350129

BuMines OFR 116-76

# EVALUATION OF COMBINED IN-SITU AND SURFACE RETORTING OF OIL SHALE TRACT C-b

Prepared for:
United States Department of
the Interior, Bureau of Mines

By:
Shell Oil Company
Mining Ventures Department
Houston, Texas 77001

Final Report
on
Cooperative Agreement No. 14-09-0070-653

Bureau of Mines Open File Report 116-76

November 1976

PB261064

**BIBLIOGRAPHIC DATA SHEET**

1. Report No. BuMines OFR 116-76

2.

3. Recipient's Accession No.

4. Title and Subtitle
Evaluation of Combined In-Situ and Surface Retorting of Oil Shale Tract C-b

5. Report Date
November 1976

6. Performing Organization Code

7. Author(s)
A. P. Grossman

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Shell Oil Company
Mining Ventures Department
Houston, TX 77001

10. Project/Task/Work Unit No.

11. ~~Contract/Grant No.~~
Cooperative agreement
14-09-0070-653

12. Sponsoring Agency Name and Address
Office of Assistant Director--Mining
Bureau of Mines
U.S. Department of the Interior
Washington, DC 20241

13. Type of Report & Period Covered Cooperative agreement, FY 1976

14. Sponsoring Agency Code

15. Supplementary Notes

Approved for release by Director, Bureau of Mines, November 24, 1976.

16. Abstracts
This report presents a case for modified in-situ oil shale retorting process in combination with surface retorting of higher grade shales. Examples and costs use Lease Site C-b as example to illustrate concept. The report indicates a combination of recovery methods that will improve resource recovery on Site C-b.

17. Key Words and Document Analysis. 17a. Descriptors

Oil shale
In situ retorting
Surface retorting

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group 17C, 10A, 11H

18. Distribution Statement
Release unlimited by NTIS.

19. Security Class (This Report) UNCLASSIFIED

20. Security Class (This Page) UNCLASSIFIED

21. No. of Pages

# Evaluation of Combined In-situ and Surface Retorting of Oil Shale Tract C-b

Prepared for:
United States Department of
the Interior, Bureau of Mines

By:
Shell Oil Company
Mining Ventures Department
Houston, Texas 77001

Final Report
on
Cooperative Agreement No. 14-09-0070-653

Bureau of Mines Open File Report 116-76

November 1976

1a

# Evaluation of Combined In-situ and Surface Retorting of Oil Shale

## Tract C-b

by A. P. Grossman

This report was prepared by Shell Oil Company, Mining Ventures Department in accordance with Cooperative Agreement No. 14-09-0070-653 dated September 10, 1976, between the United States of America, Department of the Interior, Bureau of Mines and C(b) Shale Oil Project, Ashland Oil Inc., Shell Oil Company, Operator.

After completion of this report the Shell Oil Company withdrew from participation in the C(b) Shale Oil Project and advised the Bureau of Mines that plans for publication of this report had also been withdrawn.

The Bureau of Mines acting under terms of the Cooperative Agreement hereby releases this report for general information.

> "The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Bureau of Mines or of the U. S. Government."

Shell Oil Company
Mining Ventures Department
September 17, 1976

## Abstract

The modified in-situ oil shale retorting process utilized in conjunction with surface retorting of the mined-out shale is economically more attractive than either in-situ or surface retorting alone. A combination case considered for Tract C-b would produce 54,000 barrels per day of coked and hydro-stabilized shale oil. Initial capital cost was estimated at $620 million (1976 $). On a constant dollar basis, the DCF rate of return is 12% for oil product valued at $12.50 per barrel. Potential improvements in the in-situ process could significantly reduce the product value required to obtain a satisfactory rate of return. Resource recovery is greatly increased by this combination retorting approach, compared to conventional room-and-pillar mining in the Mahogany Zone with surface retorting.

## Introduction

Shell and Ashland Oil, Inc., as joint venture partners on Federal lease tract C-b in Colorado, have diligently attempted to develop an economically viable project to produce shale oil on this prototype lease. This billion dollar project entails very large technical and economic risks. On top of this, Congress has superimposed price controls, is contemplating severely restrictive non-degradation amendments to the Clean Air Act, and threatens dismemberment of the oil companies. These obstacles forced two of the original partners in this venture to withdraw at the end of 1975.

Nevertheless, Shell and Ashland continued the project and obtained a one-year suspension of the terms of the lease, effective September 1, 1976. This will allow time for study of alternative mining methods that might increase resource recovery and improve the economic viability of the project. One method under consideration is a combination of modified "in-situ" retorting and surface retorting. This report summarizes the results of a screening type economic evaluation of this alternative.

## Basis for Cost Estimates

Yield data for in-situ retorting of oil shale has generally been related to the results obtained by the Bureau of Mines in their 150-ton Laramie (now ERDA) pilot plant.[1] Additional data has been obtained by Mobil Research and Development Company, and utilized in modeling the in-situ process.[2,3] However, use of this data and other available rock mechanics information to develop a realistic mine design and to estimate the mining and retorting costs of the "modified" in-situ process remains a formidable task. In our judgement, the best published approach to the problem is that taken by Fenix and Scisson, Inc., (F&S)

under contract to the U.S. Bureau of Mines (Contract No. S0241073). The Phase I report on this project was released to the public in January, 1976.[4] From the various mine designs considered by Fenix and Scisson, two basic approaches were considered for detailed study in Phase II of their contract. This detailed study has been completed and a report is expected to be available before the end of the year.

In order to minimize lag time, Shell entered a cooperative agreement with the Bureau of Mines which provided early access to the Phase II study of Fenix & Scisson. This enabled us to proceed expeditiously with our commitment, in our request for the lease suspension, to consider alternatives which might achieve a greater ultimate recovery of the oil shale resource on Tract C-b. With certain adjustments to reflect operations on Tract C-b, capital and operating costs for in-situ retorting were taken from the Fenix and Scisson study.

