipment cost.
Freight on Equipment	Not consistently considered previously. Estimated as $.03/$ uninstalled equipment cost.
Indirect Cost	
Engineering and Construction	Not consistently considered previously; now, estimated as $.25/$ stationary equipment investment.
Contractor's Fee	Not consistently considered previously; now, estimated as $.07/$ stationary equipment investment.
Contingency	Not consistently considered previously. Estimated as $.15/$ total equipment investment.

	Operating Cost Estimates
Direct Production Costs	
Maintenance Labor	Formerly about $3.00 in crushing and retorting, $3.50 in mining. Now $3.25 throughout complex.
Mining Labor	Formerly $3.50, now $3.25.
Underground Differential	Not consistently considered previously, now $.05/$ direct wage.
Maintenance Supervision Mining Supervision Operating Supervision	Not consistently considered previously, Now $9000/ man year, $9000/man year, and $8000/man year, for maintenance, mining and operating, respectively.
Benefits	Not consistently considered previously, now $.30/$ direct labor base wages plus supervisory salaries.
Maintenance Materials	$.025 - .03/$ of equipment investment previously, now. $.03/$ of equipment investment.
Operating and Miscellaneous Materials	Not consistently considered previously; directly estimated, now.

(Continued on next page)

TABLE 1 (CONTINUED)

CHANGE IN BASES FROM PREVIOUS STUDIES

	Operating Cost Estimates
Direct Production Costs Utilities	Not consistently considered previously; directly estimated, now.
Plant Overhead	Not consistently considered previously; directly estimated, now.
Administrative Expenses	Not consistently considered previously; directly estimated, now.

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III. DETAILED DISCUSSION

A. Overall Description of Complex

The complex which is to be studied in the three updated economic evaluations is a mining-crushing-retorting plant designed to produce 50,000 barrels per calendar day of crude shale oil from 30 gallons per ton Fischer Assay oil shale in Colorado. This plant is shown schematically in Figure 1. The subsequent refining and pipelining facilities are not to be included in this complex since these problems are beyond the scope of the Initial Program at Anvil Points.

B. General Economic Bases

The method that will be used in this discussion is to state the common economic bases dealing with the investment and operating costs of each of the elements of the complex. The particular economic and process bases which are only pertinent to a single element of the entire complex will be discussed in the memorandum dealing with that portion of the plant.

The economic index to be used in those evaluations is the sale price of crude shale oil needed to provide a 10% discounted cash flow return on investment after taxes. This sale price will be resolved into components due to mining crushing, retorting, and off-site investment and operation.

1. Investment

The investment estimation techniques to be used in these studies are summarized in Table 2.

A fifteen-year project life, the sum of the years digits' depreciation method and no salvage value are to be used as the bases for the equipment depreciation calculation.

A four-year investment period will be assumed. The extimated project development during this period is shown in Figure 2. Sixteen percent of the investment will occur in the first year of this period. In the three subsequent years, 28% of the total investment will occur in each year.

Equipment cost estimates are to be based on 1966 prices. No escalation of equipment cost from this base will be assumed.

The cost of land, access roads, site preparation (other than mine development) and working capital will be excluded from the estimates of investment. This is because the land situation and working capital policy are so unique for each particular company that a generalized treatment of these costs is virtually meaningless.

