ECONOMIC ANALYSIS OF DEEP SEABED MINING SYSTEMS: EFFECTS OF PRODUCTION RATE, INFLATION AND DEPLETION USING A REVISED FINANCIAL MODEL

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ABSTRACT

The effects of several variables affecting the economic performance of proposed manganese nodule mining ventures were evaluated using an improved version of the Texas A&M University's Ocean Mining Payout Analysis Program. After tax Internal Rate of Return (discounted cash flow) was used as the primary criterion of performance along with total funding requirements. Variables studied included ore production rate (throughput), processing plant location, construction period, depletion, corporate structure type, processing plant type and financing. Metal pricing used in the analysis was "normal" 1970's pricing which (with the exception of cobalt) is higher than current metal prices. Overall results show that favorable combinations of the variables can produce after tax rates of return as high as 30 to 35 percent.

The "pioneering" ventures (analyzed in 1982 and 1983) with 1.5 and 3.0 million dry tons per year throughput were scaled up to 4.5 and 9 million tons by using a large collector, larger capacity lift pipe, mining ship or ships, ore transport systems and scaled up ore processing and waste disposal systems. Significant economies of scale were present in going from the 3 million ton to the 4.5 million ton four-metal system, although diminishing returns are setting in at the 4.5 million ton throughput. No further improvement was seen in going from 4.5 to 9.0 million ton throughput.

A high throughput base case venture was used as a point of reference for additional studies and was defined as follows:

1. Throughput of 4.5 million dry tons per year,
2. Ammonia leach process with limited manganese production,
3. Parent/subsidiary corporate structure,
4. Inflation rate of 5 percent for both costs and metal prices,
5. A loan of 75 percent of the fixed capital at 10 percent interest rate and a 15 year payback period,
6. "First marketable product" depletion computation used,
7. Four-year construction period and
8. Southern California location for processing plant.

The high throughput base case shows an after tax Internal Rate of Return of 25 percent requiring an initial investment of 2.1 billion dollars.

Results of the effects of corporate structure, processing plant location, construction period, inflation/interest rate, depletion and process type are summarized as follows. The base case with integrated parent/subsidiary corporate structure Internal Rate of Return was 25 percent while for the independent company the corresponding Internal Rate of Return was 19 percent. Moving the processing plant to the Pacific Northwest with lower electric power rates increased Internal Rate of Return to 31 percent. Going to the slow construction period reduced Internal Rate of Return to 24 percent and net corporate funding increased to 2.2 billion dollars.

Taking a lower inflation rate for metal prices than for cost inflation drastically reduced Internal Rate of Return. Reducing price inflation to 2.5 percent (1/2 of cost inflation) reduced Internal Rate of Return to 11 percent, a drop of 14 percentage points. Zero price inflation with 5 percent cost inflation resulted in negative Internal Rate of Return. This result underscores the importance of metal pricing on nodule mining economics.

Using the more conservative "first chemical change" interpretation for depletion reduced Internal Rate of Return to 22 percent. Removing depletion entirely reduced Internal Rate of Return to 20 percent for the base case.

Four alternative processes: 3 metal ammonia leach, 4 metal ammonia leach full manganese, smelting partial manganese and smelting full manganese were evaluated for the base case. The results are summarized in the table below indicating Internal Rate of Return and capital requirements.

Alternative Process	IROR (Percent)	Net Corporate Funding Billions of 1982 Dollars No loan
1. NH_3 Leach, 3 metal, no manganese	19	1.7
2. NH_3 Leach, 4 metal, full manganese	27	2.3
3. Smelting, partial manganese	22	2.2
4. Smelting, full manganese	28	2.4

The 3 metal leach process shows a lower Internal Rate of Return (19 percent) and lower capital requirements. Smelting with partial manganese recovery reduces Internal Rate of Return slightly and shows a slight increase in up-front capital. The smelting and ammonia leach full manganese production options show some increase in Internal Rate of

Return but a higher initial investment. This Internal Rate of Return increase may not actually occur because manganese overproduction would tend to depress the price below the value used in the study.

ACKNOWLEDGEMENTS

The authors wish to thank the project monitor, Mr. John Padan of National Oceanic and Atmospheric Administration's Ocean Minerals and Energy Division, for the general guidance and helpful suggestions. Dr. Francis C. Brown prepared the cost estimates and text for Sectors 6 and 7 of the High Throughput Mining System chapter. Mr. Benjamin V. Andrews performed the costs estimates for Sections 1-5 and 8 of the Mining Systems chapter and most of the text of the Payout Analysis chapter and devised the ocean mining depletion tax treatment in Appendix C. Mr. Gerard McCoy, a graduate student at Texas A&M University, rewrote the Ocean Mining Payout Analysis Program primarily under the guidance of Mr. Andrews. Mr. McCoy performed all the computer computations. Dr. Allen H. Magnuson devised the articulated nodule collector (Figure 1) which provided the rationale for the high throughput base case. He also worked out the run strategy for the analysis of the alternative systems. Professor John E. Flipse provided general inspiration and guidance on the cost analysis and economics and contributed astute engineering insight throughout the project.

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INTRODUCTION

This report is primarily a study of the economic effects of the further scaling up a first generation or "pioneering" mining venture. Previous studies [Flipse, 1982; Andrews, et al., 1983]* have investigated throughputs as high as 3 million dry tons of manganese nodules per year. The purpose of scaling up this operation is to determine economies of scale present whereby venture returns are improved by decreasing unit costs. Scaling up is accomplished by duplicating system components (parallel trains), increasing component utilization by increasing flow rates, speeds, or by scaling up sizes and capacities of components.

The report does not describe a second generation mining system. Rather it is a study of scaling up the technology of "pioneering" ventures. No high-risk departures in the system functions or processes are made which would require major expenditures for research and development. Research and development is restricted to design problems in scaling up of system components, updating of electronics, control and sensor systems, onboard computers, and various mechanical refinements to subsystems.

The new venture is vertically integrated like the original. As a result, the whole process, from production and exploration to deep ocean mining to ore processing, is done by one corporate entity. The venture may be financially independent or a subsidiary of a parent corporation.

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*Square brackets indicate references listed at the end of the report.

In either case the functioning and structure of the mining and processing operation is the same.

Like most engineering efforts in the ocean, the venture is capital intensive requiring on the order of a $2 billion investment before any income is produced. The magnitude of the investment combined with the high technical, legal, economic risks of the venture means that potential yield on the investment must be quite high before it becomes economically feasible. Previous studies [Flipse, 1982, Andrews, et al., 1983] at Texas A&M University have indicated that nodule mining economic rates of return are too low to justify proceeding unless major improvements in the metals marketplace occur or if special government incentives or subsidies are introduced.

The present study is an outgrowth and extension of the earlier studies by Flipse [1982] and Andrews, et al. [1983] in which the economic merit of the venture is computed from the corporate cash flow for each year of operation. The internal rate of return (IROR), sometimes called the discounted cash flow, is computed as well as capital recovery factors and payback periods both before and after taxes.

The current study investigates other effects beside economies of scale. This has been done by estimating costs for the full range of variables studied and by extending the capabilities of the Texas A&M University Ocean Mining Payout Program. The modified program takes into account:

* tax depletion deductions applicable to nodule mining operations,
* corporate structure alternatives: independent and parent/subsidiary and
* inflation.

Cost data has been generated for the full range of throughputs to investigate effects of fast and slow construction periods, various extractive processes for nodule ore and an alternative location with more favorable electric power costs. The high throughput system descriptions and cost estimates are presented in the next chapter. Succeeding chapters describe the modified Texas A&M University Ocean Mining Payout Program and the results of the economic analysis.

Project Objectives

The objectives of the study presented here are to:

1. Prepare a scenario, and define mining, transportation, processing and waste disposal systems for nominal 5 and 10 million dry tons per year of manganese nodules yielding four products: manganese, nickel, copper and cobalt, under optimal U.S. conditions and location.
2. Estimate the capital and operating costs of these systems in 1982 U.S. dollars.
3. Modify the Texas A&M University Ocean Mining Payout Model to permit analyzing the returns from this system under the most recent taw law, examining:
   - alternate percentages of debt and equity
   - various tax alternatives
4. Revise the Texas A&M University Ocean Mining Payout Program to include, as practical, simultaneous evaluations of debt, inflation, depletion, and integrated corporate taxation, with the basic cost and payout analysis.
5. Prepare a comprehensive report presenting the findings, defining system sensitivities and providing recommendations for future work.

High Throughput System Conceptual Design

Increasing mining system throughput (ore production rate) must start on the ocean floor where the nodules are collected. The best low risk approach appeared to be towing a number of first generation collectors using a towing bridle. The towing bridle would be designed to allow each sled-type collector to pivot and contour the bottom independently while sweeping out a wider swath of nodules on the bottom. An assembly of three collectors was chosen. The combination significantly increases production while avoiding being excessively cumbersome and complicated. A diagram of the three-collector system is shown in Figure 1 with an A-frame towing bridle. The figure indicates an unpowered collector although the concept is equally applicable to self-propelled collectors. The diagram is suggestive of the concept from a functional standpoint, but should not be interpreted as being an actual design or even approximately to scale.

The nodule-seawater slurry from each collector is fed to a buffer/mixer unit suspended from the towing cable. The slurry is then fed from the mixer to a flexible hose that connects with the bottom of the lift pipe. Sidescan sonar mounted on the hose may be used for sensing for obstacle avoidance as the collector assembly must move sideways further because of the wider swath width.

Directly scaling up a first generation collector (with a nominal 60-foot swath) may create problems as the wider unit would not conform as well to the bottom topography. Increasing the towing speed is another possible approach. The approach was eliminated because it would require extensive streamlining (hydrodynamic design) in addition to causing difficult maneuvering and control problems. In either case it would be

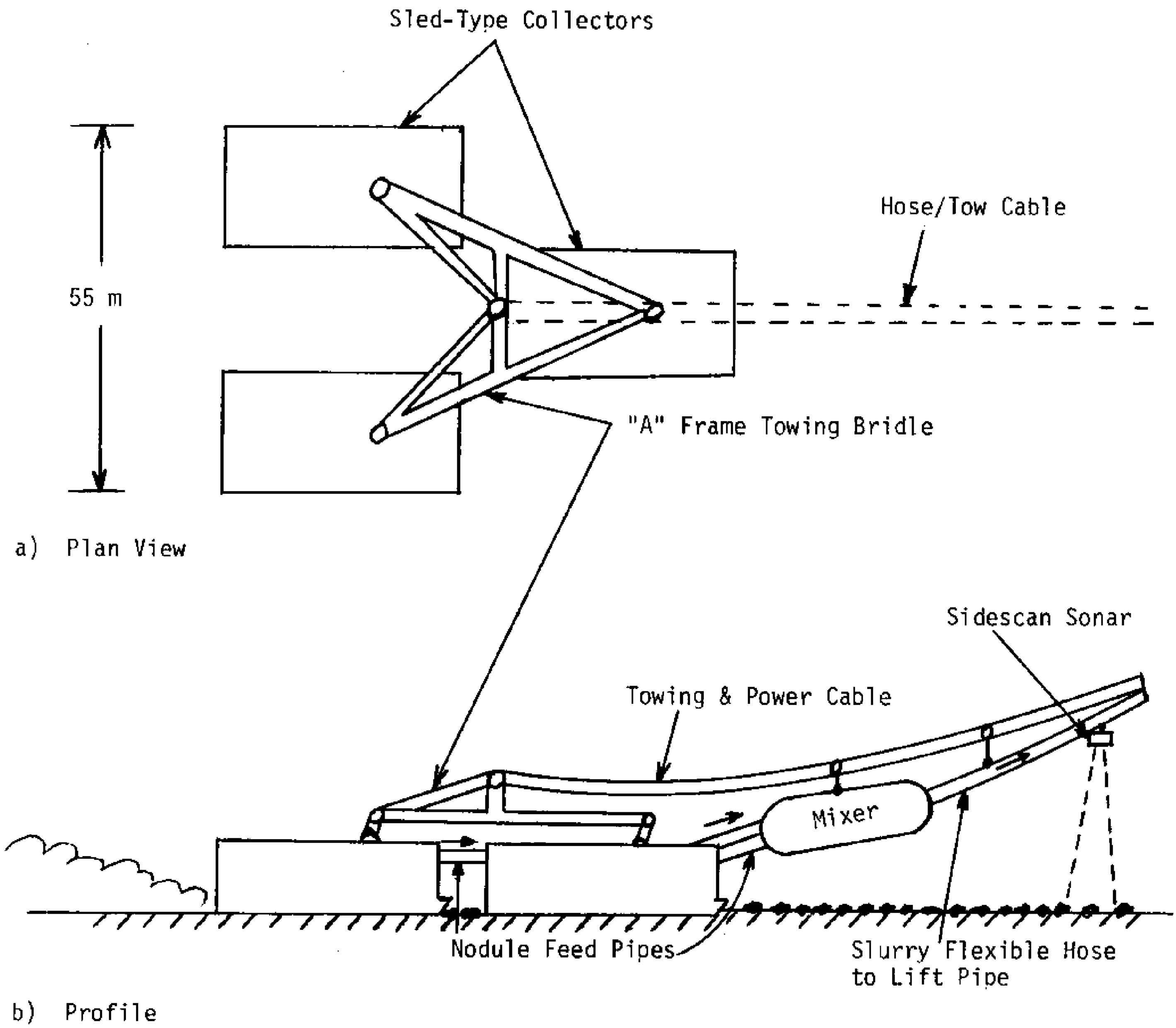

Figure 1. High Throughput Nodule Collector Assembly - Schematic Diagram

difficult to develop meaningful cost estimates due to the drastic departure from "pioneering" venture designs as developed by the four major consortia in the 1970s.

Going further "downstream", (i.e. in the direction of the nodule flow) the collector output is fed to a single larger diameter hose/lift pipe. The nodules are elevated to the water surface by hydraulic means either with an air lift system or in-line pumps or a combination. The miner ship may be somewhat larger than the first-generation ship to accommodate more buffer storage of nodules and the heavier weights and larger sizes of the collector assembly and lift pipe. The higher throughput is accommodated by the ore transport ships by increasing the number of transport ships because their size is limited by harbor channel depths. Port terminal facilities and land transport system capacities are suitably scaled up to increase the system throughput, as are the ore processing plant and waste disposal facilities. The scaling up is described quantitatively in the next chapter.

Economies of Scale

Economies of scale occur when a given system components' output or performance (throughput) is increased with a proportionately smaller increase in capital and/or operating costs. For example, the lift pipe capacity can be tripled by increasing its diameter by a factor of $\sqrt{3}$ for the same nodule concentration and flow velocities. If the pipe wall thickness remains about the same (which would be the case) the pipe weight will increase by a factor of $\sqrt{3}$ or about 1.7, thus giving economies of scale in weight and ultimately in capital cost.

There are usually limits to the amount of scaling up one can do for a given system component. When the limit is reached one must revert to parallel trains whereby one duplicates components. This results in virtual elimination of economies of scale, particularly with respect to capital costs.

Sometimes it is feasible to increase throughput by increasing component utilization or speed of performance. For example, one can increase lift pipe throughput by increasing ore concentration in the slurry and/or by an increase in flow velocity. The pipe weight will remain essentially the same, giving economies of scale in capital. The approach may result in degradation in performance and/or efficiencies and is limited in scope. One can increase lift pipe flow velocity only so much before pipe friction decreases flow efficiency. This results in proportionately higher pump power consumption affecting operating costs. In addition, higher flow velocity and higher nodule concentration will increase pipe wear on the inside walls reducing the working life of the pipe, increasing maintenance and capital costs.

The nodule collector assembly in Figure 1 uses the parallel-train approach. In fact, there is a diseconomy in scale here because of the added weight and cost of the A-frame towing bridle. Since the collector cost is small relative to the total system, significant economies are achieved further down the mining process (e.g. in the lift pipe and mining ship). The economies are described in more detail in the next chapter in the sector breakdown.

Estimating Methodology for Economies of Scale

Estimation of capital requirements as a function of throughput involves two elements. One is determination of the largest sized item(s) of equipment that can be used before parallel trains are required. The second is determination of equipment costs as a function of capacity up to the maximum size. The latter is normally done through use of cost-capacity data presented in the literature which are of the form:

$$\text{Cost} = \text{Constant} \times (\text{Capacity})^n$$

Each class of equipment items is characterized by a capacity parameter which reflects the most important sizing parameter, such as tank volume, heat exchanger area or thickener diameter. In the case of equipment item assemblies, such as the tank house of a boiler system, capacities are expressed in terms of output. An example would be tons per day of copper or thousands of pounds per hour of steam. The constant is a function of the specific design of the equipment; material of construction for a heat exchanger, tank design pressure, and fuel used in the boiler. These data are generally available in the literature and for most items of process equipment the value of n ranges from 0.6 to 0.8. Thus, for a cost-capacity exponent of 0.6, the throughput of an item of equipment can be doubled for 50 percent increase in cost and economies of scale are thereby obtained. For assemblies of equipment items, particularly for large items, the value of n may range from 0.8 to 1.0 and economies of scale are less pronounced. Use of parallel trains to double capacity implies a cost-capacity exponent of 1 and consequently no economies of scale.

Maximum equipment sizes for normal conditions are usually known, at least approximately, so the limit of single train capacity can be defined. However, operating considerations may dictate that the "break" to parallel trains should occur at lower throughputs to increase plant reliability. Once a break has occurred, it should be possible to redouble capacity and take advantage of economies of scale unless it is decided again to break to a third train before equipment limitations are encountered.

In addition, the question of the use of installed spares must be addressed. A single "spare" furnace or converter might be installed in a 1-1/2 million ton throughput smelter to allow for normal maintenance time for rebricking, etc. However, doubling plant capacity may not call for the installation of a second spare.

Cost Estimates and the Texas A&M University Ocean Mining Payout Program

The Texas A&M University Payout Program has undergone considerable evolution in the past few years. The original model based on a cash-flow analysis [Flipse, 1982] was intended for hand calculations or a desk-top computer. The analysis was refined and extended in its applicability in Andrews, et al. [1983] and further extensions are described in a subsequent chapter of this report. The program in its present form is relatively complex and is used on a "main frame" computer and produces considerable input/output printing.

The Texas A&M University Ocean Mining Payout Program on an input-output basis is shown in Figure 2. System inputs include capital and operating costs for each cost sector of the integrated venture. Metal prices, ore assay and ore processing efficiencies are other inputs governing income or revenues. Various options having to do with financial computations such as taxes, financing, corporate structure and inflation are also inputs.

The outputs are various indices of the economic merit of the venture and are solely functions of the inputs and the computer program

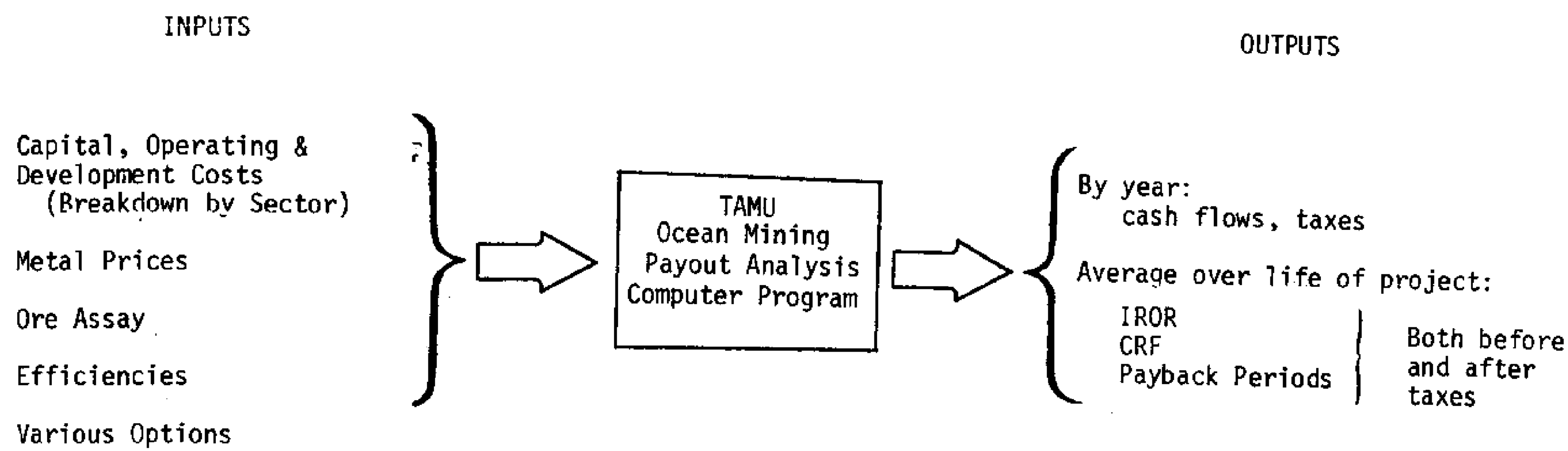

Figure 2. Texas A&M University Ocean Mining Payout Analysis: Input-Output Diagram

structure. The outputs include year-by-year printouts of cash flows, taxes, etc. and economic indices computed by averaging over the life of the venture. The major indices are internal rates of return (IROR) (or discounted cash flows), capital recovery factors (CRF) and payback periods and are computed both before and after taxes.

Computer program outputs are only as good as the inputs. The Ocean Mining Payout Analysis Program is only a small part of the analysis of a given venture. Generating cost data is a major undertaking and is critical for the success of the analysis. The input cost data generation process is shown in block diagram form in Figure 3. One starts with overall mining system performance specifications. These may be functional such as type of process and quantitative such as system or subsystem production rate. These specifications are used to develop a system conceptual design. The conceptual design consists of a general functional layout and an operational scenario. In the overall process the layout and operational scenario follow the ore as it progresses through the system.

For convenience, the overall system is broken down into functional cost sectors. Costs in each sector are estimated using various models and methods. These methods vary considerably depending on the nature of the sector and availability of a data base. For instance, ship costs (mining ship, transport ships, research vessels and supply craft) are estimated using standard naval architectural procedures [Andrews, 1978]. Ship hull structure costs are related to cubic number and an extensive (proprietary) data base is available. There is no data base for ocean floor mining system costs. Scaled down pilot systems were built and tested in the 1970s and proprietary cost data has been inferred or extrapolated from these

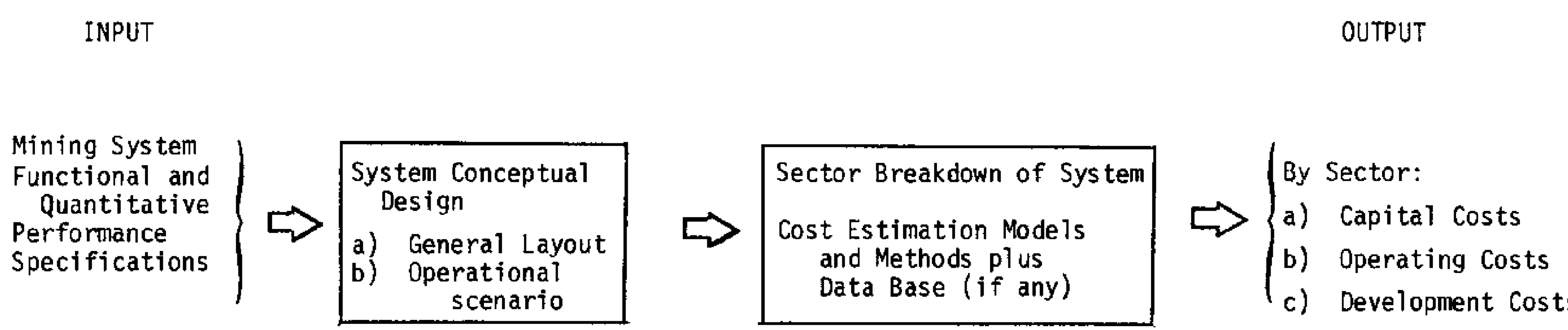

Figure 3. Generation of Cost Input Data for Texas A&M University Ocean Mining Payout Analysis Program

early results. Nodule processing costs can be developed from a step-by-step breakdown of the overall process and an extensive proprietary data base exists for each step. Labor costs can be generated from manning tables and data for each sector is suitably broken down into subsectors or sub-subsectors.

Manganese Production

The primary motivation for mining manganese nodules has been their copper, nickel and cobalt content. However, the manganese, which is present in much larger proportions (29 percent by weight, on the average) is also valuable and can increase profitability significantly. The four-metal study of Andrews, et al. [1983] showed a considerably improved rate of return over the earlier three-metal Flipse [1982] study.

Manganese is produced in enormous quantities for the four-metals venture. This can be a problem since the manganese production can easily equal or exceed total U.S. consumption, causing severe disruptions of traditional sources and possible marketing problems. The overall effect would be to further depress the price of manganese.

The present study attempts to deal with this issue in a simplified fashion by treating a processing option of limited manganese production where only the first 3 million tons of ore (annually) is processed for manganese and the processing falls back to three-metals after this level is attained. This limits ferro-silico manganese production to less than 1 million tons per year which is about one-third the predicted U.S. consumption in 2000 A.D. The ferro-silico manganese production as a function of nodule throughput used in this study is shown in Figure 4 for both full and limited production. In Figure 4 the projected U.S. consumption of

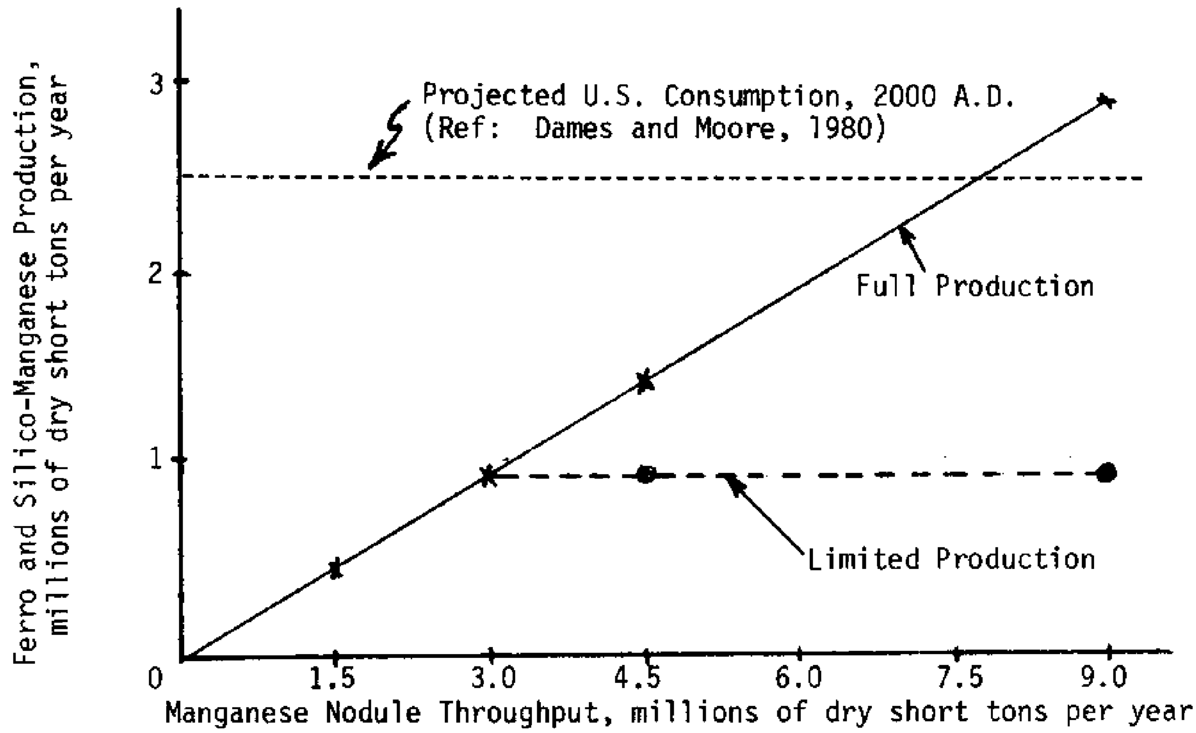

Figure 4. Manganese Production Versus Throughput:
Ferro- and Silico-Manganese Total

ferro-mayanese for 2000 A.D. is shown as 2.56×10^6 tons per year. This figure was obtained from a Dames and Moore [1980] projection of 2×10^6 tons consumption of elemental manganese for 2000 A.D. The ferro-manganese consumption was obtained from the elemental consumption by dividing by 0.78. The full production line in Figure 4 was obtained by multiplying the nodule ore throughput by the assay of 25 percent and the recovery (smelting) of 93 percent.

Texas A&M University Ocean Mining Payout Program Modifications

Other options were considered beside throughput. Accordingly, modifications were made in the program, (the program was actually rewritten) and additional input data was generated. Additional variables analyzed included:

1. Depletion deduction computations,
2. Debt and inflation
3. Electric power costs together with location of processing plant
4. Type of ore processing, and
5. Corporate structure

Descriptions of how these options were implemented are given in subsequent chapters.

HIGH THROUGHPUT MINING SYSTEMS

The introduction described the high throughput nodule collector system shown in Figure 1. The new collector triples the nodule collection rate over the pioneer collector analyzed in Flipse [1982] and Andrews, et al. [1983]. This is the basis for scaling up the throughput for the whole system down through the processing and waste disposal sectors. Four system throughputs are treated here: 1.5, 3, 4.5 and 9 million dry short tons per year. The 1.5 and 3 million ton throughputs are achieved by using the pioneering collector for one and two of the pioneering mining ships, respectively. The two higher throughputs, 4.5 and 9 million tons, use the articulated collector and one and two larger miner ships, respectively.