All shale removed in the mine development and to create a 25% void volume in the in-situ retorts was processed in surface facilities which included 3 parallel TOSCO-II retorts. Costs for the surface facilties were primarily scaled from the Colony plant design.[5]

## In-situ Retort Development

The basic Fenix and Scisson plan utilized for this evaluation has two access levels. The upper level within the retort is a "drill station" and the lower level room provides most of the void volume required for rubblization. A plan section of the retort, at both the upper and lower levels, is shown in Figure 1. A 100 ft. square central pillar is retained in the 220 ft. square retort to prevent subsidence. Eight blasting relief holes, each 8 ft. in diameter, are bored in the retort by raise drilling. Blast holes are then drilled, loaded with ammonium nitrate at a powder factor of 0.65 lb./ton, and the shale rubblized.

In Phase II, Fenix and Scisson evaluated retort heights of 230, 380, and 530 ft. With approximately 1000 ft. of overburden, as is the case on Tract C-b, only the 230 ft. retort height was feasible within the design constraints. This case was modified slightly for the C-b evaluation by allowing only 15 ft. of height in the drill room as compared to 30 ft. in the F&S design.

Core hole data from Tract C-b indicate a maximum room-and-pillar mining height of 78 ft. (average) in the Mahogany Zone. A preferred mining section of 35 ft. average height assays almost 42 gallons per ton (gpt). It is preferable to mine as much of the desired void volume as feasible from this rich section for two reasons:

1. Liquid yields from surface retorting (e.g. TOSCO II Process) are 95-100% of Fisher Assay (F.A.) as compared to an estimated 60% yield by in-situ retorting. Overall yield is therefore improved by retorting the richest shale on the surface.

2. Richer shales are more susceptible to plastic deformation than lean shale. In-situ retorting of these richer shales could cause non-uniform gas distribution and/or excessive pressure drop.

On this basis, the F&S mining plan was modified for Tract C-b as shown in Figure 2. The "swell room" was split into 2 sections with 23 ft. in the richest zone. The lower access level was also mined within this rich zone. To achieve the desired 215 ft. retort height, the retort was extended upward 137 ft. above the 78 ft. identified mining zone. It would be preferable to extend the retort below this mining zone where the shale averages greater than 20 gpt and to keep the richest (42 gpt) shale at the top of the rubble bed. (This reduces the adverse effect of bed height on the more easily deformed rich shale.) However, rock quality is poorer is below the identified mining zone. This is not expected to be a limiting factor in in-situ retorting, but as a conservative approach for a screening evaluation it was decided to assume development only in the higher quality rock above the mining zone.

## Surface Facilities

This screening type economic evaluation is premised on the combination of modified in-situ retorting and surface retorting of the mined-out shale. The overall processing concept is shown in Figure 3. The liquid product from the in-situ retorting is pumped to the surface as an oil and water emulsion. It must be separated and the water suitably treated for further plant use. This minimizes the requirement for external supplies of clean water. The emulsion and water treating facilties were included in the Fenix and Scisson study.

The F&S study assumed flaring of the low-Btu off-gas from these retorts. This will probably not be an acceptable disposition of the off-gas due to both economic and environmental considerations:

a. A minimum requirement would be to scrub the hydrogensulfide from this gas before flaring.

b. The gas will likely carry along appreciable quantities of oil and dust as a mist in the vapor. Venturi scrubbers or other mist-separation devices are required to clean the gas and recover the entrained oil.

c. Although the off-gas has a low heating value (say 60 Btu/SCF), it represents on the order of 25% additional liquid yield on an equivalent Btu basis.

Economic means must be developed to utilize this heat value within the plant, either for power generation or as fuel for the surface processing facilities. (This fuel could generate over 300 MW of electricity from the 54,000 B/D plant assumed in this study.)

The surface retorts were assumed to be the TOSCO II type for which reliable design and cost estimates are available from the Colony project. This requires secondary crushers to reduce the shale to less than 1/2 inch size. Oil product from both the in-situ and surface retorts goes to a common fractionation system which strips out the gas components and removes the $900^{o}F$ + residual fraction. The latter is processed in delayed cokers so that the final oil product will have an end-point of about $925^{o}F$. The viscosity and pour point of the residue-free shale oil are also reduced to make a product that can be shipped to distant markets via conventional pipeline facilities. The residual feed to the cokers will contain appreciable mineral matter, as very fine particles. This must be removed by high-temperature centrifuges or other means, prior to coking, to produce a salable coke product.

Earlier evaluations of the Colony[5] and C-b Project[6] have shown that severe, high-pressure hydrotreating of the shale oil product to very low nitrogen levels increases the product cost by $4 to $5 per barrel. There is a strong incentive to eliminate this additional capital and operating cost, at least for the first prototype plants. Considering the high risk of such plants, utilizing as yet commercially unproven technology, the added investment on-site for hydrodenitrification unnecessarily compounds the risk. Prototype or modular demonstration plants should therefore be designed to produce no more than a transportable and saleable synthetic fuel. Any additional processing should be done in existing refineries. In fact, some limited direct blending of high-nitrogen shale oil fuel fractions with low nitrogen fuels may be feasible for certain applications.

Concern has been expressed that raw shale oil is a highly unstable material and excessive gum and polymer will form during transport, storage, and in direct use as a fuel. Such observations result primarily from the diolefins present in most high-temperature pyrolysis products. These diolefins can be selectively saturated by hydrostabilization at relatively low temperature over conventional hydrotreating catalysts. We estimate the hydrogen consumption for this stabilization at about 100 SCF per barrel of feed, compared with approximately 1800 SCF per barrel for severe hydrodenitrification. Sufficient hydrogen may be available from the TOSCO II retort off-gas to supply the 100 SCFB hydrogen required solely for stabilization. We have assumed this high-Btu product gas would be treated with diethanolamine (or other amine) to remove essentially all $H_2S$ and $CO_2$. The hydrogen can then be recovered at high purity by cryogenic separation with molecular sieve guard beds. It should be further noted that available proprietary processes can be utilized in conjunction with the hydrostabilization unit to remove arsenic from the shale oil. It is well known that arsenic is readily removed from oil feeds over conventional hydrotreating catalysts. The proprietary processes represent modifications that increase the arsenic retention capacity of the system before a change in catalyst is required.