FIGURE 1

MINING — CRUSHING — RETORTING COMPLEX
FOR PRODUCTION OF CRUDE SHALE OIL

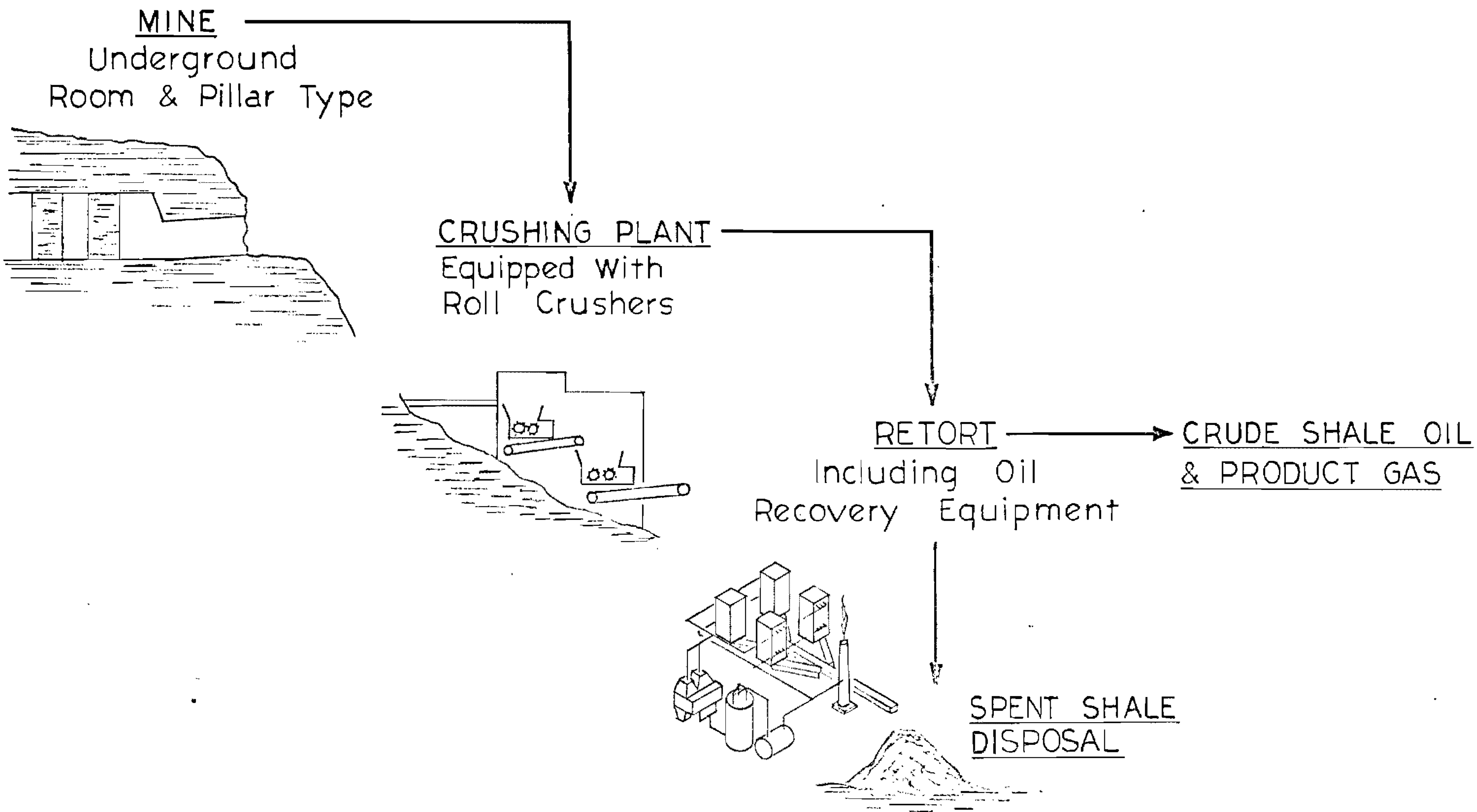

TABLE 2

INVESTMENT ESTIMATES

Direct Cost	Method of Estimation
Process Equipment a. Stationary Equipment b. Mobile Equipment	Detail of these estimates varies for each element of complex. See individual report for description of technique used.
Mobile Equipment Erection Cost	1% of mobile equipment investment.
Off-Sites a. Utilities b. Services	See Table 6 for Off-Sites investment estimate.
(Each of these items are included as operating expenses during investment period.)	
1. Freight on equipment	$.03/$ uninstalled equipment investment.
2. Colorado sales and use tax on equipment	$.03/$ uninstalled equipment investment.
Indirect Cost	
Engineering and Construction (Includes design services, field engineering, field offices and supervision, temporary construction overhead.)	$.25/$ stationary equipment investment.
Contractor's Fee	$.07/$ stationary equipment investment.
Contingency	$.15/$ total equipment investment.
Land Cost (including access roads)	Excluded from estimate.
Working Capital	Excluded from estimate.