The overall integrated mining system is broken down into sectors for cost estimating convenience. The cost sectors used in Flipse [1982] and Andrews, et al. [1983] have been revised to simplify calculation of the depletion deductions for taxation. The sectors are now:

1. Prospecting and Exploration
2. Mining
3. Marine Transport
4. Marine Terminal
5. Onshore Transport
6. Processing

7. Waste Disposal

8. Mining Support

9. Research and Development

10. General and Administration

The revisions to Sectors 1 and 8 are small and are defined below. Also, preparatory period (year 0) expenses are analyzed using the same sectors for the same reason.

Preparatory Period Expenditures

Most U.S. Corporations have a long-range planning capability in the form of a company officer, a comittee of the board of directors or a consultant to the chairman of the board and the chief executive officer (CEO). We assume this entity has investigated the high throughput venture to the extent that the CEO will authorize, with Board approval, $3 to $5 million for a two-year preliminary Research and Development effort to:

1. Organize a research team headed by a capable manager;
2. Search the literature;
3. Interview officers of companies currently engaged in ocean mining
4. Complete a patent search;
5. Perform bench tests in refinements in nodule processing and metal winning;
6. Perform subsystem tests (or witness vendor and supplier subsystem demonstrations) of scaled up ocean mining equipment;
7. Study the manganese, nickel, copper and cobalt markets to forecast future key metal prices;

8. Design, test and use an economic computer model consistent with that company's business and financial practices, to determine the potential rewards of the deep ocean mining venture; and
9. Prepare design criteria, specifications and plans, schedules, and budgets for a research and development program to meet the commercial objectives.

The above activity in the "Preparatory Period" may precede Prospecting and Exploration and Research and Development called for in the schedule, or it may be done during the first two years of that period.

Research and Development in the Preparatory Period

Assuming that the findings of the effort are favorable and corporate interest is sustained or heightened, the Research and Development program will be conducted over a 10-year period, for approximately $140 million, assumed to be about half spent on mining systems and therefore shown for cost sectors and tax purposes as split between Sector 2 for mining and Sector 9 for processing Research and Development. These Research and Development costs are largely independent of the number of mining ships built, or throughput of the different process plants. Such a program would produce:

1. Component and subsystem tests of the marine mining sector, leading to full scale tests of mining system components in the laboratory and at sea.
2. Mini-pilot plant testing of process refinements and improvements, followed by: a one-tenth to one-twentieth (approximately) scale demonstration plant of the chosen process, yielding metal tonnage for market testing, product evaluation and future sales contracts.

3. Refined cost estimates leading to further runs of an enhanced payout model.
4. Preparation of contract plans and specifications for the mining equipment and system, transportation equipment and system, and the processing equipment and system.
5. Submission of test and environmental monitoring data to National Oceanic and Atmospheric Administration, and receipt of a permit for commercial operations.

Prospecting and Exploration in the Preparatory Period

The first technical problem facing the ocean miner is prospecting for locating, defining, mapping and evaluating one or more seabed deposits of manganese nodules. The exploration of the major consortia greatly simplifies the initial surveillance for deposits, but extensive wide-grid observations are necessary to define and evaluate the mineability of a discovery. The major U.S.-affiliated consortia will have licenses for mine sites in the Clairon-Clipperton zone for the first generation operation. Their sites must be extended considerably or entirely new sites must be surveyed for the high throughput operations as more area will be mined at higher rates.

Many current advances in acoustic sensing, computation and bathymetric surveying will be applicable to this high throughput venture. Improved exploration and surveying systems should speed up the preliminary surveillance phase for potential mine sites. Automatic bottom mapping systems (Sea Beam, Sea Marc and Gloria) produce bottom contours for 1-5 kilometer beam swaths along the survey vessel's track. An acoustic multi-frequency exploration system has been developed that automatically plots and prints out nodule abundance and size along the vessel's track at or near cruising speed (Magnuson, 1983). Fine grid surveys including microtopography can be made with improved deep tow vehicles with the latest sidescan sonar equipment and automated data processing.

The major expense is one or more research or survey vessels to provide working platforms, hotel, and transportation to and from the area to be explored. These ships would normally be small, of 30 days endurance or more, diesel-propelled, seaworthy and unfortunately slow. A ship measuring just under 300 register-tons avoids stringent manning and operating regulations and is large enough to prove satisfactory as a working platform. Photography, television, and sampling, provide data on nodule coverage, population, analysis and assay. Cores also provide geotechnical data for scientific correlation and design of mining equipment. The vessel is kept on station by thrusters and main propulsion, while satellite navigation systems pinpoint the ship's position. Oceanographic data such as sea state, temperature and wind speed and direction used for scientific or engineering purposes are obtained by standard equipment.

After a deposit is judged mineable, a close grid survey is conducted to confirm the judgement and provide data for preparation of a mining plan. The seabed topography and the presence of obstacles must also be determined.

To keep ahead of the mining operation and to ensure retention of the skilled team and maintenance of the equipment, exploration will continue for the duration of the program. Details vital to the mining plan will be obtained on a timely basis; servicing the seabed acoustic range will be a periodic chore; and placing monitoring arrays, conducting surveys, and prospecting for future mine sites will use all available time.

General and Administrative Expense, Preparatory Period

Before the GO decision [Flipse, 1982], the business, marketing and planning management and technical team is used to supervise and evaluate the preparatory period activities. Their work continues during the construction and production phases. The management staff consists of well-paid professionals working in rented quarters using rented equipment. Ten years at $4 million annually has been estimated as the total general and administrative overhead expense for all processes and plants. These organizational costs in the preparatory period may require different tax treatment from the Research and Development and Prospecting and Exploration expenditures.

The estimated total cost during the preparatory period of the Research and Development and Prospecting and Exploration programs prior to the GO decision is $195 million in 1982 for the 1.5 and 3.0 million dry short tons per annum cases. Because of the large areas that must be explored for the larger throughput plants, the Prospecting and Exploration cost (Sector 1) in the preparatory periods is increased by $30 million at 4.5×10^6 tons p.a., and by $60 million at the highest throughput of 9.0 million tons.

Tax Treatments, Preparatory Period

The manner in which the preparatory period costs can be handled in the 1984 payout analysis includes three alternative tax treatments for pre-construction expenses described above:

1. Parent costs, where the Research and Development and Prospecting and Exploration expenditures by the parent, less the parent's tax savings, are shown as cash outflow in Year 0, at the start of the payout calculation. At the time of the GO/NO GO decision, the investor-parents have already expensed these costs against other income as allowed by the tax code, probably deducting almost all of them. Therefore, benefits from further tax deductions for these costs are unlikely. The parent corporation will consider the net (after tax) preparatory period expense as a loan to the integrated subsidiary if it succeeds and can repay these preparatory period expenses.
2. Written off now, when the monies are spent. This practice would allow the mining company (not the parent) to develop a tax-loss carryforward that must now be used within 15 years of the date the write-off is experienced. This practice is now allowed by the 1982 Tax Equity and Fiscal Responsibility Act (TE&FR) and is used frequently by U.S. companies. This approach would also be necessary for a new partner to buy into a consortium by paying his share of the preparatory expenses in Year 0. The method of writing off the full amount was used in Andrews, et al., 1983, and may properly be used by the independent mining venture.
3. Capitalized, and written off over the life of the project is the most conservative approach and was used in Flipse [1982] because of the old tax interpretations of the Internal Revenue Service prior to the 1982 law. Capitalization of Research and Development and of organizational expenses (General and Administrative) is sometimes differentiated from capitalization of exploration costs. The conventional amortization of

preparatory costs over the production period provides the least immediate benefits to cash flow and was not utilized. The new organizational expenses of the independent company are amortized over five years beginning with production startup.

The three methods can all be utilized in the Texas A&M University payout model. All cases show a cash outflow in Year 0.

Processing Plant Location

Costs vary depending upon the location of the nodule processing plant. Two alternatives are treated in this study: Southern California with 11 cents per kilowatt hour electric power and the Pacific Northwest with 3 cents per kilowatt hour electric power. The low rates for the Pacific Northwest are a result of plentiful hydroelectric power. (These low rates may not still be available in the time frame of the venture. However, a relative difference in rates will most likely still exist.) Ore transport costs will also vary because the distance from the mine site to port increases for the Pacific Northwest. Land costs and associated costs also vary. Differences in costs exist for Sectors 3-7 as discussed in the ensuing text.

Construction Period

To evaluate impact of different construction perods, both a fast and slow schedule can be examined for each throughput case. The two plant construction schedules, in years, are shown in Table 1.

The two schedules were intended to bracket the extreme ranges between fast and slow construction periods. For the two miner ship throughputs (3.0 and 9.0 million tons) in the slow schedule, construction and delivery of the second ship is delayed so that partial production from

Table 1. Construction Periods for Various Throughputs

Throughput (Million dry short tons, p.a.)	Mining Ship		Construction Period, years	
	Size	No.	Fast	Slow
1.5	Base	1	4	6
3.0	Base	2	4	8
4.5	Large	1	4	6
9.0	Large	2	6	10

the first ship can at least partially pay for further capital expenditures. This reduces up-front funding requirements. These estimated construction periods assume technical success at all stages and no regulatory or strike delays.

Integrated System Description by Sector

The integrated mining system and its capital and operating costs for the full range of throughputs and other options is described below. The system description is broken down on a sector, and in some cases a subsector basis.

Sector 1 - Prospecting and Exploration

Research vessels must continuously find and define mine sites. The work described in the preparatory period will be continued during the construction and production period.

The analysis assumes no capital funding for this sector because offices, piers, research ships and equipment continue to be leased (as in Preparatory Period Research and Development and Prospecting and Exploration), but operating expenses for the construction period are provided. Definition of the expanding mining site will continue essentially for the life of the program, during the entire construction and commercial production period. During construction, plus 20-year period of output standard for all the cases, the Prospecting and Exploration operating expenses continue. No capital outlay is needed.

For the lowest 1.5 million tons throughput, a 150 foot long research vessel is required, and two of this size would be needed at the 4.5 million tons per annum level to keep up with exploration and environmental monitoring. A slightly larger (200 foot) and more expensive research vessel is needed at the 3.0 million ton level, and three of these larger vessels are needed for the highest, 9 million ton per annum plant. (see Table 2) The research vessel operating costs include charter hire, crews, supplies, maintenance and repair, fuel, and insurance. Purchase of the vessel(s) is not assumed here. Operating costs are shown in Table 2. The vessel will share the marine terminal with the crew/supply boat described in Sector 8.

Table 2. Prospecting and Exploration Costs (Sector 1)

Throughput (Million dry short tons, p.a.)	Research Vessel		Annual Operating Costs (Millions of 1982 Dollars)			
	Length (ft)	Number	Res.Vessel Lease	P&E Staff	Terminal (1/2)	Total
1.5	150	1	3.5	3.0	0.2	6.7
3.0	200	1	4.8	3.0	0.3	8.1
4.5	150	2	6.7	4.5	0.3	11.5
9.0	200	3	13.6	6.0	0.5	20.1

Economies of scales appear in this sector. With multiple exploration ships one can specialize with (perhaps) one ship doing fine-grid sampling, assay and bottom micro-topography work and another doing coarse grid surveys using primarily remote acoustic sensing supplemented by free-fall grab sampling. Scientific/technical party per ship may be reduced as indicated in Table 2 as a result of specialization.

Sector 2 - Mining

This sector includes for the pioneering [Flipse, 1982] and the scaled up high throughput mining ship, all of the mining ship equipment, including the dredge collector head, the pipe and bottom hose and equipment for handling and stowing them, the nodule ore receipt, stowage and handling en route to the transport ship, and replacement of equipment and spare parts. Each of these categories is considered a subsector of Sector 2.

The Mining Ship (Sector 2.1)

The particulars of the base case and larger proposed deep ocean mining ships are presented in Table 3. Details to identify the system elements along with their capital and operating costs were shown in Andrews, et al. [1983]. The base mining ship is essentially a single ship from the two miner ship system described by Flipse [1982].

Table 3. Mining Ship Particulars

	Base Case	Super Miner
Mining rate, wet short tons/day	5,000	15,000
Length LBP	789 ft	870 ft
Beam	145 ft	157 ft
Hull depth	56 ft	74.5 ft
Draft, loaded	42 ft	47.1 ft
Loaded displacement	105,000 LT	145,500 LT
Cargo deadweight	75,000 LT	81,500 LT
Mining equipment	11,000 LT	37,000 LT
Light ship displacement	19,000 LT	27,000 LT
Shaft horsepower	21,000 diesel electric	28,000 diesel electric
Sea speed	14 knots	14 knots
New construction, U.S.A. 1982	$91.6 million	$136.6 million

Both ships are able to enter U.S. ports in light condition. The smaller ship could enter with a load of nodules too, which slightly increases its cost. Both can be ballasted to full draft, permitting better ship control and surface reference during the mining or transfer of cargo. The ship hull is strengthened because of the density of ore and liquid slurry loads.

The main propulsion and power for maneuvering, mining, ballasting, and transfer of ore are supplied by high-voltage A.C. generators driven by diesel engines. The mining ships have twin, controllable-pitch propellers driven by electric motors, and multiple retractable thrusters, both forward and aft. A closable "moon pool" is provided under the derrick and motion compensator. Superior accommodations are provided for between 80 and 100 persons, including ship's and mining crews. The ship's navigation and communication systems include satellite, Telex, Weather Fax and a long-base-line bottom acoustic system. A helicopter landing pad is provided. Current bulk-carrier costs were modified to provide for special features required in mining ships. Resulting costs are shown in Table 4.

Economy of scale appears dramatically in the mining ship (2.1) subsector. It is not necessary to triple mining ship size to triple ore throughput. A slight increase in size is all that is necessary, primarily since a small increase in buffer storage of ore is all that is required because the frequency of transport ship ore transfer at sea is increased (see Sector 3). This may require more sophisticated navigation and control during ore transfer at sea while mining underway.

Handling and Stowage (Sector 2.2)

The costs in the subsector for handling and stowage of mining equipment aboard the mining ship are significant. Equipment includes a crane of 25 tons capacity for the small ship or 80 tons for the large ship for launching and retrieving the collector; winches and racks for handling hose and pipes connecting the collector to the miner ship, handling of the in-line dredge pumps and the long power and signal cables essential to the operation of the system. Other components include a pipe transfer system, derricks, a gimbal platform, a pipe lowering and lift system, and a heave-compensation system. The systems are designed to accommodate a 3- or 6-million-pound suspended full pipe and collector load for the smaller and large ship, respectively. The estimated cost of the equipment is $23.5 million for the small and $59 million for the large mining ship.

Pumping System (Sector 2.3)

The pumping system selected consists of multi-stage, motor-driven, mixed-flow pumps located in the dredge pipe string, that pump through the dredge pipe handling system on the gimbal platform. The mining control center provides system data readouts, stress monitoring, television monitoring, and a control computer provided with manual override. The small system uses 14,000 horsepower, the larger about 35,000 horsepower. The estimated costs are $13.8 million and $41 million for the small and large systems, respectively.

Dredge Pipe and Bottom Hose (Sector 2.4)

The selected dredge pipes have clamp couplings, are of high strength welded steel, and have the following characteristics:

	Small	Large
Length	18,000 ft	18,000 ft
Size	12 inches I.D. (constant diameter)	17 inches I.D.
Thickness	1/2" minimum with stepped increases	1/2" minimum
Pipe weight	2,300,000 lbs	4,000,000 lbs
Pipe weight with joints	2,875,000 lbs	5,000,000 lbs

The large dredge pipe has twice the cross-sectional area of the small pipe. The throughput of the large pipe is tripled by also increasing the nodule concentration and the flow velocity of the slurry.

A 20-ton (wet) deadweight is employed at the lower end of the small pipe string, but is not needed on the larger pipe because of the heavier collector (Figure 1). Special pipe sections provide for the pump and motor installation, instrumentation and controls, valves,and attachment for the bottom hose. The pipe is painted on the outside with inorganic zinc and coated on the inside with an abrasion-resistant epoxy material. Stand-offs are provided to attach the cables and support the permanently installed non-buoyant fairing or splitter plates. The soft connection between the dredge pipe and the collector(s) is provided by a 1,200-foot buoyant, crush-resistant, high-tensile-strength hose.

Costs were estimated from industry data and parametric analysis. The cost in 1982 dollars is $17.5 million for the small and $35 million for the large pipes and hoses.

Collector (Subsector 2.5)

The collector must move across the ocean floor at a speed of one to two knots, separating the nodules from the sediments and delivering nodules to the dredge pipe inlet. A typical small collector would be approximately 60 feet wide [Flipse 1980]. The higher throughput collector is about three times larger, in segments as shown in Figure 1. The collector is a proprietary element of the system, and can deliver to the dredge pipe nodules clean of clinging sediments. The collector must negotiate small obstacles, while avoiding or going around major obstacles. It can temporarily store excess nodules while it meters into the dredge pipe the correct quantity of nodules to ensure high productivity without overloading the pipe. It is outfitted with a sidescan sonar system to sense obstacles on the bottom.

A single small collector would cost approximately $1.5 million. A second collector equipped with a spare hose would bring the total cost of dredge-heads and hoses for one small miner ship to $3.5 million and $10 million for a larger miner.

Ore Handling (Subsector 2.6)

This sub-sector identifies equipment used to transfer the mined ore from the dredge pipe to the mining ship and from the mining ship to the ore carriers. The system includes a hose-and-pipe equipment to accommodate the relative ship/gimbal platform movement, while transferring the nodule and water mixture to a separator where the bottom sediments are returned to the sea and the nodules and recaptured abraded nodule material (fines) are deposited on a conveyor. A conveyor distributes the nodules

	Small	Large
Length	18,000 ft	18,000 ft
Size	12 inches I.D. (constant diameter)	17 inches I.D.
Thickness	1/2" minimum with stepped increases	1/2" minimum
Pipe weight	2,300,000 lbs	4,000,000 lbs
Pipe weight with joints	2,875,000 lbs	5,000,000 lbs

The large dredge pipe has twice the cross-sectional area of the small pipe. The throughput of the large pipe is tripled by also increasing the nodule concentration and the flow velocity of the slurry.

A 20-ton (wet) deadweight is employed at the lower end of the small pipe string, but is not needed on the larger pipe because of the heavier collector (Figure 1). Special pipe sections provide for the pump and motor installation, instrumentation and controls, valves,and attachment for the bottom hose. The pipe is painted on the outside with inorganic zinc and coated on the inside with an abrasion-resistant epoxy material. Stand-offs are provided to attach the cables and support the permanently installed non-buoyant fairing or splitter plates. The soft connection between the dredge pipe and the collector(s) is provided by a 1,200-foot buoyant, crush-resistant, high-tensile-strength hose.

Costs were estimated from industry data and parametric analysis. The cost in 1982 dollars is $17.5 million for the small and $35 million for the large pipes and hoses.

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The collector must move across the ocean floor at a speed of one to two knots, separating the nodules from the sediments and delivering nodules to the dredge pipe inlet. A typical small collector would be approximately 60 feet wide [Flipse 1980]. The higher throughput collector is about three times larger, in segments as shown in Figure 1. The collector is a proprietary element of the system, and can deliver to the dredge pipe nodules clean of clinging sediments. The collector must negotiate small obstacles, while avoiding or going around major obstacles. It can temporarily store excess nodules while it meters into the dredge pipe the correct quantity of nodules to ensure high productivity without overloading the pipe. It is outfitted with a sidescan sonar system to sense obstacles on the bottom.

A single small collector would cost approximately $1.5 million. A second collector equipped with a spare hose would bring the total cost of dredge-heads and hoses for one small miner ship to $3.5 million and $10 million for a larger miner.

Ore Handling (Subsector 2.6)

This sub-sector identifies equipment used to transfer the mined ore from the dredge pipe to the mining ship and from the mining ship to the ore carriers. The system includes a hose-and-pipe equipment to accommodate the relative ship/gimbal platform movement, while transferring the nodule and water mixture to a separator where the bottom sediments are returned to the sea and the nodules and recaptured abraded nodule material (fines) are deposited on a conveyor. A conveyor distributes the nodules and fines to the specially configured holds while reclaimers deliver the nodules and fines to the stern. There they enter a slurry system that transfers them to the ore transports. At the same time a hose transfers fuel from the transport to the mining ship. The estimated cost is $13.3 million for the small and $26.6 million for the larger mining ship.

Capital Costs

As noted, the ship has two collectors on board. Their costs are included in the above estimates. A spare pipe string and two spare bottom hoses are stored at the ship operating base because accidental loss of a pipe string at sea probably would result in damage requiring a trip to the operating base or shipyard for repairs. The estimated cost of the spare pipe string (not including engineering) and the two spare bottom hoses is $17.3 million and $35 million. The total capital costs are shown in Table 4a.

Annual Operating Costs

Annual operating costs were estimated by developing a system-manning roster and fuel-use schedule and applying 1982 industry costs. Costs were estimated on the following basis for the larger mining ships:

Manning costs include a 40-man ship crew, a 48-man mining crew, and a full relief crew resulting in two full crews with provision for overtime, vacation, food and supplies.

Maintenance and repair (M&R) at the following rates:

(1) Ship: two percent of capital costs;

(2) Pipe string and collector: 50 percent of capital cost (equivalent to one loss in alternate years);

(3) Other mining and transfer gear: five percent of capital cost;

Table 4. Capital and Operating Costs for Mining, Sector 2

a. Capital costs per ship in millions of 1982 dollars.

	Capital Costs/Ship Set Small	Large
Mining ship	$ 91.6	$136.6
Handling and stowage equipment	23.5	59.0
Pumping system	13.8	41.0
Dredge pipe and bottom hose	17.5	35.0
Collector	3.5	10.0
Ore handling	13.3	26.6
Subtotal	$163.2	$308.6
Spare pipe string	17.3	35.0
Total	$180.5	$343.6

b. Operating costs per ship in millions of 1982 dollars.

	Small	Large
Manning	$ 11.2	$ 14.0
Maintenance and repair	21.6	44.0
Insurance	2.0	4.9
Fuel	4.3	12.4
Total	$ 39.1	$ 75.3

Insurance premiums are included at 1.5 percent of the value, plus $1,500 per crew member per year.

Fuel (U.S. West Coast-delivered #6 ASTM Marine Diesel) at $185 per long ton. The estimated fuel consumption is:

300 days mining at 16,000 HP or 195 LT/day

54 days transferring nodules at 27,600 HP or 111 LT/day

20 days in transit at 15,600 HP or 62 LT/day

15 days in a shipyard (negligible fuel use)

30 days pipe handling at 13,600 HP or 54 LT/day

Total fuel usage 23,300 LT/year @ $184.56/LT

Annual operating costs are estimated from these values and are given in Table 4b. Costs for the smaller mining ship are also summarized in Table 4b, from Andews, et al. [1983].

Sector 3 - Ore Marine Transport

The differing weight of wet nodules to be mined annually requires ships of the number and size shown in Table 5, with the particulars of the ships. A typical 1,700 nautical mile one-way voyage between the mine site and Southern California at 14.5 knots loaded, plus port times, takes almost 12 days for the round trip. A Panamax hull of less than 108 foot maximum beam and with a draft acceptable for 45 foot channels is required. Propulsion is provided by a single slow-speed diesel engine burning heavy fuel. Transports would load nodules in a slurry through a special transfer hose, using onboard receiving equipment and distribution piping. Hold decanting and dewatering systems are provided, but ship discharging is performed at onshore terminal facilities. Data used in price analysis for the transports are reported in Andrews, et al. account for inflation through 1982, except for fuel costs, which are $27.61 per barrel for residual marine fuel oil for main propulsion and $40 for diesel fuel used for the generators.

For the Pacific Northwest location, the 2,275 nautical mile voyage results in a need for more transport capacity. Although alternative sizes were examined, within the 45 foot low water channel depth limitation, ore transports of 74,000 deadweight tons were needed, each with an annual (300 day) route capacity of 1.5 million wet short tons of cargo.

Therefore, only two transports are needed for the smallest plant increasing to four, six, and twelve ships for the larger throughputs.

Capital Costs

The American ship cost data in Flipse [1982] have been updated to 1982 dollars. These estimates include provisions for handling the transfer hoses for fuel oil and nodules, a shipboard ore distribution system, a helo-pad with fuel service, and full set of spare parts, but do not include construction differential subsidy funds. Ninety-seven percent learning curve is assumed for multiple ship orders. The ships' estimated cost in 1982 U.S. dollars is shown in Table 5b and c.

Annual Operating Costs

Annual operating costs are estimated using U.S. crews for the ships, but no operating differential subsidy. Helicopters are provided for crew transfers to the mining ships. For both ships, operating costs in 1982 dollars are given in Table 5.

Table 5. Ore Marine Transport (Sector 3): Ship Particulars and Costs

a. Transport ship particulars, Southern California Route

Throughput (dry short tons p.a.):	1.5	3.0	4.5	9.0*
Number of ships:	2	3	5	10
Length B.P.:	720'	768'	742'	753'
Beam:	110'	131'	122'	126'
Depth:	59'	64'	61'	62'
Draft (S.W.):	39.6'	42.1'	41.2'	41.5
DWT (long tons):	60,000	81,000	71,000	74,000
Speed (loaded):	14.6	14.3	14.5	14.4
Brake horsepower:	17,300	19,000	18,200	18,500

b. Ore marine transport costs, in millions of 1982 dollars, Southern California Route

Deadweight tonnage per ship	60,000	81,000	71,000	74,000
Sector 3 Total, Capital	114.5	192.1	309.6	584.0
Sector 3 Total, Operating	15.28	25.14	39.7	80.3

c. Ore marine transport costs in millions of 1982 dollars, Pacific Northwest Route

Number of 74,000 DWT Ships	2	4	6	12
Annual Thruput (million wet short tons)	1.5	3.0	4.5	9.0
Sector 3 Capital Costs	$125.3	243.1	358.3	695.0
Sector 3 Operating Costs	$ 16.1	32.1	48.2	96.7

*Also applicable to Pacific Northwest Route

Sector 4 - Ore Marine Terminal

The ore marine terminal would be a dedicated waterfront facility on a deep-water harbor on the U.S. South Pacific Coast. A lease from a Port Authority for the needed land is necessary in most ports, while all improvements are the responsibility of the user.

Facility Description

A large vacant site would be graded and water, sewer and electrical services would be installed. Access roads within the area would be paved. A dock for the necessary size of ships would be dredged to 45 feet at low water and a suitable pier or wharf and mooring dolphins would be installed. A major element of the cost is the nodule re-slurrying and unloading system, which includes cranes on tracks to lift the unloading gear into the holds, pumps and hoses, and slurry water storage tanks. Holding ponds would be provided for two shiploads of nodules. Offices for the operating staff, and facilities for spare parts, stores, and maintenance and repair would be built. Fuel pipelines are also provided.

Southern California

Throughput (dry millions s.t.p.a.)	1.5	3.0	4.5	9.0
Berth Length and Number	950'/1	1040'/1	970'/1	985'/2
Cranes and unloaders	6	8	7	11
Terminal area, acres	9	15	21	39
Building area, 1000 sq.ft.	40	40	50	80

Pacific Northwest

Throughput:	1.5	3.0	6.0	9.0
Berth Length and Number	985'/1	985'/1	985'/1	985'/2
Cranes and Unloaders	7	7	8	11

Capital Costs

The berth space for one ship at a time except for the largest throughput, at a pier equipped with unloading cranes, including building and pipeline costs in millions of 1982 dollars are:

Ore Marine Terminal

Throughput m.d.s.t.p.a.:	1.5	3.0	4.5	9.0
Southern California				
Pier and dock	$ 10.5	$ 11.8	$ 11.0	$ 16.70
Ore unloading and storage	16.0	20.8	18.4	27.2
Site improvement	0.9	1.6	2.2	4.1
Building	1.5	1.5	1.9	3.1
Sector 4 Total	$ 28.9	$ 35.7	$ 33.5	$ 51.1
Pacific Northwest (site and buildings the same as Southern California)				
Pier and dock	$ 11.2	11.2	11.2	16.7
Ore unloading and storage	18.9	18.9	20.7	27.2
Sector 4 Total	$ 32.5	$ 33.2	$ 36.0	$ 51.1

Annual Operating Costs

Annual operating costs were estimated using the same updated formula. Maintenance and repair and unloading the ships are the major operating costs. Electricity costs 11 cents per kilowatt hour in Southern California, but only 3 cents per kilowatt hour in the Pacific Northwest. The estimated costs in millions of 1982 dollars are summarized as follows:

Southern California Route:

Throughput, million dry s.t.p.a.	1.5	3.0	4.5	9.0
Marine terminal dredging, M&R	$0.5	$0.6	$0.5	$ 0.8
Ore unloading and storage	2.8	3.8	5.0	9.3
Site rent, insurance, taxes, utilities	0.2	0.4	0.5	1.0
Building services	0.1	0.1	0.2	0.3
Sector 4 Total	$3.6	$4.9	$6.2	$11.4

Pacific Northwest Route:

Marine terminal dredging, M&R	0.5	0.5	0.5	0.8
Ore unloading and storage	2.4	2.9	3.8	6.2
Site rent and expenses	0.2	0.4	0.5	1.0
Building services	0.1	0.1	0.2	0.3
Sector 4 Total	$3.2	$3.9	$5.0	$8.3

Sector 5 - Onshore Transportation

The ocean mining system scenario locates the nodule process plant 25 miles inland from the port facility and locates the waste disposal ponds in a remote arid area 60 miles from the plant. An access road from the public highway to the plant site would be built to comply with local codes and donated to the local government. A rail spur was also provided. Roads within the processing plant are included in Sector 6.