Gulf Research & Development Co. has tested the combustion properties of hydrostabilized shale oils[7] and found them to be stable in storage and cleaner burning than conventional oil fuels of equivalent boiling range. The adverse aspect of such hydrostabilized shale fuels is still the high $NO_x$ emmissions. Heat exchanger tests at the Shell Development Co. laboratory have indicated that raw shale oil has a lower fouling tendency than some conventional crude oils. Further research is required on the optimum refinery processing or other utilization of such high-nitrogen shale oils.

## Capital and Operating Costs

Investment and operating costs for the combined system are shown in Table 1. The inital capital expenditure required to reach the full production capacity of 54,000 B/SD is over $600 million, in constant 1976 dollars. This does not include lease bonus payments, which at this time are $71 million for Tract C-b, nor other sunk costs for environmental background monitoring, engineering studies and preparation of the Detailed Development Plan. Shaft costs are higher than indicated in the F&S study; this reflects an adjustment based on a site-specific engineering estimate for the C-b Project. The higher cost may be due largely to the need for concrete lining and grouting to prevent water influx from the upper acquifer on the C-b site. The surface plants include the emulsion and water treatment plants from the F&S studies plus gas demisting, cooling and quench facilities.

The quench facilities warrant futher elaboration. The F&S study did not allow for cooling the recycle and off-gas from the retorts. During the first portion of a retort combustion, the gas stream will be adequately cooled by downstream rubblized shale. However, as the combustion front advances, the effluent gas temperature at the bottom of the retort increases eventually to 800-900°F. This gas may be quenched with recycle process water, requiring additional condensing facilties on the surface with related pumps, piping to the retorts, and water sprays in the outlet gas lines.

As mentioned earlier, the low-Btu off-gas from the in-situ retorts is both a problem and an opportunity. It could be used to generate over 300 MW of power in combined-cycle gas and steam turbines, if the gas turbines can be designed to burn satisfactorily on this low-Btu fuel. Alternatively, a conventional steam power plant could be built with a mixture of fuels - e.g. low-Btu gas plus by-product coke. For purposes of this study, it was assumed that the off-gas had zero value but not capital or operating costs were included for gas compression, selective low-pressure $H_2S$ removal (e.g. Stretford or Shell's MDEA process), or power generation. A detailed design study of this portion of the system will be required to determine if the off-gas is an asset or a liability.

## Production

Net oil plus condensate (LPG) production for the combined in-situ and TOSCO II surface retorts is estimated at 54,000 B/SD. This is based on a liquid yield from the in-situ retorts of 60% of Fisher Assay (F.A.) and a net liquid yield (after subtracting internal fuel requirements) from the surface retorts of 92% of F.A. By-products are 40,000 LT/year of sulfur and 230,000 T/year of coke.

This base case assumes the F&S mine design as applied to Tract C-b and shown in Figures 1 and 2. From this design, 45% of the oil is produced via surface retorts and 55% via the in-situ process. Total oil production over a 30 year plant life would be on the order of 510 million barrels. This represents a 55% increase in resource recovery relative to the estimated 330 million barrels that could be produced solely by room-and-pillar mining in the Mahogany Zone with all surface retorting.

## Economic Assessment

Discounted cash flow calculations were made at several oil price levels to obtain a curve depicting annual rate of return as a function of the value of the shale oil product. All calculations were based on constant 1976 dollars. The oil price can therefore be related to the current cost of imported oil and the controlled price of domestic oil. As a first approximation, the rate of return will be close to the "true" return on investment if product prices inflate at the same rate as the inflation of construction and operating costs. All calculations assume 100% equity investment.

Other premises used in this evaluation are as follows:

- Lease bonus and other sunk costs are not included.
- Development period is 8 years including 3 years for demonstration tests of the in-situ process.
- Full production is achieved in the third year after start-up. Production in the first and second years is 50% and 75%, respectively, of design capacity. On-stream factor is 0.90.
- Depletion allowance is 15% on the retorted product.
- Federal plus State Income Taxes are 52% of gross.
- Investment tax credit is 7% taken after plant startup.
- Federal royalty is 21¢/barrel.
- Project life is 30 years.
- By-product coke and sulfur are valued at $20/ton and $10/long ton, respectively.

Results of this evaluation are shown in Figure 4.

The value of the 925$^{o}$F end-point shale oil has been estimated at $12.50/bbl at the plant site. At this price, the annual rate of return is about 12%.

For comparison, prior studies of surface retorting only, with product coking and hydrostabilization, indicate a 9.5% annual rate of return. Furthermore, total resource recovery is only 330 million barrels with Tract C-b able to support a 52,000 B/SD plant for only 20 years.

An evaluation was also made of in-situ retorting alone, assuming the mined-out shale is discarded. This case is shown on Figure 4, for comparison with surface retorting and the combined operation. The same basic C-b mine design was used except that the entire 38 ft. high "swell room" was located at the bottom of the retort to achieve maximum recovery from the richest shale in the Mahogany Zone.

Results of these three cases are summarized in the following table:

| | Surface Retorting | In-situ Retorting | Combination |
|---|---|---|---|
| Capital Investment, $MM | | | |
| Initial | 775 | 300 | 620 |
| Deferred | 150 | 230 | 220 |
| Total | 925 | 530 | 840 |
| Operating Cost, $MM/yr. | 51 | 60 | 69 |
| Annual Rate of Return, % (Oil at $12.50/bbl) | 9.5 | 8.9 | 11.8 |
| Required Oil Price for 10% Annual Rate of Return, $/bbl | 13.10 | 13.40 | 10.90 |
| Production, MM bbl. | 330 | 290 | 510 |
| Bbl/stream day | 52,300 | 30,500 | 54,100 |
| Project Life, years | 20 | 30 | 30 |

This study shows the advantage of preferentially creating as much of the required in-situ retort void volume as feasible from the richest shale layers and retorting this shale in surface retorts. The potential rate of return for the combined operation appears high enough to justify further consideration for development of Tract C-b.