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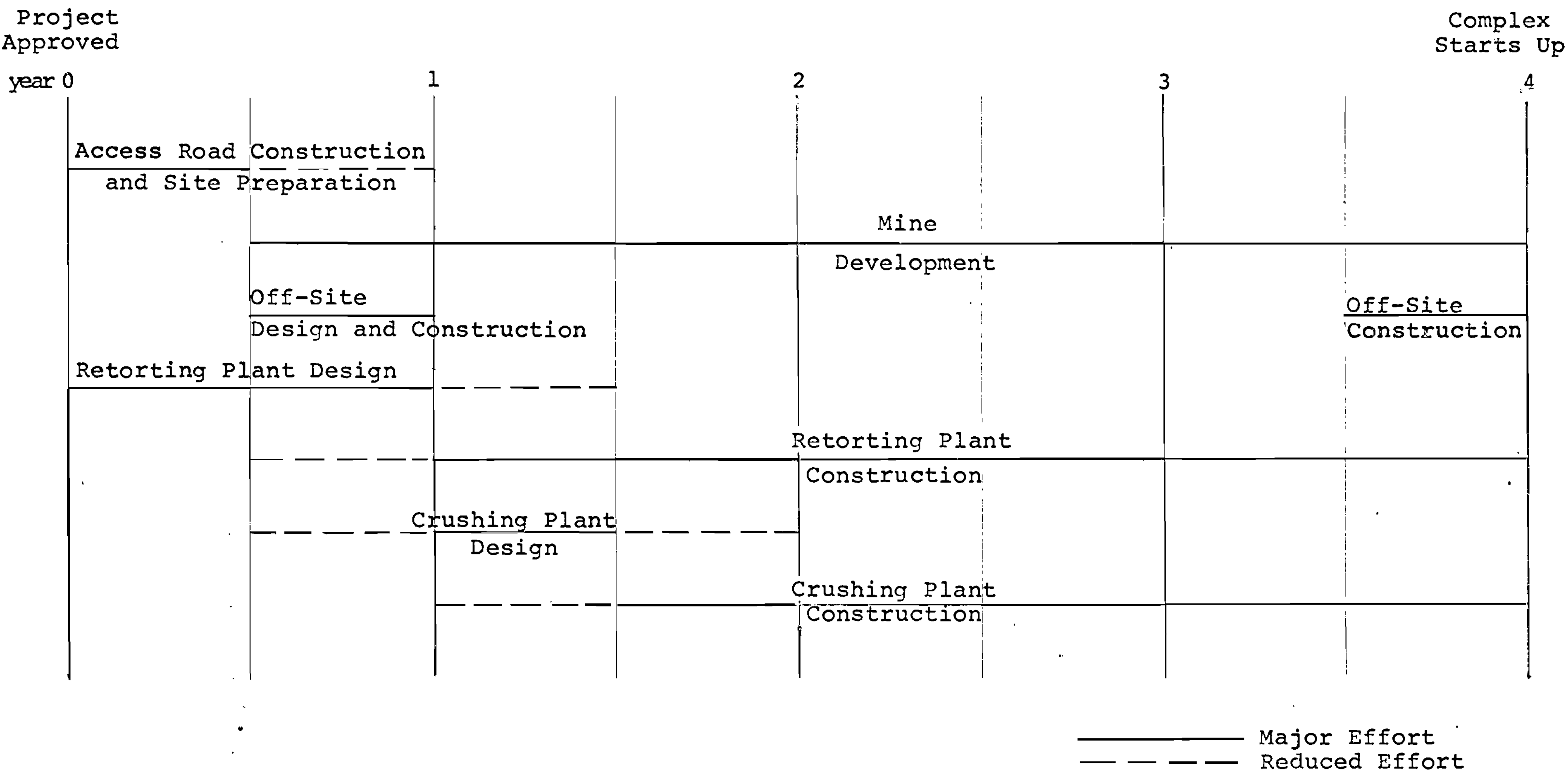
FIGURE 2

ESTIMATED PROJECT DEVELOPMENT DURING
PRE-STARTUP PERIOD



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2. Rate of Return on Investment

The rate of return which is to be assumed in calculating the sale price of crude shale oil is 10% on a discounted cash flow rate of return basis.

3. Income Tax

A federal income tax of 50% and a Colorado state income tax of 5% will be considered in these analyses. An investment credit of 7% has also been allowed on qualifying investments. Although this credit had been suspended in 1966 it was reinstated on March 9, 1967 and is considered to be a probable feature of the tax structure in the future.