Facility Descriptions

The 25-mile port-to-plant slurry system consists of land at six acres per mile, a port pumping station and several booster pumping stations, a surface slurry pipeline, and a slurry-water return line with required pumps. Seawater, pumped from the harbor, is the slurry medium.

A 60-mile-long pipeline delivers the tailings slurry from the plant to the waste site, and includes land and pumping stations. The fine-particle waste slurry is distributed at the waste site by a piping system included in Sector 7. The disposal slurry pipeline costs depend upon the process and the amount of waste produced, as explained in Sectors 6 and 7. The three-metal plant has the greatest disposal need and is shown below.

The rail spur is assumed to be on essentially level ground and includes expensive land ($10,000 per acre), a dozen switches, and single track to the plant site. The rail provided within the plant is included in the processing sector. The two-lane highway built to code specifications and capable of carrying heavily loaded trucks, is assumed to cross essentially level terrain. Costs of land for the road are included.

Capital Costs

The Sector 5 sizes and capital costs for both Southern California and Pacific Northwest locations in 1982 dollars are:

Onshore Transportation:

Throughput (m. dry s.t.p.a.)	1.5	3.0	4.5	9.0
Rail line (miles)	5	7	9	15
Road (miles)	5.5	8	10	16
Port-to-plant slurry system	$ 14.3	$ 20.2	$ 24.7	$ 26.7
Plant-to-waste site slurry system - 3 metal	12.1	16.4	19.9	28.0
Rail lines	3.3	4.7	6.0	10.0
Access road	1.7	2.5	3.1	5.0
Sector 5 Total	$ 31.5	$ 43.9	$ 53.7	$ 79.8

Annual Operating Costs

About 70 percent of the operating costs for two slurry pipelines is for electric power at 11 cents per kilowatt-hour in Southern California and only 3 cents in the Pacific Northwest. The only difference is in pipeline operating costs. Also provided are labor for the pumping stations and pipelines, maintenance and repair, local taxes, and liability insurance. By sub-sector, the operating costs in 1982 dollars are given below for the three-metal, maximum disposal process.

Operating Costs

Sector 5 operating costs in millions of 1982 dollars are as follows:

Throughput (m. dry s.t.p.a.)	1.5	3.0	4.5	9.0
Southern California:				
Port-to-plant nodule slurry pipeline	$ 7.3	$ 13.5	$ 19.3	$ 37.1
Three-metal plant-to-disposal waste pipeline	1.8	2.7	3.6	6.0
Rail line	0.3	0.4	0.5	0.8
Access road	0.1	0.1	0.2	0.3
Sector 5 Total	$ 9.4	$ 16.6	$ 23.6	$ 44.3
Pacific Northwest:				
Port to plant nodule slurry pipeline	$ 3.2	$ 5.3	$ 7.3	$ 13.0
Three metal plant to disposal waste pipeline	1.3	1.7	2.1	3.1
Rail line and access road	0.4	0.5	0.7	1.1
Sector 5 Total	$ 4.9	$ 7.5	$ 10.1	$ 17.2

Alternative Processes

For alternative processes to the three-metal plant, Sector 5 costs for the disposal pipeline only should be replaced by those shown next.

Throughput (m. dry s.t.p.a.)	Process (in millions of 1982 $) 1.5	3.0	4.5	9.0
Three-Metal + Full Manganese				
Capital Cost	$ 8.4	$ 11.0	$ 13.1	$ 17.9
Annual Operating Cost, Southern California	1.2	1.7	2.1	3.3
Annual Operating Cost, Pacific Northwest	1.0	1.3	1.8	2.2
Three-Metal + Limited Manganese				
Capital Cost	8.4	11.0	15.8	26.2
Operating Cost, Southern California	1.2	1.7	2.8	5.9
Operating Cost, Pacific Northwest	1.0	1.3	2.3	3.4
All Smelting Cases				
Capital Cost	6.7	8.7	10.2	13.6
Operating Cost, Southern California	1.0	1.3	1.5	2.3
Operating Cost, Pacific Northwest	0.9	1.1	1.4	1.6

Sector 6 - Processing

Process descriptions and capital requirements and operating cost estimates for both three- and four-metal nodule processing plants have been presented in Flipse [1982] and Andrews, et al. [1983]. Plant configurations were determined and costs estimated for a three-metal process based on reduction-ammonia leach technology at 3 million tons per year throughput, for a four-metal plant at 3 million tons per year throughput in which manganese is recovered from three-metal plant tailings, and for a four-metal plant at 1-1/2 million tons per year throughput based on smelting technology.

Overall material and energy balances were developed for each process and were used with information on equipment capabilities to estimate the sizes of the major items of equipment shown in the plant description. The items in the plants were organized into appropriate functional groupings at the subsector level to take advantage of data available in the equipment cost estimating literature and proprietary data. Plant capital requirements were estimated by a factoring technique which accounted for the costs of commodities and labor and indirect costs of engineering, construction, fees, and a contingency. Material and energy balances were used, with appropriate unit costs, to estimate the costs of materials, supplies, and energy consumed within the plant. Labor costs were estimated by developing a rough manning table, and fixed costs were taken as a percentage of the plant investment. These descriptions and costs were used as the bases from which all the following estimates were derived.

Plant configurations were revised and capital requirements and operating costs were re-estimated for the three processes described above at capacities of 1.5, 3.0, 4.5 and 9.0 million tons. Because of the marketing problems associated with full manganese production at the higher throughputs, two additional cases were evaluated: operation of both a smelting plant and a reduction-ammonia leach plant with full manganese recovery from tailings up to a throughput of 3 million tons per year and recovery of only nickel, copper and cobalt at higher rates.

Plant configurations developed in Flipse [1982] and Andrews, et al. [1983] were reviewed to determine which items of equipment or assemblies of items were already installed in parallel trains or were near the normal limits of capacity. In addition, spares were identified as well as operations which are carried out only periodically, such as rail car unloading and product shipment. Throughput in these categories can be increased at little or no cost by increasing the frequency of use. When these limits had been identified, equipment costs for larger (or smaller) plants were re-estimated at the sub subsector level using cost capacity data from the literature for equipment of the appropriate size. Plant capital requirements were then derived by the same factoring technique that was used previously.

The revised capital requirements were used, in turn, to estimate the fixed costs of production as a function of throughput. The cost-capacity exponent methodology described in the introduction was used. The materials, supplies, and utilities components of operating costs were assumed to vary directly with thruput. Some economies of scale are possible for labor as plant size is increased. They are most pronounced at smaller throughputs, however, and in some plant sections, such as the tank houses, few additional savings in man hours per ton are possible at the higher rates. The rough manning tables were therefore revised for each throughput examined, and labor costs were re-estimated and added to those mentioned above to give total direct operating costs as a function of throughput.

Capital requirements and operating costs for two new cases, involving partial manganese recovery, were found by developing appropriate plant descriptions and material balances. For the most part, this simply involved deleting extra manganese recovery operations from the four-metal plant descriptions at throughput exceeding 3 million tons per year. However, some modification to the plant descriptions and material and energy balances was also required in materials handling and plant services subsectors to reflect intermediate service requirements in these areas.

Breakdowns of capital requirements and operating costs at the subsector level for the smelting and reduction-ammonia leach processes with and without full manganese recovery are shown in Appendix A.

The breakdowns illustrate how economies of scale are or are not obtained in various plant operations. For example, at low throughputs, cost-capacity exponents range from about 0.5 to 0.6 in the materials handling sectors since increased throughput can be obtained by using the same sized equipment more frequently. These economies are lost at higher throughputs since it is not possible to move unit trains of coal through a dumping station beyond a certain rate. The cost capacity exponent increases to about 0.7. In other plant areas, increased throughput must be obtained by using larger equipment and/or breaking to parallel trains. In the services sector, for example, the cost-capacity exponent exceeds 0.95 at the higher throughputs since larger steam requirements and cooling loads are provided by use of multiple boilers and cooling towers.

Consumptions, and therefore costs, of materials and supplies, fuels and power increase almost directly with throughput. The indicated cost-capacity exponent is 1.0. Significant savings are possible with labor, however, as higher throughputs per total labor hour are obtained at the higher rates with plant General and Administrative requirements that are more or less fixed. The indicated labor cost-capacity exponents range from about 0.3 to 0.5. Variations in fixed charges, which are taken as a percentage of fixed capital requirements, reflect economies of scale that are obtained in increasing size of process equipment.

Processing System Capital Requirements

Fixed capital requirements for the processing plant for the five cases evaluated are summarized in Table 6 and are plotted in Figures 5 and 6.

As expected, capital requirements for the three metal plant are lowest, but revenues are also lower since manganese is not recovered. Data also indicate that capital requirements for a smelting process are somewhat higher than for a reduction-ammonia leach with manganese recovery from tailings process at the same throughput. However, the differences are within the range of uncertainty of the estimating technique.

The indicated plant cost-capacity exponents are in the range of 0.7 - 0.8 for all processes at throughputs between 1.5 and 4.5 million tons per year. At higher throughputs, plants with no or full manganese recovery show cost-capacity exponents of about 0.9 indicating extensive use of parallel trains and few remaining economies of scale. The indicated cost capacity exponents for partial manganese recovery plants are somewhat lower. However, this is misleading because the configuration of the plant has been changed. Essentially, the cost of a partial recovery plant is equal to a plant without manganese recovery, plus a constant amount for manganese recovery at the chosen rate.

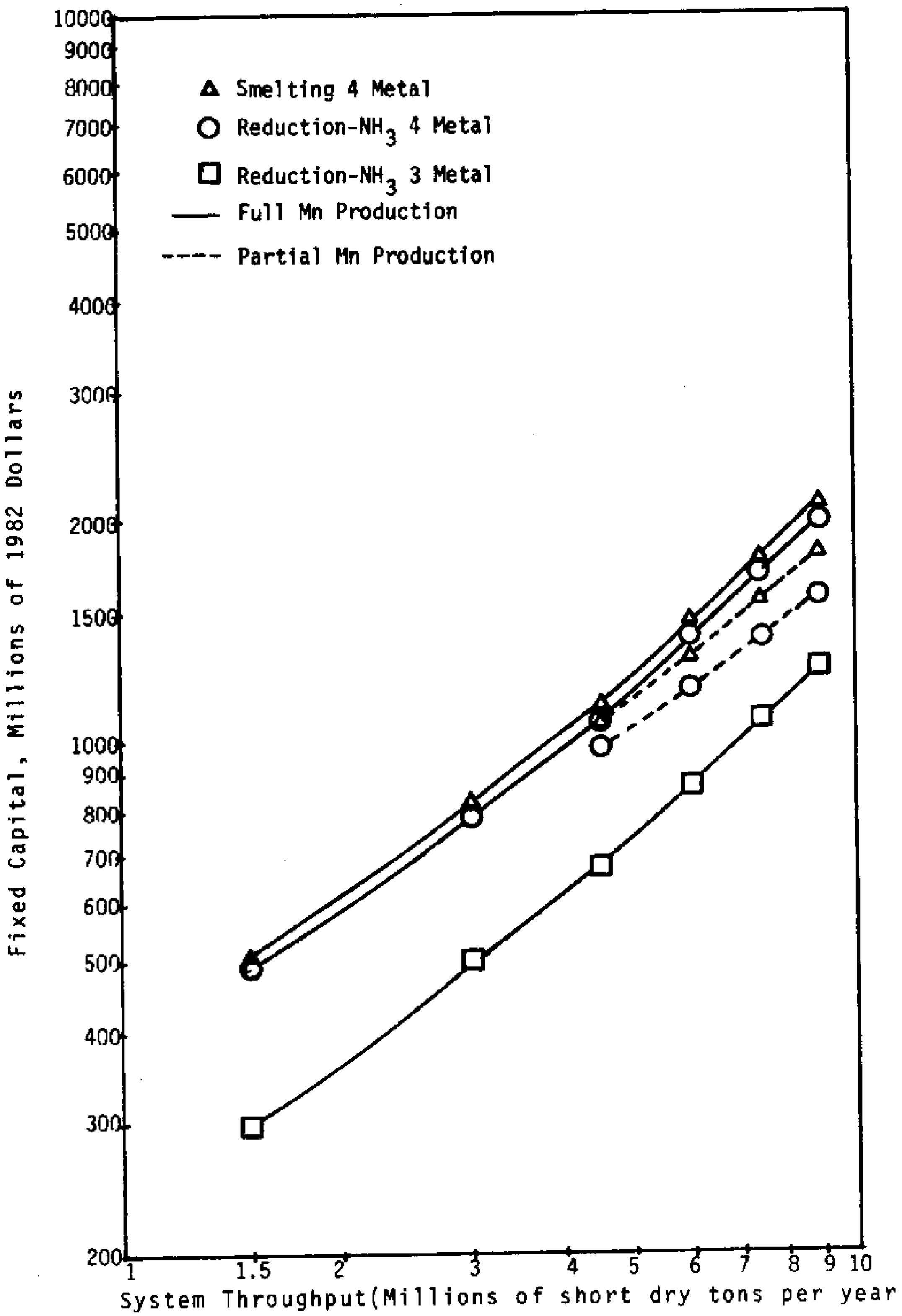

Figure 5. Fixed Capital for Processing(Sector 6) Versus Throughput

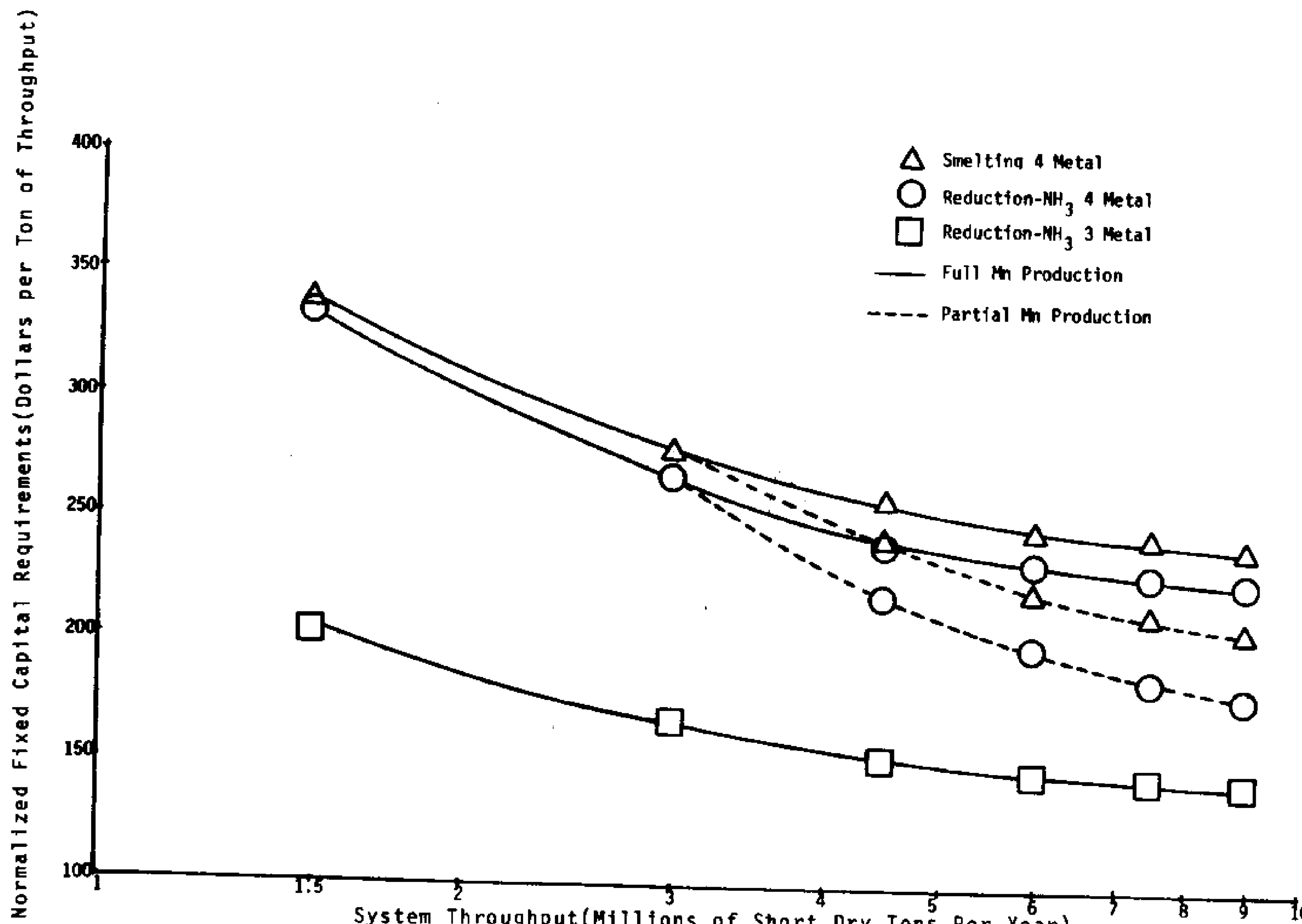

Figure 6. Fixed Capital for Processing(Sector 6) per Ton of Throughput Versus Throughput

Table 6. Process Plant Fixed Capital Requirements as a Function of Throughput for Five Alternative Nodule Processing Plants

Throughput[1]	1.5	3.0	4.5	9.0
Fixed Capital Requirements, Millions of Dollars per Year[2]				
Reduction-NH_3 Leach[3]	305.4	501.8	690.2	1293
Red'n-NH_3 with Full Mn[4]	503.4	801.3	1081	2030
Red'n-NH_3 with Partial Mn	503.4	801.3	989.6	1593
Smelting[5]	506.1	849.7	1175	2176
Smelting with Partial Mn	506.1	849.7	1096	1882

Note: Footnotes same as Table 7.

Plant Operating Costs

Total direct operating costs for the processing plant for the cases evaluated are summarized in Table 7 and are depicted in Figure 7 normalized to the throughput rate. The costs have been tabulated for power costs of 3 cents and 11 cents per kilowatt-hour because of the importance of this item in the total operating costs.

With power at 11 cents per kilowatt-hour, operating costs with full manganese recovery exceed those without manganese recovery by about $100-120 per ton of throughput; with 3 cents power the difference is about $55-70 per ton. However, at 90 percent recovery revenues from the manganese produced amount to about $210 per ton with manganese priced at 40 cents per pound.

The data on operating costs do not show as great a reduction in cost per unit of throughput at higher capacities as do those on capital requirement. This results from the fact that power, materials and

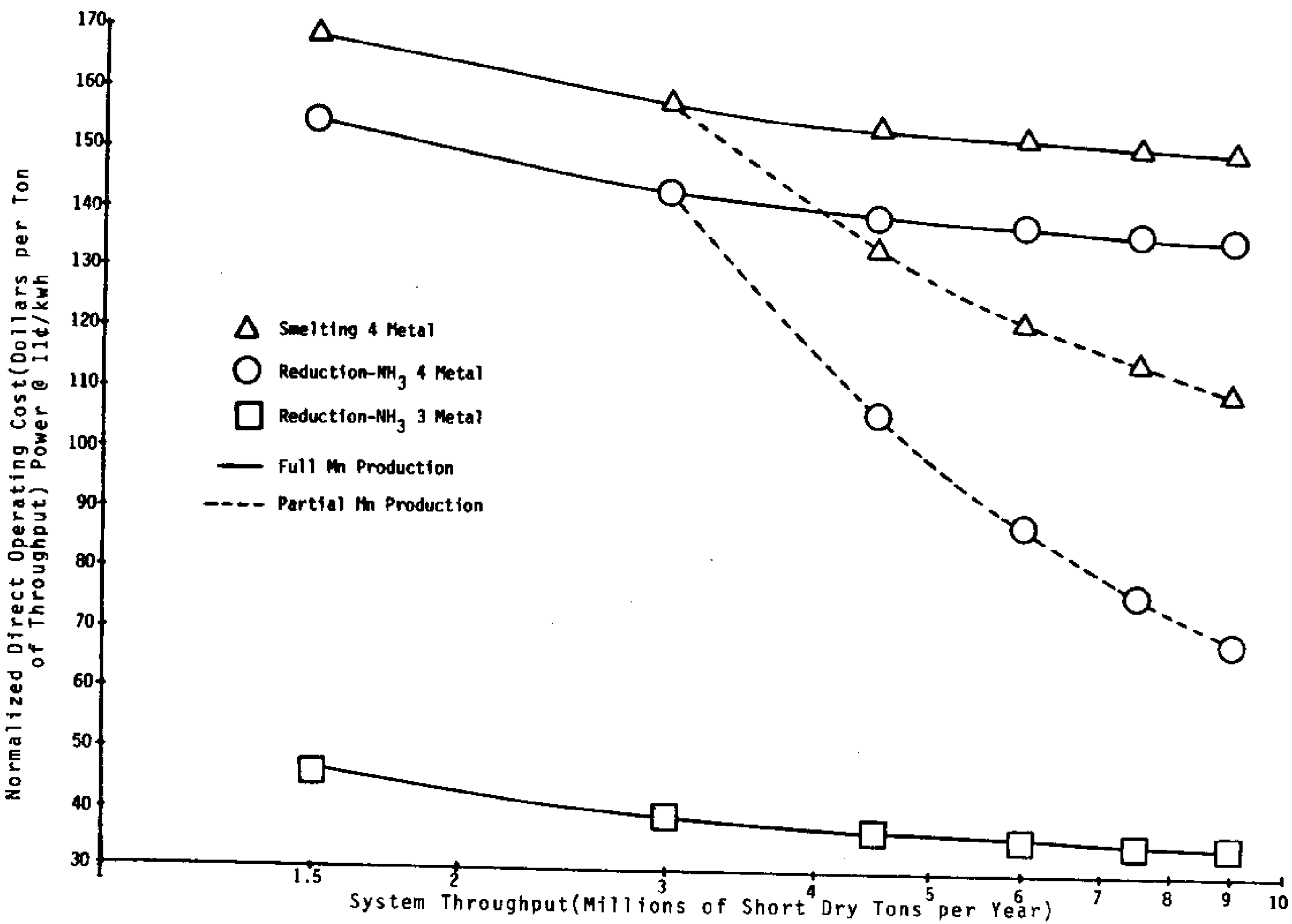

Figure 7. Operating Costs for Processing(Sector 6) in Dollars per Ton of Throughput Versus Throughput

Table 7. Process Plant Direct Operating Costs as a Function of Throughput for Five Alternative Nodule Processing Plants

Throughput[1]		1.5	3.0	4.5	9.0
Direct Operating Cost, Millions of Dollars per Year[2]					
Reduction-NH_3 Leach[3]	3¢	62.7	105.3	146.0	270.8
	11¢	68.8	117.4	164.2	306.9
Red'n-NH_3 with Full Mn[4]	3¢	152.5	278.2	397.7	768.5
	11¢	231.3	430.0	625.2	1223
Red'n-NH_3 with Partial Mn	3¢	152.5	278.2	319.0	443.7
	11¢	231.3	430.0	476.8	619.5
Smelting[5]	3¢	166.6	301.1	433.3	830.6
	11¢	253.3	475.7	694.9	1350
Smelting with Partial Mn	3¢	166.6	301.1	383.8	635.9
	11¢	253.3	475.7	602.6	989.6

[1]Millions of dry short tons per year
[2]In 1982 dollars
[3]Recovery of Ni, Cu, Co only
[4]As ferro and silicomanganese
[5]With full recovery of ferro and silicomanganese

supplies vary almost directly with throughput. Both labor and fixed costs show only slight economies of scale.

Sector 7 - Waste Disposal

The amount of each type of waste generated by each process evaluated was defined in executing the plant material balance as a function of throughput. Except for the partial manganese recovery cases, the amount of waste is directly related to throughput. For partial recovery a break in the relation occurs at rate above 3 million tons per year but the relationship remains linear. As was the case in the previous description of a smelting process Andrews, et al. [1983], it has been assumed that smelting and manganese reduction slags will be disposed in a controlled dump on the plant site. Costs are included in the processing sector. Only costs of constructing and operating remotely located holding areas for tailings and other process solid and liquid wastes are reported here.

The disposal area consists of active and reclaimed slurry holding areas, a decant pond for evaporation of excess liquid, and capital equipment for slurry distribution, a monitoring system, and support facilities. Costs for holding areas are a function of the amount of earth moved to prepare the area and construct dikes; install underdrain and monitoring equipment; render the area impermeable to seepage; and install distribution piping. The costs are functions of either the area required or the periphery. The area needed is directly related to the amount of waste to be disposed.

The disposal area configurations and costs developed in Flipse [1982] and Andrews, et al. [1983] were used as the basis for all costs presented here. New area requirements were computed for each throughput rate for all cases evaluated and costs were estimated for each. Operating costs were estimated from revised manning tables and estimates of materials, supplies, and utilities consumptions and the annual costs of new disposal area construction and old area reclamation.

Capital Requirements

Capital requirements for the waste disposal system are presented as a function of throughput for the cases evaluated in Table 8, along with the total land area required for the project life. Costs include both depreciable equipment and construction costs of the disposal area for the first three years of plant operation.

Table 8. Disposal System Fixed Capital and Land Area Requirements as a Function of Throughput for Five Alternative Nodule Processing Plants

Throughput[1]		1.5	3.0	4.5	9.0
Costs, Millions of Dollars[2] and Area Required, Acres					
Reduction-NH_3 Leach[6]	First[3]	12.1	21.1	29.5	54.1
	Equip[4]	0.4	0.6	0.75	1.2
	Area[5]	1100	2100	3200	6300
Red'n-NH_3 with Full Mn[7]	First	9.6	17.3	24.7	46.1
	Equip	0.5	0.75	1.0	1.5
	Area	550	1100	1600	3200
Red'n-NH_3 with Partial Mn	First	9.6	17.3	21.3	43.5
	Equip	0.5	0.75	0.9	1.4
	Area	550	1100	2200	5300
Smelting[8]	First	4.8	8.8	12.5	23.3
	Equip	0.5	0.75	0.9	1.4
	Area	300	600	900	1800
Smelting with Partial Mn	First	4.8	8.8	12.8	24.5
	Equip	0.5	0.75	1.05	1.7
	Area	300	600	1000	2200

[1]Millions of dry short tons per year
[2]In 1982 dollars
[3]Cost of initial three years area construction
[4]Capital equipment
[5]Total area over project life, acres
[6]Recovery of Ni, Cu, Co only
[7]As ferro and silicomanganese
[8]With full recovery of ferro and silicomanganese

Some economies of scale are indicated in capital equipment, as expected, and in area construction costs since costs of dike construction are a function of the periphery or square root of the area involved. Recovery of manganese decreases disposal area costs by reducing waste volumes as expected.

Operating Costs

Direct operating costs for the waste disposal system are presented in Table 9 as a function of throughput for the cases evaluated. The costs include materials, supplies and labor, as well as the annual costs for construction of new areas and reclamation of old areas. Some economies of scale are shown. Operating costs are lower for four than three metal processes for the same reasons that apply to capital requirements in each case.

Sector 8 - Mining Support

Certain mining costs are included here. Most of the equipment can be chartered or rented. An exception is the crew and supply boat which must be specially purchased because of its high capacity and sea speed, distance to mining site, and large number of passengers carried. The terminal for the boat is assumed to be rented from the port authority of a metropolitan city (e.g., San Diego, Hilo or Honolulu) that will also serve as the base of operations of the chartered research vessel. As a result the cost of the terminal is split between mining support and preparatory and exploration. Crew members of the mining ship and transport personnel will be trained by others (the Kings Point research facility or commercial services) to assure the required ship handling skills.

Table 9. Disposal System Direct Operating Costs as a Function of Throughput for Five Alternative Nodule Processing Plants

Throughput[1]		1.5	3.0	4.5	9.0
		Direct Operating Costs, Millions of Dollars per Year[2]			
Reduction-NH_3 Leach[5]	Pond[3]	3.6	6.2	8.6	15.6
	Other[4]	0.55	0.7	0.85	1.05
Red'n-NH_3 with Full Mn[6]	Pond	1.65	2.65	3.6	6.2
	Other	0.4	0.45	0.5	0.65
Red'n-NH_3 with Partial Mn	Pond	1.65	2.65	3.65	9.75
	Other	0.4	0.45	0.7	0.95
Smelting[7]	Pond	0.85	1.4	1.85	3.15
	Other	0.25	0.3	0.35	0.4
Smelting with Partial Mn	Pond	0.85	1.4	1.95	3.55
	Other	0.25	0.3	0.4	0.65

[1]Millions of dry short tons per year
[2]In 1982 dollars
[3]Annual pond constuction and reclamation cost
[4]Materials, supplies, utilities, labor, and fixed costs
[5]Recovery of Ni, Cu, Co only
[6]As ferro and silicomanganese
[7]With full recovery of ferro and silicomanganese

Capital Costs

The only non-rented item of this sector is the high-speed crew-supply boat, which is estimated to cost, in 1982 dollars, $1.6 million.