## Occidental's Modified In-situ Process

So far as we have been able to determine from published literature, the principal difference between Occidental's process and the concepts used in this study lies in their mine design. By rubblizing to a "bulked full" retort, Oxy claims the rubble provides sufficient support to the barrier pillars and roof to permit areal extraction efficiencies of 60 to 70%.[8,9] This concept also permits retorting greater depths of shale without subsidence and therefore greater resource utilization in the vertical dimension. However, we are not aware of any confirmatory data that would substantiate Oxy's mine design.

The significance of this mining concept, if it can be proven in practice, can be demonstrated basis the C-b design shown in Figure 5. Retaining the basic F&S mine layout (Figure 1), the retort was extended downward 300 ft. from the top of the Mahogany mining zone. Surface retorting of the mined shale plus in-situ retorting at 60% of F.A. yield gives a 30 year oil production of 675 MM bbl (70,000 B/SD). This still represents only 40% areal extraction efficiency. At the 60% areal recovery claimed by Occidental and the same 300 ft. retorting zone, ultimate oil recovery is increased to over 900 million barrels (97,000 B/SD) - again assuming combined surface and in-situ retorting.

Equally important to this design concept is the potential reduction in unit costs. At the higher area recovery factor, development mining (tunnels and drifts) is much less relative to retort mining. In this respect, it is similar to the stripping ratio factor in surface mining. In addition, the extra height of the retort increases the in-situ yield proportionately while increasing operating costs only marginally.

## Other Design Considerations and Research Suggestions

In-situ yields above 60% of F.A. are entirely feasible. This is largely a matter of developing good control of the blasting technique to obtain reasonably uniform rubble size, good gas distribution with a horizontally uniform combustion advance rate, further optimization of process variables, and minimizing secondary reactions that form gas and coke. Some reported data also indicate that liquid yield (expressed as a % of the F.A. yield) increases at higher shale richness, other variables being constant. Occidental[10,11] report yields of 70-75% F.A. from 25 gpt shale, compared to 50-60% F.A. from 10 gpt shale. The in-situ retorted shale used for the combination base case in this study (Figure 2) averaged 24 gpt. If the yield from the in-situ retorts is taken as 75% of F.A. (relative to 60% in the base case), overall production would be increased 14% and the rate of return on investment would increase from 12 to 13%.

while cooling the rock. This steam can be used to displace recycle gas in other retorts, with the same effect as described above.

Additional research is also needed in retorting shales well above 30 gpt. Limits at which plastic deformation causes plugging or excessive pressure drop must be defined.

Finally, improved modeling of the in-situ process and its many variables is needed. Excellent work along these lines is in progress at the Lawrence Livermore Laboratories. Additional data for in-situ design is being developed in a sophisticated experimental retort of 127 kg. capacity. The results of these studies should be helpful in the ultimate recovery of the world's largest oil shale reserves in the Piceance Basin of Western Colorado.

## Political Uncertainties

In spite of the potential improvement in the economic viability of shale oil production indicated by these studies, it appears unlikely that any company will commit several hundred million dollars to a commercial project until the major political obstacles are no longer perceived as being a significant threat. We refer here to pending legislation to dismember the major oil companies, to add severely restrictive non-degradation amendments

Another possibility that warrants further testing was suggested by M. Prats of Shell Development Co. Mike recommends considering the deliberate injection of water, in a manner similar to wet combustion techniques used in secondary recovery methods on oil fields. Potential advantages of such a process include:

1) more efficient heat transfer from the burned out section downstream to the retorting zone, which should result in a faster advance rate of the retorting front,
2) improved removal of liquid products by the resultant steam drive, reducing secondary reactions that form coke and gas, thereby increasing liquid yields,
3) moderation of peak temperatures, thus reducing carbonate decomposition, $CO_2$ generation, heat requirements, and further increasing the rate of advance of the retorting front,
4) promotion of water-gas shift reactions that convert organic matter to CO and $H_2$,
5) improvements in the heat transfer coefficient between the vapor stream and solids, and
6) perhaps eliminate the need for recycle gas, thus yielding higher-Btu off-gas after steam condensation.

As the retorting front passes the bottom of the retort, oil yield decreases rapidly and retorting will be terminated. Residual heat in the spent shale can be used to generate steam to the Clean Air Act, and to continuation of crude oil price controls. If shale oil is produced in commercial quantities, will Congress <u>then</u> include it under controlled prices at a level that prohibits a return on investment commensurate with the risks involved?

An additional concern that will have to be resolved before commitment to a commercial venture relates to safety regulations that will apply to in-situ retorting. Safety aspects of all underground mining operations are monitored by the Mining Enforcement and Safety Administration (MESA) of the U. S. Department of the Interior to insure compliance with Federal regulations. Pending legislation (HR 13555 and S 1302) may transfer this function to the Department of Labor where it will be combined with their function of enforcing OSHA regulations. For in-situ retorting, a variance or eventual modification of one regulation will be required. This one is:

> 57.4-58 MANDATORY. Fires shall not be built underground; open flame torches and candles shall not be left underground.

Additional regulations are under consideration that may prohibit or severely restrict the use of diesel equipment in underground mines. These and perhaps other pending safety legislation must be clearly defined and their economic consequences carefully considered before proceeding with development of in-situ technology.

## Conclusion

There appears to be sufficient potential economic incentive to justify continued research and development of the modified in-situ shale retorting technology. Commercial application of this technology should be considered in conjunction with surface retorting of the mined-out shale. The latter should preferentially be excavated from the richest layers of shale deposits.