4. Cost of Capital For A $1,000,000 Investment

A table showing the calculation of the cost of capital for a $1,000,000 investment is shown in Table 3. The derivation of the equation used in this calculation is shown in the Appendix.

5. Operating Costs

The operating cost estimation techniques are listed in Table 4. Royalties and depletion allowance are to be excluded from these analyses because of the uncertainty of these two items. Because the methods of charging research and development costs vary widely among companies and because the methods of financing projects of this nature are quite unique to each company, these cost items have also been excluded from these analyses.

Labor costs are based on 1966 wage rates and no escalation of labor costs will be assumed.

C. Off-Sites Cost Estimate

A separate cost estimate has been made for the utility and service facilities comprising the off-sites for the mining-crushing-retorting complex. The separate estimate prevents possible duplication or omissions that could occur if an off-site estimate was included with each of the on-site cost estimates, and should also improve the accuracy of the off-site cost estimate. Estimated investment for off-sites is $15,700,000, while the total cost chargeable to off-sites is 29.6 cents per barrel.

The revised cost estimates for mining and crushing were not complete when the off-sites cost estimate was made. Consequently, the off-sites were based on the earlier cost studies reported in Technical Memoranda 66-5 and 67-5, as well as the Allis-Chalmers flowsheet type design for an 84,000 tons per calendar

TABLE 3

COST OF CAPITAL FOR A $1,000,000 INVESTMENT

iable ment	I_i X DF_i	Depreciation D_i	D_i X DF_i	Expenses[1] E_i	E_i X DF_i	Investment Credit[2] C_i	C_i X DF_i
000	160,000			5,760	5,760	11,200	11,200
000	254,548			10,080	9,164	19,600	17,818
000	231,392			10,080	8,330	19,600	16,197
000	210,364			10,080	7,573	19,600	14,725
		125,000	85,375				
		116,667	72,439				
		108,333	61,154				
		100,000	51,320				
		91,667	42,763				
		83,333	35,342				
		75,000	28,913				
		66,667	23,367				
		58,333	18,585				
		50,000	14,485				
		41,667	10,971				
		33,333	7,990				
		25,000	5,440				
		16,667	3,297				
		8,333	1,499				
000	856,304			36,000	30,827	70,000	59,940
		1,000,000	462,940				

$$DF_i + (1-t)\sum E_i \times DF_i - \sum C_i \times DF_i + t\sum D_i \times DF_i \Big\}$$

$$56,304 + 0.45 \times 30,827 - 59,940 - .55 \times 462,940 \Big\}$$

estment

shale oil

reight (assuming that 60% of investment is due to material), $E_i = I_i \times .6 \times .03 + .03$
or $= .036 I_i$

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TABLE 4

OPERATING COST ESTIMATES

Direct Production Costs	Method of Estimation
Maintenance Labor	$3.25/man hour[1] (No. of men directly estimated)
Mining Labor	$3.25/man hour[2] (No. of men directly estimated)
Operating Labor	$3.00/man hour[1] (No. of men directly estimated)
Underground Differential	$0.05/$ direct wage
Maintenance Supervision	$9000/man year (No. of men directly estimated)
Mining Supervision	$9000/man year (No. of men directly estimated)
Operating Supervision	$8000/man year (No. of men directly estimated)
Benefits	$.30/$ of labor base wages plus supervisory salaries
Raw Materials	None
Maintenance Materials	$.03/$ of equipment investment
Operating and Miscellaneous Materials	Directly estimated
Utilities	Directly estimated
Royalties	Excluded
Fixed Charges	
Rent	None
Insurance and Property Taxes	$.015/$ equipment investment/yr
Depreciation	Sum of years digits for 15 year project life
Depletion	Excluded
Plant Overhead (includes medical, safety, protection, cafeteria, laboratories, storage facilities, general plant and payroll overhead, engineering services)	Directly estimated (See Table 7)
Administrative Expenses (includes executive salaries, clerical wages, office supplies, communications)	Directly estimated (See Table 7)
Distribution and Selling Expenses	None (since product is unfinished)
Research and Development Charges	Excluded
Financing Charges	Excluded

(1) CHEMICAL WEEK, pp. 95 - 118, October 29, 1966.
(2) Private Communication, Kennecott Copper Corporation, Bingham Canyon, Utah.