Annual Operating Costs

Estimates of crew-supply boat operating costs include manning, supplies, fuel and insurance for 38 to 58 round trips per annum between the terminal and mining ships. A small staff at the terminal would provide management, clerical and warehouse functions in rented facilities to both the research vessel and supply boat. Both mining ship and transport crews will be trained by others. This sub-sector provides for that training, as well as travel and subsistence costs.

Mining Support (Sector 8) Annual Operating Costs

Throughput (million tons p.a.)	1.5	3.0	4.5	9.0
Crew-supply boat	$0.9	$1.0	$1.1	$1.2
Terminal (1/2)	0.2	0.2	0.3	0.4
Maritime training	0.2	0.3	0.4	0.7
Sector 8 Total	$1.3	$1.5	$1.8	$2.3

Sector 9 - Research and Development

This sector now includes only processing, waste disposal and other research and development that cannot also be claimed as mining-related expense. The sector cost can be estimated at 1 percent of the Process Sector 6 annual operating costs, and thus with inflation, about $4.8 milion in the base case.

General and Administrative Costs and Startup Costs

A headquarters staff provides the usual management, financial, legal and marketing services necessary for the smooth operation of the project. The staff are different from management personnel at the processing plant, ore terminal and supply base. Space, facilities, support staff and salaries are provided in Sector 1 for Prospecting and Exploration personnel, and in Sector 9 for Research and Development activities in processing.

A rented office complex (perhaps in the port or the processing plant area) with rented equipment is included in this sector. A management organization is assumed, with competitive pay and incentive budgets. Utilities, insurance, computer services and extensive travel costs were estimated. Mining community experience was used as a basis for costs.

This overhead cost cannot be used in determining depletion deductions and is estimated at one-half percent of fixed plant total cost annually, inflating after the plant is complete. In the base case, this amounts to $4 million yearly; the same as during the preparatory period.

Startup Costs

The expense of testing, modifications and adjustments for each sector of the system can be broadly classified as a startup cost. For each throughput and construction period in Table 1, an estimate has been prepared on the fraction of full operating costs incurred until full production is achieved (see Appendix B). Thus trials and startup costs are shown as a sector operating expense before and during production, and capitalization of all plant costs can be avoided. Also, since these costs are estimated by sector, those available for the depletion deduction can be utilized directly in the payout analysis program.

TEXAS A&M UNIVERSITY OCEAN MINING PAYOUT ANALYSIS COMPUTER PROGRAM (1984 VERSION)

The previous investigators' (Flipse's, Andrews' and Brown's) experience in the shipbuilding, minerals processing, and ocean resource development strongly influenced the approach to the Texas A&M University Ocean Mining Payout Analysis Program. Most payout calculations are performed in industry to assist the corporate directors and top management in making investment decisions among competing proposals. Hence, as long as the same formula is used for all projects under consideration, the relative merits can be fairly judged if the cost and revenue estimates are consistent and accurate. Estimating costs precisely is far more difficult than computing rates of return.

The historic low interest rates in the United States from the 1930s until the early 1970s encouraged comparison to be made on the "simple average return", "capital recovery factors", or "pay-back period" values, both before and after taxes. With higher interest rates, the real-time cost of the funds invested also become important, resulting in the comparisons by use of Internal Rate of Return (IROR), also called Discounted Cash Flow Return (DCFR), both before and after taxes [see, e.g. Collier and Ledbetter, 1980]. The Internal Rate of Return as used here is defined as the percent interest at which the annualized present net worth (over the life of the project) equals zero. The net present worth equals the present worth of income, minus the present worth of costs.

Another industry influence reflected in this payout approach is the emphasis on cash flow, with its attention to full and earliest possible use of all tax shelters available to the corporate entity. The Tax Equity and Fiscal Responsibility Tax Act of 1982 resulted in a major revision of the tax carryforward schedules.

Program Changes

The Texas A&M University Payout Model has been modified in several steps to reflect the provision of several tax laws enacted during the last few years, and the different types of deep ocean mining programs. The original computer model [Flipse, 1982] included the 1981 Economic Recovery Tax Act (1981 ERTA) changes, and applied to three-metal plants. The following model [Andrews, et al., 1983] included changes of the 1982 Tax Equity and Fiscal Responsibility Act (82 TE&FRA) and incorporated debt financing computations, as well as other changes. The model used in the present analysis is derived from these past programs, with further changes incorporated to:

- Permit computation of the depletion allowances for both cost and percentage depletion deductions.
- Permit easier specification of the construction period, and expenditures during plant and facilities erection and for testing, and the start of operations over a short phase-in period.
- Permit computation of payout under input-specified uniform rates of cost inflation.
- Permit computation of the payout for an ocean mining venture which is integrated into its parent's taxation, as well as the

past reports' conventional tax evaluation as an independent U.S. corporation.

- Permit some combinations of these features to be calculated simultaneously from a single input, thus further simplifying use of the model.

Basic Approach

The previous reports [Flipse, 1982; Andrews, et al., 1983] outlined reasons for taking the industrial approach to evaluating the payment of deep ocean mining ventures. These reasons are still valid and applied to the current revisions of the Texas A&M University payout model. In brief, since cost estimating has a higher level of uncertainty than sophisticated economic analysis of competing investment proposals, simplified programs for financial evaluations are suitable for judging relative merits of alternatives. The measurements of payback period, simple average return, capital recovery factors, and internal rate of return (or discounted cash flow return) in increasing order of complexity, are all used by industry as the measures of merit. The proper financial management of a corporation directs efforts to minimize investment and maximize cash returns as early as possible, thus requiring full use of all available tax shelters and deferrals.

To achieve this last goal, the provisions of the Federal Tax Code, Sections 611, 612, 613, 614, 616, and 617 primarily were carefully examined at length. A computational procedure was devised for the payout analysis that should closely approximate choices that may actually be made under the 1983 tax laws, regulations, rulings, and court decisions. The 1982 TE&FR Act also included some changes affecting the depletion deduction, which are of course included in the revised Texas A&M University program.

Project investigators expected and found several substantial difficulties in preparing depletion, exploration and mine development deductions allowed under many conditions in the relevant regulations. One, these laws were written for and defined in terrestrial terms, not for deep ocean mining. They are therefore difficult to interpret, much less to secure a definitive application to manganese nodule mining. Two, the definition of mining in the United States has been construed to include mining on the high seas defined in ocean areas as not under the jurisdiction of a foreign country. If this interpretation is not correct, then most of the depletion treatment is inapplicable. Three, many of the IRS allowable choices for tax treatment do not further the objective of prompt use of tax deductions or credits, and would not be selected by a rational mining venture management. These alternative tax methods, such as deferral of mine development costs and amortizing them over the production of the mine, have not been included in the payout analysis.

Four, the specific tax treatment depends upon the financial character and condition of the mining venture. This may range from a large profitable, existing corporation to a small, under-capitalized and highly leveraged partnership. Therefore, in practice, the specific tax elections year by year will be made to suit the owners and management for both current conditions and the expected near term. To illustrate a range of conditions the evaluation now includes the case of a deep ocean mining venture which is wholly-owned by a large American corporation with essentially unlimited tax liability from continuing operating profits, and able to benefit from any tax deduction or credit when it first becomes available. Also, the parent is assumed to have sufficient cash flow to invest all sums as needed for the preparatory period, construction, testing and start-up operations.

This description is in distinct contrast to the previously described stand-alone, independent new venture, where investor monies in the corporation cannot be offset with tax advantages (as a partnership could do). Thus, the independent enterprise must delay use of tax treatment to reduce outflow to a time after production begins and cash flows in. Both cases approximate extremes of tax treatment. Most real cases probably would fall between these two extremes.

Five, the only published analysis of deep ocean mining taxation [Dworin, 1979] is generally reported to have reached inappropriate conclusions. Unfortunately, the work was originally intended to be a guideline. Therefore, a basic, practical tax treatment for mining and metal processing ventures has been devised here and is described below. Special treatment of smaller items, such as for pollution control equipment and facilities funded by industrial development bonds are excluded. This description outlines the internal revenue rules and their application in the Texas A&M University program. Although relatively complicated, it is an extremely concise and clear statement compared to the sources and references [Commerce Clearing House, 1982(a),(b)].

Construction Period and Startup Costs

Construction periods have been made a variable in this revised Texas A&M University model. Examples have been calculated with four, six, eight and ten year pre-production periods from GO to completion of the plant, roughly increasing in time for larger plants and their higher throughputs as shown in Table 1. For each nodule throughput level, both a fast and slow construction period have been analyzed to illustrate the financial impact of an extended investment period. For the two mining ship cases, construction and start of mining by the second ship is delayed in the slow schedule as compared to the fast schedule. The slow construction schedules for the two ship cases (eight and ten years) were formulated in such a way that the revenue from the initial one-ship production period at least partially pays for further capital expenses, thus reducing up-front costs. The fast and slow schedules assumed for the construction period bracket the normal schedules assumed in the past reports for the same throughput.

For each schedule, an arbitrary estimate of the percentage construction expenditure each year by each sector has been input as part of the computer program. The approximate time distribution of investment outlay is based upon review of the subsector components and their detailed cost estimates, and determination as to when each item must be finished and when started, from the time needed to build each component. These estimates, as a percentage of total sector costs, have been rounded to indicate their level of inaccuracy. The values of the cost percentages by sector and year of investment are shown in Appendix B for each of the four schedules presently in the program. Others can be input or changes can be made simply in existing schedule values.

Directly related to the construction schedule are operating expenses paid in each sector that have been separated as tax-deductible currently, rather than capitalized. These expenses include labor, fuels and reagents for testing, environmental monitoring, etc. Values selected by year for each sector are also shown in Appendix B, as a percentage of normal sector annual operating costs at full production.

Standard Mining Taxation

Standard taxation of corporate enterprises does not generally apply to United States' mining and metals producing companies. Special treatments of mining enterprises, for mine exploration and mine development expenses are permitted under the Internal Revenue Codes. A detailed discussion of the tax codes including depletion computations is given in Appendix C. A simplified discussion of special tax provisions for mining is given below.

Certain pre-production non-capital expenses can be deducted at the time of expenditure. These include pre-production mine exploration costs (Sector 1) and pre-production mine development costs (Sectors 2 and 8). This benefits the parent company of the subsidiary venture if the parent has income to shelter. A fifteen year carry-forward of the deduction can be used by the independent once production has started and income is being produced through metal sales. Pre-production capital expenditures for mine exploration and development can be depreciated on an accelerated schedule starting at the time of expenditure.

Depletion, a separate tax deduction for mining ventures intended to compensate for depletion of the ore-deposit, can be computed two ways: as cost depletion and percentage depletion. Each year depletion is computed both ways and the largest value is used. Cost depletion allows the venture to deduct mine acquisition costs and mine development expenses in excess of the pre-production deductions mentioned above. The subsidiary venture ordinarily would not use cost depletion as the parent would already deduct the pre-production mining costs described above. Percentage depletion is based on gross income from mining, i.e. metal or ore sales. It is computed by taking 15 percent of copper sales and 22 percent of the nickel, cobalt and manganese sales and multiplying the sum by the ratio of mining costs to total costs. Percentage depletion may be deducted up to 50 percent of annual taxable income. The precise method of computation is outlined in Table C-1 on Page 9 of Appendix C.

Two interpretations of mining costs may be used in the percentage depletion computation. For the purposes of the percentage depletion computation (as discussed in detail in Appendix C) the mining costs include Sectors 2, 3, 4, 5 and part of 6. The percentage of Sector 6 (processing) costs used depend upon which interpretation of mining costs is used. The two interpretations are:

* Mining costs are all costs up to the "first marketable product",
* Mining costs include all costs up to the point where the "first chemical change" takes place in the ore during processing.

The second is the more conservative interpretation for nodule mining, as the first marketable product is also the output from the full processing plant. The first chemical change comes very early in the processing after drying, crushing and grinding. As a result, there is a great disparity in mining costs depending on the interpretation, because processing costs are a large part of total system costs. The "first marketable product" depletion interpretation has been used throughout this study except for the no depletion cases and for the study on depletion alternatives.

Corporate Structure

Two corporate structures for the mining ventures are considered: an independent company and a subsidiary to a much larger, profitable parent company. The stand-alone enterprise is an independent entity where all funds are invested in the corporation and all tax benefits come to it. This is unlike most actual practices in which the consortium members are in partnership and the expenditures of the joint venture flow back to the partners as both cash expenditures and tax deductions. Therefore, the stand-alone venture cannot benefit from immediate tax write-offs.

Program Changes for Integrated Corporation

The parent corporation both advances all funds except debt financing, and takes all tax savings so incurred. Thus, beginning with preparatory period expenditures in Year 0, the full tax savings at input tax rate are taken from deducting all the tax savings from the equity. Therefore, net cost to the parent and their equity invested is reduced by 100 percent less the tax rate for expenses and depreciation and the investment is reduced up front. Later tax deductions (amortizing) will not be available, though.

There will be no tax loss carryforward for an integrated corporation, but all deductions will be used to reduce the parent's taxes. The IRS also allows the parent investment in a new subsidiary to be treated as debt to be repaid with interest as ordinary income. This approach contrasts with the analysis where an equity (stock) position is taken, and parent return on investment is computed. The debt approach has not been computed as the IRS imputes a minimum interest rate of 5 percent per annum on funds advanced.

For cash flow purposes the gross outflow for discounting is the net of expenses and investments less tax savings, less debt, each year. The gross inflow is the sales when production begins. The capitalized investment less net profit is the cash flow each year.

For the integrated case, the key appears to be the permission to have a "negative tax profit", i.e. a negative tax payment which equals a tax savings. Therefore, the existing basic calculation and presentation formats will work with only the one change. When the depletion deduction or depletion investment tax credit is allowable, only another two lines are needed in the tax payment calculation.

Basic Assumptions

The revised Texas A&M University computer program has substantial capacity to calculate the payouts for input data variables through a wide number of items and range of values. To reduce the analysis to a manageable number of outputs, several less-important variables are fixed, and are listed below.

The limiting assumptions in all of the cases include:

1. The program is a technical and management success.
2. All equipment functions for the 20-year operating life of the project, with necessary replacements provided for as maintenance and repair in annual operating costs.
3. Payments of 0.75 percent of gross revenues to an escrow account are made under Public Law 96-483.
4. Straight-line depreciation or the alternate accelerated cost recovery schedule, is used as the five-year depreciation life for

all non-mining, non-R&D capital equipment, and fully protects earnings from taxes until this shelter is fully utilized. The full investment tax credit (ITC) is taken, reducing depreciation by half of the ITC.

5. Coal is the primary energy source for cogeneration of the minimum amount of power required to produce plant steam and gases. The price of electricity is fixed at 11 cents per kilowatt-hour in Southern California, and the port depth is 45 feet. The electric cost for the Pacific Northwest is 3 cents per kilowatt-hour.
6. Research and development, mining, and prospecting and exploration costs accumulated in the preparatory period before the GO/NO GO decision are expensed and included as a negative cash flow in Year 0. (As alternatives, these preparatory expenses can be amortized over the plant life, or sunk). The Preparatory Period general and administrative expenses are amortized over five years beginning with production.
7. All working capital, and land at cost, including inflation, are recaptured in the last year of the program.
8. The salvage value of the plant and equipment is equal to the clean-up costs.
9. The capital and operating costs of any regulatory regime are zero. The costs of monitoring do not discernibly affect returns.
10. The venture will not be unduly delayed by the regulatory and permitting process.
11. Metal prices are "normal" rather than artificially high (as when cobalt was at $20 per pound) or low (e.g., copper at 65 cents per pound). Recovery rates depend upon the process used.

12. A 46 percent tax burden (when applicable) is used with no modification for small initial earnings.

13. A single constant inflation rate is used for the life of the project for all capital and operating costs. Three alternative assumptions are made on metal price inflation to account for the lag between cost inflation and price inflation.

The assumptions represent the authors' best judgment, and in balance, are not intended to force an unrealistic high or low return on investment.

Input Data Sheet

The input data sheet and a description of input options is given in Appendix D. The Texas A&M University Payout Program is very versatile in types of options or variables that can be evaluated for each hypothetical venture (see Figure 2). The input variables that can be evaluated may be divided into two major types: cost and price data (external to program), and various options internal to the program.

The variables considered in this study falling into the first category include: throughput, type of process, location of processing plant, and electric power cost.

Cost input data must be generated for each of these options on a sector basis as discussed in the high throughput mining systems chapter and indicated schematically in Figure 3.

The second category of variables (internal to program) include: corporate structure (independent vs. parent/subsidiary), inflation, loan amount and interest rate, depletion, and construction period.

The Texas A&M University Ocean Mining Payout Program has been modified to automatically compute and print out eight options from the secondary category for each input data sheet. These options include all combinations of inflation (yes/no), debt (yes/no), and depletion (yes/no). Discussion of the variables and their values is given in the next chapter.

The program is extremely versatile and its accuracy is primarily limited by the skill of the investigators in estimating input cost data and the ability to forecast metal prices and such factors as inflation and interest rates. Variables that can be treated by the Texas A&M University Ocean Mining Payout Program, but which were beyond the scope of the present investigation include:

* Variations (improvements) in the design of subsystem components and operational scenarios of the major sectors,
* Various forecasts of metal prices,
* Variability of ore assay and abundance,
* Alternative debt financing,
* and, use of foreign ships or crews and overseas processing.

<u>Program Flow Chart</u>

The 1984 Texas A&M University Ocean Mining Payout Program flow chart is shown in Appendix E. Input data format and a sample of the output printout is given in Appendix D.

<u>Eight Case Printout</u>

One of the project's tasks was to produce a printout with combinations of inflation, debt, and depletion. This allows greater flexibility with a minimum of user time. The eight (yes/no) combinations of inflation, debt, and depletion are automatically printed out for each program execution. Program execution cost and terminal time are reduced over accessing the program and executing it eight different times. Figure 8 shows the different combinations and order of printout for each

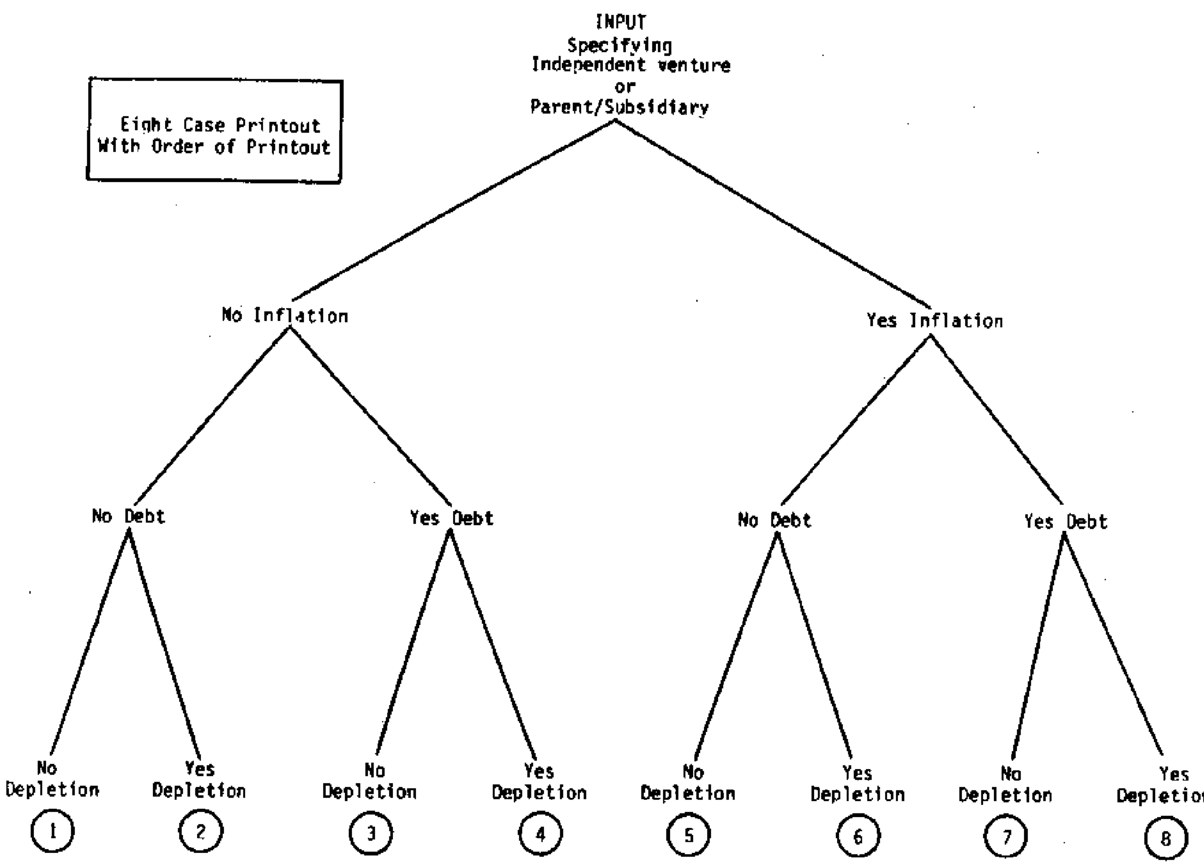

Figure 8. Eight Case Printout With Order of Printout

combination. Should the user desire the "No Inflation" case only, then simply input the inflation rate equal to zero. Only the four combinations under "No Inflation" will be executed and printed. If the "No Debt" cases are only desired, then input the debt percentage equal to zero. This will suppress all program executions and printouts under the "Yes Debt" columns. With this method the program executions and printouts can be for explicit runs desirable to the user, without duplicate and unnecessary runs. All "No Depletion" and "Yes Depletion" cases are executed and printed.

Metals Prices, Processing Efficiencies and Ore Assay

Metal prices are taken as "normal" using the same values as Flipse [1982] and Andrews, et al. [1983]. The nickel price of $3.75 per pound is close to the $4.00 per pound price quoted by Sibley [1983] as necessary to trigger new production from terrestrial laterite deposits. The $0.40 per pound price for manganese is for manganese contained in ferroalloy (as opposed to electrolytic manganese). Prices are indicated in Table 10 along with the metal recovery efficiencies for the reduction/NH_3 leach and smelting processes and ore assay by weight. The variables govern income or revenues of the venture. The assay is an average of values for nodules in the Clarion-Clipperton Zone. It is derived from an extensive data base obtained from at least 10 years of exploration and sampling. The metal recoveries are also taken from Flipse [1982] and Andrews, et al. [1983]. The values given in Table 10 have been used throughout this study.

Because this information is input to the 1984 Texas A&M University Ocean Mining Payout Analysis Program, other values for prices and assay could easily have been used. Sensitivity studies on these variables could have been run because of the versatility of the program. This was not done. No rationale for varying prices or assay was devised since this was beyond the scope of the current effort.

Table 10. Metal Prices, Processing Efficiencies and the Assay

Metal	Price (Dollars/lb)	Assay (Percent by wt.)	Percent Recovery	
			Red'n NH_3	Smelting
Nickel	3.75	1.30	94	95
Cobalt	5.50	0.25	70	90
Copper	1.25	1.10	94	95
Manganese	0.40	29.00	82	93

PAYOUT ANALYSIS RESULTS

The revised Texas A&M University Ocean Mining Payout Analysis Program was used to investigate the effects of manganese ore throughput (production rate), corporate structure, depletion, inflation, debt, location plus power costs, construction period, and processing type for the alternative nodule mining ventures. Results of the computations are described below.

Variable Throughput Investigation Results

Primary interest in the study was in the effect of throughput on integrated mining system economics. Consequently, four throughput levels were analyzed: 1.5, 3, 4.5, and 9 million dry short tons per year. Two corporate structures were analyzed: independent (as in Flipse 1982 and Andrews, et al., 1983) and parent/subsidiary which approximates the consortium structure of the 1970s. The effects of full versus partial manganese production (as discussed in the first chapter) were also determined.

Results are shown in Figures 9-13 as plots of Internal Rate Of Return versus throughput for the fast construction period, Southern California processing plant location and the reduction-ammonia leach four-metal process. These figures show the effects of inflation, loans and depletion as well as throughput. Figure 9 is for no inflation, no loan and no depletion.

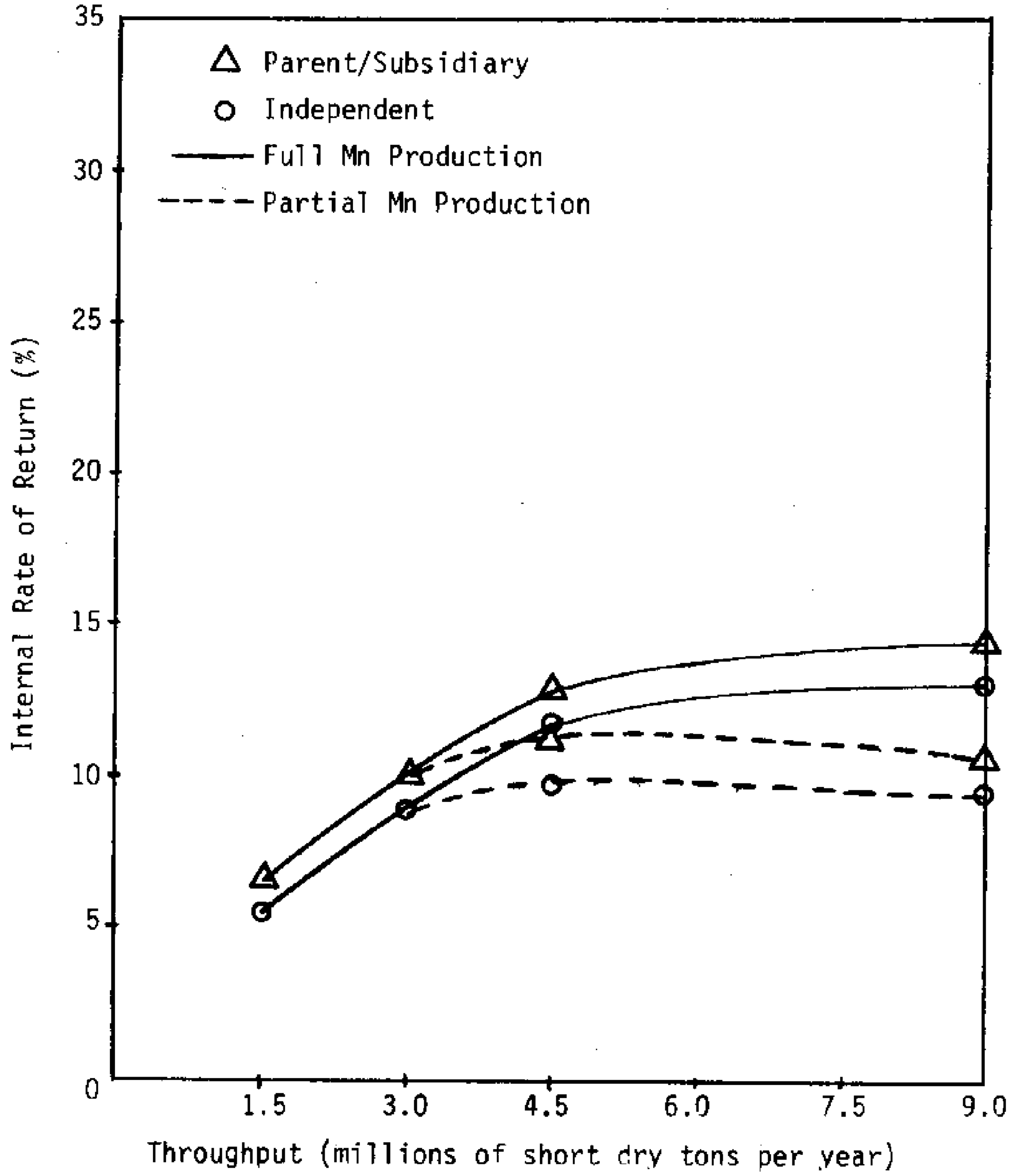

Figure 9. Internal Rate of Return Versus Throughput for:

Inflation Percent	0.0
Loan	No
Depletion	No
Construction Period	Fast
Location	Southern California
Process	NH_3 Leach, 4-Metal

The independent corporate results in Figure 9 for the 1.5 million ton throughput most closely approximate the results of the 1983 (Andrews, et al.) study. The corresponding Internal Rate of Return in Andrews, et al. (1983) is 6.4 percent after taxes while in the present study the Internal Rate of Return is about 5.5 percent. The difference is due primarily to the slight re-arrangement of cost sectors used to expedite the depletion computation, the differences in construction schedule and allocating the preparatory period expenses in year 0 instead of year 1.

Internal Rate of Return increases one to two percent going from independent to parent/subsidiary. Economies of scale are considerable for the throughputs up to 3.0 to 4.5 million tons (for partial and full manganese production, respectively), as indicated by the steep slopes. There is a marked leveling off of Internal Rate of Return for the higher throughputs. There is an apparent diseconomy of scale for the partial manganese case in going from 4.5 to 9 million tons (i.e. the Internal Rate of Return actually drops slightly). It will be shown that the dropoff is due solely to differences in scheduling because construction periods differ for the various throughputs (see Table 1).

The effect of depletion can be seen by comparing Figure 10 with Figure 9. Conditions in both figures are the same except for depletion. An upward shift of Internal Rate of Return of two or three percent is shown. The results are for the "first marketable product" interpretation of depletion. Alternative interpretations of depletion will be discussed below using the high throughput base case as a point of reference.