## Acknowledgement

Appreciation is expressed to the U. S. Bureau of Mines for making available to Shell, prior to normal public disclosure, the results of the Fenix and Scisson in-situ retorting study. The study was done under BOM Contract No. S0241073. Access to this study was under terms of a Cooperative Agreement dated August 6, 1976, between the BOM and the C-b Shale Oil Project. Special thanks are due to Mr. R. B. Stone, Fenix and Scisson's Project Manager, for his cooperation and assistance in reviewing and analyzing the design and cost data contained in their report.

# REFERENCES

1. A. E. Harak, L. Dockter, A. Long, and H. W. Sohns. Bureau of Mines R. I. 7995 (1974), "Oil Shale Retorting in a 150-Ton Batch-Type Plant."

2. P. W. Snyder, T. H. Timmins, and W. F. Johnson. "Evaluation of In-situ Oil Shale Retorting." Presented at NSF Workshop on In-situ Oil Shale Retorting, Univ. Calif., San Diego, LaJolla, Calif., Sept. 3-7, 1974.

3. W. F. Johnson, D. K. Walton, H. H. Keller and E. J. Couch. "In-situ Retorting of Oil Shale Rubble: A Model of Heat Transfer and Product Formation in Oil Shale Particles." Presented at 8th Oil Shale Symposium, Colorado School of Mines, April 17-18, 1975.

4. R. B. Stone, et. al. "Technical and Economic Study of an Underground Mining, Rubblization, and In-situ Retorting System for Deep Oil Shale Deposits." USBM Contract No. S0241073. Phase I Report, August, 1975, NTIS No. PB-249.344.

5. R. G. Vawter, "Shale Oil Production Costs." Presented at the February, 1976, ACS Symposium on Commercialization of Synthetic Fuels in Colorado Springs.

6. R. E. Meeker. Record of March 17, 1976, hearings on Senate Bill S.2413 before the Committee on Interior and Insular Affairs, Subcommittee on Minerals, Materials and Fuels.

7. E. R. Dzuna. "Combustion Tests on Shale Oil Fuels." Presented at the Spring meeting of the Central States Section of the Combustion Institute, April 1976, in Columbus, Ohio.

8. R. D. Ridley. Testimony on May 14, 1974, before Energy Subcommittee of the House Committee on Science and Astronautics.

9. H. E. McCarthy. "In-situ Oil Shale - Resource Recovery." Presented August 31, 1976, at the Annual Meeting of the American Chemical Society in San Francisco.

10. H. E. McCarthy, C. Y. Cha. "Development of the Modified In-situ Oil Shale Process." Presented at the 68th Annual A.I.Ch.E. Meeting in Los Angeles, November 1975.

11. C. Y. Cha and D. E. Garrett, "Energy Efficiency of the Garrett In-Situ Oil Shale Process." Presented at the Eighth Oil Shale Symposium, Colorado School of Mines, April 17-18, 1975.