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day crushing plant. Cost estimating was done by detailed estimates where the off-sites could be sufficiently defined, or as a percentage of the on-site cost where the off-site requirements could not be well defined. The cost estimate is described in detail below.

1. Off-Site Facilities Included in the Cost Estimate

The off-sites conform to the bases given in the first part of this memorandum. No storage and handling facilities (product tankage and pumping station in this case) are included. All utilities are furnished except for utility lines into the plant and utility lines between the plant and mine. All necessary services are included except for the road between the mine and plant. Figure 3 gives a schematic diagram of the off-site facilities.

2. Investment Estimates

Details of the investment estimate are given in Table 5 for the utilities, and Table 6 for the services. Table 7 gives the development of the fixed capital investment and the cost of capital.

It may be noted in Table 5 that 325 gallons per minute of water have been allowed for spent shale quenching and dust control. This water need is based on very limited experimentation and should be used with caution in evaluating the water economy of this complex, however, it is a minor cost item.

3. Plant Overhead and Administrative Cost

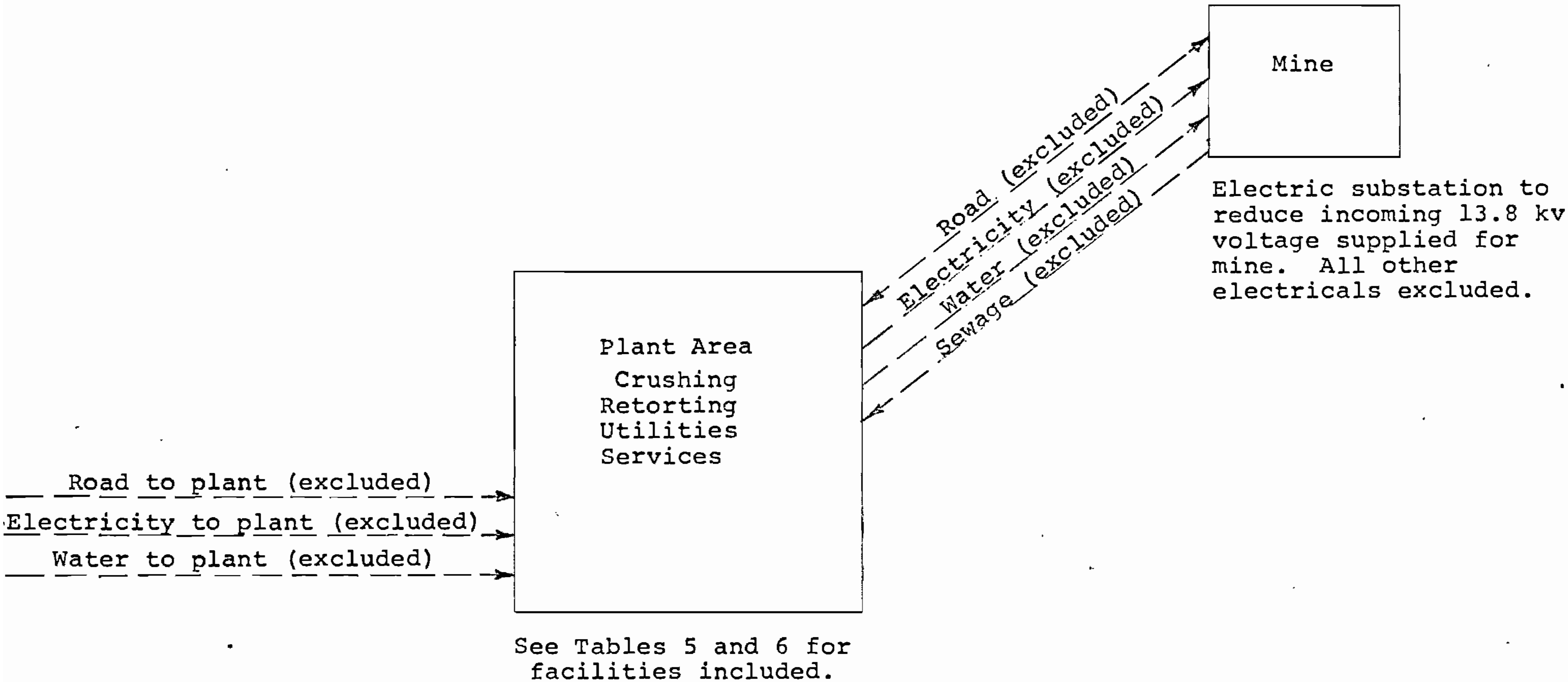
Usually plant overhead and administrative cost are estimated as percentages of the direct labor and supervision costs. Results from this type of estimate looked questionable, so that a more detailed calculation was made. An estimate was prepared containing every job in the plant overhead and administrative area and the number of people required to fill these positions. This estimate is summarized in Table 8. The materials used were assumed to be a percentage of the labor cost.