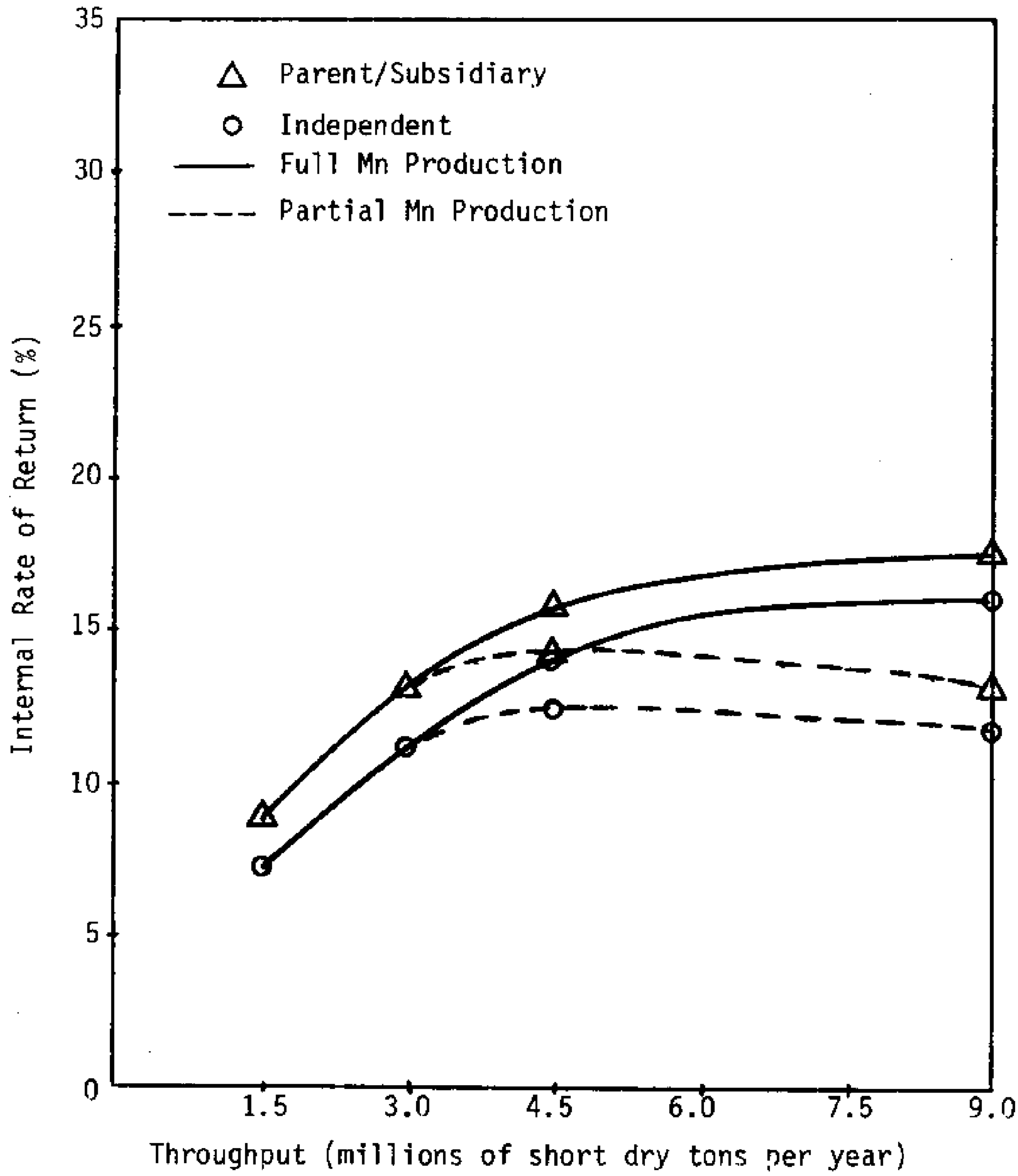

Figure 10. Internal Rate of Return Versus Throughput for:

Inflation Percent	0.0
Loan	No
Depletion	Yes
Construction Period	Fast
Location	Southern California
Process	NH_3 Leach, 4-Metal

The effects of combined loan and depletion are indicated by comparing Figure 11 to Figures 9 and 10. The loan (75 percent of fixed capital at 10 percent interest, with a 15 year payback period) shifts upward and increases the spread in Internal Rate of Return between the parent/subsidiary and independent curves from one to two percent to five to seven percent. This indicates the effect of leverage since the Internal Rate of Return for the higher throughputs without loan was higher than the loan interest rate. The leverage amplifies the profitability of the parent/subsidiary relative to the independent venture because less up-front capital is required.

Figure 12 shows the combined effects of 5 percent inflation and depletion with no loan. Comparison with Figure 10 (no inflation or loan, but with depletion) shows that inflation increases the Internal Rate of Return by four to five percent. This is because the inflation is assumed to affect both costs and revenues at the same rate. That is, metal prices inflate the same as costs, which is not necessarily realistic. A more detailed investigation of inflation is given below where cost and metal price inflation rates differ.

Combined effects of the loan, inflation and depletion are shown in Figure 13. The parent/subsidiary case in this figure most closely approximates a realistic mining venture. A high throughput base case was defined using the 4.5 million ton throughput, partial manganese data point for the parent/subsidiary curve in this figure. The corresponding Internal Rate of Return is 25 percent. The high throughput base case was used throughout the rest of the study as a point of reference for other changes or variations. That is, effects of other variables were determined one at a time off the base case to determine sensitivities.

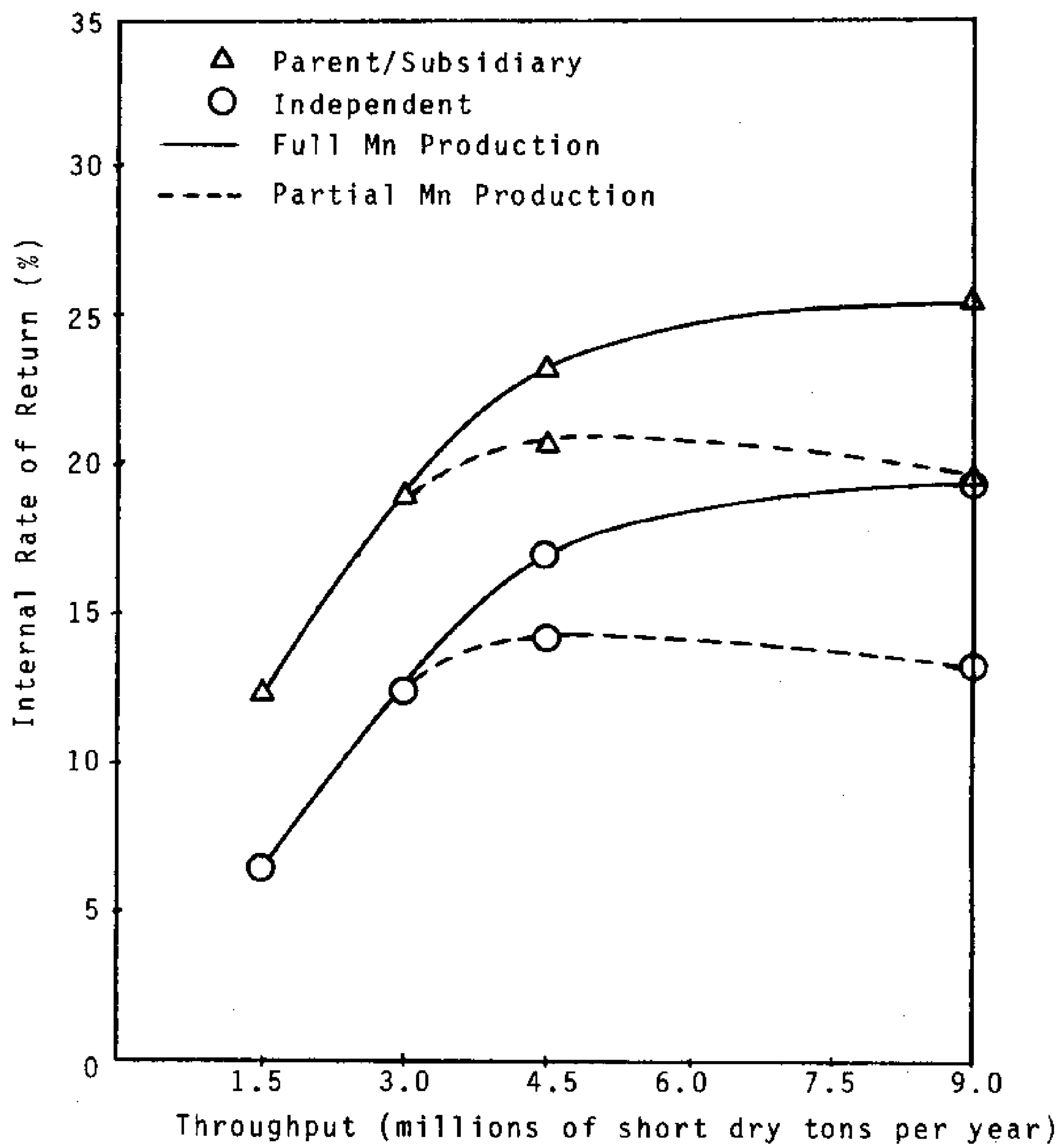

Figure 11. Internal Rate of Return Versus Throughput for:

Inflation Percent	0.0
Loan	Yes (10 percent interest, 75 percent of fixed capital)
Depletion	Yes
Construction Period	Fast
Location	Southern California
Process	NH_3 Leach, 4-Metal

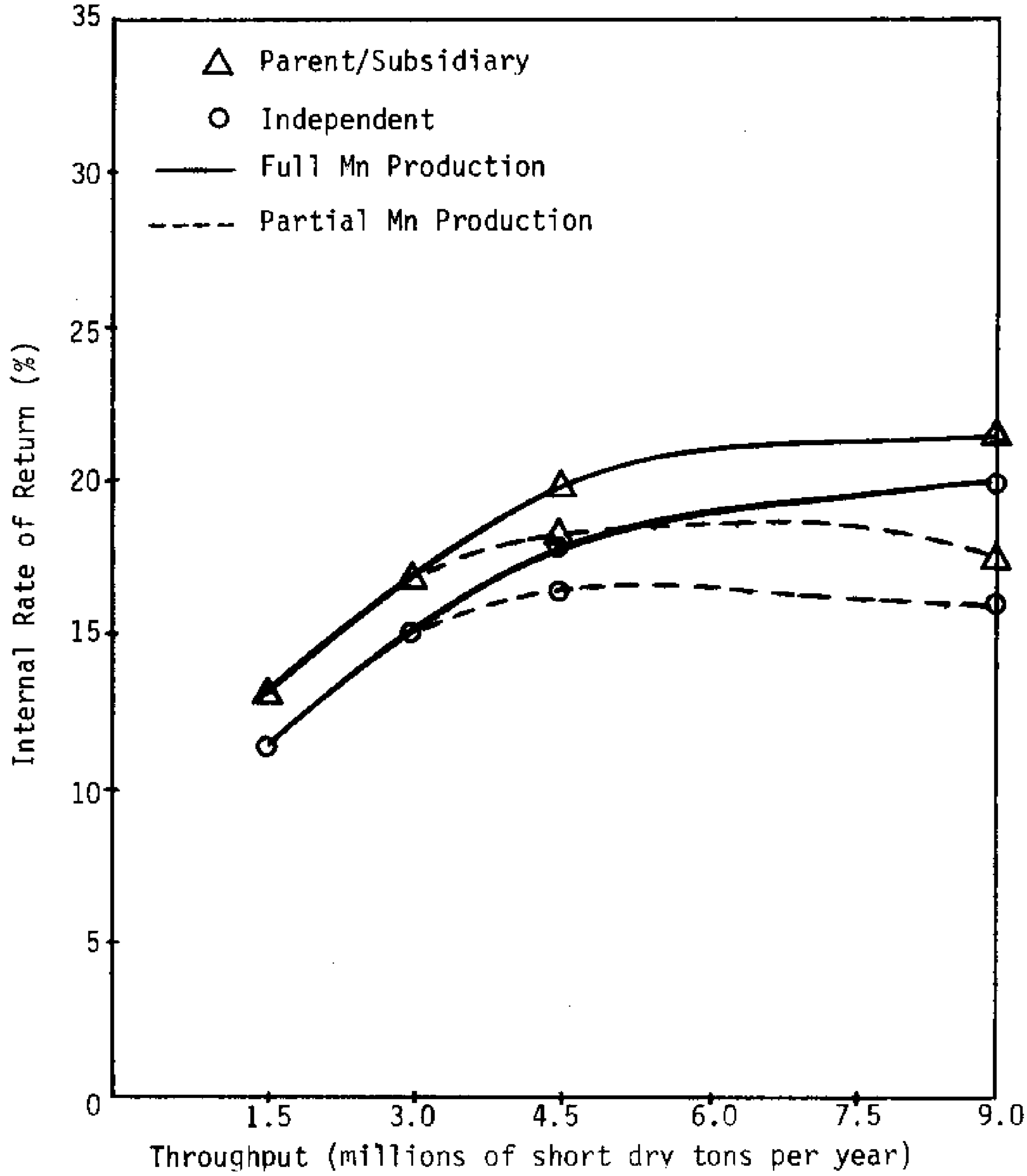

Figure 12. Internal Rate of Return Versus Throughput for:

Inflation Percent	5.0
Loan	No
Depletion	Yes
Construction Period	Fast
Location	Southern California
Process	NH_3 Leach, 4-Metal

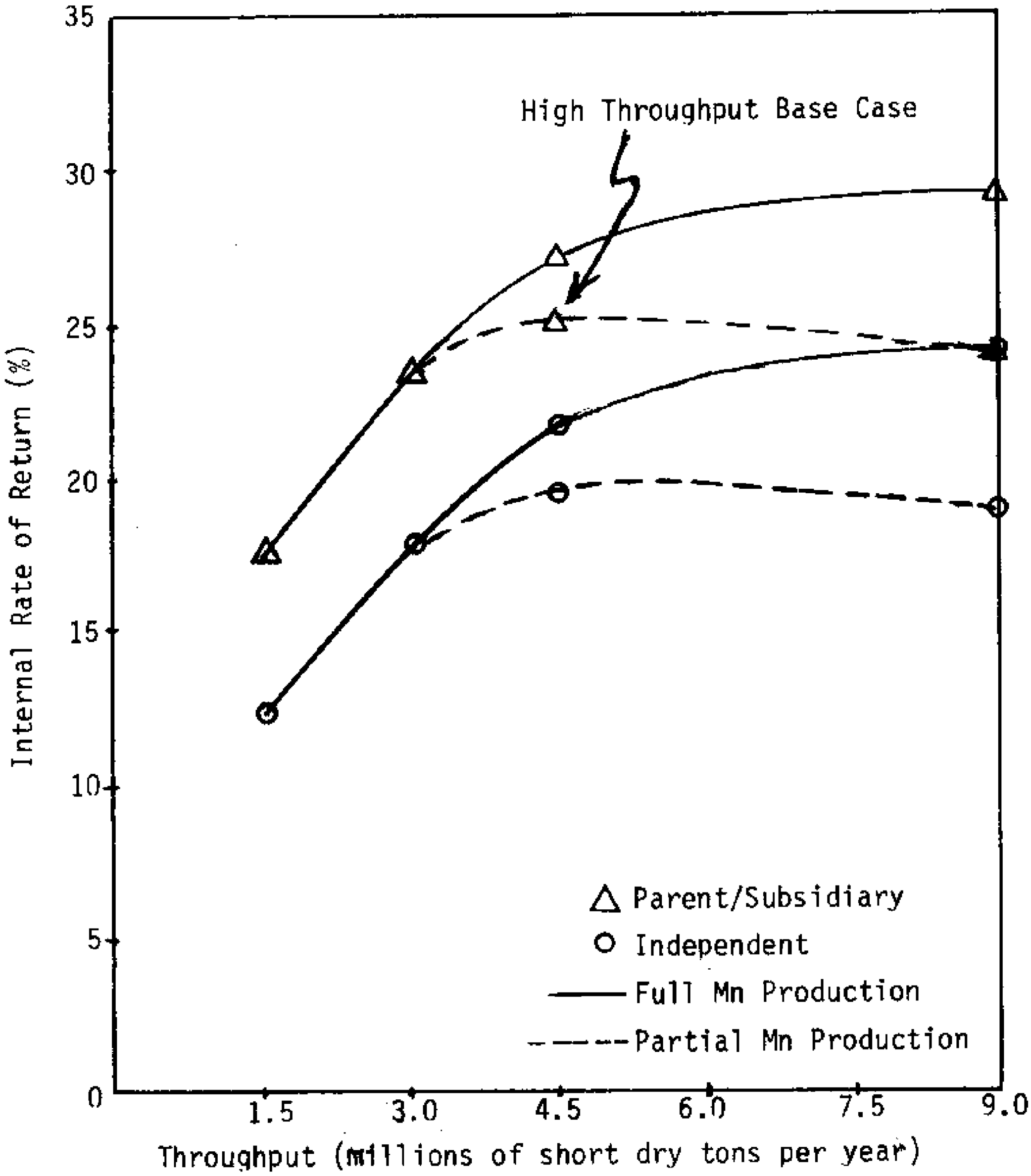

Figure 13. Internal Rate of Return Versus Throughput for:

Inflation Percent	5.0
Loan Interest Percent	10.0 (amount 75 percent of fixed capital)
Depletion	Yes
Construction Period	Fast
Location	Southern California
Process	NH_3 Leach, 4-Metal

Corporate Funding Requirements

Ordinarily the rate of return is sufficient to compare the economic performance of alternative ventures. However the absolute magnitude of the "up-front" money required to start up a given venture has some bearing on the economic feasibility as no company has virtually unlimited ability to raise venture capital. This is normally the case with large scale ocean engineering projects which tend to be capital intensive. One cannot increase the scale of a mining operation indefinitely as startup costs will become prohibitive. To take the capital intensity of alternative ventures into consideration a criterion was developed that takes into account the corporate structure.

The capital intensity criterion is computed using "total funding" which is an output variable in the program (see Appendix F). Total funding includes preparatory period expenses, operating costs during the construction period and fixed capital. To take into account funding from commercial banks, equity is introduced where equity is the total funding minus the debt.

For the independent corporate entity, the up-front money is simply equity. For the parent/subsidiary entity the tax savings resulting from the immediate writeoff of expenses during the preparatory period and the construction period must be taken into account. That is, the parent company can immediately write off all expenses, whereas the independent must use tax loss carryforwards deferring the writeoff until profitable production starts. This means the net equity put up by the parent is reduced by the amount of the tax savings. Equity minus tax savings is called in the program the "parent advance net of taxes"

(PANT). The PANT for the parent/subsidiary and equity for the independent are referred to here as "net corporate funding" which is used as the index for capital intensity. For the alternatives where there is a loan the loan amount is fixed as 75 percent of fixed capital. It is assumed that the venture has no difficulty in obtaining a loan of this amount.

The net corporate funding is dependent on inflation rate because spending, which is indexed to inflation, is spread out over the construction period. The period varies from four to ten years (see Table 1). The inflated value of corporate funding is computed by the program. However, a better indication of funding is given by taking the zero inflation figure. The zero inflation total gives the total in constant (1982) dollars that is required to start up the venture. Net corporate funding for the various ventures is given in the Tables 11-13. The amounts in Tables 11-13 are for zero inflation (i.e. constant dollars) while the effect of inflation rate on corporate funding for the modified base case is given in Table 15.

Table 11 shows net corporate funding as a function of throughput for the independent and parent/subsidiary both with and without the loan. Funding is given as the constant dollar value at the start of Year 1 in billions of 1982 dollars. That is, the zero inflation figure was used. One sees the parent/subsidiary net funding requirements are substantially lower than the independent's (by ten to 25 percent depending on throughput). Variation with throughput is also apparent, ranging from $1.3 billion for the 1.5 million ton venture to $5.2 billion for the nine million ton full manganese venture. Economies of scale are apparent in total funding as capacity can be doubled with considerably less than twice the funding.

Table 11. Net Corporate Funding as a Function of Throughput for:

Process	NH_3 Leach, 4-Metal
Inflation	0.0
Loan Interest % (75% of Fixed Capital)	10.0
Construction Period	Fast
Location	Southern California

Throughput in millions of short dry tons per year	Net Corporate Funding in Billions of 1982 Dollars			
	No Loan		With Loan	
	I	P/S	I	P/S
1.5	1.3	1.1	0.7	0.4
3.0	2.1	1.7	1.0	0.6
4.5 Partial Mn	2.5	2.1	1.2	0.7
4.5 Full Mn	2.7	2.3	1.3	0.8
9.0 Partial Mn	4.4	3.7	2.1	1.3
9.0 Full Mn	5.2	4.4	2.6	1.7

I=Independent Corporate Structure
P/S=Parent/Subsidiary Corporate Structure

Output Printout for The Base Case

A complete output printout for the high throughput base case (defined above) is given in Appendix F. The printout is for the 4.5 million ton throughput, ammonia-leach processing with partial manganese production and the parent/subsidiary corporate structure. The Southern California processing plant location was used, with full depletion, fast construction period, 5 percent inflation and a 10 percent interest loan on 75 percent of the fixed capital.

Page 1 of Appendix F is a printout of the input data as a check to insure the input sheet in Appendix D has been filled out properly. Page 2 is a printout by year and sector of the capital investment and expense buildup during the construction period. Various totals such as total operating costs and total funding are printed out as well. Pages 3-7 are the cash flow tabulations by year for the life of the venture. Finally, page 8 gives various totals and/or averages over the life of the project, both before and after taxes. Payback periods, capital recovery factors and internal rates of return are also given on this page.

The most important indicator of economic productivity is the after tax internal rate of return. For the base case this is seen from the last line of page 8 to be 25 percent. An indication of the corporate funding requirements is given in the last line of page 2. The total parent advance net of taxes is $1.2 billion with inflation.

Complete output printouts were also generated for all the alternative ventures. The results are presented here in condensed form in the form of plots and tables of Internal Rate of Return and net corporate funding to save space.

Effect of Processing Plant Location

Figure 14 shows the effect of changing location on rate of return from the parent/subsidiary venture in Figure 13. The alternative Pacific Northwest location improves Internal Rate Of Return by 7-8 percent over the Southern California Location, giving yields of over 30 percent for mid-range throughput.

The improved Internal Rate of Return is due primarily to decreased electric power costs (3 cents per kilowatt-hour vs. 11 cents per

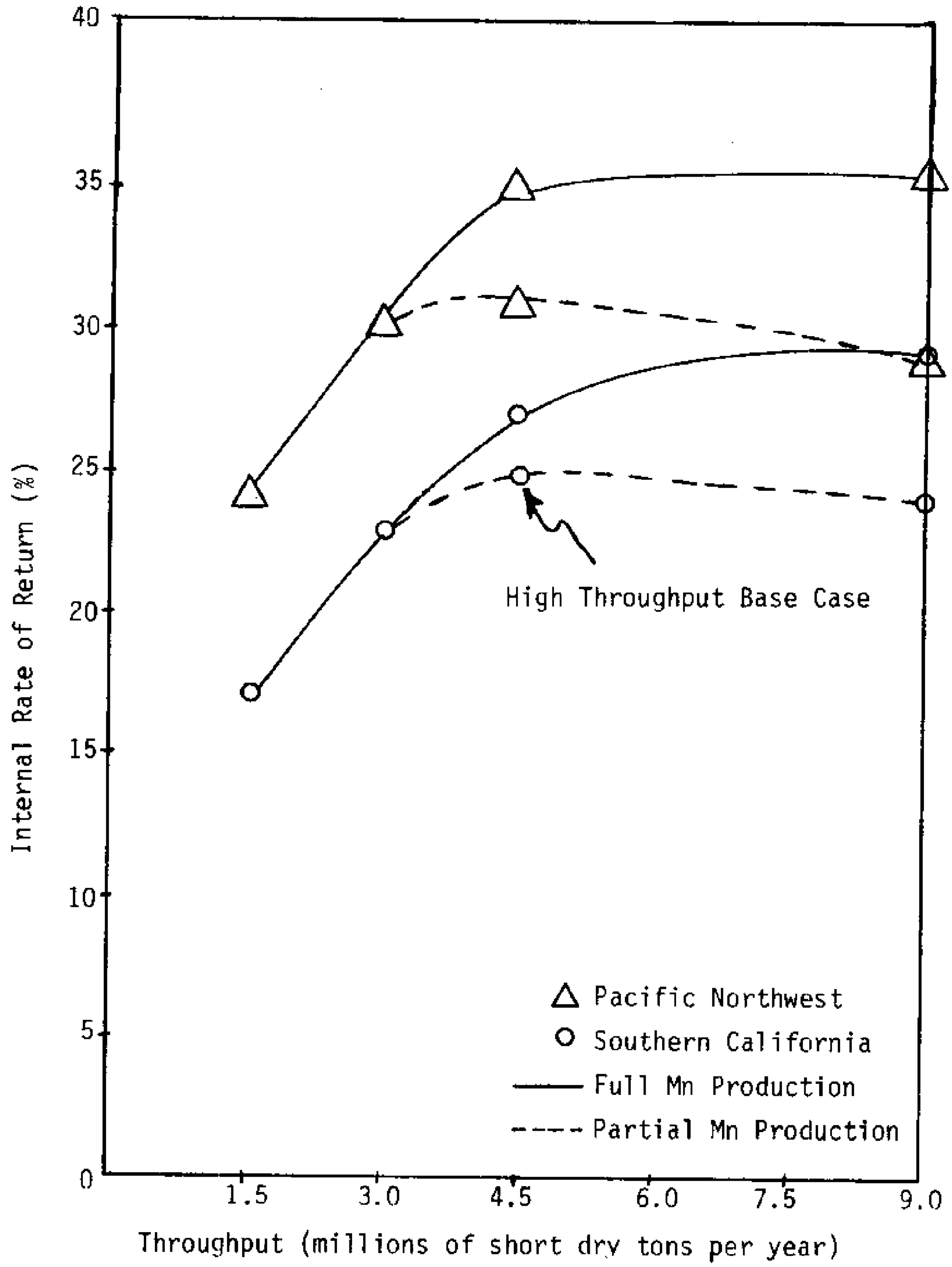

Figure 14. Internal Rate of Return Versus Throughput for Two Processing Plant Locations and:

Inflation Percent	5.0
Loan Interest Percent	10.0 (amount 75 percent of fixed capital)
Depletion	Yes
Construction Period	Fast
Corporate Structure	Parent/Subsidiary
Process	NH_3 Leach, 4-Metal

kilowatt-hour for So. Cal.). The transit distance to the Pacific Northwest is longer, increasing transportation costs. However, the increase is more than offset by the cheaper power. This makes the Pacific Northwest a potentially attractive location for the processing plant, providing a site can be found with a suitable port and environmental concerns can be satisfactorily resolved with the local authorities.

Table 12 shows net corporate funding as a function of throughput for two process plant locations for no interest and no loan. The funding requirements for the Pacific Northwest are in some cases slightly lower than for Southern California. This is because of the differences in working capital. Working capital is lower in the Pacific Northwest because of the lower electric power costs. This offsets the larger transport ships required for the Pacific Northwest.

Table 12. Net Corporate Funding as a Function of Throughput for Two Process Plant Locations and:

Process	NH_3 Leach, 4-Metal
Corporate Structure	Parent/Subsidiary
Inflation	0.0
Loan	No
Construction Period	Fast

Throughput in millions of short dry tons per year	Net Corporate Funding in Billions of 1982 Dollars	
	Southern California	Pacific Northwest
1.5	1.1	1.1
3.0	1.7	1.7
4.5 Partial Mn	2.1	2.1
4.5 Full Mn	2.3	2.2
9.0 Partial Mn	3.7	3.7
9.0 Full Mn	4.4	4.3

Effect of Length of Construction Period

Effect of length of construction period on Internal Rate of Return is shown in Figure 15 for the parent/subsidiary partial manganese production venture in Figure 13. The fast and slow construction periods for the four throughputs are given in Table 1. The figure shows that the apparent diseconomy of scale between 4.5 and 9 million tons is actually due to scheduling differences. The fast construction period for the 9 million ton throughput is the same as the slow period for the 4.5 million ton throughput (6 years). The Internal Rate of Return in both cases is about 24 percent indicating no economies of scale. This is because the 9 million ton throughput was achieved from the 4.5 million ton plant by parallel trains. The differences in Internal Rate of Return are small between the two construction periods, 1 percent or less.

Table 13 shows net corporate funding for fast and slow construction periods as a function of throughput for the modified base case (no interest and no loan, variable throughput). There is a considerable drop in funding required for the slow construction for the 3 and 9 million ton throughputs (both two-ship cases). This occurs because partial production starts before the second ship is completed so revenues from partial production pay for part of the delayed capital expenses (see Appendix B).