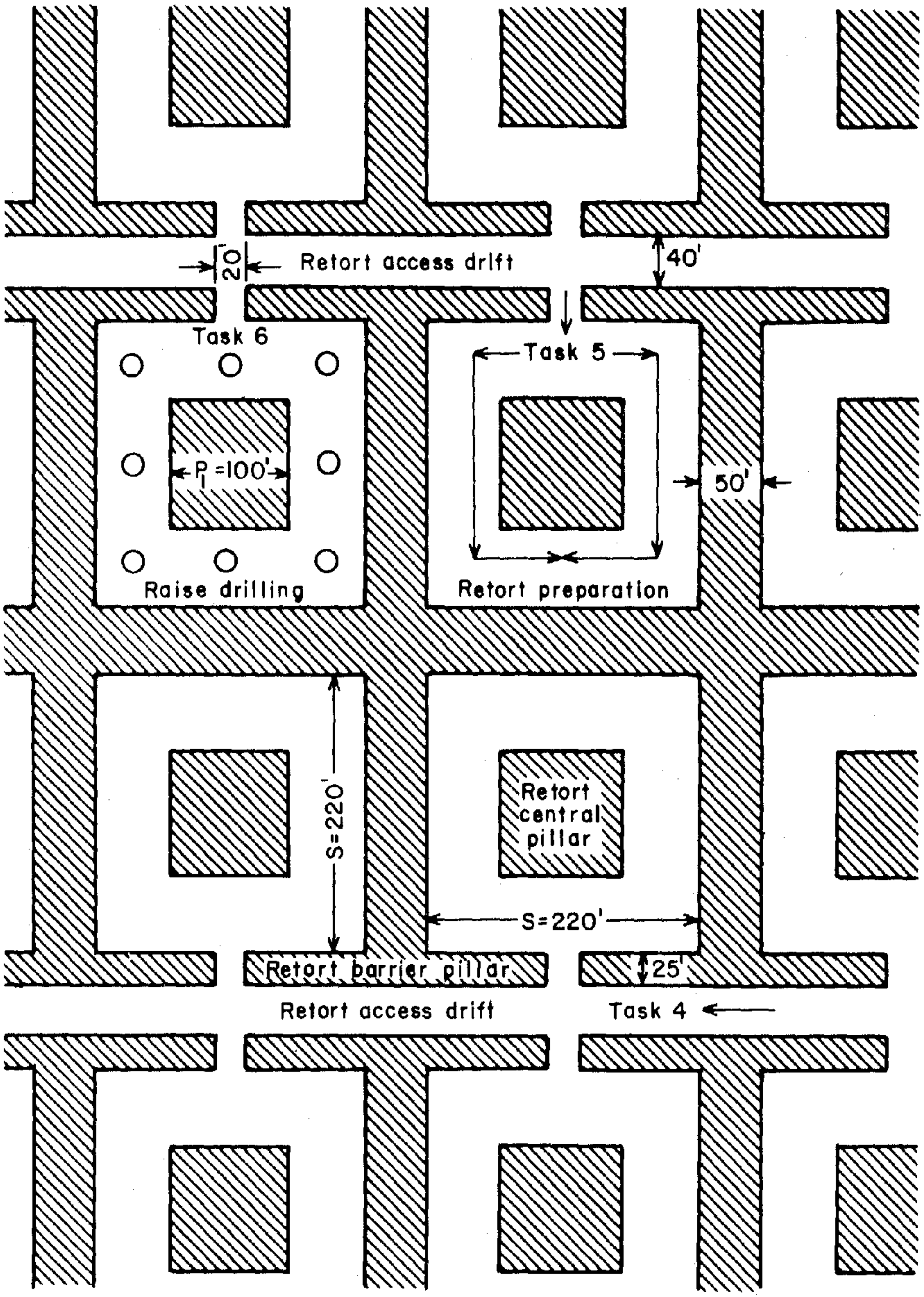

FIGURE 1.– In-Situ Mine Design by Fenix and Scisson, Inc.