4. Total Cost of Off-Site Facilities

The total cost of the off-site facilities is developed below.

FIGURE 3

SCHEMATIC DIAGRAM OF THE OFF-SITE FACILITIES
FOR MINING-CRUSHING-RETORTING COMPLEX
FOR CRUDE SHALE OIL PRODUCTION



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UTILITIES ESTIMATE

Utility	Installed Capacity	Physical Cost $M
Electrical System(1)	45,000 kva	1,790
Steam Generation and Distribution	30,000 lbs/hr	200
Water System	864 M gal/day(2)	1,000(2)
Compressed Air System	--	200(3)
Sewer and Drainage System	--	300(3)
Gas System	None	--
Utility Buildings	--	1,000(3)
Miscellaneous		200(3)
Total		4,690

Estimated Utility Consumption For Off-Sites

Electricity: $\frac{29400\ \text{kwhr}}{\text{day}} \times \frac{1¢}{\text{kwhr}}$ = 29,400 ¢/day X 0.75 use factor = 22,050

Steam: $\frac{7000\ \text{lbs}}{\text{M}} \times \frac{24\ \text{hr}}{\text{day}} \times \frac{50¢}{1000\ \text{lbs}}$ = 8400 ¢/day X 0.33 use factor = 2772

Water: $\frac{45\ \text{M gal}}{\text{day}} \times \frac{2.5¢}{\text{M gal}}$ = 113 ¢/day X 0.9 use factor = 1017

25839 ¢/day

Maximum cost/barrel = $\frac{25839\ ¢\ \text{day}}{\text{day}\ 50000\ \text{bbl}}$ = 0.517¢/bbl   0.5¢/bbl

Notes:

(1) Electrical system includes main transformer station, switchgear and primary distribution feeders, and substation for reduction to 4.2 kv and 440 volts where necessary. Second distribution feeders, motor controllers and wiring, etc. assumed to be included in on-site estimates for mine, crushing, and retorting, but are included in this estimate for off-site facilities.

(2) Includes water for spent shale dust control. Experiments to data show that about 10% water mixed with spent shale is required to supress dust (May 24, 1967 Monthly Progress Memorandum, p. 38). This is about 1120 gpm for 84,000 T/CD of raw shale.

It is assumed that future work will reduce this requirement to 500 gpm, 150 gpm of which will be the retort water make, 25 gpm of which is used water recovered from miscellaneous plant usages, leaving a total of 325 gpm of new water required.

(3) Estimate by percentage method.

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TABLE 6

SERVICE FACILITIES

Physical Investment Estimate	M$
Service Buildings	
Plant Level	
Administration Building	700
Laboratory (equipped)	230
Employee Building (changehouse, lockers, cafeteria, medical)	280
Shops (equipped)	500
Warehouse (space parts, supplies, etc.)	450
Mine Level	
Office, changeroom, cafeteria building	450
Garage (equipped)	800
Warehouse	200
sub total	3,610
Fence, gatehouse, parking lot, and intraplant roads	1,000
Service equipment	500
Miscellaneous items (10% of above)	511
	5,621
round to	5,600