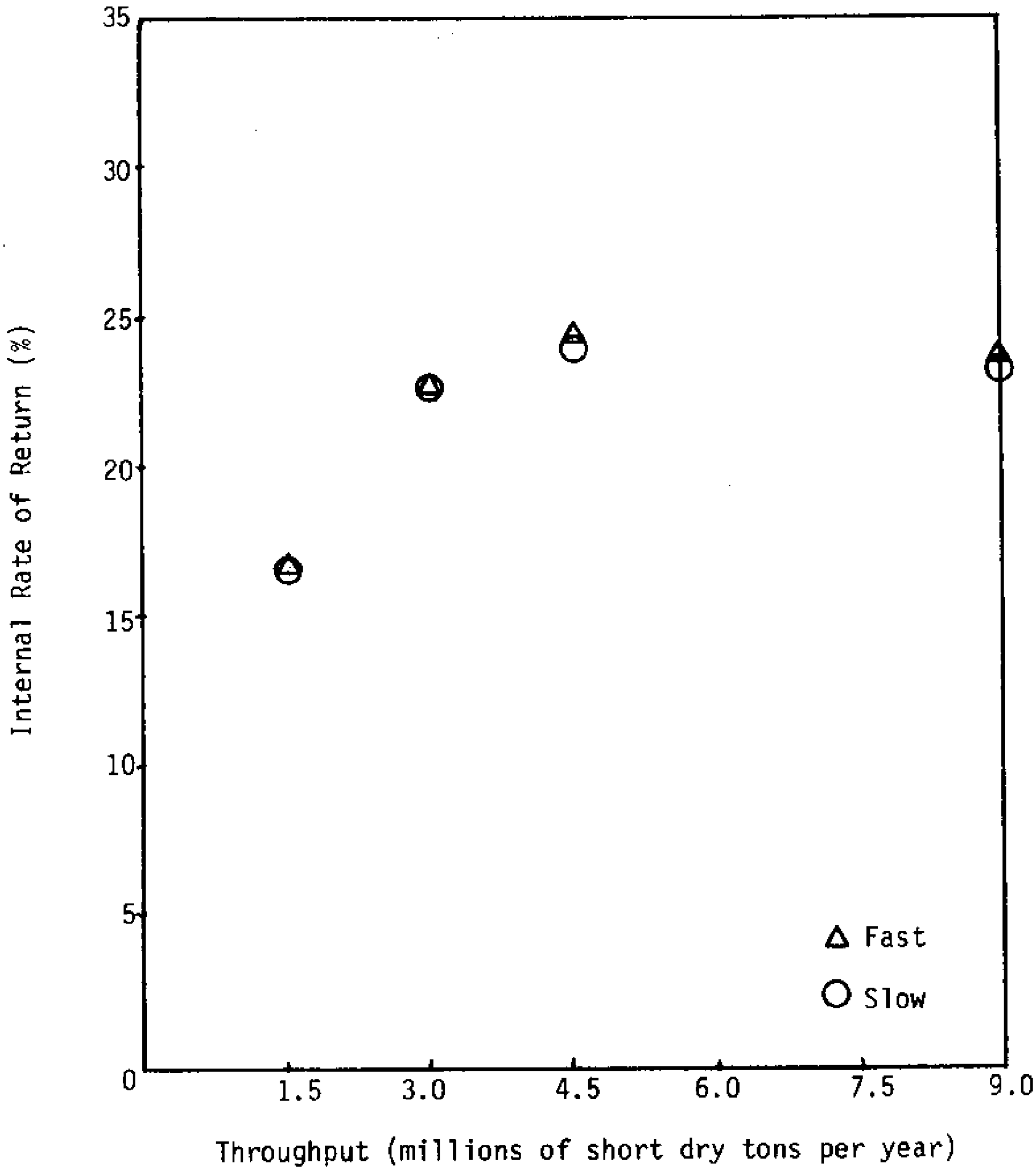

Figure 15. Internal Rate of Return Versus Throughput for Fast and Slow Construction Periods for:

Process	NH_3 Leach Partial Mn Production
Corporate Structure	Parent/Subsidiary
Inflation Percent	5.0
Loan Interest Percent	10.0 (amount 75 percent of fixed capital)
Depletion	Yes
Location	Southern California

Table 13. Net Corporate Funding Versus Throughput for Fast and Slow Construction Periods and:

Process	NH_3 Leach, Partial Mn
Corporate Structure	Parent/Subsidiary
Inflation	0.0
Loan	No
Location	Southern California

Throughput in millions of short dry tons per year	Net Corporate Funding Required in Billions of 1982 Dollars	
	Fast Construction	Slow Construction
1.5	1.1	1.1
3.0	1.7	1.3
4.5	2.1	2.2
9.0	3.7	1.8

Effect of Linked Inflation and Interest Rate

Results of a more detailed investigation of inflation and interest rate are shown in Figure 16. Interest rate and inflation are varied for the base case parent/subsidiary partial manganese venture at a 4.5 million ton throughput shown in Figure 13. Cost (operating and capital) inflation is assumed to be 5 percent lower than the loan interest rate. Metal price inflation effects were computed for three cases, equal to, one half of and zero times cost inflation. The variations in interest, cost inflation and price inflation are shown in Table 14. Figure 16 plots Internal Rate Of Return versus interest rate and inflation rate for the three types of inflation. When the price inflation equals the cost inflation, a slight increase in Internal Rate of Return is seen as interest rate and cost inflation increase. However, if the metal price inflation is below the cost inflation Internal Rate of Return rapidly plummets as interest rate increases. For example, at 10 percent interest the Internal Rate of Return is 25 percent for full price inflation,

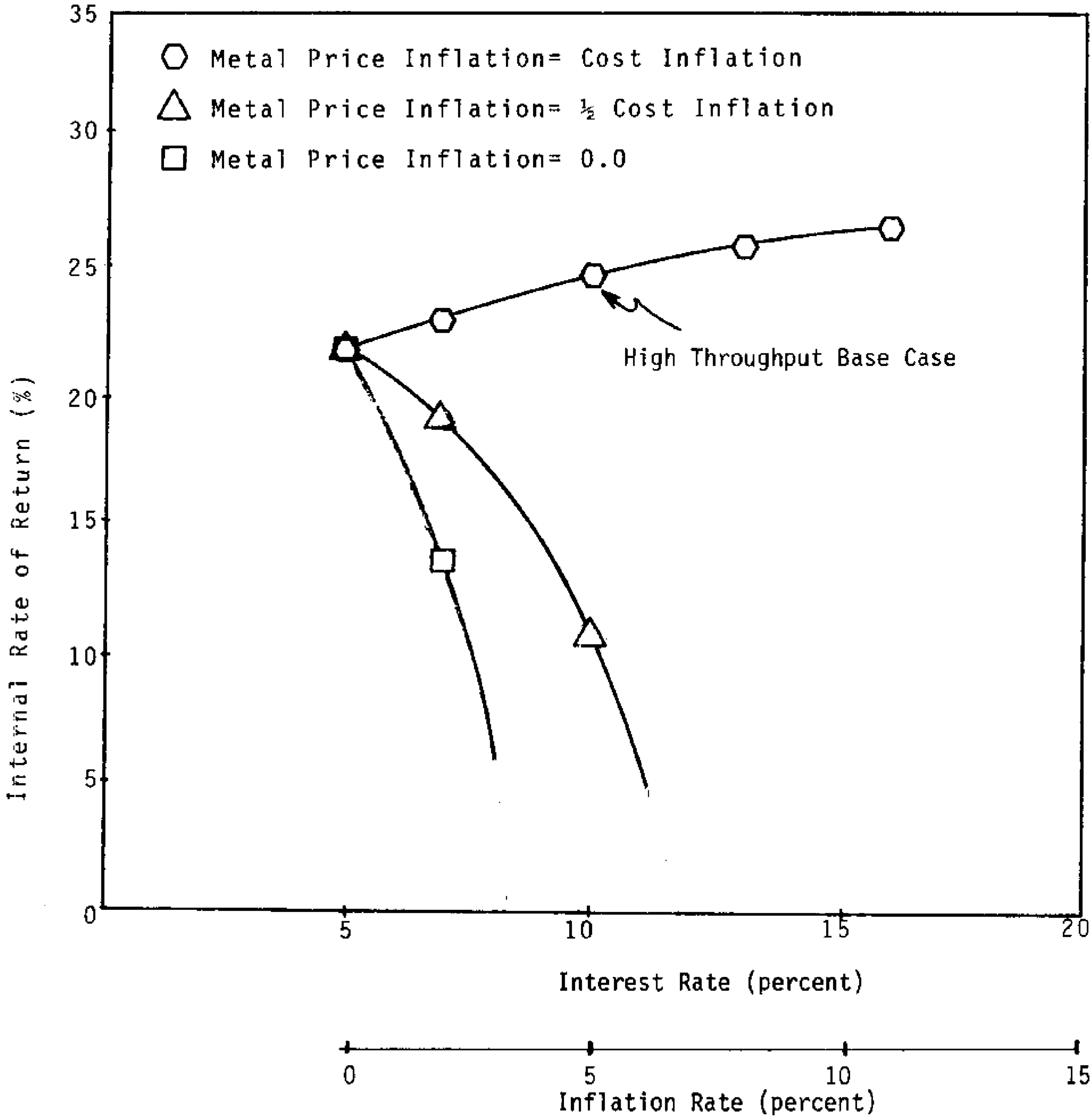

Figure 16. Internal Rate of Return Versus Interest Rate for:

Throughput (MDSTPY)	4.5
Process	NH_3 Leach, Partial Mn Production
Corporate Structure	Parent/Subsidiary
Inflation	Cost Inflation: Interest Percent minus 5.0 Percent Metal Price Inflation: Various
Loan	Yes
Depletion	Yes
Construction Period	Fast
Location	Southern California

11 percent for one-half inflation, is negative for zero price inflation. This figure underscores the importance of metal pricing on ocean mining economic feasibility.

Table 14. Variation in Cost and Price Inflation as a Function of Interest Rate

Case	Interest %	Cost Inflation %	Price Inflation @1/2 of Cost Inflation
1	5	0	0
2	7	2	1
3*	10	5	2.5
4	13	8	4
5	16	11	5.5

*High Throughput Base Case

Net corporate funding as a function of inflation rate is shown in Table 15 for the modified base case with and without the loan. The loan interest rate has been taken as 5 percent higher than the inflation rate. The funding is independent of metal price inflation. Total funding is very sensitive to inflation because of the construction period being spread out over several years.

Table 15. Net Corporate Funding Versus Inflation Rate for:

Throughput(MSDTPY)	4.5
Process	NH_3 Leach, Partial Mn
Corporate Structure	Parent/Subsidiary
Construction Period	Fast
Location	Southern California

		Net Corporate Funding Required in Billions of 1982 Dollars	
Inflation	Interest (Five Percent Spread)	No Loan	With Loan (75% of Fixed Capital)
0.0%	5.0%	2.1	0.8
2.0%	7.0%	2.3	0.9
5.0%	10.0%	2.7	1.2
8.0%	13.0%	3.3	1.6
11.0%	16.0%	4.2	2.4

Comment: Present Cost = 0% Inflation
Funding independent of depletion

Effect of Alternative Processes

Effects of alternative processes are shown in Table 16 for the high throughput base case. Five alternative processes treated in the 1982 and 1983 studies were analyzed. They were ammonia leach three metal, ammonia leach with full and partial manganese production from the tailings and smelting with full and partial manganese production. The respective Internal Rate of Return's are shown in the first column of Table 16. The three metal ammonia leach process shows a drop of 6 percent from the base case which occurs because of the loss of manganese sales. The partial manganese smelting process has a drop of 3 percent from the base case, because of higher processing costs. The full manganese production for smelting and ammonia leach shows increases over the base case of 3 and 2 percent, respectively. These increases may not in fact occur because of the manganese glut problem discussed above in which the massive introduction of manganese from modules would depress prices.

Net corporate funding for zero inflation for the five processes is shown in the last two columns of Table 16 for the "no loan" and "with loan" cases, respectively. The slight reduction in funding for the partial manganese (vs. full manganese) is due to a less costly processing plant.

Table 16. Internal Rate of Return and Net Corporate Funding for Various Processes and:

Throughput (MDSTPY)	4.5
Corporate Structure	Parent/Subsidiary
Inflation percent	5.0*
Loan Interest percent (75 percent of Fixed Capital)	10.0
Depletion	Yes
Construction Period	Fast
Location	Southern California

Process	IROR (%)	Net Corporate Funding Required in Billions of 1982 Dollars	
		No Loan	With Loan
NH_3 - Three Metal	19	1.7	0.5
NH_3 - Partial Mn**	25	2.1	0.7
NH_3 - Full Mn	27	2.3	0.8
Smelting - Partial Mn	22	2.2	0.8
Smelting - Full Mn	28	2.4	0.9

* Zero inflation is used for Net Corporate Funding
** High Throughput Base Case

Effect of Depletion

A more detailed analysis of depletion was conducted for the high throughput base case. Two interpretations of mining costs may be used in the percentage depletion computation as discussed in the chapter describing the Texas A&M Ocean Mining Payout Analysis Program. The two interpretations are:

* Mining costs are all costs up to the "first marketable product",
* Mining costs include all costs up to the point where the "first chemical change" takes place in the ore during processing.

Table 17 indicates the percentage of mining costs in processing used for the two interpretations. The resulting Internal Rate of Return is also indicated for the two interpretations plus the no depletion case. The less conservative interpretation (first marketable product) shows a 5 percent improvement over no depletion while the more conservative interpretation (first chemical change) shows a 2 percent improvement. The first marketable product interpretation significantly improves the economies of the venture. It should be noted that depletion has no effect on the net corporate funding requirements.

Table 17. Effect of Depletion Interpretations for the High Throughput Base Case

Interpretation	Percent of Total Processing Costs Used in Mining Costs		IROR (percent)
1) First marketable product	Capital Operating	100% 100%	25
2) First chemical change	Capital Operating	7.1% 6.2%	22
3) No depletion	Capital Operating	-0- -0-	20

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

In the Introduction the basis for scaling up the size of a nodule mining venture is established. An articulated nodule collector assembly consisting of three first-generation collectors operating in parallel (Figure 1), is used as the basis to triple the system throughput. The approach is a conservative one requiring no major new technology development and is used throughout the integrated mining system. In general, system or subsystem throughput can be increased in three ways. They are

* Scaling up size of system components,
* Increasing utilization, rates or speeds of components,
* and, parallel trains (duplicating or repeating units).

All three approaches are used to scale up the system depending on the throughput and subsystem component. How each of the approaches can be used and the effects on economies of scale are also discussed.

The Texas A&M University Ocean Mining Payout Model is described using an input-output approach (Figure 2). Generating capital and operating cost data required as inputs to the model is the major task for any engineering economic analysis. This process is indicated as an input-output relation in Figure 3.

In the High Throughput Mining Systems chapter the project is broken down into nine cost sectors on a functional basis. They include prospecting and exploration; mining; marine transport; marine terminal; onshore transport; processing; waste disposal; mining support; and research and development.

Costs are estimated for each sector for four throughputs: 1.5, 3, 4.5 and 9 million short dry tons per year of nodules (ore). The 1.5 and 3.0 million ton throughputs use one and two, respectively, of the pioneering baseline mining ships described in Flipse [1982]. The 4.5 and 9 million ton systems use the articulated collector; a scaled up lift pipe and one and two (respectively) larger mining ships. The highest throughput system (9 million tons) uses almost exclusively parallel trains in scaling up from the 4.5 million ton system, so economies of scale turn out to be nonexistent.

Each sector and how it is scaled up is described. Capital and operating costs are also estimated for each throughput. Preparatory period expenses are estimated and their tax treatment is discussed. Effects of two processing plant locations with differing electric power rates are analyzed. They are Southern California (11 cents per kilowatt-hour) and Pacific Northwest (3 cents per kilowatt-hour). Two construction periods (fast and slow) are also treated by setting up tables of distributions of capital and operating costs and production rates by year for each throughput. Five ore processing plant alternatives were also analyzed. They are

* Reduction - NH_3 leach (3-metal).
* Reduction - NH_3 leach (4-metal, full Mn production).
* Reduction - NH_3 leach (4-metal, partial Mn production).
* Smelting (4-metal).
* and, smelting (4-metal, partial Mn production).

The partial Mn production options (3 and 5) were introduced to address (in a simplified way) the potential manganese glut problem (Figure 4).

The next chapter describes the 1984 version of the Texas A&M University Manganese Nodule Mining System Payout Analysis Computer Program. Background information is given on previous versions of the program and its emphasis on annual cash flow computations. Major changes in the program required a complete revision of the earlier (1983) program. Depletion allowance deductions can be computed for both cost and percentage depletion. Construction period alternatives are built into the program, and inflation effects can be computed. Two corporate structures - independent (used in the pioneering venture analysis) and subsidiary of an affluent parent corporation - can be analyzed. Other changes were made in input and output formatting. Automatic computation and printout of several alternatives for a single input data set was also implemented. A detailed discussion of how mining depletion tax law may be applied to ocean nodule mining is given since this is a substsntial extrapolation from terrestrial mining practices. Basic assumptions used in the program are listed and the input data sheet variables are described.

Payout Program analysis results are given in the Payout Analysis Results chapter . The effects of throughput were determined first for ventures varying depletion, corporate structure; full versus partial manganese production; inflation, and loan. Results were presented as plots of rate of return versus throughput in Figures 9 through 13. Corresponding data on start up capital requirements is presented in Table 11. The plots show considerable economy of scale at the lower throughputs with diminishing returns setting in around a throughput of 4.5 million tons.

A high throughput base case was defined by taking values of the above variables most closely simulating conditions envisioned by the four U.S.-based consortia of the 1970's. The base case was taken as:

* Throughput of 4.5 million dry tons per year.
* Ammonia leach process with limited manganese production.
* Parent/subsidiary corporate structure.
* Inflation rate of 5 percent.
* A loan of 75 percent of the fixed capital at 10 percent interest rate and a 15-year payback period.
* "First marketable product" depletion computation used.
* Fast construction period.
* and, a Southern California location for processing plant.

The base case was used as a point of reference for detailed studies of alternate variables whereby each was varied one at a time to determine sensitivities.

A complete printout of the Texas A&M University Payout Program output for the high throughput base case is given in Appendix F. The complete printout includes a year by year cash flow and tax computations as well as various totals and average quantities over the life of the project. Results are given in condensed form in terms of Internal Rate Of Return and capital requirements for all cases other than the base case.

Effects of moving the process plant from Southern California to the Pacific Northwest are shown in Figure 14 and Table 12. The Pacific

Northwest location has lower electric power rates, significantly reducing costs in the processing sector. This improves the Internal Rate of Return.

Length of construction period effects are shown in Figure 15 and Table 13. The effect is minor for Internal Rate of Return and for capital for the one-ship mining systems. The two-ship ventures (4.5 and 9.0 million tons) indicate reduced capital is required in slow construction periods. Phased-in production with one ship assists in paying for construction of the second ship and expansion of the processing plant.

Combined effects of interest and inflation are shown in Figure 16 and Tables 14 and 15. Here a 5 percent difference between loan interest rate and cost inflation has been assumed, while varying the interest rate from 5 to 15 percent. Metal price inflation was taken as equal to half and zero times the cost inflation rate. The Internal Rate of Return is shown to plummet if the price inflation is less than cost inflation. Corporate funding requirements are shown as a function of inflation rate in Table 15. Funding requirements increase dramatically with inflation rate because of the spread out of spending over the construction period.

Effect of the various ore treatment processes on Internal Rate of Return and capital requirements is shown in Table 16 for the high throughput base case. The effects are shown to be secondary. Finally three (tax) depletion interpretations are investigated for the base case in terms of Internal Rate of Return. The results are shown in Table 17. Depletion is shown to have a significant effect on Internal Rate of Return.

Conclusions

The major conclusions can be drawn from inspection of Tables 18 and 19. This information has been extracted from the Payout Analysis Results chapter. Table 18 shows the effect of varying throughput for the base case defined in the Summary section. The table lists after tax Internal Rate of Return in percent, Internal Rate of Return increment off the 4.5 million ton high throughput base case and net corporate funding in billions of dollars. The effect of diminishing return in economies of scale can be seen quite clearly in the Internal Rate of Return increments column. The Internal Rate of Return peaks at the 4.5 million ton throughput with a slight decline at 9 million tons. The 3 million ton throughput shows a two percent decrease while the 1.5 million ton case shows a seven percent decrease off the base case.

Table 18. Internal Rate of Return and Net Corporate Funding for the Variable Throughput Base Case.

Throughput (millions of dry short tons per year)	IROR (Percent)	IROR Increment Relative to High Throughput Base Case (Percent)	Net Corporate Funding Required (Billions of 1982 $)
1.5	17	-7	1.1
3.0	23	-2	1.7
4.5*	25	0	2.1
9.0	24	-1	3.7

*Base Case

The level of the Internal Rate of Return is quite high compared to the 1982 [Flipse] and 1983 [Andrews, et al.] studies with Internal Rate of Return's in the 25 percent range. This is because the base case considered includes the combined effects of depletion, parent/subsidiary corporate structure, and loan leverage, in addition to economies of scale. It must be emphasized that the study is based on "normal" metal prices shown in Table 10 that are considerably higher than current prices (except for cobalt). The relatively higher rate of return for the base case reflects these high metal price levels.

Start up capital requirements are also indicated in Table 18. The start up capital called "net corporate funding" is defined in the results chapter. The base case (4.5 million ton throughput) funding is $2.1 billion. Economies of scale in funding come into play as it takes less incremental money to increase production. For example, to triple production from 1.5 to 4.5 million tons requires only an increase of 91 percent in capital (from $1.1 to $2.1 billion).

Results of additional studies are shown in Table 19 in the form of Internal Rates Of Return and increments in Internal Rate Of Return off the base case. The high throughput base case Internal Rate Of Return of 25 percent is indicated at the top of the table. The results of seven variations off the base case are shown in the remainder of the table. The base case is described in the summary of the results chapter. Corporate structure change in going from parent/subsidiary to independent as in Flipse [1982] and Andrews, et al. [1983] is shown as item 1 in Table 19. The loss in Internal Rate of Return for the independent venture is 6 percent due to the parent/subsidiary being able to immediately write off all expenses without having to use tax loss carryforwards before production.

Table 19. Internal Rate of Return and Increments for Key Variables

Variable Incremented	IROR (%)	Increment in IROR (%) from Base Case
(Base Case: for comparison)	(25)	0
1. Corporate Structure (independent)	19	-6
2. Depletion		
None	20	-5
"First Chemical Change"	22	-3
3. Inflation		
None, 5% interest	22	-3
Metal Price Infl = 2.5% (Cost Infl = 5%)	11	-14
Metal Price Inflation = 0 (Cost Infl = 5%)	Negative	Worse than (-25)
4. Debt (None @ 5% Infl)	18	-7
5. Location Plus Power Costs (Pac. N.W.)	31	+6
6. Construction Period (slow)	24	-1
7. Processing		
NH_3-3 metal	19	-6
NH_3-full Mn	27	+2
Smelting-partial Mn	22	-3
Smelting-full Mn	28	+3

Alternative depletion changes are shown as Item 2. The base case uses the "first marketable product" interpretation. The more conservative "first chemical change" interpretation results in a decrease in Internal Rate of Return of 3 percent while leaving out depletion entirely drops Internal Rate of Return by 5 percent.

Various inflation cases are shown in Item 3. No inflation with 5 percent interest on the loan (maintaining the 5 percent spread) gives a drop of 3 percent in Internal Rate of Return from the base case with 5 percent inflation and 10 percent interest. This is assuming metal price inflation is the same as cost inflation. Since historically metal prices have not advanced as fast as costs (and in fact in general, prices have actually dropped), price inflation at half and zero times cost inflation were also analyzed. Price inflation at half cost inflation shows a drop in Internal Rate of Return of 14 percent, while for zero price inflation the Internal Rate of Return actually goes negative. The results underscore the importance of metal prices in ocean mining economics.

Effect of removing the loan at 10 percent interest at a 5 percent inflation rate decreases the Internal Rate of Return from 25 percent to 18 percent. The loan provides positive leverage for the company as the interest rate is lower than the no loan Internal Rate of Return.

The effect of a location change from Southern California to the Pacific Northwest with its attractive low cost electric power rates increases the Internal Rate of Return by 6 percent. This is the only significant increase in Internal Rate of Return of all the alternatives considered here.

Effect of construction period stretchout is shown in Item 6 of Table 19. The effect is seen to be minor on Internal Rate of Return with a decrease of 1 percent.

The processing alternatives are indicated in Item 7. The base case processing is ammonia leach with partial manganese production. Eliminating manganese production entirely reduces Internal Rate of Return by 6 percent because of the loss in manganese sales. Full manganese production increases Internal Rate of Return by 2 percent assuming manganese prices are the same as for partial production. This may not be the case as the massive introduction of manganese will tend to reduce prices, and the Internal Rate of Return may actually drop. Smelting with partial managanese production decreases Internal Rate of Return by 3 percent because of the higher processing costs. Going to full manganese production with smelting increases Internal Rate of Return by 3 percent assuming prices remain the same. However, the increase may not be realized because of the manganese glut problem.

Recommendations

Research topics and ideas related to or outgrowths of the present work and also of potential interest to the National Oceanic and Atmospheric Administration are described below. These may form the basis for continuing the team effort centered at Texas A&M University, for further development of ocean mining technology and economic anlaysis and improvements in Texas A&M University's Ocean Mining Payout Model. The first two tasks taken together repesent an integrated approach to a second generation mining system.

Second Generation Systems

The results of research carried out to date show that the economics of a nodule processing venture are marginal at best unless a combination of circumstances occurs in which all or almost all technical, marketing, and cost elements are favorable. This conclusion is supported by the evidence shown in the lack of activity on the part of the various consortia. Cost estimates developed to support this research and the scenarios for the venture timing and operation were based on the premise that a "first generation" system would be used by a pioneer developer. The descriptions of the mining and processing systems were based on "known" technology; that is on approaches that had been supported by at least some industrial design work and limited pilot plant or scaled-down system testing, with only limited extrapolation.

One may ask whether a developer using "second generation" mining and processing technology could significantly reduce costs in these areas and thereby enhance the prospects for the development of a viable deep ocean mining industry? This possibility is proposed for investigation in the tasks described below.

Updating prospecting and exploration and environmental sensing systems for nodule mining. Many advances in "high-tech" electronics, microprocessors and sensor technology applicable to nodule mining have been made since the consortium pilot plant studies of the 1970s. Major advances have been made in automated bathymetry and nodule exploration. Major advances in sidescan sonar applicable to the bottom microtopography have also been made. The Japanese [Takahara and Handa, 1984] are currently investigating applicability of fiber optics for underwater sensing and data transmission. Deep-tow sensing technology has also improved. The applicability of this new technology to nodule mining and environmental monitoring should be investigated. Major changes may be made in prospecting and exploration procedures as a result of the technology (e.g. speeding up the survey process and automation of data processing). Revised scenarios for prospecting and exploration may be developed and the economic impact assessed.

Novel process routes. Second generation process routes radically different from the smelting and leaching processes used in this study may be feasible. These novel processing plant configurations should be designed without regard to the need to draw analogies to the processing of terrestrial ores or to produce products that meet current market specifications. The new process may be defined based on a survey of the literature to determine which of the most recent advances in extractive metallurgy could be used advantageously on this complex ore. This study may give a first order evaluation of the prospects for improving process economies via a breakthrough technology.

Foreign processing. High energy costs and the need to construct plants that will conform to stringent environmental standards, increase the costs of process plants constructed on the U.S. West Coast or Hawaii. It is possible that there may be locations in other jurisdictions along the Pacific rim where these and other constraints are not as severe, and the economics of nodules processing would be more favorable. In general, environmental restrictions are less severe and labor costs are much lower in the developing countries in this area, although infrastructure costs may be higher.

The total venture capital requirements and operating costs may be reestimated for alternative processing in each area, and the Texas A&M University model may be used to determine the returns expected for each.

Texas A&M University Ocean Mining Payout Program Modifications

The program may be modified to handle the "inverse problem" (i.e. given a satisfactory Internal Rate of Return, what must the system costs or metal prices be to produce this Internal Rate of Return?). This is a reversal of the input-output relation in Figure 2. The approach may be useful in targeting capital and/or operating costs in certain sectors or subsectors to produce an economically viable mining system. Threshold metal pricing levels for economic viability may also be developed.

In addition, terms, conditions and restrictions of licenses and permits for ocean mining are currently being generated. These terms, conditions and restrictions have an economic impact on any mining venture. Alternative lease terms have been proposed or considered as economic incentives to mining companies. These factors may be evaluated quantitatively by modifying the Texas A&M University Ocean Mining Payout Analysis Program.

REFERENCES

Andrews, B.V. (1978), "Relative Costs of U.S. and Foreign Nodule Transport Ships", Report to NOAA, April, Menlo Park, Ca.

Andrews, B.V., Flipse, J.E., Brown, F.C. (1983), "The Economic Viability of a Four-Metal Pioneer Deep Ocean Mining Venture", Texas A&M University Sea Grant College Program Report, TAMU-SG-84-201, October.

Collier, C.A. and Ledbetter, W.B. (1980), Engineering Cost Analysis, Sixth Ed., Collegiate Press of Gainesville, Gainesville, FL.

Commerce Clearing House, Inc., Publishers of Topical Law Reports, (1982a), Chicago, IL, "1982 Depreciation Guide Featuring the Accelerated Cost Recovery System", Vol. 69, No. 19, April 30.

Commerce Clearing House, Inc., (1982b), Publishers of Topical Law Reports, "Tax Planning 1982",

Dames and Moore (1980), "Environmental, Social and Economic Effects of Continued Reliance on Land Mining to Produce Metals Available from Manganese Nodules", Final Report to NOAA, NTIS #PB 81 180119, September.

Dworin, Lowell (1979), "The Taxation of Deepsea Mining", Final Report to NOAA, January 1, Austin, TX.