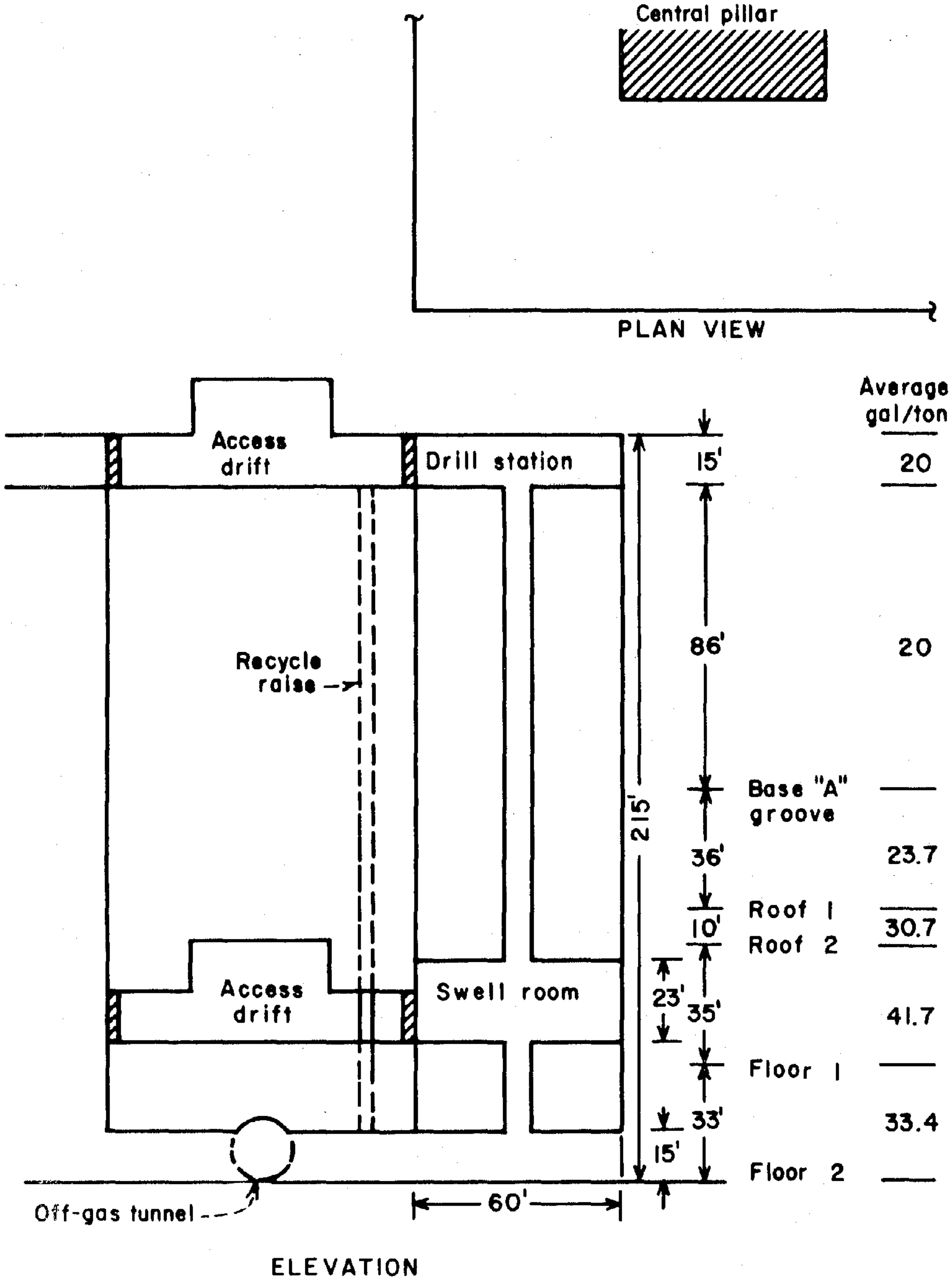

FIGURE 2.-Tract C-b In-Situ Retort Development

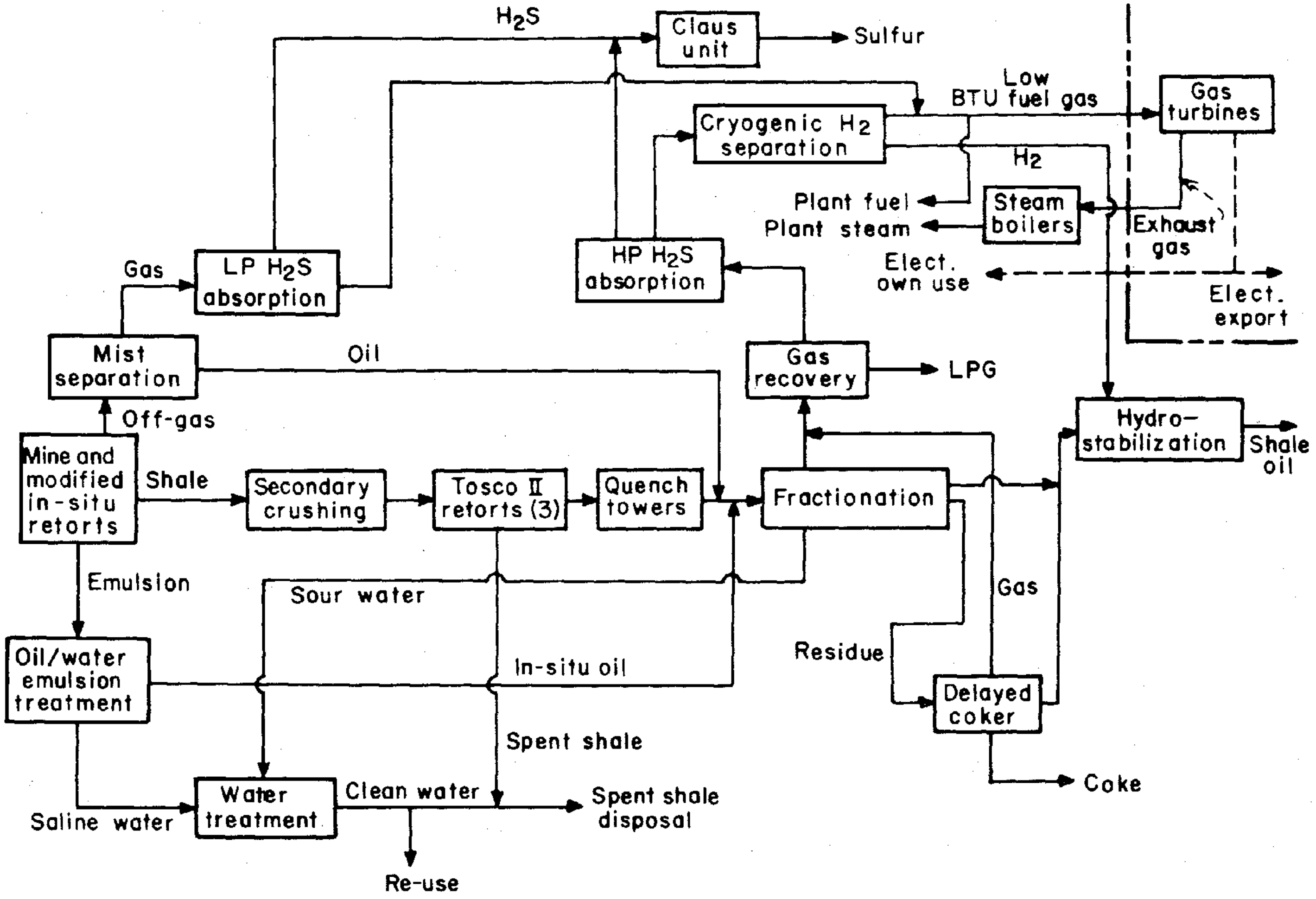

FIGURE 3.-Block Diagram-Combined In-Situ and Surface Retorting

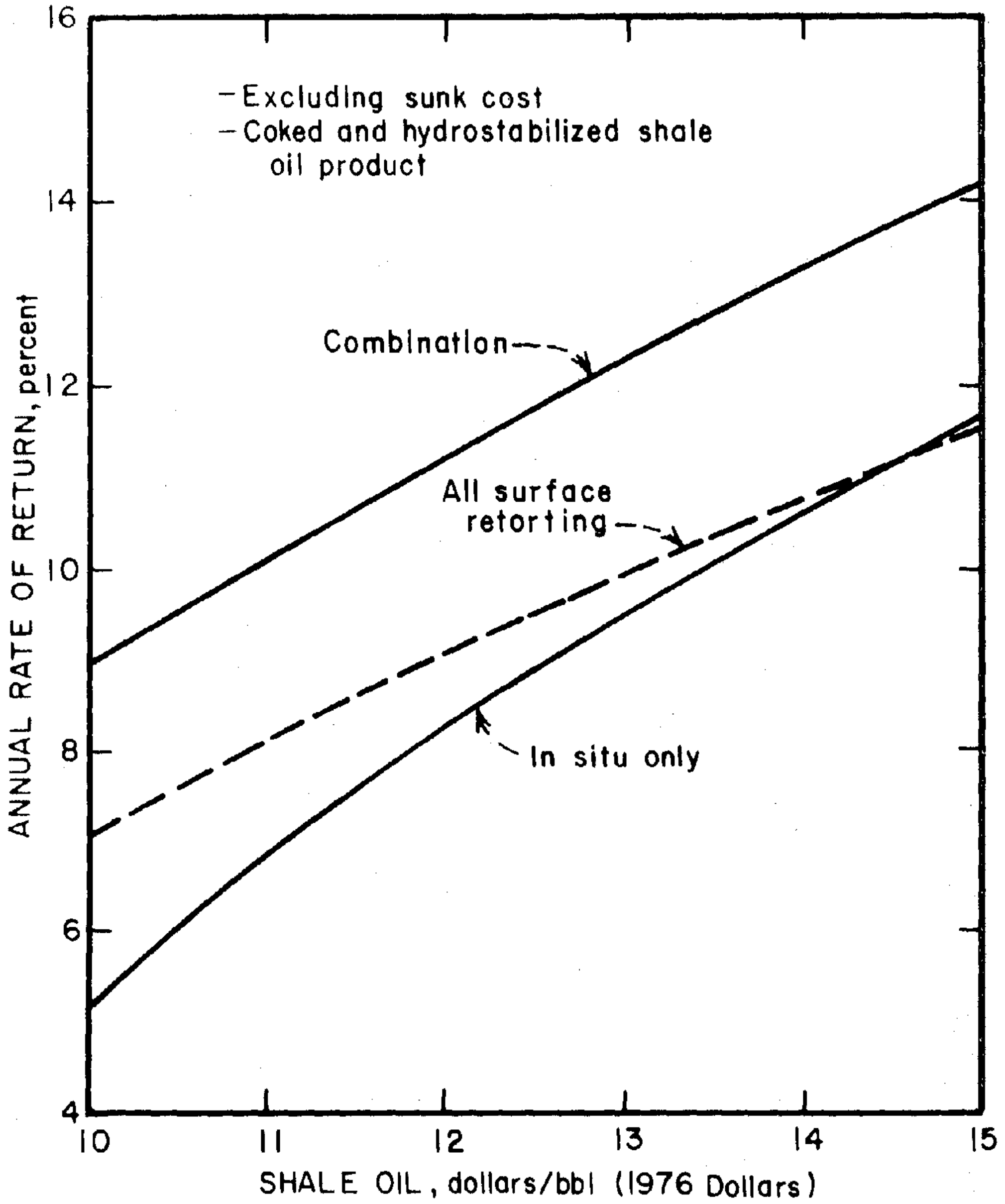

FIGURE 4.- Tract C-b, Priliminary Evaluation Combination In-Situ/Surface Tosco Retorts

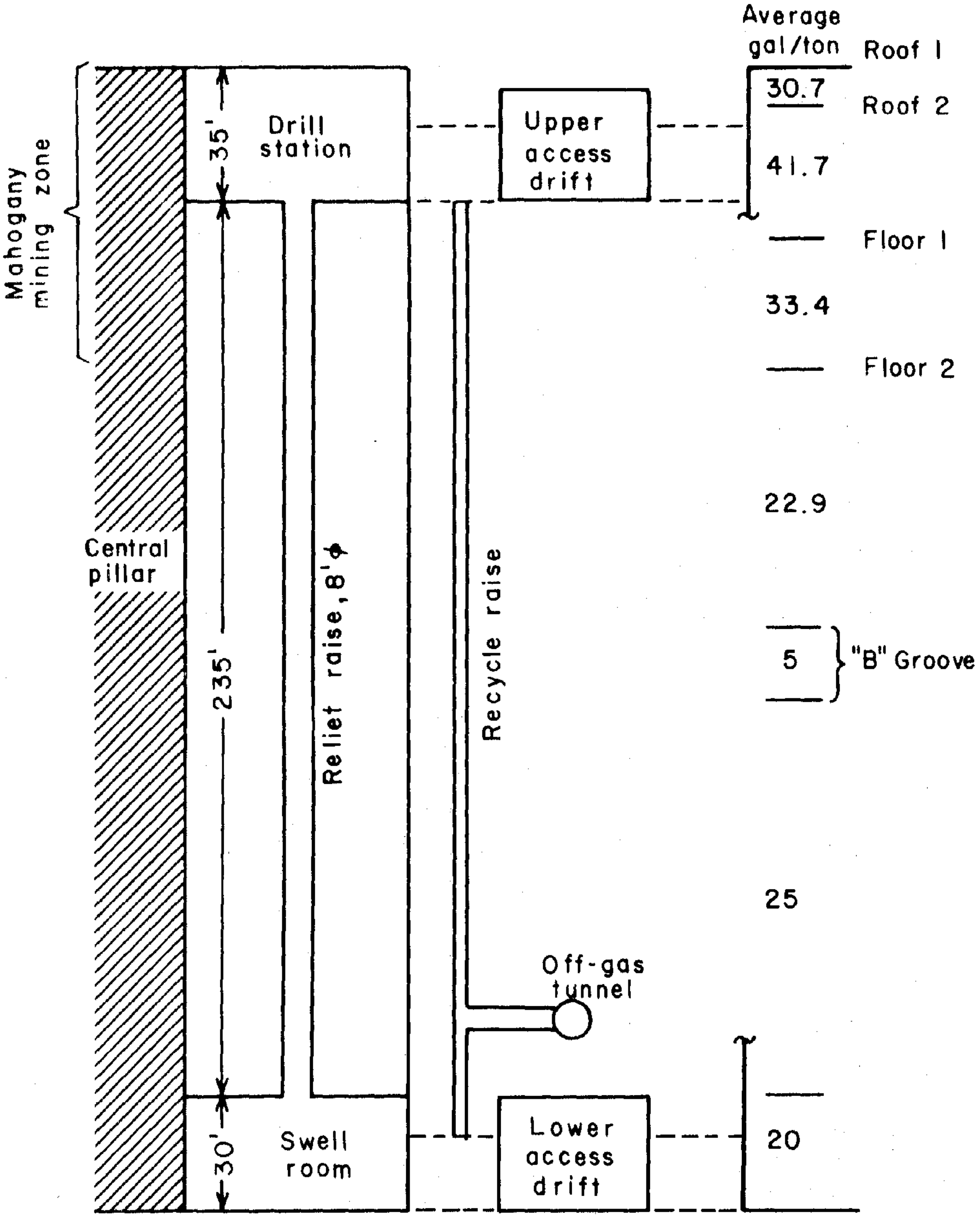

FIGURE 5.-Alternate Design for 300 ft Retort Height.

## Table 1

## Combination In-situ and Surface Retorting

Capital Investment ($MM, 1976)

| | |
|---|---|
| In-situ Retorting: | |
| Surface Plants | 8.3 |
| Shafts, Tunnels, Drifts | 56.6 |
| Retort Development & Operation | 58.9 |
| Crushing, Ore Handling, Spent Shale Disposal | 65.4 |
| Surface Pyrolysis | 141.7 |
| Process Facilities | 126.6 |
| Utilities and General Facilities | 120.6 |
| Predevelopment, Community Assistance and Miscellaneous | 38.4 |
| | 616.5 |
| Deferred Mining Equipment ($7.7MM/year average) | 223.3 |
| | 839.8 |

Operating Costs ($MM, 1976)

| | |
|---|---|
| Annual cost, at full capacity | 69 |
| Initial in-situ demonstration | 70 |