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TABLE 7

INVESTMENT AND COST OF CAPITAL

	As estimated	Rounded
Direct Costs		
Utilities	$ 4,690,000	$ 4,700,000
Services	5,621,000	5,600,000
Freight to site[(1)]	186,000	200,000
Colorado Sales Tax[(1)]	186,000	200,000
	$10,683,000	$10,700,000
Indirect Costs[(2)]		
Engineering and construction	$ 2,670,000	
Contractor's fee	745,000	
	$ 3,415,000	$ 3,400,000
Fixed Capital Investment		$14,100,000
Contingency		1,500,000
Total Fixed Capital Investment		$15,600,000
Depreciable Investment[(3)]		$15,200,000

Cost of Capital =

$$\left(\frac{1.18\ \text{¢/bbl}}{\text{\$MM Depreciable Invest}}\right)\left(15.2\ \text{MM\$}\right) = 17.9\ \text{¢/bbl}$$

Notes:

(1) 3% of materials with 60/40 material to labor split on off-sites.

(2) Engineering and construction is 25% and contractor's fee is 7% of direct cost excluding sales tax and freight.

(3) Excludes freight and sales tax.

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PLANT OVERHEAD AND ADMINISTRATIVE COST

Plant Overhead Cost	Wages	Benefits	Overtime	Total
Hourly employees on days				
maintenance 3 men X $6760/man yr	$ 20,280	$ 6,084	$ 1,014 (1)	
other 18 men X $4680/man yr	84,240	25,272	4,212 (1)	
Hourly employees on shift				
48 men X $6240/man yr	299,520	89,856	74,880 (2)	
Salaried employees				
52 men X $9000/man yr	468,000	140,400	--	
Sub Total				$1,213,758
Materials (15% of labor cost)				182,064
Total				$1,395,822
Administrative Cost				
Salaried employees				
13 men at $12,000/man yr	156,000	46,800	--	
Hourly employees (office staff)				
20 people at $5400/man yr	108,000	32,400	5,400 (1)	
Sub Total				$ 348,600
Materials (15% of labor cost)				52,290
Total				$ 400,890
Total Cost				$1,796,712

$$\frac{180000000 \text{ ¢}}{\text{year}} \times \frac{\text{year}}{5000\ (365)\ \text{bal}} = 9.86 \text{ ¢/bbl}$$

Notes:

(1) 5% overtime

(2) 25% overtime for shift coverage

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Cost of Capital		17.9 ¢/bbl
Insurance and Local Taxes (1.5% of Investment per year)		1.3
Utilities Consumed		0.5
Plant Overhead and Administrative Expenses		9.9
	Total	29.6 ¢/bbl

The estimate fixed capital investment for the off-site facilities is $14,100,000 excluding contingency and $15,600,000 including contingency.

IV. REFERENCES

Monthly Progress Memoranda

August 17, 1964 pp. 12 through 15

September 17, 1964 pp. 9 through 11

August 20, 1965 pp. 20 through 25

August 19, 1966 pp. 29 through 34

Octuber 21, 1966 pp. 38 through 42

December 21, 1966 pp. 30 through 32

Technical Memoranda

66-3 Sellers, J. B. - PRELIMINARY COST STUDY ON UNDERGROUND MINING OF OIL SHALE BY THE ROOM AND PILLAR METHOD, September 2, 1966.

67-3 Snyder, P. W., Jr. - ECONOMIC OPTIMUM OPERATING CONDITIONS FOR THE GAS-COMBUSTION RETORT, January 27, 1967.

67-5 Reitz, R. A. - COST STUDY ON THE PRODUCTION OF 84,000 T/D OF CRUSHED SHALE FROM GYRATORY-CONE CRUSHING PLANTS, February 8, 1967.

APPENDIX

DERIVATION OF DISCOUNTED NET CASH FLOW EQUATION USED IN CALCULATING COMPONENT COSTS

DCF = Discounted net cash flow over project life
DCF_i = Discounted net cash flow in year i
I_i = Investment in year i
DF_i = Discount factor for year i
S_i = Sales required to offset investment, operating expenses and income tax
E_i = Expense in year i
D_i = Depreciation in year i
C_i = Investment credit in year i
t = Income tax rate

$$DCF_i = S_i \times DF_i - I_i \times DF_i - E_i \times DF_i - \left\{ \left[S_i - (E_i + D_i) \right] t - C_i \right\} DF_i$$

Over the life of project

$$DCF = 0 = \sum DCF_i = (1-t) \sum S_i \times DF_i + t \sum D_i \times DF_i + \sum C_i \times DF_i - \sum I_i \, DF_i - (1-t) \sum E_i \times DF_i$$