Flipse, J.E. (1982), "The Economic Analysis of a Pioneer Deep Ocean Mining Venture", Texas A&M University, Sea Grant College Program, TAMU-SG-82-201, August, College Station, TX, pp. 131.

Magnuson, A.H. (1983), "Manganese Nodule Abundance and Size from Bottom Reflectivity Measurements", Marine Mining, Vol. 4, Nos. 2/3, pp. 265-296.

Sibley, Scott F. (1983), "Mineral Commodity Profiles, 1983: Nickel", U.S. Department of the Interior, Bureau of Mines.

Takahara, H. and Handa, K. (1984), "Research and Development Project of Manganese Nodule Mining System in Japan", Paper No. OTC 4782, Offshore Technology Conference, Houston, TX, Vol. 3, pp. 69-74, May.

APPENDIX A

Capital and Operating Cost Breakdown for Various Ore Processes

Table A-1. Distribution of Costs for Reduction/NH_3 Leach Process With no Recovery of Manganese as a Function of Throughput

Throughput, millions of d.s.t.p.y.	1.5	3.0	4.5	9.0
Capital Requirements				
Millions of Dollars in				
Materials handling	57.1	84.1	108.0	171.7
Reduction/extraction	40.9	63.1	81.5	147.2
Metals separation	32.6	51.9	73.0	146.1
Reagent recovery	38.0	59.7	77.9	147.4
Metals recovery	60.8	110.1	156.8	302.8
Services	76.0	132.9	193.0	378.0
Total	305.4	501.8	690.2	1,293.2
Operating Costs				
Millions of Dollars/Year				
Materials/supplies	1.9	3.8	5.7	11.4
Fuels	21.4	42.8	64.1	128.3
Power @ 11¢/kwh	8.3	16.6	24.9	49.6
Labor	15.8	19.1	21.2	27.1
Fixed charges	21.4	35.1	48.3	90.5
Total	68.8	117.4	164.2	306.9

Table A-2. Distribution of Costs for Smelting Process for Differing Throughputs

	With Full Manganese Recovery				With Partial Manganese Recovery			
Throughput, millions of d.s.t.p.y.	1.5	3.0	4.5	9.0	1.5	3.0	4.5	9.0
Capital Requirements								
Millions of Dollars in								
Materials handling	86.7	129.5	167.6	268.5	86.7	129.5	161.9	249.3
Reduction/extraction	203.9	347.8	474.8	870.2	203.9	347.8	419.5	639.2
Metals separation	48.5	78.0	109.9	218.8	48.5	78.0	109.9	218.8
Reagent recovery	7.5	11.7	15.9	28.0	7.5	11.7	15.9	28.0
Metals recovery	61.0	110.3	157.1	303.2	61.0	110.3	157.1	303.2
Services	98.5	172.4	250.1	487.6	98.5	172.4	237.8	443.4
Total	506.1	849.7	1175.4	2176.3	506.1	849.7	1096.1	1881.9
Operating Costs								
Millions of Dollars/Year								
Materials/supplies	18.8	37.6	56.5	113.0	18.8	37.6	54.8	109.5
Fuels	52.0	103.9	155.9	311.7	52.0	103.9	130.1	208.7
Power @ 11¢/kwh	119.1	238.3	357.4	714.8	119.1	238.3	299.4	482.8
Labor	22.9	27.9	31.1	39.4	22.9	27.9	30.7	38.0
Fixed charges	40.5	68.0	94.0	174.1	40.5	68.0	87.6	150.6
Total	253.3	475.7	694.9	1353.0	253.3	475.7	602.6	989.6

Table A-3. Distribution of Costs for Reduction/NH_3 Leach Process for Differing Throughputs

	With Full Manganese Recovery				With Partial Manganese Recovery			
Throughput, millions of d.s.t.p.y.	1.5	3.0	4.5	9.0	1.5	3.0	4.5	9.0
Capital Requirements								
Millions of Dollars in								
Materials handling	91.2	125.9	155.8	248.1	91.2	125.9	149.8	213.5
Reduction/extraction	40.9	63.1	81.5	147.2	40.9	63.1	81.5	147.2
Metals separation	32.6	51.9	73.0	146.1	32.6	51.9	73.0	146.1
Reagent recovery	38.0	59.7	77.9	147.4	38.0	59.7	77.9	147.4
Metals recovery	218.1	355.9	487.7	931.3	218.1	355.9	402.6	548.6
Services	82.6	144.8	210.0	409.6	82.6	144.8	204.8	389.8
Total	503.4	801.3	1080.9	2029.7	503.4	801.3	989.6	1592.6
Operating Costs								
Millions of Dollars/Year								
Materials/supplies	16.6	33.2	49.8	199.5	16.6	33.2	35.1	140.8
Fuels	51.2	102.3	153.6	307.1	51.2	102.3	123.6	187.8
Power @ 11¢/kwh	104.3	208.6	312.7	625.6	104.3	208.6	216.9	241.6
Labor	22.0	26.8	29.5	41.8	22.0	26.8	28.9	34.8
Fixed charges	37.2	59.1	79.6	149.4	37.2	59.1	72.3	114.5
Total	231.3	430.0	625.2	1223.4	231.3	430.0	476.8	619.5

APPENDIX B

Capital and Operating Costs and Output Buildup Schedules

Table B-1. Capital and Operating Costs and Output Buildup Schedules: Four-Year Construction Period

	Year from Start							
Sector	1	2	3	4	5	6	7	(Land, Year 1)
a. Capital Spending in Percent of Total Capital								
1	100							
2	20	20	35	25				
3		20	50	30				
4	45	25	30					
5	20	30	25	10				15
6	10	30	35	24				1
7			30	65				5
8				100				
9	100							
b. Annual Operating Cost Buildup In Percent of Full								
1	100	100	100	100	100	100	100	
2				75	95	100	100	
3				60	90	100	100	
4				30	90	100	100	
5		10	10	20	90	100	100	
6					90	100	100	
7					60	80	100	
8	80	80	80	100	100	100	100	
9	100	100	100	100	100	100	100	
c. Annual Output in Percent of Full Production								
					60	80	100	

Table B-2. Capital and Operating Costs and Output Buildup Schedules: Six-Year Construction Period

	Year from Start							
Sector	1	2	3	4	5	6	7	8(Land, Year 1)
a. Capital Spending in Percent of Total Capital								
1	100							
2		5	15	20	35	25		
3				20	50	30		
4		20	25	30	25			
5	10		15	30	25	5		15
6		10	25	30	25	9		1
7					20	75		5
8						100		
9	100							
b. Annual Operating Cost Buildup In Percent of Full								
1	100	100	100	100	100	100	100	100
2					35	70	100	100
3					10	80	100	100
4					5	50	95	100
5		5	10	10	20	40	90	100
6						10	100	100
7						5	80	100
8	80	80	80	80	80	100	100	100
9	100	100	100	100	100	100	100	100
c. Annual Output in Percent of Full Production								
							80	100

Table B-3. Capital and Operating Costs and Output Buildup Schedules: Eight-Year Construction Period

	Year from Start										
Sector	1	2	3	4	5	6	7	8	9	10	(Land, Year 1)
a. Capital Spending in Percent of Total Capital											
1	50	50									
2		10	20	20	10	10	20	10			
3			10	25	15	20	20	10			
4		10	20	30	10	10	10	10			
5	20	30	25	10							15
6		5	15	20	20	15	20	14			1
7				10	40			45			5
8					100						
9	100										
b. Annual Operating Cost Buildup In Percent of Full											
1	100	100	100	100	100	100	100	100	100	100	
2					30	50	50	60	100	100	
3					10	50	50	60	100	100	
4					10	60	70	80	100	100	
5			10	10	20	70	80	90	100	100	
6						60	50	50	100	100	
7						40	50	50	95	100	
8	80	80	80	80	80	100	100	100	100	100	
9	100	100	100	100	100	100	100	100	100	100	
c. Annual Output in Percent of Full Production											
						40	50	50	95	100	

Table B-4. Capital and Operating Costs and Output Buildup Schedules: Ten-Year Construction Period

	Year from Start											
Sector	1	2	3	4	5	6	7	8	9	10	11	(Land, Year 1)
a. Capital Spending in Percent of Total Capital												
1	50	50										
2		10	20	20	10	--	10	10	10	10		
3			10	25	15	10	10	10	10	10		
4		10	20	30	10	10	--	10	10	10		
5	20	30	25	10					5			10
6		5	15	20	20	--	--	15	20	14		1
7				10	40					45		5
8					100							
9	100											
b. Annual Operating Cost Buildup In Percent of Full												
1	100	100	100	100	100	100	100	100	100	100	100	
2					30	50	50	50	50	59	100	
3					10	50	50	50	50	60	100	
4					10	60	60	60	60	90	100	
5			10	10	20	70	70	70	70	90	100	
6						60	50	50	50	50	100	
7					5	40	50	50	50	50	95	
8	80	80	80	80	80	80	80	100	100	100	100	
9	100	100	100	100	100	100	100	100	100	100	100	
c. Annual Output in Percent of Full Production												
						40	50	50	50	50	95	

APPENDIX C

Standard Mining Taxation

by

B. V. Andrews

Standard Mining Taxation

Standard taxation of corporate enterprises does not generally apply to United States' mining and metals producing companies. Special treatments of mining enterprises, for mine exploration and mine development expenses are permitted under Internal Revenue Code Sections 616 and 617, since the minerals produced are eligible for percentage depletion (even though percentage depletion may not necessarily be claimed or allowable) since the taxpayer-venture need not have an "economic interest." Mine exploration costs[1] are found only in Sector 1 now, and mine development costs[2] are in Sector 2 and 8 as redefined now. During the pre-production period, these expenses can be deducted directly, and capital investments in these sectors can be depreciated (over 5 years ACRS) beginning at the time of the expenditure. In combination with the 15-year carryforward now allowed, this is very fast (almost immediate) writeoff of all mine

[1]Mine exploration expenditures are costs to ascertain the existence, location, extent or quality of a mineral deposit before the beginning of the mine development stage. Since mining in international waters may be treated as non-foreign, domestic mining results, and the dollar amount of deductions is not limited. Even after commercial mining begins, exploration expenditures may be deductible.

Operating expenses of a mine during the development and production states include expenditures to determine extent or quality of a known deposit in the mine, and to locate or find other ore. As applied to deep ocean mining the difference between nodule exploration and operating expense is debatable and is relevant only during the construction period for tax treatment of the integrated operation.

[2]Mine development costs are expenses for all activities to make a deposit "accessible for mining after the existence of commercially exploitable deposits is disclosed, that is in marketable quantities." Even after production begins, mine development costs are deductible or deferrable. During the mine development stage, these costs minus the net receipts from only partial production are deductible. If deducted, these costs may not be included in the cost depletion basis. If deferred development costs, not used here, are to be deducted annually, proportional to the output of the mine; with uniform production, these defined costs are thus amortized by a straightline method over the life of the mine.

development and exploration expenses, as compared to normal tax treatment of capitalizing all preproduction expense, and amortizing over either their useful life or several years, beginning when production starts.[3]

In addition, research and development expenditures, (found in new Sector 9 for processing, land transport, and waste disposal) under IRS Code Section 1974 and applicable to any and all taxpayers, is a deductible amount in the year of payment.[4] Otherwise, any Research & Development capital plant, even in pre-production years, can be depreciated beginning in the first year of the investment, on the accelerated three year ACRS.

Non-mining, non Research & Development expenses are not so generously treated, in that like other industries, the pre-production expenses must be capitalized as plant, and be depreciated over five years ACRS beginning when production starts. Similarly, organization costs and business start-up costs, now stated separately as General & Administrative must be amortized (straight-line) for 60 months beginning at the start of production. With the new sector definitions, direct comparison of the values and tax treatment in the two prior Texas A&M University reports is not practical.

The mining taxation treatment for exploration and development expenses permits rapid deduction for tax purposes, but that is most useful only if the mining venture has tax payments to make at the time of these

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[3]A mine is in the producing stage when the major production comes from workings other than those being developed, or when the mine's principal activity is producing rather than developing. In the production stage, all mine development expenses must be either deducted or deferred as a unit for each natural deposit.

[4]If a mine development cost item (such as for R&D) is currently deductible under any other IRS code provision, then it may not be included as a mine development cost.

expenditures. Early write-off (deduction) and years of carryforward before being able to deduct taxes is of restricted value, especially during periods of rapid inflation. When five year carryforward was the maximum allowed, danger of losing the write-off existed. With 15 year carryforward now allowed under the 1981 ERTA, if you cannot produce a taxable profit in that time, the investment certainly is poor. Therefore, the tax election for an independent mining venture, with no taxable income until sales are made, will differ from that of an already profitable corporation with profits to shield from taxation.

Depletion

Depletion is a separate tax deduction for mining ventures, which reflects wasting assets (ore deposit). Once production has begun, the higher amount of depletion calculated by either the cost or percentage method is allowed, with some restrictions. Cost depletion is limited to the amount of acquisition cost of the mine, plus mine development expenses, and is reduced by the amount of any up-front deductions taken as just described, and cost depletion deductions can regain only the cost outlays. Percentage depletion is a continuing deduction and can well exceed costs, and provides an ongoing shelter to production profits. In a mining venture, if the cost depletion amount calculated is higher than the percentage depletion amount, it must be used. Therefore, both depletion types have to be computed for each type of organization, each year.

Cost Depletion. The purpose of cost depletion is to allow a mining venture to recover those costs invested in an enterprise prior to production and during production, if these are expenditures are comparable to the mine development expenses.

Cost Depletion Basis and Adjustment. The basis of property for cost depletion is price if purchased, fair market value when acquired, or adjusted basis of seller. None of these definitions fits the many costs of prospecting and exploring a deep ocean mining site, acquiring permits and licenses, including environmental research and chemical analysis, which might someday bring a sale price much higher than the pioneer's costs, if the site was completed and saleable on the free market. Certainly land and non-mineral property is not included in the cost depletion basis, and use of leased boats and buildings (rather than buying equipment) permits these expenses to be included in cost depletion.

The Date of Acquiring the Property. When either a mining license or a permit is received will be a determinant of the "cost of acquisition" by expenditures up to that date. Clearly, until the permit is recieved, little value is obtained in a specific mine site. Therefore, the GO date is the earliest likely time at which date the pioneer has invested at least $195 million in 1982 dollars, almost all in Prospecting & Exploration and Research & Development. The requirement for a United Nations royalty or production payment does not change this cost basis, unless it is added on as a front-end "bonus" type payment to acquire the permit. Internal Revenue Guide Section 636 is too complicated to guess how the payments to the Sea Bed Authority will be treated, and therefore, this analysis is based upon the existing tax of P.L. 96-483.

The basis of cost depletion can change each tax year as minerals are recovered decreasing the basis, or as expenditure of mine development capitalized cost may increase the basis, both before and during commercial production. The increased costs depletable may be expensed, or capitalized and depreciated, and fit the category of "mine development costs".

The cost depletion original basis is reduced as mineral production proceeds. To simplify this analysis, the entire mining tract is treated as a single property. Cost (and percentage) depletion may be reduced by the minimum tax on tax preference items, but this computation for an integrated corporate taxpayer depends upon other unknown information and has not been estimated in this analysis. When cost basis is either all deducted or recaptured or small, the mine operator can then switch to percentage depletion for the remainder of the production.

In the Texas A&M University program, the acquisition cost is set initially at the sum of Sectors 1 and 2 in the preparatory period. Then in each year of the analysis, the amount of any cost depletion deduction is subtracted from the acquisition cost, the initial basis for depletion, until the basis account is reduced to zero. (In the integrated subsidiary case, this happens immediately.) When the 20 year production begins, at a uniform rate, 1/20th of the basis is computed as the annual amount, of which 85 percent is allowed as an immediate tax deduction and the remaining 15 percent is deducted over five years ACRS, with an investment tax credit of 10 percent on the 15 percent amount.

Percentage Depletion. The percentage depletion deduction is not based on cost, but is a specified percentage of the gross income from mining a mineral, up to 50 percent of annual taxable income, and continuing without regard to any cost basis as long as income continues.

Gross costs to produce income from a mine property includes the transportation necessary and initial treatment of processing steps before a chemical change in the ore, or up to production of the first saleable product according to IRS sources, including extraction of ores from the ground, and from mine tailings. Specific treatment cost portions includable for the three- and four-metal plants are crushing, drying, grinding, concentration, leaching, separation and precipitation.

Transportation costs beyond 50 miles are allowed as part of mining costs by the IRS only if found physically necessary for application of the treatment process, which should be easily demonstrable for deep ocean mining and its unusual process plants. Therefore, Sectors 2 through part of 6 can be considered part of "mining" costs. The gross income includes the proportional share of all income as "mining" costs relate to total costs.

Percentage depletion is taken at a rate or blend of rates fixed for each mineral. For nodules, the percent is 22 percent for all metals except copper which is 15 percent. The percentage times "mining costs" as a fraction of total costs, is applied to the gross revenue to obtain the tax deduction called percentage depletion (see Table C-1). This tax deduction cannot exceed 50 percent of the taxpayer's "taxable income on the property." The taxable income on the property relates only to the proportionate share of income from "mining,' after allowable deductions such as General and Administrative, operating expenses, depreciation, taxes, losses, mine development and exploration expenses. However, expenses after the cut off process point are not deducted, nor are capitalized expenses, nor are losses carryable to other tax years. Questionable allowances for percentage depletion include the Law of the Sea mining payments, and selling costs of the final product, and are ignored. Methods to maximize percentage depletion by deferring expenses have not been used.

The Texas A&M University payout model follows the steps in Table C-1 in computing the percentage depletion, comparing that amount with cost depletion, and selecting the amount to be deducted. The sequence applies to both corporate organizational forms, although an integrated parent-subsidiary always promptly expenses mine exploration and development costs, will never have any basis for cost depletion, and therefore percentage depletion can only be used.

Table C-1. Percentage Depletion Deduction Computation

Step	
A	Compute "Mining Costs" each year, equal sum of annual cost of Sectors 1 through 4, plus Sector 8, plus input = x percent of Sector 6 costs x Sector 6 dollar value. Include both direct operating costs during production years and depreciation on capital costs for Sectors 1-4, 8 and percent of 6.
B	Calculate "Ratio of Mining to Total Costs" (including Depreciation) for each production year.
C	Calculate "Gross Income from Mining" = Ratio x Gross Sales
D	Compute "Percentage Depletion Rate" based on sales value of each metal:
	$\text{Percentage Depletion Rate} = \sum_{i}^{n} \frac{(\$ \text{ Sales of Metal}_i \times \text{Rate Metal}_i)}{\text{Gross Sales of All Metals}}$
	Note: Rate = 22 percent except copper, 15 percent
E	"Percentage Depletion Amount" = "Percentage Depletion Rate" x "Gross (each year) Income from Mining"
F	"Mining Profit Before Tax" = "Gross Income from Mining" less (-) "Mining Cost", each year.
G	"Maximum Percentage Depletion" (MPD) = 50 percent ("Mining Profit Before Taxes")
H	Compare "Percentage Depletion Amount" (PDA) against "Maximum Percentage Depletion" (MPD) and label the selected result "Allowable Percentage Depletion" (APD).
I	Now compare "Allowable Percentage Depletion" (APD) to "100 Percent Cost Depletion" and take the higher of the two amounts.
J	If "Allowable Percentage Depletion" is higher, then insert 100 percent of this value as depletion amount in tax calculation for the year. If "100 Percent Cost Depletion" amount is higher, then see Cost Depletion instruction (that allows deduction in current year of only 85 percent, and 5 year ACRS plus 10 percent ITC of remaining 15 percent).

APPENDIX D

Variable Case Input Data Sheet for the 1984 Texas A&M University

Deep Ocean Mining Payout Analysis

VARIABLE CASE INPUT DATA SHEET FOR THE
1984 TAMU DEEP OCEAN MINING PAYOUT ANALYSIS

1. TOTAL CAPITAL COSTS FOR EACH SECTOR, MINING COSTS IN PROCESSING SECTOR

Prospecting and Exploration PAE1CC=	Mining MIN2CC=	Ore Marine Transportation TRA3CC=
Ore Marine Terminal PRT4CC=	Onshore Transportation SHR5CC=	Processing PRO6CC=
Waste Disposal DIS7CC=	Additional Support SUP8CC=	Research and Development RAD9CC=
Mining Costs in Processing MCIPRC=		

2. TOTAL ANNUAL OPERATING COSTS FOR EACH SECTOR, MINING COSTS IN PROCESSING SECTOR

Prospecting and Exploration SECT(1)=	Mining SECT(2)=	Ore Marine Transportation SECT(3)=
Ore Marine Terminal SECT(4)=	Onshore Transportation SECT(5)=	Processing SECT(6)=
Waste Disposal SECT(7)=	Additional Support SECT(8)=	Research and Development SECT(9)=
Mining Costs in Processing MCIPRA=		

3. CONSTRUCTION PERIOD SPEED

Fast or Slow Construction
ICONYR=

4. METAL PRICES, PROCESS EFFICIENCIES, NODULE ASSAYS, ANNUAL PRODUCTION, SECONDARY METAL REVENUES

Nickel Price PRINI=	Cobalt Price PRICO=	Copper Price PRICU=	Manganese Price PRIMN=
Nickel Efficiency EFFNI=	Cobalt Efficiency EFFCO=	Copper Efficiency EFFCU=	Manganese Efficiency EFFMN=
Nickel Assay ASSYNI=	Cobalt Assay ASSYCO=	Copper Assay ASSYCU=	Manganese Assay ASSYMN=
Annual Nodule Production ANPRD=		Secondary Metal Revenues SECREV=	

5. PARENT/SUBSIDIARY VENTURE OR INDEPENDENT VENTURE

Type of Venture
MCORP=

6. COGENERATION, PREPARATORY PERIOD EXPENDITURES & METHOD, G & A RATE

Cogeneration Alternative COGEN=	Preparatory Period Expenditures PPEXP=	Preparatory Period Expenditures Expensing Method MPPEXP=	G & A Rate GANDA=

7. DEPRECIATION METHOD, PROFITS TAX RATE, INVESTMENT TAX CREDIT TREATMENT

Depreciation Method IDEPR=	Profits Tax Rate TXRATE=	Depreciation Length MDEPR=	ITC Treatment IITC=

8. DEBT FINANCING METHOD

Debt Percentage DETFIX=	Interest Rate RATINT=	Repayment Method MREPAY=	Initial Repayment Year MSTART=	Final Repayment Year MFINIS=

9. INFLATION RATE

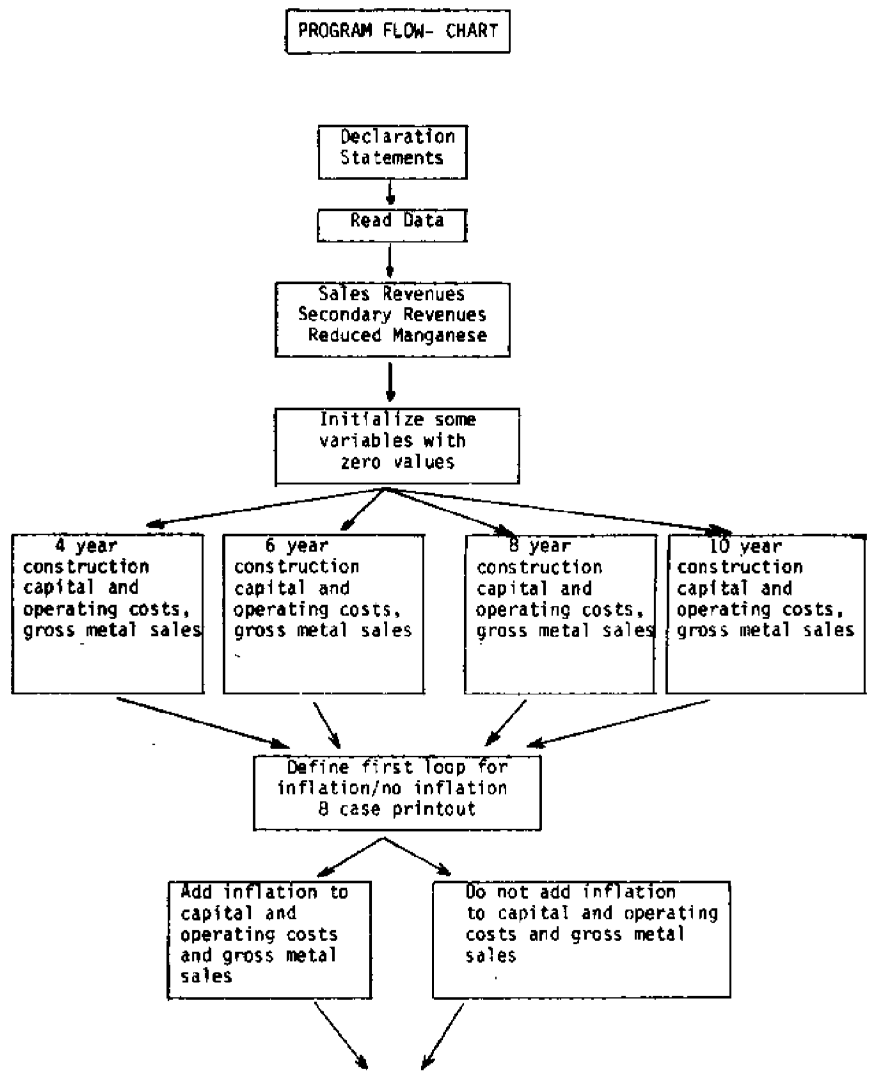
Inflation Rate
INFLT=

10. ELECTRICITY COST, WATER DEPTH, LOCATION, PROCESS

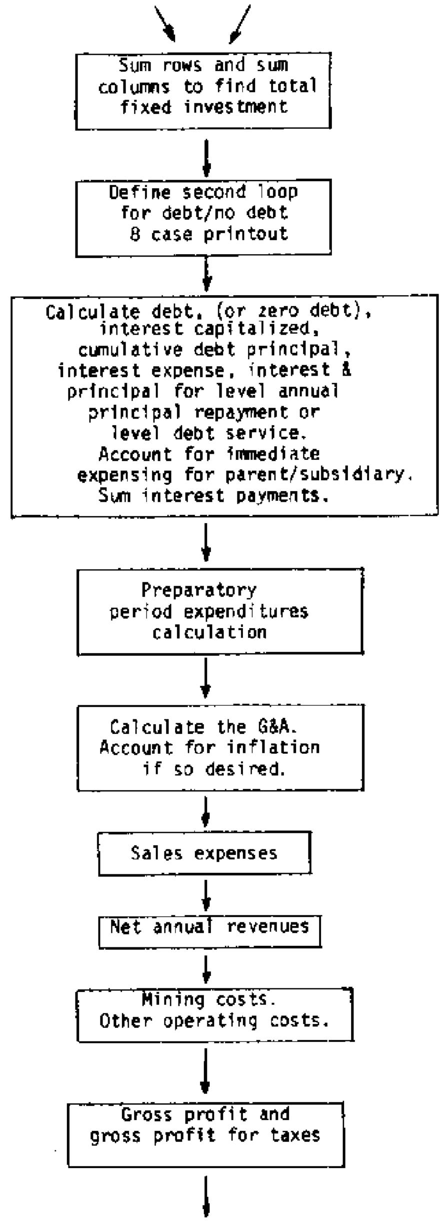
Electricity Cost NELECT=	Water Depth NDEPTH=	Location NLOC=	Process NPROC=

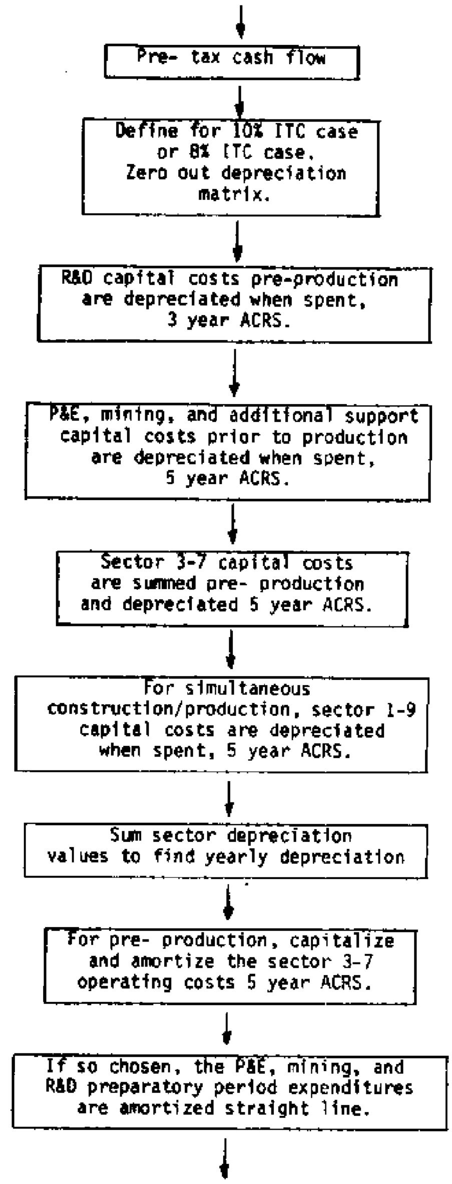
APPENDIX E

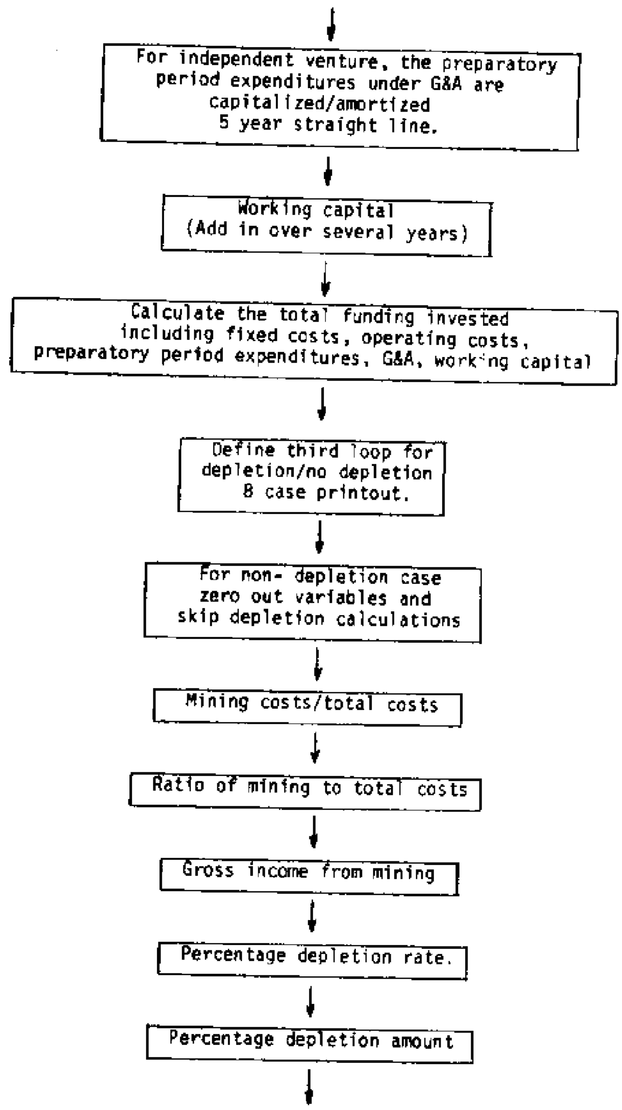
Flow Chart for Texas A&M University Ocean Mining Payout Analysis

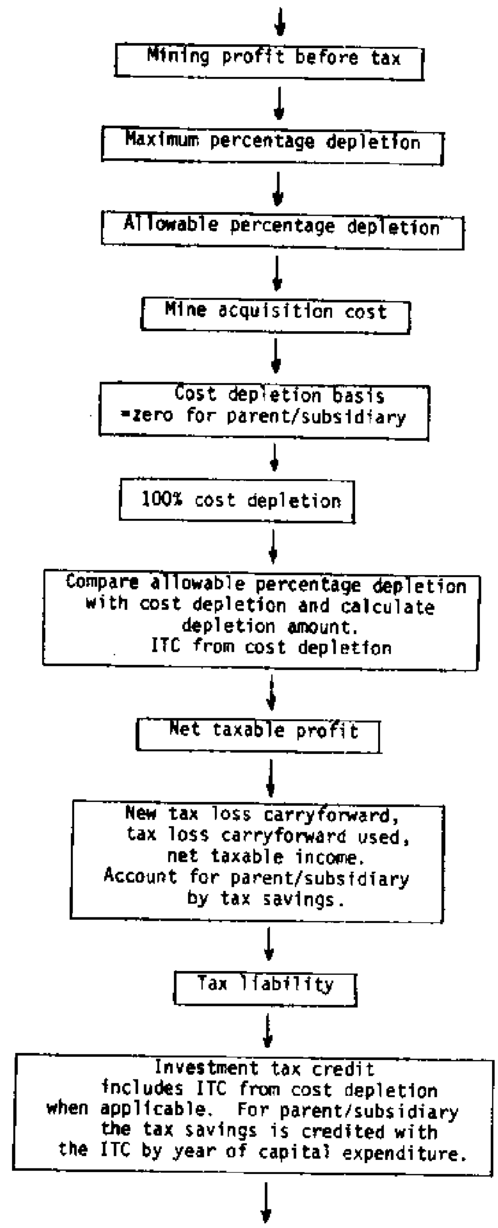


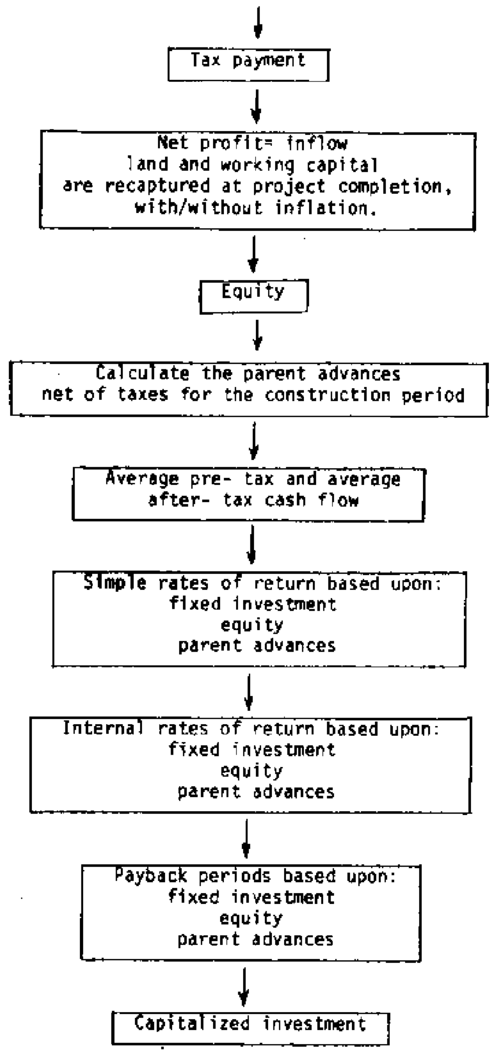
PROGRAM FLOW- CHART
Declaration Statements
Read Data
Sales Revenues Secondary Revenues Reduced Manganese
Initialize some variables with zero values
4 year construction capital and operating costs, gross metal sales
6 year construction capital and operating costs, gross metal sales
8 year construction capital and operating costs, gross metal sales
10 year construction capital and operating costs, gross metal sales
Define first loop for inflation/no inflation 8 case printout
Add inflation to capital and operating costs and gross metal sales
Do not add inflation to capital and operating costs and gross metal sales


Sum rows and sum columns to find total fixed investment
Define second loop for debt/no debt 8 case printout
Calculate debt, (or zero debt), interest capitalized, cumulative debt principal, interest expense, interest & principal for level annual principal repayment or level debt service. Account for immediate expensing for parent/subsidiary. Sum interest payments.
Preparatory period expenditures calculation
Calculate the G&A. Account for inflation if so desired.
Sales expenses
Net annual revenues
Mining costs. Other operating costs.
Gross profit and gross profit for taxes

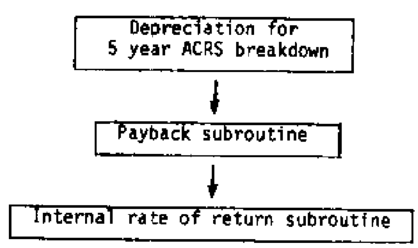

Pre- tax cash flow
Define for 10% ITC case or 8% ITC case. Zero out depreciation matrix.
R&D capital costs pre-production are depreciated when spent, 3 year ACRS.
P&E, mining, and additional support capital costs prior to production are depreciated when spent, 5 year ACRS.
Sector 3-7 capital costs are summed pre- production and depreciated 5 year ACRS.
For simultaneous construction/production, sector 1-9 capital costs are depreciated when spent, 5 year ACRS.
Sum sector depreciation values to find yearly depreciation
For pre- production, capitalize and amortize the sector 3-7 operating costs 5 year ACRS.
If so chosen, the P&E, mining, and R&D preparatory period expenditures are amortized straight line.


For independent venture, the preparatory period expenditures under G&A are capitalized/amortized 5 year straight line.
Working capital (Add in over several years)
Calculate the total funding invested including fixed costs, operating costs, preparatory period expenditures, G&A, working capital
Define third loop for depletion/no depletion 8 case printout.
For non- depletion case zero out variables and skip depletion calculations
Mining costs/total costs
Ratio of mining to total costs
Gross income from mining
Percentage depletion rate.
Percentage depletion amount


Mining profit before tax
Maximum percentage depletion
Allowable percentage depletion
Mine acquisition cost
Cost depletion basis
=zero for parent/subsidiary
100% cost depletion
Compare allowable percentage depletion with cost depletion and calculate depletion amount.
ITC from cost depletion
Net taxable profit
New tax loss carryforward, tax loss carryforward used, net taxable income.
Account for parent/subsidiary by tax savings.
Tax liability
Investment tax credit
includes ITC from cost depletion when applicable. For parent/subsidiary the tax savings is credited with the ITC by year of capital expenditure.



SUBROUTINES



APPENDIX F

Output Printout for High Throughput Base Case

TEXAS A&M UNIVERSITY, OCEAN ENGINEERING PROGRAM, DEEP OCEAN MINING PAYOUT ANALYSIS, MAY 1984, PAGE 1

TOTAL CAPITAL FOR EACH SECTOR, INCLUDING LAND, IN THOUSANDS OF DOLLARS

PROSPECTING/EXPLORATION=	0.	MINING=	343600.	ORE MARINE TRANSPORT=	309600.
ORE MARINE TERMINAL=	33500.	ONSHORE TRANSPORTATION=	49600.	PROCESSING=	989600.
WASTE DISPOSAL=	22200.	ADDITIONAL SUPPORT=	1600.	RESEARCH/DEVELOPMENT=	0.

MINING COSTS IN PROCESSING SECTOR=100.00%

TOTAL ANNUAL OPERATING COSTS FOR EACH SECTOR, IN THOUSANDS OF DOLLARS

PROSPECTING/EXPLORATION=	11500.	MINING=	75300.	ORE MARINE TRANSPORT=	39700.
ORE MARINE TERMINAL=	6200.	ONSHORE TRANSPORTATION=	22800.	PROCESSING=	476800.
WASTE DISPOSAL=	4350.	ADDITIONAL SUPPORT=	1800.	RESEARCH/DEVELOPMENT=	4768.

MINING COSTS IN PROCESSING SECTOR=100.00%

4 YEAR CONSTRUCTION. FAST. (ICONYR=1)

METAL PRICES, PROCESS EFFICIENCIES, NODULE ASSAYS, PRODUCTION/SECONDARY REVENUES

NICKEL PRICE=	3.75$/LB	COBALT PRICE=	5.50$/LB	COPPER PRICE=	1.25$/LB	MANGANESE PRICE=	0.40$/LB
NICKEL EFFICIENCY=94.00%		COBALT EFFICIENCY=70.00%		COPPER EFFICIENCY=94.00%		MANGANESE EFFICIENCY=82.00%	
NICKEL ASSAY=	1.30%	COBALT ASSAY=	0.25%	COPPER ASSAY=	1.10%	MANGANESE ASSAY=	29.00%

ANNUAL PRODUCTION= 4500000. SHORT DRY TONS PER YEAR, SECONDARY METAL REVENUES OF 1.0%   NH3 LEACH, PARTIAL MN (NPROC=2)

PARENT/SUBSIDIARY VENTURE(MCORP=1)

DEPLETION IS INCLUDED(MDEPL=1)   SOUTHERN CALIFORNIA (NLOC=2)

WORKING CAPITAL= 735000.   PREPARATORY PERIOD EXPENDITURES= 225000.

THE PREPARATORY PERIOD EXPENDITURES ARE PLACED IN YEAR 0, (MPPEXP=1)

15%,22%,21%,21%,21%, OVER THE 5 YR PERIOD DEP

ITC=10%, REDUCED DEPRECIABLE BASIS(IITC=1)

TAX RATE= 46.000%   INFLATION RATE= 5.000%   G & A RATE= 0.500%

MINIMUM COGENERATION- 28% SECT(6) OPERATING COST. (COGEN=1.)

75.00% DEBT   10.00% INTEREST RATE
LEVEL ANNUAL PRINCIPAL REPAYMENT (MREPAY=1) BETWEEN YEARS 5 AND 19

TEXAS A&M UNIVERSITY, OCEAN ENGINEERING PROGRAM, DEEP OCEAN MINING PAYOUT ANALYSIS, MAY 1984, PAGE 2

CAPITAL INVESTMENT AND EXPENSES BUILDUP, (1982 DOLLARS X 1000 BY YEAR)

CAPITL	0*	1	2	3	4	5	6	7	8	9	10	LAND	TOTAL
PAE1CC		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
MIN2CC		72156.	75764.	139216.	104412.	0.	0.	0.	0.	0.	0.	0.	391547.
TRA3CC		0.	68267.	179200.	112896.	0.	0.	0.	0.	0.	0.	0.	360362.
PRT4CC		15829.	9233.	11634.	0.	0.	0.	0.	0.	0.	0.	0.	36696.
SHR5CC		10416.	16405.	14355.	6029.	0.	0.	0.	0.	0.	0.	7440.	54645.
PRO6CC		103908.	327310.	400954.	288687.	0.	0.	0.	0.	0.	0.	9896.	1130754.
DIS7CC		0.	0.	7710.	17540.	0.	0.	0.	0.	0.	0.	1110.	26359.
SUP8CC		0.	0.	0.	1945.	0.	0.	0.	0.	0.	0.	0.	1945.
RAD9CC		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
TOTDEP		202308.	496978.	753068.	531507.	0.	0.	0.	0.	0.	0.	18446.	2002306.
TOTFIX		220754.	496978.	753068.	531507.	0.	0.	0.	0.	0.	0.	0.	2002306.
OPERATING COSTS													
PAE1OC	17308.	12075.	12679.	13313.	13976.								69352.
MIN2OC	80769.	0.	0.	0.	68645.								149415.
TRA3OC	0.	0.	0.	0.	28953.								28953.
PRT4OC	0.	0.	0.	0.	2261.								2261.
SHR5OC	0.	0.	2514.	2639.	5543.								10696.
PRO6OC	0.	0.	0.	0.	0.								0.
DIS7OC	0.	0.	0.	0.	0.								0.
SUP8OC	0.	1512.	1588.	1667.	2188.								6954.
RAD9OC	80769.	5006.	5257.	5520.	5796.								102347.
TOTOPE	178846.	18593.	22037.	23139.	127364.								369978.
G && A	46154.	10012.	10012.	10012.	10012.								86200.
WKCAP		0.	0.	0.	735000.	0.	0.	0.	0.	0.	0.		735000.
TOTFND	225000.	249359.	529026.	786218.	1403882.								3193485.
EQUITY	225000.	249359.	311872.	33150.	872375.								1691756.
DEBT		0.	217154.	753068.	531507.	0.	0.	0.	0.	0.	0.	0.	1501729.
INTCAP		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
PANT	121500.	211240.	236685.	-89212.	694379.	0.	0.	0.	0.	0.	0.	0.	1174592.

* PREPARATORY PERIOD EXPENDITURES

TEXAS A&M UNIVERSITY, OCEAN ENGINEERING PROGRAM, DEEP OCEAN MINING PAYOUT ANALYSIS, MAY 1984, PAGE 3
CASH FLOWS AND TAXES BY YEAR OF PROJECT, 1982 DOLLARS X 1000

		YR1	YR2	YR3	YR4	YR5	YR6
	CAPITALIZED INVESTMENT	220754.	496978.	753068.	1266505.	0.	0.
*CASH *	GROSS METAL SALES	0.	0.	0.	0.	917352.	1284291.
FLOWS	SALES EXPENSES	0.	0.	0.	0.	29814.	41739.
	NET ANNUAL REVENUE	0.	0.	0.	0.	887538.	1242551.
	R&D, P&E, MINING COSTS	18593.	19523.	20499.	90607.	114358.	125121.
	OTHER OPERATING COSTS	10012.	12525.	12651.	46768.	640431.	746720.
	GROSS PROFIT	-28605.	-32048.	-33150.	-137375.	132749.	370709.
	INTEREST AND PRINCIPAL	0.	0.	21715.	97022.	250289.	240277.
	PRE TAX CASH FLOW	-28605.	-32048.	-54865.	-234398.	-117540.	130432.
	TAX PAYMENT(BELOW)	-38119.	-75187.	-122362.	-177996.	-151731.	-84439.
	NET PROFIT= INFLOW	9514.	43139.	67496.	-56402.	34191.	214871.
TAXES	GROSS PROFIT FOR TAXES	-28605.	-29535.	-30511.	-100619.	132749.	370709.
	DEPRECIATION	10282.	25877.	50068.	73762.	306139.	396494.
	DEPLETION	0.	0.	0.	0.	0.	8398.
	AMORTIZATION	0.	0.	0.	0.	6286.	9220.
	INTEREST EXPENSE	0.	0.	21715.	97022.	150173.	140161.
	NET TAXABLE PROFIT	-38887.	-55411.	-102294.	-271402.	-329850.	-183564.
	NEW TAX LOSS CARRYFORWARD	0.	0.	0.	0.	0.	0.
	TAX LOSS CARRYFORWARD USED	0.	0.	0.	0.	0.	0.
	NET TAXABLE INCOME	-38887.	-55411.	-102294.	-271402.	-329850.	-183564.
	TAX BEFORE CREDIT	-17888.	-25489.	-47055.	-124845.	-151731.	-84439.
	INVESTMENT TAX CREDIT	20231.	49698.	75307.	53151.	0.	0.
	TAX PAYMENT	-38119.	-75187.	-122362.	-177996.	-151731.	-84439.
	CUMULATIVE DEDUCT. CARRYFORWARD	0.	0.	0.	0.	0.	0.
	CUMULATIVE INVEST. TAX CREDIT	0.	0.	0.	0.	0.	0.
	CUMULATIVE DEBT PRINCIPAL	0.	217154.	970222.	1501729.	1401613.	1301497.
	100% COST DEPLETION DEDUCTION	0.	0.	0.	0.	0.	0.
	PERCENTAGE DEPLETION DEDUCTION	0.	0.	0.	0.	-77720.	8398.

TEXAS A&M UNIVERSITY, OCEAN ENGINEERING PROGRAM, DEEP OCEAN MINING PAYOUT ANALYSIS, MAY 1984, PAGE 4
CASH FLOWS AND TAXES BY YEAR OF PROJECT, 1982 DOLLARS X 1000

		YR7	YR8	YR9	YR10	YR11	YR12
	CAPITALIZED INVESTMENT	0.	0.	0.	0.	0.	0.
*CASH *	GROSS METAL SALES	1685631.	1769911.	1858405.	1951324.	2048889.	2151332.
FLOWS	SALES EXPENSES	54783.	57522.	60398.	63418.	66589.	69918.
	NET ANNUAL REVENUE	1630848.	1712388.	1798006.	1887906.	1982300.	2081413.
	R&D, P&E, MINING COSTS	131377.	137946.	144843.	152085.	159690.	167674.
	OTHER OPERATING COSTS	785280.	824543.	865769.	909057.	954509.	1002234.
	GROSS PROFIT	714190.	749898.	787393.	826763.	868101.	911505.
	INTEREST AND PRINCIPAL	230266.	220254.	210242.	200230.	190219.	180207.
	PRE TAX CASH FLOW	483925.	529644.	577151.	626533.	677882.	731298.
	TAX PAYMENT(BELOW)	-389.	18640.	36870.	137419.	153796.	170675.
	NET PROFIT= INFLOW	484314.	511004.	540281.	489113.	524086.	560623.
TAXES	GROSS PROFIT FOR TAXES	714190.	749898.	787393.	826763.	868101.	911505.
	DEPRECIATION	366270.	338497.	317279.	0.	0.	0.
	DEPLETION	209815.	241941.	271034.	427910.	443658.	460381.
	AMORTIZATION	8801.	8801.	8801.	0.	0.	0.
	INTEREST EXPENSE	130150.	120138.	110126.	100115.	90103.	80092.
	NET TAXABLE PROFIT	-846.	40522.	80153.	298738.	334340.	371033.
	NEW TAX LOSS CARRYFORWARD	0.	0.	0.	0.	0.	0.
	TAX LOSS CARRYFORWARD USED	0.	0.	0.	0.	0.	0.
	NET TAXABLE INCOME	-846.	40522.	80153.	298738.	334340.	371033.
	TAX BEFORE CREDIT	-389.	18640.	36870.	137419.	153796.	170675.
	INVESTMENT TAX CREDIT	0.	0.	0.	0.	0.	0.
	TAX PAYMENT	-389.	18640.	36870.	137419.	153796.	170675.
	CUMULATIVE DEDUCT. CARRYFORWARD	0.	0.	0.	0.	0.	0.
	CUMULATIVE INVEST. TAX CREDIT	0.	0.	0.	0.	0.	0.
	CUMULATIVE DEBT PRINCIPAL	1201381.	1101265.	1001150.	901035.	800919.	700804.
	100% COST DEPLETION DEDUCTION	0.	0.	0.	0.	0.	0.
	PERCENTAGE DEPLETION DEDUCTION	209815.	241941.	271034.	427910.	443658.	460381.

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CASH FLOWS AND TAXES BY YEAR OF PROJECT, 1982 DOLLARS X 1000

		YR13	YR14	YR15	YR16	YR17	YR18
*CASH *	GROSS METAL SALES	2258896.	2371840.	2490430.	2614950.	2745695.	2882978.
FLOWS	SALES EXPENSES	73414.	77085.	80939.	84986.	89235.	93697.
	NET ANNUAL REVENUE	2185481.	2294755.	2409491.	2529964.	2656459.	2789281.
	R&D, P&E, MINING COSTS	176057.	184860.	194103.	203808.	213998.	224698.
	OTHER OPERATING COSTS	1052344.	1104960.	1160207.	1218217.	1279127.	1343081.
	GROSS PROFIT	957079.	1004934.	1055180.	1107938.	1163333.	1221501.
	INTEREST AND PRINCIPAL	170196.	160184.	150173.	140161.	130150.	120138.
	PRE TAX CASH FLOW	786883.	844750.	905007.	967777.	1033184.	1101363.
	TAX PAYMENT(BELOW)	188080.	206040.	224580.	243730.	263521.	283985.
	NET PROFIT= INFLOW	598803.	638710.	680427.	724047.	769663.	817378.
TAXES	GROSS PROFIT FOR TAXES	957079.	1004934.	1055180.	1107938.	1163333.	1221501.
	DEPRECIATION	0.	0.	0.	0.	0.	0.
	DEPLETION	478129.	496953.	516905.	538043.	560427.	584118.
	AMORTIZATION	0.	0.	0.	0.	0.	0.
	INTEREST EXPENSE	70080.	60069.	50057.	40046.	30034.	20023.
	NET TAXABLE PROFIT	408870.	447913.	488217.	529849.	572871.	617360.
	NEW TAX LOSS CARRYFORWARD	0.	0.	0.	0.	0.	0.
	TAX LOSS CARRYFORWARD USED	0.	0.	0.	0.	0.	0.
	NET TAXABLE INCOME	408870.	447913.	488217.	529849.	572871.	617360.
	TAX BEFORE CREDIT	188080.	206040.	224580.	243730.	263521.	283985.
	INVESTMENT TAX CREDIT	0.	0.	0.	0.	0.	0.
	TAX PAYMENT	188080.	206040.	224580.	243730.	263521.	283985.
	CUMULATIVE DEDUCT. CARRYFORWARD	0.	0.	0.	0.	0.	0.
	CUMULATIVE INVEST. TAX CREDIT	0.	0.	0.	0.	0.	0.
	CUMULATIVE DEBT PRINCIPAL	600689.	500574.	400458.	300343.	200228.	100113.
	100% COST DEPLETION DEDUCTION	0.	0.	0.	0.	0.	0.
	PERCENTAGE DEPLETION DEDUCTION	478129.	496953.	516905.	538043.	560427.	584118.

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CASH FLOWS AND TAXES BY YEAR OF PROJECT, 1982 DOLLARS X 1000

		YR19	YR20	YR21	YR22	YR23	YR24
*CASH *	GROSS METAL SALES	3027124.	3178478.	3337400.	3504268.	3679479.	3863450.
FLOWS	SALES EXPENSES	98382.	103301.	108466.	113889.	119583.	125562.
	NET ANNUAL REVENUE	2928742.	3075177.	3228934.	3390379.	3559895.	3737887.
	R&D, P&E, MINING COSTS	235933.	247729.	260116.	273121.	286777.	301116.
	OTHER OPERATING COSTS	1410235.	1480745.	1554782.	1632520.	1714145.	1799851.
	GROSS PROFIT	1282574.	1346702.	1414036.	1484737.	1558972.	1636920.
	INTEREST AND PRINCIPAL	110124.	0.	0.	0.	0.	0.
	PRE TAX CASH FLOW	1172450.	1346702.	1414036.	1484737.	1558972.	1636920.
	TAX PAYMENT(BELOW)	305155.	327066.	343420.	360591.	378620.	397550.
	NET PROFIT= INFLOW	867295.	1019636.	1070616.	1124146.	1180352.	2031025.
TAXES	GROSS PROFIT FOR TAXES	1282574.	1346702.	1414036.	1484737.	1558972.	1636920.
	DEPRECIATION	0.	0.	0.	0.	0.	0.
	DEPLETION	609182.	635688.	667472.	700844.	735886.	772680.
	AMORTIZATION	0.	0.	0.	0.	0.	0.
	INTEREST EXPENSE	10011.	0.	0.	0.	0.	0.
	NET TAXABLE PROFIT	663380.	711014.	746564.	783893.	823086.	864240.
	NEW TAX LOSS CARRYFORWARD	0.	0.	0.	0.	0.	0.
	TAX LOSS CARRYFORWARD USED	0.	0.	0.	0.	0.	0.
	NET TAXABLE INCOME	663380.	711014.	746564.	783893.	823086.	864240.
	TAX BEFORE CREDIT	305155.	327066.	343420.	360591.	378620.	397550.
	INVESTMENT TAX CREDIT	0.	0.	0.	0.	0.	0.
	TAX PAYMENT	305155.	327066.	343420.	360591.	378620.	397550.
	CUMULATIVE DEDUCT. CARRYFORWARD	0.	0.	0.	0.	0.	0.
	CUMULATIVE INVEST. TAX CREDIT	0.	0.	0.	0.	0.	0.
	CUMULATIVE DEBT PRINCIPAL	0.	0.	0.	0.	0.	0.
	100% COST DEPLETION DEDUCTION	0.	0.	0.	0.	0.	0.
	PERCENTAGE DEPLETION DEDUCTION	609182.	635688.	667472.	700844.	735886.	772680.

NOTE: THE WORKING CAPITAL AND LAND ARE RECAPTURED IN THE FINAL YEAR OF OPERATION AS NET PROFIT

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NET FUNDING INVESTED- PARENT	1174592.	
FIXED INVESTMENT CAPITAL REQUIREMENTS	2002306.	
NET ANNUAL REVENUE(GROSS MINUS SALES EXPENSES)	2409491.	
ANNUAL OPERATING COSTS DURING PRODUCTION	1354310.	
TOTAL INTEREST PAYMENTS	1320113.	
PREPARATORY PERIOD EXPENDITURES (YR O)	225000.	
BEFORE TAXES		
AVERAGE PRE TAX CASH FLOW (20 YRS)	894605.	1 LARGE MINER SHIP ANNUAL PRODUCTION= 4500000.
RETURN ON PARENT= CAPITAL RECOVERY FACTOR	76.16%	NH3 LEACH, PARTIAL MN (NPROC=2) MN(SHORT DRY TONS)= 713399.
RETURN ON FIXED INVESTMENT CAPITAL	44.68%	SOUTHERN CALIFORNIA (NLOC=2) ELECTRICITY COST= 11CENTS/KWH
BEFORE TAX PAYBACK PERIOD ON PARENT	8YRS 3MO	PORT DEPTH(FT)= 45
BEFORE TAX PAYBACK PERIOD ON FIXED INVESTMENT CAPITAL	9YRS 7MO	YEARS CONSTRUCTION= 4 YEAR START PRODUCTION= 5 YEAR FULL PRODUCTION= 7 START PRODUCTION %= 60
INTERNAL RATE OF RETURN BEFORE TAXES	25.26%	
AFTER TAXES		
AVERAGE PROFIT AFTER TAXES (20 YRS)	744029.	PARENT/SUBSIDIARY VENTURE
RETURN ON PARENT= CAPITAL RECOVERY FACTOR	63.34%	INFLATION= 5.00%
RETURN ON FIXED INVESTMENT CAPITAL	37.16%	DEPLETION INCLUDED
AFTER TAX PAYBACK PERIOD ON PARENT	7YRS10MO	
AFTER TAX PAYBACK PERIOD ON FIXED INVESTMENT CAPITAL	9YRS 5MO	DEBT= 75.00% OF FIXED COST INTEREST RATE=10.00%
INTERNAL RATE OF RETURN AFTER TAXES	24.55%	

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STATEMENTS EXECUTED=   52477
CORE USAGE       OBJECT CODE=   63368 BYTES,ARRAY AREA=    8532 BYTES,TOTAL AREA AVAILABLE=  366592  BYTES
DIAGNOSTICS        NUMBER OF ERRORS=       0, NUMBER OF WARNINGS=       0, NUMBER OF EXTENSIONS=      51
COMPILE TIME=     0.68 SEC,EXECUTION TIME=     1.12 SEC,     15.40.56    WEDNESDAY    25 JUL 84    WATFIV - MAR 1980 V2L0
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