But, S_i is constant

Therefore,

$$S = \frac{1}{(1-t) \quad DF_i} \left\{ \sum I_i \times DF_i + (1-t) \sum E_i \times DF_i - t \sum D_i \times DF_i - \sum C_i \times DF_i \right\}$$

For the special case when all the investment is made before startup:
(Let i = o - investment starts
i = s - plant starts up
i = e - project completed)

$$S = \frac{1}{(1-t) \sum_{s}^{e} DF_i} \left\{ \sum_{o}^{s-1} I_1 \times DF_i + (1-t) \sum_{o}^{e} E_i \times DF_i - t \sum_{s}^{e} D_i \times DF_i - \sum_{o}^{s-1} C_i \times DF_i \right\}$$

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INTEROFFICE COMMUNICATION

Ponca City, Oklahoma
November 1, 1967

TO: Harold Gilliland

SUBJECT: REVIEW OF TECHNICAL MEMORANDUM NO. 67-29, "CORROSION-EROSION PROGRAM" ANVIL POINTS OIL SHALE PROJECT BY L. J. SKOWRONEK

General

Based on this report and some discussion with John Hasz, I would generally agree with Skowronek's evaluation with the exception of corrosion in gas handling system. It is not clear to me why he feels that measured metal loss rates of 25-50 mpy are "very mild."

SPECIFIC COMMENTS

A. Erosion

My experience in erosion problems is limited to blast joint protection. From the information in this report, it would appear that they are overlooking some approaches that might be practical, e.g., use of tough, resiliant materials (rubber, polypropylene, etc.) as protection for "free fall" impact areas; minimize free falls by smooth curves.

The use of high strength steel dump truck beds would seem to be a natural. In fact, the U. S. Steel book on T-1 steels has a number of examples of ore, rock and coal hauling vehicles.

B. Corrosion

It is my opinion that this conclusion is not representative of the data reported for some parts of the system. At least some economic justification should be included. The corrosion rates on the piping in the gas and water handling areas were frequently in the .025-.050 inches per year range, which would require a 1/8-1/4" corrosion allowance for a five year service life. The situation may be worse in the future, as the gas corrosion occurred under a dust-laden tarry deposit up to 1/2" thick. Elimination of the tarry binder as recommended in C would expose the metal to the combined action of corrosion and dust abrasion. The marked disagreement (about 100 times) between the equipment metal loss and the test panel metal losses is disturbing to me, but no mention was made of the disparity.

During my discussion with John Hasz, some additional facts not mentioned in the report were brought out which led to a plausible explanation of the observed corrosion as well as offer some clues to future behaviour under modified conditions. Table 2 summarizes the equipment corrosion data: The "atmosphere" column is misleading to a novice in that the gas is predominantly combusion product (60% N_2, 30% CO_2, a few percent H_2 + CO trace O_2 and 125-150°F H_2O dew point). The product off gas has a definite ammonia odor and NH_4HCO_3 is the primary dissolved salt in the produced water. The pH of this water is generally high (8. 8 ±.2) from the acid and base constants of NH_4OH and H_2CO_3 as expected. Since the high solubility of the ammonia in water probably results in a rapid stripping of the ammonia from the gas, little or no ammonia passes the electrostatic precipitator. As additional water condenses downstream on the cool uninsulated pipe walls, CO_2 and trace oxygen will dissolve therein to produce acidic corrosive conditions since no ammonia is present to buffer the solution. The tarry deposit would probably help reduce the corrosion by shielding the water film from free access to CO_2 and O_2. It could also contribute to the corrosion by preventing direct wall contact with the 200-250°F gas which might keep the water evaporated. This mechanism could be checked by examining a section of line for $FeCO_3$ and Fe_2O_3 corrosion product under the tar and evidence of pitting attack resulting from the oxygen.

C. Fouling

While there would be a number of other factors to be considered, it would seem that some of the fouling of the gas handling system could be eliminated by recycling some of the product oil (and/or possibly water) into the gas stream as it enters the collector pipes in the retort. If enough liquid is present to keep the solid-liquid mixture fluid, operation of the multiclone should be greatly improved.

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